Microreactor AGile Non-nuclear Experimental Testbed Aspen HYSYS Analysis

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Abstract

There is a lot of interest in modular nuclear microreactors and the benefits they bring for mobile power in remote areas and process heat applications (World Nuclear Association, 2020). Many companies in the nuclear power industry are developing various types of reactors, ranging from high temperature gas reactors (HTGRs), sodium-cooled fast reactors, molten salt reactors, light water reactors, and heat pipe cooled reactors. Each reactor type requires different thermal conditions to achieve their most efficient operations. Many of these miniaturized transportable reactor designs remain largely untested and unproven. To aid in the development of the miniaturized reactors, Idaho National Laboratory (INL) is developing a Microreactor AGile Non-nuclear Experimental Testbed (MAGNET). The MAGNET will be used to simulate the thermal conditions (pressures, temperatures, heat transfer fluids, etc.) that microreactors are expected to deliver. The MAGNET facility will accommodate various electrically heated microreactor prototypes. However, the first reactor type under consideration is a heat pipe cooled test article. The working fluid being considered to cool the heat pipes in the MAGNET system is nitrogen or helium with a max operating temperature of 600°C. To help in the development of the MAGNET facility, models were developed in Aspen HYSYS (Aspen Technology, Inc., 2016) to approximate the thermal conditions throughout the test loop.

The MAGNET models created could be used to simulate the experiments and potential experiments for the MAGNET. This could save time and money by reducing the number of costly experiments that provide little information. It could also be used to simulate off design conditions to determine safety parameters that could be potentially dangerous, like extreme pressures or temperatures. From the analyses, it was shown that the upper end temperature while using helium could reach close to 635°C. This approaches the upper limit of the piping at 650°C, making helium potentially dangerous unless changes are made to the mass flow rate or heat pipe power load. The models also showed a detailed pressure drop throughout the system showing that the MAGNET's compressor could handle the required mass flow rates. Another major application drawn from the HYSYS models was a representation of the heat loss and temperature loss throughout the piping. This showed that the heat loss from the piping was minimal when the power applied to the heat pipes was at least greater than 75 kW.

Modular nuclear microreactors generate power using various power conversion units (PCUs). Several common PCUs include steam Rankine cycles, air Brayton cycles, closed helium Brayton cycles, recuperated Brayton cycles, supercritical carbon dioxide cycles, and organic Rankine cycles. Combined power cycles can also be used to increase the thermal efficiency of the PCU. Combined cycles could include a Brayton cycle with a steam Rankine bottoming cycle. An advantage of the MAGNET is having the ability to easily attach a PCU to the MAGNET. Two options were considered for adding a PCU to the MAGNET. The first option was to find a physical PCU unit to attach to the test loop and the second option was to develop a PCU simulator.

The MAGNET HYSYS models were designed with a compressor and turbine to model a PCU. The configuration made was a recuperated Brayton cycle. The cycle was optimized by varying the outlet pressure of the turbine to achieve the highest thermal efficiency of 8.57% with nitrogen and 15.5% with helium. A PCU simulator was also designed from the research that Brayton cycles can be uniquely identified by three state points and knowing the pressure ratio. The PCU simulator simulates simple and recuperated Brayton cycles using a series of heat exchangers and valving. The major advantage of the PCU simulator was that it could simulate various Brayton cycles under various compressor and turbine efficiencies. However, the major disadvantage was that the system has be large capital cost estimated near 2.15 million dollars.

A simple Brayton cycle start up process was analyzed to provide understanding for the startup process of a nuclear powered Brayton cycle. The data provided an upper limit for realistic compressor and turbine adiabatic efficiencies of 85% and 90%, respectively. From the analysis, the three key state points were collected which would allow the PCU simulator to simulate start up processes. An understanding for how a nuclear powered Brayton cycle could start up was also learned from the analysis. One could say that the nuclear powered PCU start up is similar to a conventional natural gas PCU except when the start up process begins. The nuclear reactor would be at operating temperatures before the PCU started. Then the heat could be applied to the PCU instantly instead of at conventional timing in natural gas PCU.

This thesis details the development of the Aspen HYSYS MAGNET model as well as the development of the PCU simulator, including cost estimates and start up analysis.

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I would like to thank the University of Idaho for providing a great place to pursue my master's degree. They have outstanding professors who have aided me in my educational goals. Specifically, Dr Michael McKellar for all the effort, time, and guidance in helping develop my engineering skills. His input was monumental in my success. I would like to thank my committee for their efforts with my learning and the development of this thesis, Dr John Crepeau and Dr David Arcilesi. I would also like to thank Donna Guillen and James O'Brien at the Idaho National Laboratory for providing great projects and funding for me.

Dedication

To my wife, Kali, for willingly supporting me and our kids through the busy extra years of graduate school and delaying our future plans.

To my dad, Terry, for answering hundreds of silly questions and for the extra time he has given to teach me.

To my mom, Nonalee, for always supporting and loving me and my family in our goals.

To God, our Heavenly Father, for the countless blessings to myself and my family which have helped us in our goals.

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Chapter 1: Introduction

1.1 Background

1.1.1 Modular Nuclear Microreactors

The idea of small modular nuclear power has reignited people's interest in nuclear power. This form of nuclear power adds a lot of versatility to what used to be a stagnant field. Instead of being a large, expensive, and stationary plant, small microreactors are transportable and reduce the impact of capital costs. This class of microreactors is new, which bring many new advantages and challenges (World Nuclear Association, 2020).

Modular nuclear microreactors are versatile reactors. This versatility comes from their factory fabrication, transportability, and self-adjustability. These reactors are simply designed so that many of the components are fabricated and assembled in a factory. This removes the need for large construction zones for assembling the micronuclear reactor. It removes large overhead and capital costs. It decreases the required time to set up and operate the unit. Once the units are assembled, they should be quick to install and allow for a "plug-and-play" setup (Office of Nuclear Energy, 2018; Vitali, Lamothe, Toomey, Peoples, & Mccabe, 2018). Customers can purchase these units without the worry of on-site construction zones and gain electrical access rapidly.

Once the units are assembled, they can be shipped directly from the factory to the desired location. Many of the current designed units are small and can fit within international standard organization (ISO) shipping containers. ISO containers are easily transportable by truck, train, boat, and airplane. An example rendering of a current reactor design being shipped is the HolosGen Holos Reactor, shown in Figure 1.1. Transportability is a desirable feature for many applications. Because the units are small, they require only a small amount of land, and can operate virtually anywhere.

A design consideration for microreactors is that they are designed to be self-adjusting and self-regulating. This is achieved by implementing passive cooling systems that are cooled by the ambient air. This prevents overheating and reactor meltdown, suggesting that the reactor would not require many specialized operators to be present continuously to monitor and operate

the reactor (Office of Nuclear Energy, 2018). The use of passive cooling systems makes the reactors safe and require little maintenance while operating in public.



Figure 1.1 Rendering of the HolosGen Holos Reactor Shipping (HolosGen, 2017)

There are many reasons for the development of modular microreactors because of the large number of possible applicational uses for them. Some of the possible applications include providing power for military bases, military forward operations, remote areas, and for disaster areas. The Department of Defense (DoD) and Department of Energy (DOE) facilities have major interest in this technology and plan on operating these reactors by the end of 2027 (Charles, 2018). In 2016, the DoD was the largest consumer of energy using 21% of the total federal energy consumption. They used 201.4 billion BTUs which cost 3.7 billion dollars. Most of the energy demand was met by the use of electricity, natural gas, and other fuels like coal and oil. A remote domestic military airbase in Alaska is an example of a military facility that has a constant need of fuel. This airbase uses 800 tons of coal per day and consistently produces between 10-15 MWe. The use of a small modular microreactor could reduce or remove the constant need of coal for the airbase. One or two reactors could supply the needed power to this airbase (Nuclear Energy Institute, 2018).

Another major application of microreactors for the US military is for their forward operating bases. As designed, microreactors are easily transportable, robust, reliable, and quick to set up. An example for military use is the Westinghouse eVinci reactor, shown in Figure 1.2. Several major advantages for microreactors in forward operating bases are that they create energy independence, provide process heat applications, and remove the need for constant fuel resupplying which saves lives and money. Microreactors are being designed to operate 24/7 for several years without shutting down which provide energy resilience and independence. Power

is generated by using the heat from the microreactor, while the excess heat is removed to cool the system. The excess heat from the reactor could be used in these forward bases to desalinate water and provide heating for the bases (Nuclear Energy Institute, 2018). Also, Juan A. Vitali et al showed in a report that energy independence would be beneficial since approximately 18,700 casualties (52%) of the approximately 36,000 total US casualties over the last nine years came from land transport missions. Removing the need for constant refueling caravans can save lives. Along with saving lives, it is estimated that there is an annual fuel cost of 256 million dollars to operate the 286 annual refueling convoys (Vitali, Lamothe, Toomey, Peoples, & Mccabe, 2018; Allen, Hartford, & Merkel, 2018).

Another use of the small reactors includes being transported to natural disaster areas to provide electricity for hospitals and other emergency responders. Since the microreactors are designed to be small, transportable, and quick to set up, use in a natural disaster area could provide power quickly and efficiently to critical infrastructure. (Vitali, Lamothe, Toomey, Peoples, & Mccabe, 2018). HolosGen, a microreactor company, showed that they have a model that can be airlifted into a disaster area and quickly provide power to emergency responders, water pump and sewage stations, water purification plants, ect. This would bring needed relief to cities hit by a disaster and could prevent further damage and provide necessities to the cities (HolosGen, 2017). A rendering of the HolosGen Holos reactor is shown in Figure 1.3.

Microreactors could also be used to supply power and heat to isolated communities and mining towns where it could be difficult or expensive to transport fuels to (Charles, 2018). The use cases in these locations are similar to that of the remote military bases and forward operating bases. These units could provide power, district heating, and heat process applications like desalinization of water to these areas. This allows these communities to thrive while not being tethered to the need of fuel. HolosGen provided data for their reactor in isolated communities. They detail that many of these areas receive their power from diesel generators costing around 34.5¢/kWh or more. The price per kWh depends on the difficulty of transporting fuel to the area. HolosGen estimated that they could produce electricity under similar conditions at a cost of 5.19¢/kWh with fuel that could last years (HolosGen, 2017). The heat from the microreactor could also be used for heating in the town and for cleaning water. A rendering of a possible application for the reactors in rural or mining towns is shown in Figure 1.4.



Figure 1.2 Rendering of Westinghouse eVinci Military Transportation (Charles, 2018)



Figure 1.3 HolosGen HOLOS Microreactor Deployed for Natural Disaster Aid (HolosGen, 2017)



Figure 1.4 Modular Nuclear Microreactor Application in Rural or Mining Town (Charles, 2018)

There are a wide variety of microreactors proposed by the nuclear power industry, including sodium-cooled fast reactors, molten salt reactors, high-temperature gas reactors (HTGRs), light water reactors, and heat pipe cooled reactors. Each reactor type has unique working fluid temperatures, which in turn have a profound effect on the efficiency of the PCU to produce power and provide process heat (McKellar, Boardman, Bragg-Sitton, & Sabharwall, 2018). Some examples of companies developing modular nuclear microreactors are X-energy, HolosGen LLC, General Atomics, NuScale, MicroNuclear LLC with INL and the University of Idaho, Westinghouse with Los Alamos National Laboratory (LANL), and Oklo (Nuclear Energy Institute, 2018).

X-energy designed the Xe-Mobile which is a high temperature gas cooled reactor. Their design uses helium to cool the reactor which produces at least 1 MW of electrical power. The Xe-Mobile is an easily transportable design contained in an ISO container (X-Energy LLC, 2020) They also developed the X-battery, which is another high temperature gas cooled reactor with a thermal rating of 10 MW_{th}. Their reactor designs are designed to be operated autonomously and are capable of providing power, heat, and to support hydrogen production (Nuclear Energy Institute, 2018).

The Holos reactor by HolosGen LLC uses subcritical nuclear fuel cartridges in their reactor. This fuel is inserted into a large metal block with cooling channels and cooled by helium or carbon dioxide. Their design is mobile and quick to begin operating. Their design is also modular which makes it possibly to create large varying power ratings. The reactor can supply 3 MW_e and up to 81 MW_e using a closed recuperated Brayton cycle with a bottoming organic Rankine cycle to generate the power (Filippone & Jordan, 2018).

General Atomics is developing a mobile nuclear power supply that can supply 4-10 MW_e . Their design is transportable through shipping containers and can be operated autonomously. They estimate that their refueling period is greater than 10 years. From General Atomics expertise in advanced military products, their nuclear power supply is high performance with a high degree of safety (Nuclear Energy Institute, 2018; General Atomics, 2018).

NuScale's microreactors is their NuScale Power Module. This unit is a light-water microreactor and has a power range of 1 to 10 MW_{e} . Their design estimates that their plant can operate 10 or more years without the need for refuel and also have highly automated control room as they have These units are being considered to produce power, heat, desalination, and hydrogen production for DoD facilities, towns, and industry (Nuclear Energy Institute, 2018).

MicroNuclear, INL, and the University of Idaho are developing the Molten Salt Nuclear Battery. This microreactor is described as a battery as once the operational lifetime has expired, a new unit would be inserted. This microreactor operates of natural convection like heat pipes with the reactor core installed on the inside of the unit. The reactor core is cooled by molten salt and transfers heat to the desired process. This unit will produce 10 MW_{th} and have an expected operational lifetime of ten years (MicroNuclear LLC, 2020).

Westinghouse is developing a microreactor with LANL. This is a heat pipe cooled reactor and is a solid monolith which contains many holes to hold nuclear fuel and heat pipes. LANL developed a heat pipe reactor for space exploration that is currently under development to become a microreactor with Westinghouse. The reactor is known as the eVinci microreactor. This reactor operates within the range of 600°C to 700°C and can provide between 200 kW_e to 15 MW_e. They project that their reactor can operate up to 10 years without the need for refueling or maintenance since there is little moving parts in their design. (Kennedy, et al., January 2019; McClure, Poston, Rao, & Reid, 2015; Westinghouse, 2019; Nuclear Energy Institute, 2018). Oklo is developing the Aurora reactor which is another heat pipe cooled reactor. Their design uses little moving parts and operates on natural physical forces. The reactor is a fast reactor and is not easily transportable as their design is meant to be installed underground. They project that their microreactor can produce 1.5 MW_e and have a refueling life span of more than 20 years (Nuclear Energy Institute, 2018; U.S. NRC, 2020).

1.1.2 Power Conversion Units

Power conversion units (PCU) are how modular nuclear microreactors generate power. PCUs can be structured in many ways to produce power, while the most common types for large power generation are Brayton cycles, recuperated Brayton cycles, and Rankine cycles. Combinations of those cycles are also used to create a combined thermal cycle, which have higher thermal efficiencies (Çengel & Boles, 2011).

Thermal efficiencies are an important factor when discussing power cycles. Thermal efficiency is a measure to determine how effective the system is at producing the desired product with the given input. In terms of power cycles, it is how much electrical power is produced from the given heat input from the heat source, as shown in Equation 1.1 (Çengel & Boles, 2011). This is a common method of comparing different power cycles. It is more desirable to have a higher thermal efficiency as it means the heat addition to the system is being utilized better. Companies search for higher thermal efficiencies because the heat input is generally the cost of fuel.

$$\mathfrak{y}_{th} = \frac{W_{out} - W_{in}}{Q_{in}} \qquad \qquad Equation \ 1.1$$

Where:	W_{out}	\rightarrow net work out of the system
	W _{in}	\rightarrow net work into the system
	Q_{in}	\rightarrow heat into the system

Temperature and entropy (T-s) diagram and a pressure and specific volume (P- ν) diagram are often used to aid in understanding of power cycles. T-s diagrams detail how the temperature and entropy change throughout the power cycle with the addition and removal of heat (q) at varying pressures. P- ν diagrams show how the pressure specific volume of the working fluid

change throughout the system. These two diagrams provide the same network produced by the cycle and is represented by the area enclosed, see Figure 1.5. These diagrams are useful to show how the power cycle operates, including where heat is added or removed (Çengel & Boles, 2011).



Figure 1.5 Example of a T-s and P-v Diagram (Çengel & Boles, 2011)

Non-recuperated Brayton cycles are common power cycles to use when the working fluid is a gas. These cycles can either be "open" or "closed" which refer to the cycle either using ambient air or recirculating the same working fluid in a closed loop. In an open loop air Brayton cycle, ambient air would be drawn into the compressor and then exhausted back to the ambient air through the turbine. An example of an open air Brayton cycle is shown in Figure 1.6. This orientation is considered an open loop because the working fluid is not being recirculated throughout the system. A closed loop orientation would take the exhaust from the turbine, cool the working fluid, and then flow back into the compressor, as shown in Figure 1.7. The working fluid in a closed loop orientation could be helium (He), carbon dioxide (CO2), air, etc, since the working fluid remains within the loop. An example of the T-s and P-v diagrams are shown in Figure 1.8.



Figure 1.7 Closed Loop Brayton Cycle



Figure 1.8 T-s and P-v Diagrams for an Ideal Closed Loop Non-Recuperated Brayton Cycle (Çengel & Boles, 2011)

Recuperated Brayton cycles operate similarly to non-recuperated Brayton cycles, other than it operates with the addition of an intermediate heat exchanger, see Figure 1.9. In the heat exchanger, the compressor exhaust exchanges heat with the high temperature turbine exhaust. This decreases the required heat addition for the heat source and can greatly increase the thermal efficiency of the system (Çengel & Boles, 2011). For a closed loop recuperated Brayton cycle, the working fluid leaving the recuperating heat exchanger would then pass through a chiller and then flow back into the compressor. An example of a T-s diagram is shown in Figure 1.10. It is shown that recuperation increases the heat input which would lower the required heat input. This increases the thermal efficiency of this power cycle. These cycles have higher thermal efficiencies and operate at lower pressure ratios compared to their non-recuperated counter parts, as shown in Figure 1.11 where T_1/T_3 is the ratio between the lowest temperature and highest temperature in the cycle.



Figure 1.9 Recuperated Open Air Brayton Cycle



Figure 1.10 T-s Diagram of a Closed Loop Recuperated Brayton Cycle (Çengel & Boles, 2011)



Figure 1.11 Pressure Ratios Compared Between Recuperated (Regeneration) and Non-Recuperated Brayton Cycles (Çengel & Boles, 2011)

A Rankine cycle is another possible power cycle that can be used with modular microreactors. Rankine cycles consist of four components: Gas turbine, pump, boiler, and a condenser. An example of a steam Rankine cycle is shown in Figure 1.12. This cycle is a closed loop cycle. As an example, water can be used as the working fluid for the power loop. Liquid water enters the pump and becomes pressurized. The water then passes through the boiler and vaporizes. The vapor passes through the gas turbine which converts mechanical energy into electrical energy. Once through the turbine, the water vapor passes through a condenser, condenses back into liquid water, and then reenters the pump. This process can be seen in the T-s diagram shown in Figure 1.13. The working fluids for this power loop are liquids that can vaporized. Refrigerants or other organic working fluids can also be used within this power cycle and are called Organic Rankine Cycles (ORC) (Çengel & Boles, 2011).



Figure 1.12 Steam Rankine Cycle



Figure 1.13 T-s Diagram for Steam Rankine Cycle (Cengel & Boles, 2011)

A common way to raise the thermal efficiency of power cycles is to create a combined cycle. Combined cycles have a main power cycle operating off the main heat source, as described above, and a secondary cycle connected to the cooler on the main cycle. The cooling section of the main power loop heats the secondary loop and then generates extra power. A common combined cycle would be a recuperated open air Brayton cycle with a bottoming steam Rankine cycle, an example is shown in Figure 1.14. The hot exhaust leaving the Brayton cycle would use natural gas as the fuel, instead of a nuclear reactor, and have high inlet turbine temperatures. The hot air exhausted from this cycle would then boil the water in the steam Rankine cycle. A

T-s diagram of an open air Brayton cycle topping cycle with a bottoming steam Rankine cycle is shown in Figure 1.15. The state point numbers correlate with the state points in Figure 1.14. It is observed that the exhaust heat from the gas cycle heat provides the required heat for the steam cycle (Çengel & Boles, 2011). An example of an increase in thermal efficiencies from combined cycles is shown in a recent scoping study by Idaho National Laboratory (INL) and the University of Idaho (UI). They have shown that for a microreactor operating on a recuperated open air Brayton cycle with a reactor outlet temperature of 650°C (heat pipe or molten salt reactor), the thermal efficiency can increase from 36% to 40% with the addition of an ORC attached to a recuperated air Brayton cycle (Litrel, Guillen, & McKellar, 2018).



Figure 1.14 Combined Open Air Brayton Cycle with Bottoming Steam Rankine Cycle



Figure 1.15 T-s Diagram for Combine Open Air Brayton Cycle with Bottoming Steam Rankine Cycle (Çengel & Boles, 2011)

1.2 Scope of Work

The new class of modular nuclear microreactors are largely untested and unproven. Thus, to aid in the development of the new class of modular nuclear microreactors, INL is developing the Microreactor AGile Non-nuclear Experimental Testbed (MAGNET) which will allow for the testing of various nuclear reactor types under safe conditions. The reactor types will be tested using electrically heated cartridges to mimic the heat produced from nuclear fission. This makes testing the reactor types safe from radiation and the article can be tested in steady state conditions, off design conditions, and safely tested to failure (Guillen, et al., 2019). Aspen HYSYS (Aspen Technology, Inc., 2016) has been used to develop the MAGNET and aid in its development. Aspen HYSYS models have been created for the MAGNET as well as PCU and a PCU simulator.

1.3 Thesis Outline

The course of discussion throughout this report begins in Chapter 2 with the development of the MAGNET Aspen HYSYS models. This entails detailed components and various process parameters at normal operations as well as off design conditions. Chapter 3 begins the Aspen HYSYS development of a physical PCU attached to the MAGNET as well as the development of a PCU simulator. The final chapter, Chapter 4, details the analysis of a simple Brayton cycle start up for off design simulations in the PCU simulator.

Chapter 2: Microreactor AGile Non-nuclear Experimental Testbed

2.1 Introduction

Experimental work will be performed at INL at the Microreactor AGile Non-nuclear Experimental Testbed (MAGNET) shown in Figure 2.1. The purpose of the MAGNET is to assists with the development, demonstration, and validation of microreactor components and systems. It will aid in moving the microreactor technology further by reducing the uncertainty and risk relative to the operation and deployment of these units. The MAGNET is being designed such that the systems and components can be safely tested in steady state operations, off design conditions, and to failure points. This will provide valuable information on failure mechanisms and limits. A goal of the MAGNET is to be diverse enough to test multiple microreactor concepts. The first test article the MAGNET is being designed for is a heat pipe cooled reactor prototype (Guillen, et al., 2019).

The MAGNET has the following specifications operating with a heat pipe cooled reactor (Guillen, et al., 2019):

- Power: nominal 250 kWth.
- Heat pipe working fluid: Sodium.
- Heat pipe operating temperature: 650°C.
- Heat pipes are cooled with a closed nitrogen or helium loop.
- Experiments may require up to 300 hours of continuous testing.
- Horizontally oriented heat pipes.

Aspen HYSYS v. 9 from AspenTech[©] (Aspen Technology, Inc., 2016) has been used to help aid in the development of the MAGNET. Aspen HYSYS is a chemical thermo-process modeling program that simulates process conditions throughout systems. Aspen HYSYS models of the MAGNET have been designed to estimate the process conditions throughout the testbed.



Figure 2.1 Rendering of the INL MAGNET Facility Design

2.2 MAGNET Aspen HYSYS Model Development with 250 kW of Heat Pipe Power

A process flow diagram of the INL MAGNET facility is shown in Figure 2.2 (O'Brien, 2019). The current testbed was designed to operate with a maximum gas coolant temperature of 600°C and a maximum design pressure of 2200 kPa. The working fluid within the loop will be either nitrogen or helium, depending on the tests. Aspen-HYSYS was utilized to create a process model for the test loop and is shown in Figure 2.3 with its accompanying process data sheet in Table 2.1. The process model estimates the pressure losses in the equipment and heat losses in the piping. Modeling approximations for the equipment found in the MAGNET have been made based on data sheets and assumptions which are described later in this chapter. The temperature and pressure values shown in the INL process diagram, Figure 2.2, and the Aspen HYSYS model, Figure 2.3, match closely.

The process data was based on a 250-kW heat pipe reactor with 600°C exit temperature from the vacuum chamber. There are two similar models, one using nitrogen as the working fluid and the other using helium. Both models assume the same conditions but use different fluids. The process conditions and flow sheets for both the nitrogen and the helium models are found in Appendix A for comparison. The models and figures shown throughout the chapter are the nitrogen cycles unless specified otherwise. The conditions surrounding the heat exchangers were set as close as possible to the information found in their respective data sheets, found in Appendix E and Appendix F.



Figure 2.2 Nitrogen Process flow diagram of INL's Microreactor AGile Non-nuclear Experimental Testbed (O'Brien, 2019)



Figure 2.3 Aspen HYSYS Process Model of 250 kW Nitrogen Microreactor AGile Non-nuclear Experimental Testbed
		Material Strea	ams		
	HX-01			HX-01	RHX-01
	Hot In	CWR	CWS	Hot Out	Cold In
Temperature (°C)	283.15	17.78	6.67	20.00	32.95
Pressure (kPa)	1222.01	473.89	500.01	1210.68	1285.14
Mass Flow (kg/s)	0.92	6.76	6.76	0.92	0.92
	RHX-01	Vacuum		~ ~ ~ ~	
	Cold Out	Chamber In	6	Chiller In	Chiller Out
Temperature (°C)	358.75	358.07	19.97	17.78	6.66
Pressure (kPa)	1274.36	1272.00	1194.00	483.36	473.69
Mass Flow (kg/s)	0.92	0.92	0.92	6.76	6.76
	CWS-04	CWR-01	CWR-05	CWS-02	15
Temperature (°C)	6.66	17.78	17.78	6.66	32.95
Pressure (kPa)	485.46	451.51	483.52	520.19	1286.02
Mass Flow (kg/s)	6.76	6.76	6.76	6.76	0.92
	4.6			RHX Hot	RHX Cold
F (AG)	16	Comp Out	4-2	Avg	Avg
Temperature (°C)	19.97	33.14	33.07	440.94	195.85
Pressure (kPa)	1193.41	1326.67	1302.91	1232.14	1279.75
Mass Flow (kg/s)	0.92	0.92	0.92	1.00	1.00
	2	Vacuum Chombor Out	Hot In	KHA-01 Hot Out	Comp In
Temperature $(^{\circ}C)$	6.65		508 47	283 42	10.04
$\frac{1}{2} \frac{1}{2} \frac{1}$	520.39	1246.93	12/1 33	1222 96	1180.88
Mass Flow (ka/s)	676	0.92	0.02	0.92	0.02
W1035 110w (Kg/S)	CWS-03	CWS-06	13	14	CWR-02
Temperature ($^{\circ}C$)	6.66	6.67	33.07	32.95	17 78
$\frac{1}{2} \frac{1}{2} \frac{1}$	519.99	484 84	1302 35	1286 59	451 31
Mass Flow (kg/s)	676	676	0.92	0.92	676
W1035 1 10 W (Kg/5)	CWR-03	CWR-04	CWS-05	0.92	0.70
Temperature (°C)	17 78	17 78	6 67		
Pressure (kPa)	450.90	483 72	485.03		
Mass Flow (kg/s)	676	676	676		
101005 1 10 W (KZ/S)	0.70	Energy Stree	0.70		
			PIPE-	PIPE-	
		PIPE-RHX-	RHX-01	RHX-01	
		01 Cold Out	Hot In	Hot Out	PIPE-HV-
	Heat Pipes	Heat	Heat	Heat	03 Heat
Heat Flow (MW)	2.50E-01	6.88E-04	1.62E-03	2.64E-04	7.91E-05

Table 2.1 Aspen HYSYS Process Model of 250 kW Nitrogen Microreactor AGile Non-Nuclear Experimental Testbed Process Conditions

	PIPE-HX- 01 Hot Heat	PIPE-HV-02 Heat	Comp Power	Chiller Duty	PIPE- CWS-06 Heat
Heat Flow (MW)	-6.77E-06	-6.67E-07	1.25E-02	2.60E-01	-5.76E-06
	PIPE- CWS-03 Heat	PIPE-CWR- Heat	PIPE- CWR-05 Heat	PIPE- CWS-01 Heat	PIPE-HV- 01 Heat
Heat Flow (MW)	-2.03E-05 PIPE- Comp	-7.01E-06 Chiller Pump	-2.42E-06 PIPE- CWR-02	-1.03E-05 PIPE- CWR-03	5.91E-06 PIPE- CWS-04
Hoot Flow (MW)	Heat	Power	Heat	Heat	Heat
	Heat Excl	nangers	-0.12E-00	-4.0312-00	-2.0111-03
		RHX-01	Chiller HX- 01		
Duty (MW)		0.324	0.260		
LMTD (°C)		245.17	84.80		
UA (W/°C)		1320.68	3065.07		
Minimum Approach	$(^{\circ}C)$	239.72	13.33		

2.2.1 MAGNET Piping and Valves

The MAGNET model is used to estimate the expected conditions of the testbed. This detailed model incorporates the piping and fittings found within the system. The piping components model the length of the pipe, the pipe size, the pipe insulation, pipe fittings, and the change in height for each pipe segment. The piping data was obtained from INL documentation and AutoCAD *.dwg files detailing exact pipe lengths and elevation changes. The pipe segment lengths, heights, and fittings were constructed as described in Aspen HYSYS Operations Guide. An example of the configuration is shown in Figure 2.4. The reference height for all the pipes is 10 inches from the ground, as that is the height of the skid the MAGNET is mounted on.

Each pipe segment includes all the piping and fittings between the components in their names. For example, "Pipe-CWS-HV-003 to HX-01" is the cold-water service pipeline from the valve HV-003 to chiller HX-01. It includes the piping, lengths, elevation changes, and the fittings. Figure 2.5 shows the first 5 elements out of the 14 total elements for "Pipe-CWS-HV-003 to HX-01." These elements represent different pipe fittings: such as pipes, reducers, tees, and elbows. Pipe unions were also modeled as piping with an equivalent length to approximate

the correct pressure drop. These elements are used to calculate the pressure loss due to friction and minor losses throughout the piping section.



Figure 2.4 AspenTech HYSYS Operations Guide for Pipe Sections (Aspen Technology, 2005)

Segment	1	2	3	4	5
Fitting/Pipe	Pipe	Swage:Abrupt	Pipe	Elbow: 90 Long	Pipe
Length/Equivalent Length	0.7361	0.0000	0.3658	1.403	0.4514
Elevation Change	0.0000	0.0000	0.0000	0.0000	-0.4514
Outer Diameter	114.3	<empty></empty>	88.90	<empty></empty>	88.90
Inner Diameter	102.3	<empty></empty>	77.93	77.93	77.93
Material	Mild Steel				
Roughness	4.572e-005	4.572e-005	4.572e-005	4.572e-005	4.572e-005
Pipe Wall Conductivity	45.00	45.00	45.00	45.00	45.00
Increments	5	1	5	1	5
FittingNo	<empty></empty>	<empty></empty>	<empty></empty>	1	<empty></empty>

Figure 2.5 Pipe-CWS-HV-003 to HX-01 Piping Elements

Various data can be obtained for each pipe segment found within the Aspen HYSYS model. Examples of the information that can be gathered from the pipe segments are shown in Figure 2.6. This information can be turned into useful plots and broken down across the length of the pipe segment. This allows for graphical representations to determine the effects of fittings, pipe length, and elevation change. Using the pipe segment "Pipe-CWS-HV-003 to HX-01," the same as above, the elevation change and pressure in the pipe have been plotted and shown in Figure 2.7. The pressure is shown to decrease across the pipe segment from the CWS 4-inch Ball Valve and 4-inch to 3-inch reducer. The pressure makes a sharp drop at the reducer, Elevation
 Temperature
 Pressure
 Vapour Fraction
 Heat Trans
 Gradients
 Liq Holdup
 Water Holdup
 Liq Re
 Vap Re
 Liq Velocity
 Vap Velocity
 Deposit Thickness
 Deposit Volume

Figure 2.6 Pipe Segment Information

around 1.1 m along the length of the pipe, then decreases to the elbow. The pressure is shown to increase between \sim 1.1 m to \sim 3 m along the length of the pipe due to a decrease in elevation. After this change, the pipe is then kept at a constant elevation and the pressure gradually drops. The piping modeled only incorporates vertical or horizontal piping and the profile is shown in Figure 2.8. It should be noted that the pipe length is slightly longer than physically present due to the estimation of the union pressure drops using equivalent pipe lengths. It should also be noted that the fluid being used for the chilled water loop is EG50, which is a water and ethylene glycol mixture. The mass composition used is about 55% of water to 45% of ethylene glycol. The percentages were determined to match the given properties from the chiller HX-01 data sheet supplied by the manufacturer.

Figure 2.9 shows similar plots for the pipe "Pipe-HV-03 to HV-01" which has a working fluid of pure nitrogen. This pipe segment has 32 different piping elements. Figure 2.10 shows the pressure and elevation changes compared to the total pipe length of the MAGNET. The graph starts at the exhaust of the compressor and terminates at the inlet to the compressor.



Figure 2.7 Pipe-CWS-HV-003 to HX-01 Elevation and Pressure Verse Pipe Length Plot



Figure 2.8 Pipe-CWS-HV-003 to HX-01 Elevation Profile



Figure 2.9 Pipe-HV-03 to HV-01 Elevation and Pressure Verse Pipe Length Plot



Figure 2.10 MAGNET Piping Pressure Drop and Height Profile using Nitrogen at 250 kW of Heat Pipe Power

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The valving is located between the physical pipe segments in the MAGNET. The valves are all isolation valves of varying sizes and will either be fully opened or fully closed during operation. Aspen HYSYS calculated the pressure drop across the valves using the Cv supplied by the manufacturer. The gas valves are three-inch valves and the chilled water valves are four-inch valves. The Cv values used are shown in Table 2.2. The pressure drop varies for each Aspen HYSYS model depending on flow rates and fluid conditions.

Valve Flow Coefficients					
Size	C_v	Size	C_{v}	Size	C_v
1-1/2"	100	2-1/2"	285	4"	610
2"	145	3"	425	6"	920

 Table 2.2 Valve Flow Coefficients (Keckley Company)

The MAGNET is using Thermo 1200 for the piping insulation and is four inches thick. The insulation was assumed to be placed on all pipe segments. To accurately describe the pipe segments, the thermal conductivity of the insulation was considered for each pipe segment. According to the manufacturer, the thermal conductivity of the insulation is dependent on the mean temperature (Johns Manville, 2019). The manufacture's insulation information is shown in Appendix D. The mean insulation temperature was based on the average of the pipe inlet and outlet temperatures of the working fluid and the ambient temperature. The ambient air temperature surrounding the piping is assumed to be 21.11°C for all piping, both the indoors and outdoors. The MAGNET gas piping has an insulation thickness of 4 inches. The chilled water piping uses a different type of insulation with a thickness of 1.5 inches. An example of the inlet temperature, outlet temperature, mean temperature, and thermal conductivity for the nitrogen loop with the heat pipes operating at 250 kW are shown in Table 2.3. The thermal conductivity values vary for each model as the inlet temperatures differ due to the working fluid and heat pipe power load. The insulation's thermal conductivity for the chilled water loop was also adjusted for each model. The exact values for the thermal conductivities of the insulation can be seen in Appendix A through Appendix C under the Piping Segments section in the tables.

Aspen HYSYS also estimates the outside heat transfer coefficient surrounding the piping using the ambient temperature and the airflow across the pipes. The ambient air temperature is the same as above, 21.11°C, and the airflow is assumed to be 1 ft/sec (0.31 m/s). Both the ambient temperature and the airflow across the pipes can easily be adjusted. The airflow was estimated for the conditions found in the testing facility and the velocity is within the expected air speed range for thermal comfort, as shown in Figure 2.11. This figure was created from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 55 parameters (Jenkins, 2019).

	Pipe Inlet Temperature (°C)	Pipe Outlet Temperature (°C)	Average Pipe Temperature (°C)	Mean Temperature (°C)	Thermal Conductivity (W/mºC)
RHX-01 Hot in Piping	600	598.5	599.2	310	0.0844
RHX-01 Hot out Piping	283.5	283.2	283.3	152	0.0635
RHX-01 Cold in Piping	33.06	33.05	33.05	27	0.0486
out Piping	358.8	358.1	358.5	190	0.0683

Table 2.3 Piping	Thermal	Conductivity	Values
------------------	---------	--------------	--------



Figure 2.11 Thermal Comfort Chart using ASHRAE 55 Parameters (Jenkins, 2019)

2.2.2 Heat Exchangers

2.2.2.1 Recuperating Heat Exchanger

A recuperating heat exchanger is in the design of the MAGNET. These types of heat exchangers are generally used to preheat the working fluid before entering the process. Preheating the gas reduces the required heat addition to the working fluid from the heater. It can also increase the mass flow rate of the system at a constant heat load which can increase production (Çengel & Boles, 2011). The recuperating heat exchanger used in the MAGNET is a printed circuit heat exchanger (PCHE) and is used to preheat the gas before it enters the vacuum chamber containing the heat pipes. This lowers the electrical energy used to power the electric heaters to activate the heat pipes. INL specified the desired process conditions of the recuperating heat exchanger, shown in Table 2.4.

	Cold Side Parameters	Hot Side Parameters
Mass Flow Rate	0.938 kg/s	0.938 kg/s
Nominal Inlet Pressure	12 bar_g	10.625 bar_g
Nominal Pressure Difference	0.375 bar_g	0.375 bar_g
Nominal T _{in}	38 °C	600 °C
Nominal T _{out}	360 °C	290 °C

Table 2.4 MAGNET Recuperating Heat Exchanger Design Conditions

An approximation for the MAGNET recuperated heat exchanger was modeled in Aspen HYSYS to approximate its performance in the Aspen HYSYS models. This allowed the recuperating heat exchanger to be operated at off design conditions, where the design conditions are nitrogen at 250 kW of heat pipe power. The heat transfer and pressure drop correlations were found in the Physical Model Development and Optimal Design of PCHE for Intermediate Heat Exchangers in HTGRs (Kim & No, 2012). The correlations shown in Kim and No's paper for pressure drop are shown in Equation 2.1 and Equation 2.2. Their Nusselt number correlation is shown in Equation 2.3. They did not include the Prandtl number in their correlations and their justification was that the Prandtl numbers remained nearly constant. In the MAGNET models for both helium and nitrogen, the Prandtl numbers also remain nearly constant. The model may be a better approximation for helium compared to nitrogen as there is little variation in the helium Prandtl number. The Prandtl numbers are shown in Table 2.5. The "Hot Avg" and "Cold

Avg" Prandtl numbers are based off the average temperature across the heat exchanger, not the averages of the Prandtl numbers.

f

Re

$$f \cdot Re = 15.78 + a \cdot Re^{b}$$
 Equation 2.1

$$f = \frac{\triangle P D_h}{2L_p \rho v^2} \qquad \qquad Equation \ 2.2$$

$$Nu = 4.089 + c \cdot Re^d$$
 Equation 2.3

Where:

→ Fanning Factor

 \rightarrow Reynolds Number

Nu	\rightarrow Nusselt Number

 $\triangle P \longrightarrow$ Pressure Drop

 $D_h \rightarrow$ Hydraulic Diameter

 $L_p \rightarrow$ Actual Channel Length in a Pitch

 $v \rightarrow$ Velocity

 $\rho \rightarrow$ Fluid Density

 $a, b, c, d \rightarrow$ Fitting Constants for Geometry

a	b	с	d
0.009126	0.9913	0.001255	1.058

NOTE: a, b, c, and d were interpolated between the listed values

Table 2.5 Recuperating Heat Exchanger Prandtl Number Comparison

Recuperating Heat Exchanger Prandtl Number Comparison						
	Hot In	Hot Out	Hot Avg	Cold In	Cold	Cold
					Out	Avg
Pr (N2)	0.8112	0.7469	0.7747	0.7461	0.7584	0.7395
Pr (He)	0.6722	0.6729	0.6728	0.6714	0.6727	0.6729

A PCHE was sized and designed to meet the conditions set by INL by following Kim and No's approach. This heat exchanger approximates how the MAGNET PCHE could perform. The manufacture has not provided details on the performance or internal structure for a more accurate model. However, this is a good approximation and starting point for the heat exchanger. The design was set to match Kim and No's heat exchanger found in their report. They assumed that the flow channels are half circles and are counter current that are oriented parallel to each other, but the channels could be zig-zagged, as shown in Figure 2.12. The physical dimensions of the recuperating heat exchanger were approximated to fit within the manifold manufacturing drawings, shown in Appendix E. With the estimated outer dimensions, the PCHE was designed in Dassault SolidWorks to develop a reasonable sized PCHE with an appropriate plate count, channel count, channel size, channel angle, and heat transfer surface area. This ensured a design that could physically be made. The parameters were adjusted to match the UA from the MAGNET design specifications, which was approximately 1332 W/°C. The overall heat transfer coefficient (U) was found using the correlation found in Equation 2.3, which produced a distinct heat transfer area (A). The flow channel parameters and number of plates were adjusted to match the needed U and A. The found area was held constant for every Aspen HYSYS model. The exit temperatures were also adjusted to match the calculated UA from the known U and A from the correlation. The resulting heat exchanger design is shown in Figure 2.13. The accompanying table detailing the internal structure of the heat exchanger is shown in Table 2.6. It should be noted, again, that this could approximate the MAGNET recuperating heat exchanger and is not the exact heat exchanger being supplied.

The advantage of having a designed heat exchanger in the model is that it can simulate results when off design conditions are used. The recuperated heat exchanger design functions from an imbedded spread sheet found within Aspen HYSYS. The process variables are adjusted to match the heat exchanger's UA and pressure drop calculated in the spread sheet. The heat transfer area remains constant and the overall heat transfer coefficient and pressure drops are calculated using the correlations. A comparison between the inlet and outlet conditions using helium and nitrogen compared to the MAGNET design conditions are shown in Table 2.7. From the table, the nitrogen cycle matches closely to the MAGNET design conditions. The text in red shows the difference in the temperatures coming out of the heat exchanger. The nitrogen and helium temperatures vary greatly from each other, but it is also seen that the nitrogen has a much larger mass flow rate.



Figure 2.12 Kim and No's PCHE Design (Kim & No, 2012)



Figure 2.13 MAGNET Recuperating Heat Exchanger Design

Recuperating Heat Exchanger Internal Parameters						
Diameter (D)	2.00 mm	0.002 m				
Hydraulic Diameter (Dh)	1.22 mm	0.00122 m				
Pitch (P)	24.60 mm	0.0246 m				
Theta (Degrees)	6.43					
Theta (Rad)	0.112					
Length per Pitch (Lp)	24.76 mm	0.02476 m				
Flow Area per Channel (Af)	1.571 mm^2	1.57 E-6 m^2				
Channels per Sheet	65					
Number of Sheets	112					
Number of Pitches	9					
Af for Cold Channel	5.718 E-3 m^2					
Af for Hot Channel	5.718 E-3 m^2					
Perimeter	5.142 E-3 m					
Surface Area per Pitch (As)	1.273 E-4 m^2					
As Cold per Channel	1.146 E-3 m^2					
As Hot per Channel	1.146 E-3 m^2					
Total As Cold	4.170 m^2					
Total As Hot	4.170 m^2					

Table 2.6 MAGNET Recuperating Heat Exchanger Interal Parameters

Table 2.7 Recuperating Heat Exchanger Performance Comparison at 250 kW of Heat Pipe Power

RHX-01 Comparison at 250 kW Heat Pipe Power						
	Nitrogen	Helium	MAGNET Design			
Temperature [°C]						
Hot In	598.5	598.9	600			
Hot Out	283.5	208.5	~290			
Cold In	33.05	34.88	38			
Cold Out	358.8	425.1	360			
Hot Side Pressure Drop (kPa)	18.45	17.28	37.5			
Cold Side Pressure Drop (kPa)	10.83	11.16	37.5			
Duty (kW)	323.8	556.1	326.95			
U (W/m^2C)	316.8	767.7				
UA (W/C)	1321	3201	1332			
A (m^2)	4.170	4.170				
Mass Flow Rate (kg/s)	0.919	0.274	0.938			

It should be noted, for all heat exchangers shown in this report, that there is a smaller difference in temperature when helium is used compared to nitrogen. This is due to a difference

in the specific heat (C_p) values for the two fluids. Since both fluids in these operating ranges can be assumed to be ideal gases, the governing equation can be simplified and is shown in Equation 2.4. The equation shows that helium has the same amount of heat transfer for a smaller change in temperature compared to nitrogen as helium's C_p is approximately 5 times large than nitrogen at room temperature (Çengel & Boles, 2011).

$$\dot{Q} = \dot{m}C_p \Delta T$$
 Equation 2.4

2.2.2.2 Heat Pipe Heat Exchanger Approximation

Los Alamos National Laboratory (LANL) is currently developing a heat pipe heat exchanger using a plenum to distribute flow to the tubes surrounding the heat pipes. These tubes perform like many tube-in-tube heat exchangers that are connected in parallel. Figure 2.14 shows a general schematic of LANL's heat pipe cooled reactor with attached heat exchanger (McClure, Poston, Rao, & Reid, 2015). A double tubed heat exchanger was designed in an Aspen HYSYS spread sheet to approximate the performance of the heat pipe heat exchanger under varying process parameters. This heat exchanger was designed assuming a pure double tubed heat exchanger in parallel. It is not LANL's heat exchanger design as their information is unknown. The design in Aspen HYSYS is only an approximation to give a general idea of how different conditions affect the performance of MAGNET. This is, however, a good approximation. The double tubed heat exchanger was sized to heat nitrogen to 600°C assuming the full power load of 250 kW at 2 kW per heat pipe. This means there are 125 heat pipes in the system, and they are assumed to operate at 650°C (Guillen, et al., 2019). Figure 2.15 shows the configuration of the heat exchanger attached to the heat pipes in the MAGNET Aspen HYSYS model. The heat exchanger is a bunch of double tubes in parallel which increases the total heat transfer area, illustrated in Figure 2.16. It is assumed that the total MAGNET flow is split evenly across each heat pipe. The heat pipes are filled with sodium and sodium's properties have been estimated using "Thermodynamic and Transport Properties of Sodium Liquid and Vapor" (Fink & Leibowitz, 1995). This allows for an approximation for the outlet temperature of the working fluid.



Figure 2.14 LANL's Sample Schematic of Heat Pipe Reactor with Heat Exchanger Attached (McClure, Poston, Rao, & Reid, 2015)



Figure 2.15 Heat Pipe Heat Exchanger Model



Figure 2.16 MAGNET Double Tubed Heat Pipe Heat Exchanger Illustration

The heat exchanger was designed from standard double tubed heat exchanger correlations. The equations used were obtained in *Design of Fluid Thermal Systems* by William Janna. To solve for this type of heat exchanger, it was assumed that the heat pipes were isothermal. This is a fair assumption as heat pipes only vary by a small amount across the condenser (Advanced Cooling Technologies, 2020; Meseguer, Perez-Greande, & Sanz-Andres, 2012). Therefore, the process of finding the required heat transfer coefficient was done by finding the heat exchanger effectiveness and number of transfer units (NTU) at the design conditions. Since the heat pipe is isothermal and condensing, the equations for the solution simplify greatly. From the correlations, U was found and then the inner diameter of the outer pipe was adjusted to match the required UA. The diameters were held constant after the correct area was found.

$$Nu = \frac{hD}{k_f} = 0.023 (Re)^{\frac{4}{5}} Pr^{0.4}$$
 Equation 2.5

The double tubed heat exchanger was sized around heat pipes that have condenser lengths of 3.28 ft (1 m) and diameters of 5/8 in. The outside tube's inner diameter for the heat exchanger is 0.7772 in. This allows for an accurate approximation of the outlet temperature of the working fluid in the MAGNET during varying process parameters. The heat exchanger is designed in

an Aspen HYSYS embedded spread sheet. The sizing of the double tubed heat exchanger is shown in Table 2.8 with an single tube illustration in Figure 2.17.

Double Tubed Heat Pipe Heat E	xchanger Design
Heat Pipe Outer Diameter	1.59 e-2 m
Outer Pipe Inner Diameter	1.97 e-2 m
Length of Heat Pipe	1.00 m
Heat Transfer Surface Area	4.99 E-2 m^2
Heat Pipe Power	250 kW
Single Heat Pipe Power Load	2 kW
Number of Heat Pipes	125

Table 2.8 Double Tubed Heat Pipe Heat Exchanger Design





The described double tubed heat exchanger was created in an Aspen HYSYS heat exchanger model to compare the spread sheet results. The Aspen HYSYS heat exchanger used the same design parameters and tube sizes as was designed in the Aspen HYSYS spread sheet. The Aspen HYSYS heat exchanger model was a single double tubed heat exchanger. The model could not simulate a duty load of 250 kW since it could only have 9 heat exchangers in parallel. This limited the comparison and validation to 9 heat pipes at 3 kW each. Thus, the models were

compared to a heat pipe power load of 27 kW. The resulting temperatures were similar to each other, as shown in Table 2.9. The Aspen HYSYS heat exchanger shows that the heat pipe temperature decreased slightly while still undergoing a near complete phase change. The fluid's phase changes from 1 (pure vapor) down to 0.0553 (near liquid). The pressure drop on the cold side (MAGNET gas) calculated by Aspen HYSYS is approximately 2% of the vacuum chamber's inlet pressure. Since the actual geometry of the real heat exchanger is not known, an assumption of a 2% pressure drop from 1266 kPa has been made across the spread sheet heat exchanger. This assumed pressure drop is held constant for each of the different variations in the process conditions.

Heat Pipe Heat Exchanger at 27 kW				
	Aspen HYSYS Spread Sheet	Aspen HYSYS Heat Exchanger		
Number of Heat Pipes	9	9		
Temperature [°C]				
Hot In	650.00	650.00		
Hot Out	650.00	649.9		
Cold In	442.3	442.3		
Cold Out	604.1	595.2		
Hot Side Pressure Drop (kPa)	0.00	0.011		
Cold Side Pressure Drop (kPa)	25.03	20.70		
Duty (kW)	27.00	25.51		
U (W/m^2°C)	562.5			
UA (W/°C)	252.5	222.3		
A (m^2)	0.449			
Cold Fluid Mass Flow Rate (kg/s)	0.147	0.147		

Table 2.9 Heat Pipe Heat Exchanger 27 kW Aspen HYSYS Comparison

The use of an approximated heat pipe heat exchanger has allowed for the comparison of the heat pipe performance between nitrogen and helium. Using nitrogen as the working fluid, the vacuum chamber outlet is approximately 600°C, while the helium loop temperature is closer to 634°C. The pipe insulation, thermo 1200, is rated to 650°C and the design operating temperature of the test loop is 600°C. The comparison between nitrogen and helium are in Table 2.10. The models using the heat pipe heat exchanger are found in Appendix B.

Heat Pipe Heat Exchanger				
250 kW				
	Nitrogen	Helium		
Number of Heat Pipes	125 @	2 kW		
Temperature [°C]				
Hot In	650	650		
Hot Out	650	650		
Cold In	358.1	451.7		
Cold Out	600.0	634.3		
Hot Side Pressure Drop (kPa)	0	0		
Cold Side Pressure Drop (kPa)	25.33	25.0		
Duty (kW)	250.0	250.0		
U (W/m^2°C)	293.9	556.8		
$UA(W/^{o}C)$	1832	3471		
A (m^2)	6.234	6.234		
Cold Fluid Mass Flow Rate (kg/s)	0.919	0.264		

Table 2.10 Heat Pipe Heat Exchanger Comparison for 250 kW

2.2.2.3 Chiller Heat Exchanger

Modelling the chiller heat exchanger, HX-01, was attempted; however, it was determined that critical information of the internal structure was lacking. This heat exchanger uses corrugated tubes, which enhance the heat transfer and increase the pressure drop considerably. Two separate shell and tube heat exchangers were modeled in an attempt to simulate the MAGNET chiller heat exchanger: one was modeled with the Aspen HYSYS heat exchanger component and the other was with standard equations. These heat exchanger models were built using the specifications provided by the manufacturer but used smooth tubes instead of corrugated tubes. This was done since the heat transfer correlations were known. The results were vastly different from the manufacturer's data, as shown in Table 2.11 to Table 2.13. The cold side is the chilled water entering the chiller heat exchanger and the hot side is the nitrogen in the MAGNET. The manufacturer's datasheet is found in Appendix F.

The exit temperatures shown in Table 2.12 and Table 2.13 are very comparable. The two varied slightly from each other because Aspen HYSYS used the current process fluid properties at the current temperatures while the book calculations used average properties between the large ranges set by the manufacture.

Table 2.11 Chiller HX-01 Manufacturers Data

Manufacturer									
Cold In Cold Out Hot In Hot Out									
Temp (°F)	44	64	527	68					
Pressure Drop (Psi)	3.79		1.64						
Log Mean Temp Difference (°F)	148.3								
Fitted Heat Transfer Area (ft^2)	24.09								
Duty (BTU/hr)	9.13 E5								
UA (BTU/hr °F)	6.15 E3								
U (BTU/hr ft^2 °F)	255.4								

Table 2.12 Chiller HX-01 Book Calculations using Equations and Correlations Found in
Design of Fluid Thermal Systems 4th ed (Janna, 2015)

Book Calculations							
Cold In Cold Out Hot In Hot Ou							
Temp (°F)	44	53.72	527	303.8			
Pressure Drop (Psi)	2.38		0.73				
Log Mean Temp Difference (°F)	355.9						
Fitted Heat Transfer Area (ft ²)	23.98						
Duty (BTU/hr)	4.55 E5						
UA (BTU/hr °F)	1.28 E3						
U (BTU/hr ft^2 °F)	53.48						

Table 2.13 Chiller HX-01 Aspen HYSYS Model using the Heat Exchanger Design Module

HYSYS Calculations									
Cold In Cold Out Hot In Hot Out									
Temp (°F)	44	53.11	527	320					
Pressure Drop (Psi)	1.60		0.70						
Log Mean Temp Difference (°F)	366.3								
Fitted Heat Transfer Area (ft^2)	-								
Duty (BTU/hr)	4.260 E5								
UA (BTU/hr °F)	1.16 E3								
U (BTU/hr ft^2 °F)	-								

Several different attempts were used to obtain the exit temperatures the manufacturer showed. First, the lengths of the designed heat exchangers were adjusted while the rest was held constant. The lengths needed to be around 30.5 ft long (up from 4.92 ft) to obtain similar outlet temperatures. This made the UA similar between the manufacturer's specifications, but the heat

transfer area was about 6 times larger than what the manufacturer showed. This is most likely not an effective design. Second, Richard Christensen, The Nuclear Engineering Program Director at the University of Idaho and heat exchanger expert, said that the fluted tubes could enhance heat transfer between 2 to 5 times (Christensen, 2020). Using this idea, the heat transfer coefficients were scaled by about 5.7 on the tube side and about 5.2 on the shell side. This was done while keeping the original length and design. This produced an appropriate exit temperature that matched the manufacturer's data. However, simply scaling the heat transfer coefficient might not accurately describe the effects of flow, fluid mixing, pressure drop, and heat transfer. Lastly, other heat transfer correlations were found and tested. Some had many values, like the Reynolds number, that were way out of the expected ranges while other correlations produced decent values, but the exit temperatures were still too high. It may be necessary to perform tests on the chiller HX-01 and collect data to build an accurate Aspen HYSYS heat exchanger model. The performance data could be used to create heat transfer correlations and could be simulated within Aspen HYSYS. The current values found within the nitrogen and helium MAGNET models are shown in Table 2.14. An approximation applied to adjust the chiller unit's mass flow rate to maintain a chilled water outlet temperature of 64°F (17.77°C). This makes the inlet and exit temperature of the chilled water and the MAGNET gas exit temperature to remain constant, which matches the chiller HX-01 manufacture's data sheet.

Table 2.14 Current Chiller HX-01 Values for the Nitrogen and Helium MAGNET Cycles using 250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

Current Chiller HX-01 Values							
Nitrogen Helium							
Duty (kW)/(BTU/hr)	260 (887200)	269 (916200)					
UA (W/°C)/(BTU/hr °F)	3065 (5810)	4611 (8740)					
Min. Approach (°C)/(°F)	13.33 (24.00)	13.33 (24.00)					
LMTD (°C)/(°F)	84.81 (152.7)	58.26 (104.9)					

2.2.3 Compressor

The compressor in the MAGNET is used to drive the flow and control the pressure of the MAGNET working fluid. A Corken Inc compressor, model FD691-4, has been purchased for the MAGNET. It is a 25 hp reciprocating compressor. The compressor is single staged with a variable speed drive. An attempt was made in Aspen HYSYS to model the compressor making it function from the rotational speed of the unit. However, the results from Aspen HYSYS did

not match the manufacture's data; therefore, the unit does not operate off the compressor specifications.

Aspen HYSYS has an option to model reciprocating compressors and requires internal information about the compressor to function. This information lets Aspen HYSYS simulate the compressor using the rotational speed. The needed data required for the compressor model is shown Table 2.15. To accurately model the compressor specification sheet is shown in Figure 2.18 and provides the needed information for Aspen HYSYS. A performance sheet was also obtained from INL and is shown in Figure 2.19. The pressures and temperatures in the performance sheet were used to determine the default fixed clearance volume to match the volumetric efficiency listed. For some of the conditions in the performance sheet to be met, the adiabatic efficiency of the compressor needed to be 100% to match the outlet temperature of 126°F. It was also determined that the default fixed clearance volume needed to be 24.25%. Though the exhaust temperature and volumetric efficiency were met, the flow rate of the gas was incorrect. The performance sheet showed a piston displacement of 48 CFM and Aspen HYSYS calculated 22.08 ACFM or 363.19 SCFM. This model was also used to check the compressor performance at the MAGNET conditions.

HYSYS Reciprocating Compressor Input Data				
Number of Cylinders	1			
Cylinder Type	Single-Acting, Outer End			
Bore (ft)	0.333			
Stroke (ft)	0.333			
Piston Rod Diameter (ft)	8.202 E-2			
Const. Vol. Efficiency Loss (%)	4.00			
Default Fixed Clearance Vol. (%)	24.25			
Zero Speed Flow Resistance (k)	0.0 lb/hr/sqrt(psia-lb/ft^3)			
Typical Design Speed (RPM)	825			
Volumetric Efficiency (%)	92			
Speed (RPM)	825			

Table 2.15 Aspen HYSYS Reciprocating Compressor Input Data

Specifications			Single-S	tage Con	npressor	s
D-style (single- distance piece)	D91	D291	D491	D491-3	D691	D691-4
T-style (double- distance piece)	T91	T291	T491	T491-3	T691	T691-4
Bore of cylinder inches	(mm)					
First stage	3.0 (76.2)	3.0 (76.2)	4.0 (101.6)	3.0 (76.2)	4.5 (114.3)	4.0 (101.6)
Second stage						
Stroke inches (mm)	2.5 (63.5)	2.5 (63.5)	3.0 (76.2)	3.0 (76.2)	4.0 (101.6)	4.0 (101.6)
Piston displacement CFM	(m³/hr)					
@ 400 rpm	4.1 (7.0)	8.2 (13.9)	17.5 (29.7)	9.8 (16.7)	29.5 (50.1)	23.3 (39.6)
@ 825 rpm	8.4 (14.3)	16.9 (28.7)	36.0 (61.2)	20.3 (34.5)	60.8 (103.3)	48.0 (81.6)
Maximum working pressure psig (bar g)	335 (23.1)	335 (23.1)	335 (23.1)	600 (41.4)	335 (23.1)	600 (41.4)
Maximum brake horsepower (kW)	7.5 (5.6)	15 (11)	15 (11)	15 (11)	35 (26.1)	35 (26.1)
Maximum rod load Ibs (kg)	3,600 (1,633)	3,600 (1,633)	4,000 (1,814)	4,000 (1,814)	7,000 (3,175)	7,000 (3,175)
Maximum discharge temperature °F (°C) ^b	350 (177)	350 (177)	350 (177)	350 (177)	350 (177)	350 (177)
Bare unit weight with flywheel lbs (kg)	150 (68.0)	210 (95.2)	390 (176.9)	390 (176.9)	745 (337.9)	745 (337.9)
ANSI/DIN flange option	Yes	Yes	Yes	Yes	Yes	Yes
Water-cooled option	-	-	-	-	Yes	Yes

Figure 2.18 Corken Compressors Data Sheet for D691-4 Industrial Series Compressors (Corken Inc, 2018)

Corken, Inc. Compressor Performance Worksheet

Oct. 16, 2019 Initials: MWS Notes: Idaho Nat Labs

Model: FD691-4

	Pi Displ	iston acement	Suction Pressure	Discl Pres	iarge sure	Compres	ss. Inlet Temp.	Outlet Temp.	Volum	etric Effic	iency
Stage	(C	FM)	(PSIG)	(PS	IG)	Ratio	Deg. F	Deg. F	Headend	Crankend	Overall
1	4	18.0	245.0	29	0.0	1.17	100.0	126	0.92	0.00	0.92
	Brake		Capa	acity				Efficiency		Inlet	Outlet
Stage	HP	ACFM	Discharge CFM	MCFD	SCFM	Lbs/Hr	Compress.	Mechanical	Overall	Comp.	Comp.
1	18.5	44.3	39.6	1054	731.8	3245	0.59	0.78	0.47	0.99	.99

Figure 2.19 MAGNET Compressor Performance Worksheet Calculator using Nitrogen

Several attempts were done to simulate the compressor from the given data but were unsuccessful. To perform these simulations, the found "default fixed clearance volume" was kept constant for the compressor at MAGNET conditions using nitrogen at 250 kW of heat pipe power. As a 100% adiabatic efficiency is unrealistic, an upper end compressor efficiency of 75% was used for one study and 47% for another study. The efficiency of 47% was shown in the performance sheet in Figure 2.19. The two tests consisted of defining the needed flow rate and having Aspen HYSYS calculate the needed compressor speed. For both tests, the calculated compressor speed was around 5308 rpm. The manufacture's data show an operating speed of 850 rpm. The two case studies are shown in Figure 2.20. These values are extremely large; therefore, the compressor models are not estimating the performance of the compressor using the compressor information.

_	<u> </u>		Number of Cylinders	1
Com	p Inlet	Comp Outlet	Cylinder Type	Single-acting, Outer End
67.90	F	91.86 F	Bore [ft]	0.3333
165.7	ncia	176.9 psig	Stroke [ft]	0.3333
155.7	psig	170.5 psig	Piston Rod Diameter [ft]	8.202€-002
143.3	ACFM	133.4 ACFM	Const. Vol. Efficiency Loss [%]	4.00
1642	ft3/min 🛝 _	1642 ft3/min	Default Fixed Clearance Vol. [%]	24.25
7201	lb/hr		Zero Speed Flow Resistance (k)	0.0000 lb/hr/sqrt(psia-lb/ft3)
1231	C	Compressor Power	Typical Design Speed [rpm]	850.0
	Compres	sor 16.98 hp	Volumetric Efficiency [%]	92.83
	Adiabatic Efficier	icv 75	Speed [rpm]	5309
			I	
	 (→	Number of Cylinders	1
Cor	np Inlet	Comp Outlet	Number of Cylinders Cylinder Type	1 Single-acting, Outer End
Cor 67.90	np Inlet F	Comp Outlet 105.7 F	Number of Cylinders Cylinder Type Bore [ft]	1 Single-acting, Outer End 0.3333
Cor 67.90	np Inlet F	Comp Outlet 105.7 F 176.9 psig	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft]	1 Single-acting, Outer End 0.3333 0.3333
Cor 67.90 155.7	np Inlet F psig	Comp Outlet 105.7 F 176.9 psig	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002
Cor 67.90 155.7 143.3	np Inlet F psig ACFM	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00
Cor 67.90 155.7 143.3 1642	np Inlet F psig ACFM ft3/min	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM 1642 ft3/min	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%] Default Fixed Clearance Vol. [%]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00 24.25
Cor 67.90 155.7 143.3 1642 7291	np Inlet F psig ACFM ft3/min Ib/hr	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM 1642 ft3/min	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%] Default Fixed Clearance Vol. [%] Zero Speed Flow Resistance (k)	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00 24.25 0.0000 lb/hr/sqrt(psia-lb/ft3)
Cor 67.90 155.7 143.3 1642 7291	np Inlet F psig ACFM ft3/min Ib/hr	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM 1642 ft3/min Compressor Power	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%] Default Fixed Clearance Vol. [%] Zero Speed Flow Resistance (k) Typical Design Speed [rpm]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00 24.25 0.0000 lb/hr/sqrt(psia-lb/ft3) 850.0
Cor 67.90 155.7 143.3 1642 7291	np Inlet F psig ACFM ft3/min Ib/hr Compres	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM 1642 ft3/min Compressor Power sor 27.09 hp	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%] Default Fixed Clearance Vol. [%] Zero Speed Flow Resistance (k) Typical Design Speed [rpm] Volumetric Efficiency [%]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00 24.25 0.0000 lb/hr/sqrt(psia-lb/ft3) 850.0 92.84
Cor 67.90 155.7 143.3 1642 7291	np Inlet F psig ACFM ft3/min Ib/hr Compres Adiabatic Efficier	Comp Outlet 105.7 F 176.9 psig 136.9 ACFM 1642 ft3/min Compressor Power sor 27.09 hp 1cy 47	Number of Cylinders Cylinder Type Bore [ft] Stroke [ft] Piston Rod Diameter [ft] Const. Vol. Efficiency Loss [%] Default Fixed Clearance Vol. [%] Zero Speed Flow Resistance (k) Typical Design Speed [rpm] Volumetric Efficiency [%] Speed [rpm]	1 Single-acting, Outer End 0.3333 0.3333 8.202e-002 4.00 24.25 0.0000 lb/hr/sqrt(psia-lb/ft3) 850.0 92.84 5308

Figure 2.20 Aspen HYSYS Compressor Case Studies at MAGNET Conditions using Nitrogen at 250 kW without the Heat Pipe Heat Exchanger

The compressors for the Aspen HYSYS models were assumed to have a 75% adiabatic efficiency. This value is on the upper end of compressor efficiencies and may represent the best possible scenario. The units are not dynamically solved from the compressor's specifications and rotational speed. Table 2.16 shows a comparison between the duty, horsepower, and compression ratio between the nitrogen and the helium cycle. The current compressor operates from a 25 hp motor. To maintain the pressures using helium, the compressor uses 29 hp. There

was also a slight difference in pressure ratios due to differences in the pressure losses across the MAGNET equipment.

Compressor		
	N2	He
Horse Power (hp)	16.83	28.90
Duty (kW)	12.55	21.55
Pressure Ratio	1.123	1.100
Mass Flow (kg/s)	0.919	0.274
Actual Volumetric Flow Rate (m3/h)	243.5	505.3

Table 2.16 Compressor Comparison Between Nitrogen and Helium MAGNET Cycles using250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

2.2.4 Chiller Unit

A 200-ton chiller unit is used to cool the MAGNET loop. The loop is connected to the chiller heat exchanger HX-01. The fluid being used in the chilled water loop is EG50, which is a combination of water and ethylene glycol. The piping between the heat exchanger HX-01 and chiller unit has been modeled and provides the required duty from the physical chiller unit, shown in Figure 2.21. There is a difference in chiller duties between the helium and nitrogen loops, as shown in Table 2.17. The flow rate is also different due to maintaining a constant chilled water outlet temperature from the chiller HX-01.

Table 2.17 Chiller Duty Comparison Between Nitrogen and Helium MAGNET Cycles using250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

Chiller				
	N2	He		
Duty (kW)	260.5	269.1		
Mass Flow (kg/s)	6.76	6.98		

Another Aspen HYSYS model being considered to attach to the MAGNET is the 200-ton chiller unit. This model includes the pump for the EG50 fluid. The EG50 is chilled by R-410a in the refrigeration loop, which is air-cooled. This model is lacking expected conditions of the refrigeration loop. The model is shown in Figure 2.22 and would be attached to the "Chiller In" and "Chiller Out" streams found in the MAGNET model. The chiller pump in the MAGNET model would also be removed.



Figure 2.21 MAGNET Chilled Water Loop using Nitrogen at 250 kW Heat Pipe Power without the Heat Pipe Heat Exchanger



Figure 2.22 Chiller Unit Model

2.3 MAGNET Aspen HYSYS Model Development Operating at Off-Design Heat Pipe Power

2.3.1 MAGNET Operating at 75 kW of Heat Pipe Power

One of the initial tests the MAGNET will operate at is 75 kW of power to the heat pipes. The Aspen HYSYS process flow diagram for nitrogen is shown in Figure 2.23 with its process data in Table 2.18. This test loop condition has a flow rate of 0.324 kg/s compared to full scale

flow of 0.919 kg/s. The recuperating heat exchanger also has slightly different conditions with the slower flow rate. Detailed process conditions for nitrogen and helium are found in Appendix A.

Comparison tables between the helium and nitrogen loops operating at 75 kW and 250 kW of heat pipe power are shown below in Table 2.19 to Table 2.21 for the compressor, chiller, and the recuperating heat exchanger. The heat pipe heat exchanger was also compared between helium and nitrogen at 75 kW and 250 kW of heat pipe power. The mass flow rates were adjusted to obtain the desired duty from the heat exchanger. This produced the vacuum chamber outlet temperatures for nitrogen to be approximately 600°C, while the helium loop temperatures were closer to 634°C. It is also shown that the inlet temperatures on the cold side vary greatly between the cycles. The comparisons between nitrogen and helium are in Table 2.22.



Figure 2.23 MAGNET Operating with Nitrogen at 75 kW of Power without the Heat Pipe Heat Exchanger

		Material St	reams		
	HX-01 Hot			HX-01	RHX-01
	In	CWR	CWS	Hot Out	Cold In
Temperature (°C)	232.97	17.78	6.67	20.00	24.55
Pressure (kPa)	1237.32	473.89	500.00	1225.99	1268.60
Mass Flow (kg/s)	0.324	1.923	1.923	0.324	0.324
		Vacuum			
	RHX-01	Chamber	Vacuum	RHX-01	RHX-01
_	Cold Out	In	Chamber Out	t Hot In	Hot Out
Temperature (°C)	396.85	394.67	600.00	595.67	233.56
Pressure (kPa)	1266.68	1266.33	1241.33	1240.64	1237.48
Mass Flow (kg/s)	0.324	0.324	0.324	0.324	0.324
	C	ſ		Chiller	
	Comp In	6	Chiller In	Out	CWS-04
Temperature (°C)	20.02	20.02	17.78	6.65	6.66
Pressure (KPa)	1222.48	1223.99	487.26	477.52	480.61
Mass Flow (kg/s)	0.324	0.324	1.923	1.923	1.923
	CWR-01	CWR-05	CWS-02	CWS-03	CWS-06
Temperature (°C)	17.78	17.78	6.66	6.66	6.67
Pressure (kPa)	453.89	487.28	514.49	514.47	480.54
Mass Flow (kg/s)	1.923	1.923	1.923	1.923	1.923
	13	14	15	16	Comp Out
Temperature (°C)	24.63	24.56	24.56	20.02	24.65
Pressure (kPa)	1270.74	1268.78	1268.71	1223.92	1273.88
Mass Flow (kg/s)	0.324	0.324	0.324	0.324	0.324
-	4-2	CWR-02	CWR-03	CWR-04	CWS-05
Temperature (°C)	24.63	17.78	17.78	17.78	6.67
Pressure (kPa)	1270.81	453.88	453.83	487.29	480.56
Mass Flow (kg/s)	0.324	1.923	1.923	1.923	1.923
	CWS-01				
Temperature (°C)	6.66				
Pressure (kPa)	514.51				
Mass Flow (kg/s)	1.92				
		Energy Str	eams		
			PIPE-		DIPE
		PIPE-KHX-	KHX-01	PIPE-RHX-	PIPE-
	Hoot Ding	UI Cold Out	Hot In	UI HOL OUL	Hv-03
Hoot Flow (LW)	75 00	0 792	1 61	$ \frac{1100}{0.204}$	
Heat Flow (KW)	/3.00	0.785	1.01	0.204	0.023

Table 2.18 MAGNET Operating with Nitrogen at 75 kW of Power Process Conditions without the Heat Pipe Heat Exchanger

	PIPE-HX- 01 Hot	PIPE-H	V-02	Comp		PIPE- CWS-06
	Heat	Heat	- ,	Power	Chiller Duty	Heat
Heat Flow (kW)	-6.62E-03	-6.51E-	04	1.55	74.11	-5.73E-03
	PIPE-			PIPE-		PIPE-
	CWS-03	PIPE-CV	WR-	CWR-05	PIPE-CWS-	HV-01
	Heat	Heat		Heat	01 Heat	Heat
Heat Flow (kW)	-2.08E-02	-7.17E-	03	-2.42E-03	-1.03E-02	1.70E-03
		Chille	r	PIPE-		PIPE-
	PIPE-	Pum)	CWR-02	PIPE-CWR-	CWS-04
	Comp Heat	Powe	r	Heat	03 Heat	Heat
Heat Flow (kW)	2.77E-03	8.81E-	02	-6.11E-03	-4.60E-03	-2.60E-02
	Heat Excl	hangers				
		RHX-01	Chi	ller HX-01		
Duty (kW)		130.70		73.94		
LMTD (°C)		640.71	1	1014.34		
UA (W/°C)		198.82		13.33		
Minimum Approa	uch (°C)	204.00		72.89		

Table 2.19 MAGNET Compressor Comparison for 75 kW and 250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

Compressor				
	75 I	κW	250	kW
	Nitrogen	Helium	Nitrogen	Helium
HP	2.076	5.629	16.830	28.900
kW	1.548	4.198	12.550	21.550
Pressure Ratio	1.046	1.049	1.123	1.100
Mass Flow (kg/s)	0.324	0.117	0.919	0.274
Actual Volumetric Flow Rate (m3/h)	82.51	210.10	243.50	505.30

Table 2.20 MAGNET Chiller Comparison for 75 kW and 250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

Chiller				
	75 kW 250 kW			кW
	Nitrogen	Helium	Nitrogen	Helium
Duty (kW)	74.110	76.610	260.500	269.100
Mass Flow Rate (kg/s)	1.923	1.986	6.760	6.980

RHX-01 Comparison				
	75 I	κW	250 kW	
	Nitrogen	Helium	Nitrogen	Helium
Temperature [°C]				
Hot In	595.7	597.3	598.5	598.9
Hot Out	233.6	145.8	283.5	208.5
Cold In	24.55	26.84	33.05	34.88
Cold Out	396.9	478.3	358.8	425.1
Hot Side Pressure Drop (kPa)	3.159	4.962	18.45	17.28
Cold Side Pressure Drop (kPa)	1.923	3.573	10.83	11.16
Duty (kW)	130.7	274.6	323.8	556.1
U (W/m^2°C)	153.7	553.3	316.8	767.7
UA (W/ºC)	640.7	2307	1321	3201
A (m^2)	4.17	4.17	4.17	4.17
Mass Flow Rate (kg/s)	0.3238	0.117	0.919	0.274

Table 2.21 MAGNET RHX-01 Comparison for 75 kW and 250 kW of Heat Pipe Power without the Heat Pipe Heat Exchanger

Table 2.22 Heat Pipe Heat Exchanger Comparison for 75 kW and 250 kW

	Heat Pipe Heat Exchanger			
	75	5 kW –	250) kW
	Nitrogen	Helium	Nitrogen	Helium
Number of Heat Pipes	25 @	@ 3 kW	125 @	2 kW
Temperature [°C]				
Hot In	650	650	650	650
Hot Out	650	650	650	650
Cold In	392.2	506.6	358.1	451.7
Cold Out	596.7	633.9	600.0	634.3
Hot Side Pressure Drop (kPa)	0	0	0	0
Cold Side Pressure Drop (kPa)	25.0	25.0	25.33	25.0
Duty (kW)	75.0	75.0	250.0	250.0
U (W/m^2°C)	465.3	1033	293.9	556.8
$UA(W/^{o}C)$	580.2	1288	1832	3471
A (m^2)	1.247	1.247	6.234	6.234
Cold Fluid Mass Flow Rate (kg/s)	0.325	0.113	0.919	0.264

2.3.2 MAGNET Operating at 2 kW of Heat Pipe Power

An initial test is planned for the MAGNET to operate using one heat pipe at 2 to 3 kW. The Aspen HYSYS process flow diagram and process conditions are shown in Appendix A. Is has

been assumed that the equipment in the MAGNET will remain the same as currently designed for the higher flow rates and numbers of heat pipes. For this test, however, the PCHE recuperating heat exchanger was replaced by a Sentry tube in tube heat exchanger and a low flow mass flow meter. The heat pipe heat exchanger would also be adjusted to accommodate only one heat pipe, but it is assumed in the Aspen HYSYS model that the dimensions of the tube is the same as discussed earlier in the chapter. The Sentry tube-in-tube heat exchanger model being used is the DTC-IN7/SSD-8-1-1. This uses an Inconel inner tube with a stainlesssteel outer tube. The tube in tube heat exchanger was modeled using double tubed heat exchanger equations found in *Design of Fluid Thermal Systems* by William Janna. The sizing of the heat exchanger in Aspen HYSYS can be seen in Table 2.23 and the manufacture's data sheet is in Appendix E. The wall thickness for both the inner tube (0.065 inches) and outer tube (0.083 inches) were obtained by contacting the manufacturer (Sentry, 2020). A double tubed Aspen HYSYS heat exchanger model was created to compare results to the standard equations, a similar process for validating the heat pipe heat exchanger discussed earlier. The results are similar and are shown in Table 2.24.

It was assumed that the exhaust temperature of the vacuum chamber was 600°C. This assumption was made for both the Aspen HYSYS models with and without the heat pipe heat exchanger. To obtain this temperature, the flow rate needed to be near 0.0045 kg/s. Since the flow rate is smaller than what the compressor could operate at, the flow will be driven by the compressor receiver tank. Once the pressure in the receiver tank drops below a certain threshold, the compressor will turn on and pressurize the tank to a set value and then turn off. This will allow the current compressor to be used for this low flow case.

The low flow within the system and the large pipe sizes create a lot of residence time in the piping. The piping throughout the MAGNET is mostly 3 inches in diameter, with a few sections of 4-inch pipe around the vacuum chamber. The velocity within the 3-inch pipes are near 0.068 m/s. The volumetric flow rates are also shown in Table 2.25, where the values were provided by Aspen HYSYS. This low velocity and low volumetric flow rate allow for a large amount of heat transfer from the pipes to the ambient air. This resulted in the fluid within most pipes to be at ambient temperatures. Where the temperatures are elevated, a lot of heat is lost due to the small flow.

Performance of the compressor, chiller, recuperated heat exchanger and the heat pipe heat exchanger are shown between Table 2.26 to Table 2.29. The heat pipe heat exchanger showed that the exhaust temperature is 583°C. This value could be increased to 600°C if the flow rate were decreased and the heat pipe power were increased. A smaller outer tubed diameter could also be placed over the heat pipe beside the one designed in the previous sections (0.7772-inch inner diameter).

Sentr	y's Double '	Fubed RHX-01 Sizing			
	Tub	pe Sizing			
ID Tube (ID p) (m)	9.40 E-3	ID Annulus (ID a) (m)	2.12 E-2		
OD p (m)	1.27 E-2	OD a (m)	2.54 E-2		
Tube Thickness (m)	1.65 E-3	Annulus Thickness (m)	2.11 E-3		
	Flow Areas				
A p (m^2)	6.94 E-5	A a (m^2)	2.26 E-4		
	Fluid	Velocities			
V p (m/s)	8.47 m/s	V a (m/s)	1.43		
Hydraulic Diameter (Dh) (m)	8.48 E-3	Equivalent Diameter (De) (m)	2.26 E-2		
Reynolds Numbers					
Re p	2.22 E-4	Re a	1.41 E4		
	Nussel	lt Numbers	_		
Nu p	63.7	Nu a	43.6		
	Convectio	on Coefficients			
h inner (W/m^2-C)	275.6	h a (W/m^2-C)	65.80		
h p (W/m^2-C)	204.0				
Overall Heat Transfer					
Coefficient (Uo) (W/m^2-C)	49.75				
	Outlet T	'emperatures			
R	0.987	Length (m)	5.79		
F		Outer Surface Area of Pipe (Ao)			
	0.971	(m^2)	0.231		
Hot Out (°C)	133.5	Cold Out (°C)	271.9		

Table 2.23 Sentr	y's Double	Tubed RHX-01	Sizing
------------------	------------	--------------	--------

Double Tubed RHX-01 Comp Pine Heat I	parison (2 kW) w Exchanger	ithout Heat
I ipe incut i	Spread Sheet without Heat Pipe Heat Exchanger	Aspen HYSYS
Number of Heat Pipes	1	1
Temperature [C]		
Hot In	381.1	381.1
Hot Out	133.0	121.8
Cold In	21.95	21.95
Cold Out	273.4	284.4
Hot Side Pressure Drop (kPa)	5.440	4.034
Cold Side Pressure Drop (kPa)	0.019	0.572
Duty (kW)	1.21	1.26
U (W/m^2C)	47.66	
UA (W/C)	11.01	12.8
A (m^2)	0.231	
Mass Flow Rate (kg/s)	4.46 E-03	4.46 E-03

Table 2.24 Sentry Double Tubed RHX-01 Comparison between Spread Sheet Equations and
Aspen HYSYS Heat Exchanger Model without Heat Pipe Heat Exchanger

Table 2.25 MAGNET 2 kW of Heat Pipe Power Working Fluid Residence Time without Heat Pipe Heat Exchanger

Residence Time o	Residence Time of Nitrogen in MAGNET operating heat pipes at 2 kW without Heat Pipe Heat Exchanger				
	Pipe following Compressor (3-inch pipe)	Pipe following RHX cold side (3- inch pipe)	Pipe following Vacuum Chamber (4- inch pipe)	Pipe following RHX hot side (4-inch pipe)	Pipe following Chiller HX hot side (3- inch pipe)
Volumetric Flow Rate (m^3/hr)	1.114	2.065	3.364	1.569	1.134
Time per Volume (hr/m^3)	0.898	0.484	0.297	0.637	0.882

Compressor (2 kW) Loop with Heat Pipe Heat Exchanger		
	N2	
HP	0.025	
kW	0.0187	
Pressure Ratio	1.04	
Actual Volumetric Flow (m3/h)	1.199	

Table 2.26 Compressor Performance at 2 kW with the Heat Pipe Heat Exchanger

Table 2.27 Chiller Performance at 2 kW with the Heat Pipe Heat Exchanger

Chiller (2 kW) Loop with Heat Pipe Heat			
Exchanger			
	N2		
Duty (kW)	0.586		
Mass Flow (kg/s)	0.012		

Table 2.28 Double Tubed Sentry RHX-01 with the Heat Pipe Heat Exchanger

Double Tubed RHX-01 Comparison (2 kW) with Heat Pipe Heat Exchanger			
	Spread Sheet with Heat Pipe Heat Exchanger	Aspen HYSYS RHX-01 Heat Exchanger	
Number of Heat Pipes	1	1	
Temperature [C]			
Hot In	380.2	380.2	
Hot Out	133.5	122.4	
Cold In	22.02	22.02	
Cold Out	272.0	283.0	
Hot Side Pressure Drop (kPa)	6.009	4.421	
Cold Side Pressure Drop (kPa)	0.018	0.626	
Duty (kW)	1.26	1.32	
U (W/m^2C)	49.75		
UA (W/C)	11.50	13.4	
A (m^2)	0.231		
Mass Flow Rate (kg/s)	4.70 E-03	4.70 E-03	

Double Tubed Heat Pipe Heat Exchanger (2 kW)			
	Aspen	Aspen HYSYS	
	HYSYS	Heat	
	Spread Sheet	Exchanger	
Number of Heat Pipes	1	1	
Temperature [C]			
Hot In	650.0	650.0	
Hot Out	650.0	649.7	
Cold In	200.5	200.5	
Cold Out	583.5	561.4	
Hot Side Pressure Drop (kPa)	0.00	0.0246	
Cold Side Pressure Drop (kPa)	25.33	1.952	
Duty (kW)	2.00	1.882	
U (W/m^2C)	201.6		
UA (W/C)	10.10	8.46	
A (m^2)	0.050		
Mass Flow Rate (kg/s)	4.70 E-03	4.70 E-03	

Table 2.29 Heat Pipe Heat Exchanger Performance at 2 kW
Chapter 3: Power Conversion Unit for MAGNET

3.1 Introduction

There has been new interest in modular nuclear microreactors for power generation and process heat applications over the past few years. These nuclear microreactors typically operate between 1 megawatt of thermal energy (MW_{th}) to 20 MW_{th} . Current designs are modular, allowing them to be easily transported by truck, train, or boat. Another key feature of microreactors is that their components would be able to be assembled in a factory and shipped out. The last key feature is that they are to be self-adjusting to minimize the need for a large number of operators by utilizing passive safety systems that reduce the possibility of reactor failure (Office of Nuclear Energy, 2018). These nuclear reactors are designed to provide heat and energy. They are often connected to a power conversion unit (PCU) which in turn generates power.

Power conversion units can come in many forms with different working fluids. The general process of a PCU is to increase the thermal energy of the working fluid and convert it into electrical energy. The thermal energy of the working fluid is increased by raising the pressure and temperature. The pressure is increased by using pumps for liquids in a Rankine cycle or by using compressors when vapors and gases are used, commonly found in Brayton cycles. The heat addition to the working fluid is traditionally supplied through a combustion process but could also be supplied from nuclear reactors through heat exchangers. The high energy fluid then passes through a turbine which converts mechanical energy into electrical energy (Çengel & Boles, 2011). Common working fluids for different PCUs include air, helium, carbon dioxide (CO₂), water, and organic fluids such as refrigerants. Examples of PCUs attached to a microreactor include HolosGen's Holos Reactor and Westinghouse's eVinci. Both reactors are cooled differently, but both utilize a high temperature Brayton cycle. The eVinci uses a microreactor that is cooled by heat pipes where the heat is then transferred to the PCU by the use of a heat exchanger-heat pipe interface (Westinghouse, 2019). The Holos reactor is cooled using helium or CO₂ which are directly integrated into the PCU (Filippone & Jordan, 2018).

This new class of microreactors provide many benefits but lack needed data to show that they are safe and effective. For this purpose, Idaho National Laboratory (INL) is developing the Microreactor AGile Non-nuclear Experimental Testbed (MAGNET) to aid in the development of new microreactor designs and concepts. The MAGNET is being designed to test many different reactor types in a safe environment that allows for testing of steady state conditions, transient conditions, and failure modes (Guillen, et al., 2019). The design allows for a broad range of reactor types as well as auxiliary systems, such as PCUs and process heat applications. These auxiliary systems add real loads to the system and can provide critical information regarding the impact to the reactor, such as response time to change. The first reactor type the MAGNET is being designed for is a heat pipe cooled reactor. The working fluid for this application is pure nitrogen. This is a safety feature to avoid possible reactions with the sodium in the heat pipes if failure was to be tested (Guillen, et al., 2019). The system will operate at a temperature of 600°C, which is a typical heat range for heat pipe reactors, and a pressure range of 1051 kPa to 1241 kPa following the reactor (Westinghouse, 2019). The auxiliary systems being considered in this chapter are a physical PCU attached to the MAGNET and a newly design PCU simulator unit.

Throughout this chapter there is talk of optimized cycles and the general process will be detailed here. The optimization process for Brayton cycles involves parametric studies to vary the main process variable, pressure. The type of nuclear reactor being concidered in here were heat pipe cooled reactors. The MAGNET reactor will be cooled by sodium cooled heat pipes which have an operating range between 600°C to 1100°C (Advanced Cooling Technologies, 2020). From this range, it was determined that the desire operating temperature range of the heat pipes in the MAGNET would be between 600°C to 700°C (Guillen, et al., 2019; Turner & Guillen, 2020). Since the desired reactor outlet temperature was known, 600°C for the MAGNET, the main variables to be changed were the pressure ratio, the compressor adiabatic efficiency, and the turbine adiabatic efficiency. The pressure ratio affects how much work the compressor requires as well as how much work the turine generates. The adiabatic efficiencies refer to how the unit operates to a reversable work unit. These three parameters greatly affect the maximum thermal efficiency achievable by the PCU. The optimization occured by holding the adiabatic efficiencies constant and varying the pressure ratios. This process produced thermal efficiency curves for the cycles. Two examples of optimized cycles for varying adiabatic efficiencies for this report are shown in Figure 3.1 to Figure 3.4.



Figure 3.1 Simple Brayton Cycle with 85% Compressor and 90% Turbine Adiabatic Efficiencies with Air at 50% Relative Humidity



Figure 3.2 Pressure Ratio vs Thermal Efficiency Curve for the Simple Brayton Cycle with 85% Compressor and 90% Turbine Adiabatic Efficiencies with Air at 50% Relative Humidity



Figure 3.3 Simple Brayton Cycle with 70% Compressor and 80% Turbine Adiabatic Efficiencies with Air at 50% Relative Humidity



Figure 3.4 Pressure Ratio vs Thermal Efficiency Curve for the Simple Brayton Cycle with 70% Compressor and 80% Turbine Adiabatic Efficiencies with Air at 50% Relative Humidity

3.2 Physical PCU Connected to MAGNET

An auxiliary system being considered for the MAGNET is to demonstrate electrical power generation by coupling it to an appropriately sized power conversion unit (PCU). This configuration would apply a prototypical load to the system and could test the response of the heat pipe cooled reactor under a range of conditions. The current configuration of the MAGNET lends itself to the use of a recuperated Brayton cycle. Brayton cycles are common PCU cycles. A basic recuperated air Brayton cycle is shown in Figure 3.5 and this cycle draws in ambient air and compresses it. The compressed air then exchanges heat with the hot exhaust of the turbine through the recuperating heat exchanger. Recuperation reduces the temperature difference across the reactor which increases the mass flow rate of the air for a given heat load. The hot gas then expands through the turbine and is exhausted to the ambient air after traveling through the recuperating heat exchanger. This cycle more efficiently uses the hot gases leaving the turbine and has a higher mass flow rate, which increases the PCU's thermal efficiency.



Figure 3.5 Basic Open-Air Recuperated Brayton Cycle

A similar PCU loop uses a closed loop Brayton cycle. The difference is that the turbine exhaust, once it leaves the recuperating heat exchanger, goes through a cooling unit, and then re-enters the compressor. Closed loop cycles are needed when inert gases are used, such as in the MAGNET. It can be seen in the process flow diagram of the MAGNET in Figure 2.2 that there are connections for a PCU unit. The PCU unit attached to the MAGNET would be a compressor and a turbine and it would complete a closed-loop Brayton cycle. The cycle would utilize the recuperating heat exchanger, vacuum chamber containing the heat pipes, the chiller heat exchanger, and by-pass the MAGNET compressor. The proposed configuration is shown in Figure 3.6 with the process conditions shown in Table 3.1. If the piping models and valving were removed in Figure 3.6, it would be seen that it is a standard closed loop Brayton cycle.

The PCU is assuming a compressor efficiency of 75% and a turbine efficiency of 90%. This was the same for both the helium and nitrogen models. More detailed information for both the nitrogen and helium loops are in Appendix C. Rough optimizations of the pressure, \pm 50 kPa, in the MAGNET PCU loop have been performed to obtain the highest thermal efficiency. The results are in Table 3.2.



Figure 3.6 MAGNET as a Closed Loop Brayton Cycle using Nitrogen as the Working Fluid

Material Streams								
	HX-01			HX-01	RHX-01			
	Hot In	CWR	CWS	Hot Out	Cold In			
Temperature (°C)	277.23	17.78	6.67	20.00	125.68			
Pressure (kPa)	622.69	473.89	500.01	611.36	1277.64			
Mass Flow (kg/s)	0.819	5.855	5.855	0.819	0.819			
		Vacuum						
	RHX-01	Chamber	Vacuum	RHX-01	RHX-01			
	Cold Out	In	Chamber Out	Hot In	Hot Out			
Temperature (°C)	328.68	328.00	600.00	476.63	277.53			
Pressure (kPa)	1268.13	1266.33	1241.00	650.00	624.11			
Mass Flow (kg/s)	0.819	0.819	0.819	0.819	0.819			
				Chiller				
	Comp In		Chiller In	Out	17.79			
Temperature (°C)	19.89	19.94	1/./8	0.00	1/./8			
Pressure (kPa)	562.62	584.50	484.38	4/4.69	452.13			
Mass Flow (kg/s)	0.819	0.819	5.855	5.855	5.855			
	CWR-05	CWR-03	CWR-02	CWS-02	CWS-03			
Temperature (°C)	17.78	17.78	17.78	6.66	6.66			
Pressure (kPa)	484.51	451.67	451.98	518.68	518.53			
Mass Flow (kg/s)	5.855	5.855	5.855	5.855	5.855			
	CWS-06		14					
Temperature (°C)	6.66	126.64	125.74	125.74	19.94			
Pressure (kPa)	483.70	1295.78	12/9.16	12/8.57	583.54			
Mass Flow (kg/s)	5.855	0.819	0.819	0.819	0.819			
	Comp		Turbing Inlet	CWS-01	CWS 05			
Tomporoture (°C)	126.77		508 29	6.66	6.66			
Draggura (IzDa)	120.77	120.04	J70.20 1926 52	0.00 510.01	0.00 192 95			
Mass Flow (kPa)	1321.37	1290.38	1230.33	J10.01 5 855	403.83 5 855			
WIASS FIOW (Kg/S)	CWP 04	CWS-04	0.019	5.655	5.055			
Temperature (°C)	17 78	6 66						
Dressure (LDo)	17.70	0.00 /8/ 19						
$\frac{1}{Mass} \frac{1}{Flow} \frac{1}{2} \frac{1}{2$	5 855	404.10 5 855						
WIASS FIOW (Kg/S)	5.655	J.0JJ Energy St	reame					
		PIPE-RHX-	PIPE-RHX-	PIPE-RHX-	PIPE-			
		01 Cold Out	01 Hot In	01 Hot Out	HV-03			
	Heat Pipes	Heat	Heat	Heat	Heat			
Heat Flow (kW)	250.005997	0.6111156	1.6198487	0.256712	0.7671721			

Table 3.1 MAGNET as Closed Loop Brayton Cycle using Nitrogen as the Working Fluid Process Conditions

	PIPE-HX-				PIPE-
	01 Hot	PIPE-HV-02	Comp		CWS-06
	Heat	Heat	Power	Chiller Duty	Heat
Heat Flow (kW)	-0.0068914	-0.0006879	91.707707	225.63514	-0.028819
	PIPE-				PIPE-
	CWS-03	PIPE-CWR-	PIPE-CWR	PIPE-CWR-	CWS-01
	Heat	02 Heat	Heat	05 Heat	Heat
Heat Flow (kW)	-0.0200234	-0.0061239	-0.0069015	-0.0114666	-0.01032
				Chiller	PIPE-
	PIPE-HV-	PIPE-Comp	Turbine	Pump	CWS-04
	01 Heat	Heat	Power	Power	Heat
Heat Flow (kW)	0.05734303	0.09239585	113.14103	0.319839	-0.02605
	PIPE-				
	CWR-03				
	Heat				
Heat Flow (kW)	-0.0227997				
	Heat E	xchangers			
		RHX-01	Chiller HX-0	01	
Duty (kW)		180.41	225.18		
LMTD (°C)		1203.27	2694.30		
UA (W/°C)		147.94	13.33		
Minimum Approac	h (°C)	149.93	83.58		

Table 3.2 MAGNET PCU Nitrogen and Helium Comparison

	Compressor Power (kW)	Turbine Power (kW)	Total Power (kW)	Compressor Pressure Ratio	Turbine Pressure In (kPa)	Turbine Pressure Out (kPa)	Mass Flow (kg/s)	Heat Pipe (kW)	Thermal Efficiency
N2	91.7	113	21.3	2.35	1237	650	0.819	250	8.57%
He	132	171	39	2.06	1239	675	0.194	250	15.50%

3.3 Power Conversion Unit Simulator

The MAGNET has a goal to provide a testbed that is broadly applicable to multiple microreactor concepts. Keeping that in mind, the second auxiliary system for the MAGNET is a PCU simulator. An advantage of using a PCU simulator over a physical PCU is that the simulator can simulate many different PCU cycles at varying process parameters. The main parameter that could be changed are the adiabatic efficiencies of the compressors and the turbines. The simulator can also simulate various transient conditions as well as start up and shut down state points. This is advantageous as it can show how these various cycles could influence the performance of the tested reactor type.

To reiterate, the first microreactor to be studied within the MAGNET is a heat-pipe cooled reactor. The MAGNET has the following specification (Guillen, et al., 2019):

• Power: nominal 250 kWth.

Figure 3.7 shows an iteration of a process flow diagram of INL's MAGNET that the PCU simulator's design was based on (O'Brien, 2019). This iteration of the testbed was designed to reach a temperature of 600°C and a pressure of 1050 kPa, instead of 1241 kPa as discussed in earlier chapters. The working fluid within the loop is currently designed to operate with nitrogen; while in the future, designs may change to use helium operating at a temperature of 850°C. A simplified MAGNET Aspen HYSYS process model designed around Figure 3.7 is shown in Figure 3.8. The Aspen HYSYS model estimates the pressure loss in the equipment as well as the heat loss from the piping. The values within INL's process diagram and those within the Aspen HYSYS model match closely.

A PCU simulator has been designed. The design accounts for air Brayton, recuperated air Brayton, and recuperated helium cycles. Currently, the MAGNET is not designed to operate at the higher helium cycle temperatures because the equipment for the simulator was not specified to handle the higher temperatures. The super critical CO2 cycle was not considered because the MAGNET will not operate at sufficient pressures to test the cycle. Bottoming cycles like organic Rankine cycles (ORC) are also not being considered as they do not interface directly with the microreactor. However, an ORC could be simulated from process conditions of a Brayton cycle model that is connected to a bottoming ORC. These conditions could show additional impact on the MAGNET. The layout of the PCU simulator is shown in Figure 3.9. The theory and process of design are discussed in further sections.



Figure 3.7 Process Flow diagram of INL's Microreactor AGile Non-nuclear Experimental Testbed for PCU Simulator (O'Brien, 2019)



Figure 3.8 Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed for PCU Simulator



Figure 3.9 Power Conversion Unit Simulator Layout

3.3.1 Power Conversion Unit Simulator Theory

A PCU simulator has been designed to attach to the MAGNET as a plug-and-play system as shown in Figure 3.9. The simulator's design is drawn from optimized open Brayton cycles, both recuperative and non-recuperative. First, some theory is needed to understand how the PCU simulator was designed to mimic the conditions of an actual PCU.

A simplified open Brayton cycle consists of three or four components, depending if the cycle is recuperated or not; a compressor, turbine, heat source, and a heat exchanger (Çengel & Boles, 2011). The heat source could be combustion, nuclear power, or electrical heaters (this is

the case in the MAGNET). The working fluid, typically air, in an open Brayton cycle follows this process:

- 1. Air is drawn from ambient conditions and pressurized through the compressor.
- 2. The compressed air is pre-heated through a recuperating heat exchanger (if recuperation is used).
- 3. The compressed air is fully heated through the heat source.
- 4. It is then expanded through the turbine which lowers the pressure and temperature of the air.
- 5. The hot air then exchanges heat with the compressed air in a recuperating heat exchanger (if recuperation is used).
- 6. The air is then exhausted out of the system.

Simplified process flow diagrams for both non-recuperated and recuperated open Brayton cycles are shown in Figure 3.10 and Figure 3.11, respectively.



Figure 3.10 Process Flow Diagram of Open Brayton Cycle



Figure 3.11 Process Flow Diagram of Open Recuperated Brayton Cycle

Simulating the open Brayton cycle requires certain conditions to be mimicked. The equations that govern the compressor and the turbine are derived from the first and second laws of thermodynamics. Equation 3.1 show the first law. Simplifications of neglecting potential and kinetic energy, steady-state and steady flow conditions, conservation of mass, and an adiabatic process are applied to Equation 3.1 to obtain Equation 3.2. For the cycles under consideration, the working fluids are ideal gases. Therefore, ideal gas relations, such as Equation 3.3 and Equation 3.4, may be used to clarify how the cycles can be simulated within the test loop. This is a valid assumption for nitrogen, air, and helium since they behave like ideal gases at the operating conditions found within the MAGNET. The final governing equations for the compressor and turbine are shown in Equation 3.9 and Equation 3.10.

$$\dot{Q} - \dot{W} = \sum \dot{m}(h + PE + KE)_e - \sum \dot{m}(h + PE + KE)_i$$
 Equation 3.1

 $-\dot{W}_{act} = \dot{m}(h_e - h_i) \qquad Equation \ 3.2$

$$(h_e - h_i) = C_p(T_e - T_i)$$
 Equation 3.3

$$T_{e,s} = T_i \left(\frac{P_e}{P_i}\right)^{\frac{\gamma-1}{\gamma}}$$
 Equation 3.4

$$\dot{W}_{rev} = \dot{m}C_p(T_i - T_{e,s}) = \dot{m}C_p\left(T_i - T_i\left(\frac{P_e}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right) \qquad Equation 3.5$$
$$= \dot{m}C_pT_i\left(1 - \left(\frac{P_e}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right)$$

$$\dot{W}_{turb,act} = \eta_{turb} \dot{W}_{turb,rev}$$
 Equation 3.6

$$\dot{W}_{comp,act} = \frac{W_{comp,rev}}{\eta_{comp}}$$
Equation 3.7

$$\frac{\sigma_p}{R} = \frac{\gamma}{\gamma - 1}$$
 Equation 3.8

$$\dot{W}_{turb,act} = \dot{m}RT_i\eta_{turb}\left(\frac{\gamma}{\gamma-1}\right)\left[1 - \left(\frac{P_e}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad Equation 3.9$$
$$\dot{W}_{comp,act} = \frac{\dot{m}RT_i}{\eta_{comp}}\left(\frac{\gamma}{\gamma-1}\right)\left[1 - \left(\frac{P_e}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right] \qquad Equation 3.10$$

Where:

 $\begin{array}{ll} \dot{W}_{act} \rightarrow \mbox{Actual Power for Turbine/Compressor} \\ \dot{m} & \rightarrow \mbox{Mass Flow Rate} \\ R & \rightarrow \mbox{Individual Gas Constant} \\ T_i & \rightarrow \mbox{Inlet Temperature} \\ \eta & \rightarrow \mbox{Adiabatic Efficiency of Turbine/Compressor} \\ \gamma & \rightarrow \mbox{Specific Heat Ratio} \\ P_i & \rightarrow \mbox{Inlet Pressure} \end{array}$

 $P_e \rightarrow$ Outlet Pressure

The relationships shown in Equation 3.4 and Equation 3.9 reveal that the working fluid in a turbine undergo two major changes for positive work: a drop in temperature and pressure. Therefore, simulating a turbine must include a pressure and temperature drop. Equation 3.9 also shows that the work done is a strong function of the pressure ratio. By maintaining the pressure ratio, the PCU simulator can simulate an actual field PCU while maintaining the conditions provided by the MAGNET. This also agrees with McKellar et al's finding that Brayton cycles have an optimal pressure ratio for a given set of inlet turbine conditions. Keeping the optimal pressure ratio with the same turbine inlet conditions maintains the optimal cycle (McKellar, Boardman, Bragg-Sitton, & Sabharwall, 2018). To show this is the case, standard optimized Brayton cycles were compared to modified Brayton cycles using the desired outlet conditions of the MAGNET vacuum chamber. This analysis is shown in the next section.

3.3.2 Modified Power Conversion Units for the MAGNET

The work in the section was performed primarily by Dr Michael McKellar with assistance from Clayton Turner. It is, however, needed for the development of the power conversion unit simulator.

Analyses have been performed on optimized power cycles using expected operating conditions for a heat pipe cooled nuclear reactor. The optimized power cycles were then compared to MAGNET conditions using the same working fluid. During the optimization process, the power cycles used 600°C as the turbine inlet temperature. Two cases of the air Brayton cycle were analyzed, and their thermal efficiencies were optimized by adjusting the compressor outlet pressure. The first case used compressor and turbine efficiencies of 70% and 80%, respectively; the second used compressor and turbine efficiencies of 85% and 90%, respectively. Both cases used ambient air for the compressor inlet at 21.1°C, 1 atmosphere, and 50% humidity for the field PCUs. The modified PCU used nitrogen and MAGNET conditions at the test chamber outlet. When the helium PCUs were compared, both the field and the modified PCUs used helium. As shown in Figure 3.12 and Figure 3.13, the pressures do not match but the pressure ratios do. The temperatures throughout the cycles and the thermal efficiencies are very close. The pressure ratio has a stronger influence on the efficiency of the cycles than the magnitudes of the absolute pressures or pressure differences. Also, because air is 78% nitrogen by mole fraction, using nitrogen instead of air has little effect on the performance of the cycle. The case studies with the recuperated air Brayton cycles had the same conclusions about the pressure ratio, see Figure 3.14 and Figure 3.15.

The recuperated helium Brayton cycle was also analyzed. A new Aspen HYSYS model of the MAGNET was developed to estimate the performance of the testbed with a high temperature of 850°C, keeping the pressure at 1051 kPa, see Figure 3.16. As with the air cases, the helium Brayton cycles have temperatures and thermal efficiencies close to one another regardless of the pressure magnitudes if the pressure ratios remain the same. This is shown in Figure 3.17 and Figure 3.18. All the models shown in this section are found in Appendix G: Aspen HYSYS Power Cycle Models for the Development of PCU Test Loop for Micro-Reactor Testbed.



b. Open Nitrogen Brayton Cycle

Figure 3.12 Comparison of Open Brayton Cycles: One with Air at Expected Operating Conditions, the Other with Nitrogen using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 85% and 90%, Respectively



- b. Open Nitrogen Brayton Cycle
- Figure 3.13 Comparison of Open Brayton Cycles: One with Air at Expected Operating Conditions, the Other with Nitrogen using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 70% and 80%, Respectively



- b. Open Recuperated Nitrogen Brayton Cycle
- Figure 3.14 Comparison of Recuperated Open Brayton Cycles: One with Air at Expected Operating Conditions, the Other with Nitrogen using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 85% and 90%, Respectively



a. Open Recuperated Air Brayton Cycle



- b. Open Recuperated Nitrogen Brayton Cycle
- Figure 3.15 Comparison of Open Recuperated Brayton Cycles: One with Air at Expected Operating Conditions, the Other with Nitrogen using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 70% and 80%, Respectively



Figure 3.16 Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Helium



a. Helium Recuperated Closed Brayton Cycle at Operating Conditions



b. Helium Recuperated Close Brayton Cycle at MAGNET Conditions

Figure 3.17 Comparison of Recuperated Helium Brayton Cycles: One at Expected Operating Conditions, the Other using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 85% and 90%, Respectively



a. Helium Recuperated Closed Brayton Cycle at Operating Conditions



b. Helium Recuperated Close Brayton Cycle at MAGNET Conditions

Figure 3.18 Comparison of Recuperated Helium Brayton Cycles: One at Expected Operating Conditions, the Other using MAGNET Conditions into the Turbine. Turbine and Compressor Adiabatic Efficiencies are 70% and 80%, Respectively

3.3.3 Power Conversion Unit Simulator Design

To simulate a power conversion unit within the MAGNET, the simulator needs to undergo a pressure drop and heat exchange. It is assumed that the gas turbine and compressor unit simulated were axial. A process model of the PCU simulator without temperature control ability was developed in Aspen HYSYS, see Figure 3.19. The process of this PCU simulator is described as follows: the model uses a high temperature recuperating heat exchanger to simulate the temperature drop. A control valve was used to simulate the pressure drop. A low temperature recuperating heat exchanger was used to lower the temperature more before the entering a chiller unit. The chiller unit controls the temperature entering the compressor. The use of recuperating heat exchangers instead of chiller units was to reduce the required duty of the chiller and to recover lost heat. The fluid is then compressed back to the pressure of the MAGNET and travels back through recuperating heat exchangers. The gas then reenters the MAGNET.

Each PCU case was considered independently from the others to determine the sizes of the heat exchangers, compressors, and valves unique to each simulated PCU. An assumption was made for each model that each recuperating heat exchanger had a minimum approach near 25°C. This made the results comparable. By comparing the cases, sizes of the components were selected so that all the PCUs considered could be simulated with the PCU simulator. The simulation of the six Brayton cycle cases are shown in Figure 3.19 through Figure 3.24. Detailed process information about sizing of the PCU Simulator can be found in Appendix H. The PCU simulator was designed to simulate the PCU turbine. However, by also specifying the inlet temperature into the MAGNET vacuum chamber, the cycle's compression side may also be simulated. Thus, by knowing the pressures and temperatures at the three key points (the inlet and outlet of the turbine simulator and into the MAGNET test chamber) will uniquely identify the cycle under consideration. Therefore, the simulator can simulate not only the design conditions but also the key state points of transient operations such as the start up and shutdown of a PCU. A start up analyses of a non-recuperated heat pipe Brayton cycles and their key state points are discussed in Chapter 4.

It should be noted that the nitrogen Brayton cycle at high turbine and compressor efficiencies uses two identical compressors. This splits the pressure ratio from 7.65 down to 2.79 for each compressor, which put the pressure ratio more in line with the other PCU cycles. Two compressors also reduce the size and cost of a single compressor and makes the compressor more realistic. Table 3.3 shows the compression ratios needed to achieve an accurate simulation of the PCU cycles.

The valves, compressors, and heat exchanger sizing information for each case analyzed for the PCU simulator are given in Table 3.4 through Table 3.6. These tables show the maximum and minimum conditions for the valves, compressors, and heat exchangers. The critical information is shown in red. It is shown that the largest required pressure ratio and the largest duty for HX chiller 2 occur when simulating the nitrogen Brayton cycle at high turbine and compressor efficiencies. When simulating the nitrogen Brayton cycle at low turbine and compressor efficiencies, the simulator compressor requires the most power and HX chiller 1 has the largest duty. The lowest duty for Recup HX1 and the highest duty for Recup HX2 are found simulating the recuperated nitrogen Brayton cycle with low compressor and turbine efficiencies. The desired sizing of each component is discussed in the next section.

	Compression Ratio	2 Compressor Pressure Ratio
Air Brayton Cycle with $\eta_{comp} = 85\%$ and $\eta_{turb} = 90\%$	7.65	2.79
Air Brayton Cycle with $\eta_{comp} = 70\%$ and $\eta_{turb} = 80\%$	3.14	3.14
Recuperated Air Brayton Cycle with $\eta_{comp} = 85\%$ and $\eta_{turb} = 90\%$	2.55	2.55
Recuperated Air Brayton Cycle with $\eta_{comp}=70\%$ and $\eta_{turb}=80\%$	1.85	1.85

Table 3.3 Compressor Ratios of PCU Cycle and PCU Simulator

Simulated Cycle	Turbine Efficiency	Compressor Efficiency	Cg	Cv (USGPM: 60F, 1 psi)	Pressure Drop (kPa)
Nitrogen Brayton	85%	90%	1832	54.7	881
Cycle	70%	80%	2096	62.3	665
Recuperated	85%	90%	2220	66.3	501
Nitrogen Brayton Cycle	70%	80%	2353	70.3	427
Modified	85%	90%	2200	66.3	507
Recuperated Helium Brayton Cycle	70%	80%	2220	66.3	467

Table 3.4 Valve Sizing for PCU Simulator Pressure Drop

Table 3.5 Sizing of PCU Simulator Compressor

	Turbine	Compressor	Simulator		Sim	ulator
	Efficiency	Efficiency	Compressor		Compressor 2	
Simulated Cycle			Power	Pressure	Power	Pressure
Simulated Cycle			(MW)	Ratio	(MW)	Ratio
Nitrogen Brayton	85%	90%	0.132	2.87	0.132	2.87
Cycle	70%	80%	0.145	3.14	0	0
Recuperated Nitrogen	85%	90%	.00931	2.17	0	0
Brayton Cycle	70%	80%	.00758	1.90	0	0
Modified Recuperated	85%	90%	0.121	2.20	0	0
Helium Brayton Cycle	70%	80%	0.108	2.05	0	0

Table 3.6 Sizing of Chiller and Recuperating Heat Exchangers for PCU Simulator

Simulated Cycle	Turbine Efficiency	Compressor Efficiency	Recup RHX1 (MW)	Recup RHX2 (MW)	Chiller HX-02 (MW)	Chiller HX-03 (MW)
Nitrogen Brayton	85%	90%	0.332	0.0095	0.157	0.133
Cycle	70%	80%	0.176	0.237	0.170	0
Recuperated Nitrogen	85%	90%	0.135	0.331	0.119	0
Brayton Cycle	70%	80%	0.00979	0.385	0.101	0
Modified	85%	90%	0.205	0.34	0.142	0
Recuperated Helium Brayton Cycle	70%	80%	0.165	0.392	0.129	0



a. Open Nitrogen Brayton Cycle



b. PCU Simulation of Open Nitrogen Brayton Cycle

Figure 3.19 MAGNET PCU Simulation Loop for Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



 b. PCU Simulation of Open Nitrogen Brayton Cycle
 Figure 3.20 MAGNET PCU Simulation Loop for Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



a. Open Recuperated Nitrogen Brayton Cycle



b. PCU Simulation of Open Recuperated Nitrogen Brayton Cycle

Figure 3.21 MAGNET PCU Simulation Loop for Recuperated Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



a. Open Recuperated Nitrogen Brayton Cycle



 b. PCU Simulation of Open Recuperated Nitrogen Brayton Cycle
 Figure 3.22 MAGNET PCU Simulation Loop for Recuperated Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%





b. PCU Simulation of Helium Brayton Cycle

Figure 3.23 MAGNET PCU Simulation Loop for Recuperated Helium Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



a. Helium Brayton Cycle



b. PCU Simulation of Helium Brayton Cycle

Figure 3.24 MAGNET PCU Simulation Loop for Recuperated Helium Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%.

3.3.4 Component Specifications of the Power Conversion Unit Simulator

A piping and instrumentation diagram (P&ID), shown in Figure 3.25, has been created. Each valve, compressor, and heat exchangers have unique labels. In addition, thermocouples, pressure transducers, and flow meters are labeled. The equipment was sized from similar loops for the varying power cycles, shown in the previous section. The major difference between the PCU simulator and the case studies in the previous section is that a chiller heat exchanger HX-01 has been added. Its location is between the recuperating heat exchanger RHX-02 and the control valve, as shown in Figure 3.26. Detailed process information regarding the PCU simulator with the chiller are found in Appendix I. This is an important feature as it allows for the temperature control of T3 of different simulations, shown in the P&ID in Figure 3.25. This allows for the different PCU cycles to be simulated with constant physical recuperating heat exchangers. In the previous section, the chiller heat exchanger HX-01 was not included because an assumption that the high temperature recuperating heat exchanger, RHX-01, was used to achieve the desired simulated temperature. The chiller heat exchanger HX-01 has been sized to the largest duty found in the simulations to ensure enough cooling capacity for every cycle.

The recuperating heat exchangers have been sized from Table 3.6 in the red text. The sizing was performed differently for the recuperating heat exchangers than just selecting the largest size. The recuperating heat exchanger RHX-01 was sized to the smallest duty and the recuperating heat exchanger RHX-02 was sized to the largest duty. The chosen duties determined the UA for both the recuperating heat exchangers. This combination for the recuperating heat exchangers were chosen to ensure that cooling was always required for the chiller HX-01. If RHX-01 was sized to the largest UA found, then the chiller HX-01 would require either cooling or heating depending on the simulated cycle. The PCU simulator model assumed a constant UA for each recuperating heat exchangers to determine their performance. Assuming a constant UA is a reasonable initial assumption as the conditions surrounding the recuperating heat exchangers in the different models remain within a similar range of temperatures; though it is noted that the UA would not remain constant between each case.

The other components were sized depending on their functions. The compressors were sized by determining the minimum and maximum pressure ratio range and the control valve CV-01 was sized to meet the desired range of pressure drops. The chiller heat exchangers were sized by the largest duty.

The current PCU simulator allows for different physical PCUs to be simulated. This process is accomplished by controlling the state points in the simulator to the desired PCU turbine outlet conditions. The thermocouple, T3, maintains the correct temperature by adjusting the mass flow rate of the chilled water at \dot{m} 2. The desired simulation pressure at P2 is determined from the pressure transducer which is controlled by CV-01. This makes obtaining the desired temperature and pressure obtainable by the system. Also, by knowing the conditions entering the vacuum chamber, a unique PCU can be simulated.



Figure 3.25 Piping and Instrumentation Diagram



Figure 3.26 Power Conversion Unit Simulator

3.3.4.1 PCU Simulator Company Inquiries and Detailed Component Specifications

Many companies were approached to obtain quotes for feasible component designs for the PCU simulator. The companies include Flowserve Valves, Kobelco Compressors, Corken, Root Systems Inc, Barber-Nichols, HEXCES, Vacuum Process Engineering, Heatric, and Exergy Heat Transfer Solutions. It should be noted that some of the companies were initially approached on older iterations of the PCU simulator and did not respond to the updated information.

Kobelco industries was approached to size a feasible compressor that would meet the system requirements. They determined that a screw compressor would be best suited for the component Comp-01. Kobelco gave an estimated price range of 1 to 1.5 million dollars but determined after some analysis that their company could not meet the system requirements (Kobelco). Roots System Inc was also approached about a feasible compressor design and they responded that they were able to manufacture a compressor that could handle the desired conditions of the PCU simulator. Their estimate was for one compressor including a skid that would be approximately 18 ft x 12 ft that housed the controls, piping, and intercooler, and it would cost 1 to 2 million dollars. This estimate was approximated closer to 2 million dollars during a phone conversation with the Roots System Inc representative. The proposed compressor was a 12-inch piping, two stage rotary lobe compressor with a nominal 350 HP driver motor. The compressor is also API 619 compliant. The lead time was approximated to be 40 weeks (Root Systems Inc, 2020).

Exergy Heat Transfer Solutions was approached to size the two chiller units and the recuperated heat exchanger. The company respectfully declined sizing due to challenges of high flow rates for tube-in-tube heat exchanger and the large temperature differences for shell and tubes. The other heat exchanger companies did not reply.

Flowserve was approached to size component CV-01 and BV-01/02. CB-Pacific and Flowserve fulfilled the request and these units have been fully specified. Their performance data sheets can be found in Appendix J and Appendix K.

All the component specifications are shown below between Table 3.7 to Table 3.10. The component names were determined from the P&ID shown in Figure 3.25. Some tables include condition 1 and condition 2. These are different conditions that the equipment will be exposed to and would need to be sized to handle both conditions. In the cases of the valves, many are exposed to high heat and pressures while they are closed and not in operation.

	CV-01				
Process Information	Condition 1	Condition 2			
Temperature [C]	277	506			
Inlet pressure [MPa]	1.03	1.03			
Outlet pressure [MPa]	0.143	0.601			
Flow rate [kg/s]	0.924	0.924			
Fluid	Nitrogen	Nitrogen			

Table 3.7 PCU Simulator Control Valve Specifications

Table 3.8 PCU Simulator Compressor Specifications

		Comp-01		Comp-02
Process Information	Condition 1	Condition 2*	Condition 3	Condition 1*
Temperature in [C]	21.1	21.1	21.1	21.1
Pressure In [MPa]	0.577	0.137	0.356	0.384
Pressure Out [MPa]	1.1	0.392	1.1	1.1
Mass Flow Rate [kg/s]	0.924	0.924	0.924	0.924
Fluid Type	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Pressure Ratio	1.9	2.85	3.08	2.85

* **NOTE:** Comp-01 Condition 2 and Comp-02 Condition 1 is for the nitrogen Brayton cycle at high turbine and compressor efficiency. This cycle required two identical compressors to lower the pressure ratio into a feasible pressure range.
| | BV-01 | BV-02 | | BV-03 | BV-04 BV-05 | | BV-06 | | BV-07 | |
|-----------------------|----------------|----------------|-------------|----------------|----------------|----------------|----------------|-------------|----------------|-------------|
| Process Information | Condition
1 | Condition
1 | Condition 2 | Condition
1 | Condition
1 | Condition
1 | Condition
1 | Condition 2 | Condition
1 | Condition 2 |
| Temperature [C] | 600 | 154 | 600 | 574 | 600 | 168 | 156 | 168 | 156 | 168 |
| Inlet Pressure [MPa] | 1.05 | 1.05 | 1.05 | 1.06 | 1.05 | 1.1 | 0.392 | 1.1 | 1.1 | 1.1 |
| Outlet Pressure [MPa] | 1.04 | 1.04 | | 1.05 | 1.04 | 1.09 | 0.385 | | 1.09 | |
| Mass Flow Rate [kg/s] | 0.924 | 0.924 | | 0.924 | 0.924 | 0.924 | 0.924 | | 0.924 | |
| Fluid | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen | Nitrogen |
| Cv (USGPM) | 232 | 323 | | 227 | 232 | 161 | 267 | | 318 | |
| Percentage open [%] | 100 | 100 | 0 | 100 | 100 | 100 | 100 | 0 | 100 | 0 |

 Table 3.9 PCU Simulator Isolation Valve Specifications

Table 3.10 PCU Simulator Heat Exchangers and Chillers Specifications

	Chiller HX-01		Chiller HX-02		Chiller HX-03		Recuperator RHX- 01		Recuperator RHX-02	
	Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid	Hot Fluid	Cold Fluid
Fluid Type	Nitrogen	Water	Nitrogen	Water	Nitrogen	Water	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Flow Rate [kg/s]	0.924		0.924		0.924		0.924	0.924	0.924	0.924
Temperature In [C]	344		195		156		599	479	505	99.3
Temperature Out [C]	276		21.1		21.1		506	573	125	480
Pressure In [MPa]	0.146		0.356		0.392		1.05	1.07	0.589	1.1
Allowable Pressure Drop [MPa]	0.0689		0.0689		0.0689		0.0689	0.0689	0.0689	0.0689
UA [W/C]							3680		15100	
Heat Transfer Rate [kW]	69		170		132		97.9		385	

A computer aided design (CAD) drawing is shown in Figure 3.27. This is a general representation of the P&ID but is not accurate of the actual sized component. Since the physical components are not known, only one compressor has been shown. Other considerations that the CAD does not account for are thermal expansion joints in various areas that would be needed to protect components against thermal expansion of the piping. The system may fail if expansion joints are not included in the final design. More figures of the simulator loop are included in the Appendix L.



Figure 3.27 Computer Aided Design (CAD) Concept of PCU Simulator

3.3.4.2 Design Consideration for Fluid Velocity and Pipe Noise

Concerns were raised when using 4" NPS pipe, especially after the gas was expanded following the CV-01 valve. The velocities after the expansion may reach up to 420 ft/sec.

Velocities at this rate may cause choked flow within the valves and cause them to be uncontrollable. However, the CV-01 data sheet show that the max mach number for the largest pressure drop in the valve is 0.477. It also shows that the pipe mach number is 0.265 (Flowserve, 2020). The CV-01 data sheet is shown in Appendix J. Another concern with the high velocities is the large piping noises. Table 3.11 shows the velocities and the estimated pipe noise for the different cycles. At these velocities, the pipe noise could be uncomfortably loud. It would be recommended to increase the pipe size which would decrease the gas velocity to ensure that the pipe noise falls within code. Equation 3.11 shows the "pipe noise generated in air ducts" calculation from Engineering Toolbox (Engineering Toolbox, n.d.). This calculation, however, does not include insulation around the pipes. Pipe insulation in the PCU simulator would be kept consistent with the MAGNET and therefore would have 4 inches of insulation surrounding the piping.

$$L_N = 10 + 50 \log\left(\frac{v}{197}\right) + 10 \log\left(\frac{A_{cs}}{1550}\right) [dB]$$
 Equation 3.11

Where:

$$L_N \rightarrow Sound power level (dB)$$

 $v \rightarrow Fluid velocity \left(\frac{ft}{min}\right)$
 $A_{cs} \rightarrow Cross section flow area (in2)$

Table 3.11 Pipe Noise in Duct Calculations for 4 inch Piping in the PCU Simulator for Flow Rates for MAGNET Test Chamber at 250 kW

	Velocity after CV- 01 [ft/sec] (m/s)	Cross Section Flow Area [in ²]	Pipe Noise [dB]
Air Brayton Cycle at η_{comp} =85% and η_{turb} =90%	420 (128)	12.7	94.5
Air Brayton Cycle at $\eta_{comp}=70\%$ and $\eta_{turb}=80\%$	215 (65.5)	12.7	80
Recuperated Air Brayton Cycle at $\eta_{comp}=85\%$ and $\eta_{turb}=90\%$	178 (54.3)	12.7	75.9
Recuperated Air Brayton Cycle at $\eta_{comp}=70\%$ and $\eta_{turb}=80\%$	141 (43.0)	12.7	70.8

The pipe insulation would reduce the noise of the piping. Also, the fluid velocity can be reduced to decrease the noise. The fluid velocity can be decreased by increasing the pipe diameter. Table 3.12 shows the velocities and pipe noises compared to different pipe diameters. The pipe segment length was assumed to be 9.84 ft (3 m) and all schedule 40 mild steel piping. The pipe was also considered at the highest velocity site right after CV-01 after the fluid is expanded. It would be recommended to decrease the flow through the PCU simulator or to increase the pipe size to a minimum of 8 inches to reduce the fluid velocity to a more acceptable range. The American Society of Mechanical Engineers state in ASME B31.8-2018, "Gas velocities should not exceed 100 ft/sec (30 m/s) at peak conditions... High gas velocities in piping increase turbulence and pressure drop and contribute to excessive sound pressure levels (aerodynamic noise)..." (The American Society of Mechanical Engineers, 2018).

Pipe Size	Pipe Inner Diameter [in]	Cross- Sectional Area [in^2]	Averaged Fluid Velocity [ft/s] (m/s)	Pipe Noise [dB]
4-inch sch 40	4.026	12.7	416 (127)	94.3
5-inch sch 40	5.047	20	262 (79.9)	86.2
6-inch sch 40	6.065	28.9	181 (55.2)	79.8
8-inch sch 40	7.981	50	104 (31.8)	70.2
10-inch sch 40	10.02	78.9	66.3 (20.2)	62.3
12-inch sch 40	11.938	112	46.7 (14.2)	56.2
14-inch sch 40	13.124	135	38.6 (11.8)	52.9

Table 3.12 Fluid Velocity and Pipe Noise Compared to Various Standard Pipe Sizes

3.3.5 Test Plan for Power Conversion Unit Simulator

Test plans were developed to perform shakedown tests for the PCU simulator to simulate the start up of the simple nitrogen Brayton cycles and to simulate the recuperated nitrogen Brayton cycles. The test plans for different cycles have varying turbine and compressor efficiencies. To develop the test plans, a process model of the PCU simulator was developed that kept specifications of the design constant, see Figure 3.28. The specifications for the recuperating heat exchangers, valves, chillers, and compressors were held constant. The design conditions for the high temperature recuperating heat exchanger was set to the lowest duty design specifications while the low temperature recuperating heat exchanger used the highest duty design specifications of the nitrogen cycles. This allowed a chiller to be put in place to control the desired simulated turbine outlet temperature for each case considered. Figure 3.29 shows the piping and instrumentation diagram of the PCU simulator. Each valve, compressor, and heat exchangers have unique labels. In addition, thermocouples, pressure transducers, and flow meters are labeled.

A procedure was developed to run shakedown tests on the PCU simulator. The shakedown tests have no heat from the MAGNET. After purging of gases and charging the PCU simulator and the MAGNET with nitrogen gas, the simulator is isolated from the testbed using valving. Then a series of tests are performed to ensure the operation of the simulator. Chillers, compressors, and control valves will be tested to validate operation.

The test matrix for the shakedown tests are shown in Table 3.13. The matrix includes tests that operate one compressor followed by tests in which both compressors operate. For the single compressor tests, pressure ratios across the compressor will be varied from 2 to 3. The chiller's (HX-01) duty will be varied from 0 to the duties listed in the table to achieve temperatures measured at thermocouple T3 of 25°C and 50°C. The duties listed were estimated by using an Aspen HYSYS model of the PCU simulator. The temperatures given when the chiller's duty is set to zero were also estimated using the same model. With two compressors, the pressure ratio was set to be identical for both compressors. That is the pressure ratio listed in Table 3.13. The pressure at P2 is controlled by CV-01 and the temperature measured at T3 is controlled by chiller, HX-01.



Figure 3.28 PCU Simulator with Final Design Specifications



Figure 3.29 Pipe and Instrumentation Diagram for the PCU Simulator

3.3.5.1 Shakedown Test Procedure of Power Conversion Unit Simulator

- 1. Valves BV-01, BV-02, BV-03, BV-04, BV-05, BV-06, BV-07, and CV-01 are fully open.
- 2. Purge testbed and power conversion loop of oxygen.
- 3. Fill and pressurize from nitrogen storage tanks the testbed and the power conversion loop with nitrogen.
- 4. For one compressor power conversion simulation:
 - a. Close BV-01, BV-03, BV-06, and BV-07.
 - b. Begin operation of chiller HX-02, which coolant flow is controlled by temperature T5, into compressor Comp-01.

- c. Close CV-01 to 25% of full open.
- d. Start compressor Comp-01 to achieve desired pressure at P4.
- 5. For two compressor power conversion simulation:
 - a. Close BV-01, BV-03, and BV-05.
 - b. Begin operation of chiller HX-02, which coolant flow is controlled by temperature T5, into compressor Comp-01.
 - c. Begin operation of chiller HX-03, which coolant flow is controlled by temperature T7, into compressor Comp-02.
 - d. Close CV-01 to 25% of full open.
 - e. Start compressor Comp-01 to achieve desired pressure at P3.
 - f. Start compressor Comp-02 to achieve desired pressure at P4.
- 6. Adjust CV-01 to obtain desired pressure at P2.
- 7. Allow power conversion unit simulator to come to steady state.
- 8. Begin operation of chiller HX-01 which coolant flow is controlled by temperature T3.
- 9. Allow power conversion unit simulator to come to steady state.

Single Compressor									
Test Name	Compressor Pressure Ratio	Chiller Duty (kW)	P2 (MPa)	T3 (°C)					
Shk_1Cmp_PR2_0kW	2	0	0.570	94					
Shk_1Cmp_PR2_50C	2	2.4	0.570	50					
Shk_1Cmp_PR2_25C	2	3.6	0.570	25					
Shk_1Cmp_PR2.5_0kW	2.5	0	0.456	125					
Shk_1Cmp_PR2.5_50C	2.5	4.2	0.456	50					
Shk_1Cmp_PR2.5_25C	2.5	5.6	0.456	25					
Shk_1Cmp_PR3.0_0kW	3.0	0	0.380	150					
Shk_1Cmp_PR3.0_50C	3.0	5.8	0.380	50					
Shk_1Cmp_PR3.0_25C	3.0	7.2	0.380	25					
Two Compressor									
Test Name	Compressor Pressure Ratio	Chiller Duty (kW)	P2 (MPa)	T3 (°C)					
Shk_2Cmp_PR1.5_0kW	1.5	0	0.507	51					
Shk_2Cmp_PR1.5_25C	1.5	1.4	0.507	25					
Shk_2Cmp_PR2_0kW	2	0	0.285	88					
Shk_2Cmp_PR2_50C	2	2.0	0.285	50					
Shk_2Cmp_PR2_25C	2	3.4	0.285	25					
Shk_2Cmp_PR2.5_0kW	2.5	0	0.182	121					
Shk_2Cmp_PR2.5_50C	2.5	3.9	0.182	50					
Shk_2Cmp_PR2.5_25C	2.5	5.2	0.182	25					

Table 3.13 Shakedown Test Matrix for PCU Simulator

A test procedure was developed to simulate the operation of the simple and the recuperated nitrogen Brayton cycles.

3.3.5.2 Power Conversion Unit Simulator Test Procedure

- 1. Open valves BV-02, BV-04, and CV-01.
- 2. For one compressor power conversion simulation:

- a. Close BV-01, BV-03, BV-06, and BV-07.
- b. Begin operation of chiller HX-02, which coolant flow is controlled by temperature T5, into compressor Comp-01.
- c. Close CV-01 to 25% of full open.
- d. Start compressor Comp-01 to achieve desired pressure at P4.
- 3. For two compressor power conversion simulation:
 - a. Open BV-06 and BV-07.
 - b. Close BV-05.
 - c. Begin operation of chiller HX-02, which coolant flow is controlled by temperature T5, into compressor Comp-01.
 - d. Begin operation of chiller HX-03, which coolant flow is controlled by temperature T7, into compressor Comp-02.
 - e. Close CV-01 to 25% of full open.
 - f. Start compressor, Comp-01, to achieve desired pressure at P3.
 - g. Start compressor, Comp-02, to achieve desired pressure at P4.
- 4. Adjust CV-01 to obtain desired pressure at P2.
- 5. Allow power conversion unit simulator to come to steady state.
- 6. Begin operation of chiller, HX-01, which coolant flow is controlled by temperature T3.
- 7. Allow power conversion unit simulator to come to steady state.
- 8. Set pressure, P2 using CV-01, and temperature, T3 using chiller HX-01 to simulate power conversion unit start up before heat introduction.
- 9. Open BV-01 and BV-03
- 10. Close BV-02
- 11. Close BV-04
- 12. Allow power conversion unit simulator to come to steady state.
- 13. Set pressure P2 using CV-01 and set temperature T3 using chiller HX-01 to simulate power conversion unit start up at self-sustaining state.
- 14. Allow power conversion unit simulator to come to steady state.
- 15. Set pressure P2 using CV-01 and set temperature T3 using chiller HX-01 to simulate operating design state of power conversion unit.

A test matrix was developed to simulate the nitrogen Brayton cycles, see Table 3.14. For the simple Brayton cycle, two start up conditions will be simulated. These conditions are based on the model simulations of a full-scale Brayton cycle presented in Chapter 4. The first condition that will be simulated is at the point where the PCU is driven by a motor just before heat addition. The second condition simulated is the point when the turbine can sustain the compressor without the aid of the start up motor - see Chapter 4 for detailed information on the start up of a non-recuperated Brayton cycle. All other conditions are the operating design conditions presented earlier in the report.

Simple Nitrogen Brayton Cycle	P2 (MPa)	T3 (°C)	Compressor Adiabatic Efficiency	Turbine Adiabatic Efficiency
Start up Before Heat Addition	0.711	63.1	70%	80%
Self-Sustaining State	0.503	460	70%	80%
Design	0.359	430	70%	80%
Start up Before Heat Addition	0.480	91.0	85%	90%
Self-Sustaining State	0.229	287	85%	90%
Design	0.144	284	85%	90%
Recuperated Nitrogen Brayton Cycle	P2 (MPa)	T3 (°C)	Compressor Adiabatic Efficiency	Turbine Adiabatic Efficiency
Design	.601	505	70%	80%
Design	.527	470	85%	90%

Table 3.14 PCU Simulator Tests

The PCU simulator has 16 thermocouples, 4 pressure transducers, 4 flow meters, 6 PID controllers, and 2 compressor power measurements for a total of 32 transducers. It is expected that a data file for each test will be 500 kbytes assuming 40 pieces of instrumentation (pressure transducers, thermocouple, mass flow meters, PID controllers etc.) with a test lasting 4 hours with 15 second intervals for data acquisition.

3.3.6 Economic Analysis for Power Conversion Unit Simulator

An economic analysis has been performed for the PCU simulator. Several methods of analyses have been performed to determine the estimated total capital cost for the simulator loop. Aspen HYSYS's economic package was used as well as the "0.6 rule" alongside quotes and estimates from companies to create the total cost estimate. It has been determined that the total capital cost for the PCU simulator approaches 2.15 million dollars. An equipment cost breakdown is shown in Table 3.15.

Equipment Cost [USD]								
Comp-01	\$	799,900.00						
Comp-02	\$	799,900.00						
Recup RHX-01	\$	67,500.00						
Recup RHX-02	\$	153,000.00						
Chiller HX-01	\$	8,500.00						
Chiller HX-02	\$	10,900.00						
Chiller HX-03	\$	10,000.00						
CV-01	\$	66,000.00						
BV-01	\$	55,000.00						
BV-02	\$	55,000.00						
BV-03	\$	55,000.00						
BV-04	\$	55,000.00						
BV-05	\$	1,000.00						
BV-06	\$	1,000.00						
BV-07	\$	1,000.00						
Piping	\$	10,000.00						
Equipment Cost [USD]	\$	2,150,000.00						

Table 3.15 Estimated Capital Cost for PCU Simulator Breakdown

The compressors, the heat exchangers, and the piping costs were estimated using various methods which are discussed below. The cost of CV-01 was determined from a quote from Flowserve, which is shown in Appendix J. The actuated isolation ball valves, BV-01 to BV-04, costs are determined from a quote, shown in Appendix K, and estimate from Flowserve. BV-01 quote was for a hand operated ball valve and the cost was estimated to be three times larger

to make it actuated by a controller due to the extreme temperatures the valves will be exposed to (Flowserve, 2020). BV-05 to BV-07 are standard 4-inch ball valves that are hand operated.

3.3.6.1 Aspen HYSYS Economic Analysis

Aspen HYSYS's economic package was used as a method to estimate the total capital cost for the PCU simulator. Several Aspen HYSYS models of the PCU simulator were used to generate the economic analysis. The compressor estimate came from the simulation test with the highest compression ratio and greatest power, which is the simple air Brayton cycle with the compressor and turbine efficiencies of 70% and 80%, respectively. It is assumed that the same compressor is purchased twice. The recuperating heat exchanger estimates came from the simulation of the recuperated air Brayton cycle with compressor and turbine efficiencies of 70% and 80%, respectively. The chiller units were comparable in prices between the different economic models created. Their prices were determined from the simple Brayton cycle simulation with compressor and turbine efficiencies of 85% and 90%, respectively. The piping cost was estimated by inputting values into Aspen HYSYS's economic package. The piping was described as 4-inch stainless steel 316 schedule 40 pipe with 0.5 inch of insulation. The fittings were described to be welded.

Aspen HYSYS economic package estimated the capital cost for the PCU simulator to be near 2.05 million dollars. The economic package also details an estimated install cost for each equipment. The estimated total install cost, which includes the capital cost of the equipment, is 2.91 million dollars. The Aspen HYSYS component breakdown is shown in Table 3.16.

	Equipment	Installed Cost		
	Cost [USD]	[USD]		
Comp-01	\$ 799,900.00	\$ 940,000.00		
Comp-02	\$ 799,900.00	\$ 940,000.00		
Recup RHX-01	\$ 72,200.00	\$ 260,500.00		
Recup RHX-02	\$ 54,000.00	\$ 241,300.00		
Chiller HX-01	\$ 8,500.00	\$ 97,600.00		
Chiller HX-02	\$ 10,900.00	\$ 70,900.00		
Chiller HX-03	\$ 10,000.00	\$ 69,800.00		
CV-01	\$ 66,193.00	\$ 66,200.00		
BV-01	\$ 55,350.00	\$ 55,400.00		
BV-02	\$ 55,350.00	\$ 55,400.00		
BV-03	\$ 55,350.00	\$ 55,400.00		
BV-04	\$ 55,350.00	\$ 55,400.00		
BV-05	\$ 1,000.00	\$ 1,000.00		
BV-06	\$ 1,000.00	\$ 1,000.00		
BV-07	\$ 1,000.00	\$ 1,000.00		
Piping	\$ 9,300.00	\$ -		
Equipment Cost [USD]	\$2,055,293.00			
Total Installed Cost [USD]		\$2,910,900.00		

Table 3.16 Aspen HYSYS Cost Estimate for the PCU Simulator Breakdown

3.5.6.2 "0.6 Rule" Economic Estimate

A common method used to estimate the cost of various equipment is to use the "0.6 rule" (Whitesides, 2012). This method takes an existing cost of equipment with a known size and estimates the cost of a different sized equipment. Equation 3.12 is shown below.

$$C_2 = C_1 (\frac{S_2}{S_1})^N \qquad \qquad Equation \ 3.12$$

Where: $C_1 \rightarrow \text{Cost of Equipment 1}$

- $C_2 \rightarrow \text{Cost of Equipment 2}$
- $S_1 \rightarrow \text{Size of Equipment 1}$
- $S_2 \rightarrow \text{Size of Equipment } 2$

$N \rightarrow$ Size Exponent

N, the size exponent, was assumed to be 0.6 for a generalized estimate but can change depending on various process equipment, such as compressors. An initial estimate was obtained by using quotes used for INL's MAGNET compressor, chiller, and recuperating heat exchanger. These prices were used to estimate the cost of the equipment for the PCU simulator. Through this estimate, the total capital cost for the PCU simulator is approximated at 1.39 million dollars. Table 3.17 shows the results from the analysis.

The results for the 0.6 rule give reasonable values for the recuperating heat exchangers as well as the chillers. The 0.6 rule showed that the prices for RHX-01 and RHX-02 are similar to INL's quoted recuperating heat exchanger. This is to be expected as the determined duty and conditions are very similar to the MAGNET recuperating conditions. The chiller values seem to produce a reasonable estimate from the similarly sized chiller heat exchanger in the MAGNET that was quoted to INL. Aspen HYSYS estimate was used over the 0.6 rule as some of the temperature differences could be large in Chiller HX-01 in the PCU simulator, though the estimates only vary by ~\$6000 each.

	INL Equipment	INL Quoted Cost [USD]	INL Needed Quoted kW ([kW]		Adjusted Cost [USD]	QTY	Estimated Cost [USD]	
Comp 01	25 hp							
Comp-01	Compressor	\$ 92,225.00	18.64	145.2	\$ 316,028.42	1	\$ 316,028.42	
Comp 02	25 hp							
Comp-02	Compressor	\$ 92,225.00	18.64	145.2	\$ 316,028.42	1	\$ 316,028.42	
Recup RHX-	350 kW							
01	Recuperator	\$ 145,000.00	350	97.9	\$ 67,514.46	1	\$ 67,514.46	
Recup RHX-	350 kW							
02	Recuperator	\$ 145,000.00	350	384.7	\$ 153,461.87	1	\$ 153,461.87	
	MAGNET							
11A-01	Chiller HX-01	\$ 5,550.00	274.5	68.62	\$ 2,415.67	1	\$ 2,415.67	
	MAGNET							
11A-02	Chiller HX-01	\$ 5,550.00	274.5	167.4	\$ 4,124.97	1	\$ 4,124.97	
HV 03	MAGNET							
11A-05	Chiller HX-01	\$ 5,550.00	274.5	132	\$ 3,576.94	1	\$ 3,576.94	
CV-01					\$ 66,193.00	1	\$ 66,193.00	
BV-01-04					\$ 55,350.00	4	\$ 221,400.00	
BV-05-07					\$ 1,000.00	3	\$ 3,000.00	
Piping					\$ 9,300.00	1	\$ 9,300.00	
Total Capital								
Cost [USD]							\$1,163,043.75	

Table 3.17 0.6 Rule Cost Estimate for the PCU Simulator Breakdown

The compressor estimate was based off the Corken compressor that was quoted for the MAGNET. This compressor's estimate was determined to be low and was rejected. The compressors in the PCU simulator are expected to deliver much higher-pressure ratios. The size of the compressors are also nearly 8 times the size of the MAGNET compressor. The reason for rejecting this price is for three reasons:

- During initial cost estimates to compressor companies, Kobelco was approached to size a single compressor that could handle all the test conditions of the PCU simulator. This compressor would need to handle compression ratios from 1.8 to 7.6. They determined that a screw compressor would work best and gave an estimated cost for the compressor of 1.5 million dollars. Aspen HYSYS showed that the estimated capital cost for two compressors was close to 1.6 million dollars.
- 2. Another estimate of the cost ratio shown in Equation 3.12 was used to compare the costs for the compressors. The new comparison used a sizing ratio for the CFM into the compressors with a size exponent, N, equal to 0.67 up from 0.6 for single stage compressors (Whitesides, 2012). Table 3.18 shows the results of using the CFM ratio instead of a power ratio as shown in Table 3.17. This resulted in a wide variety of costs ranging for a single compressor of 356 to 865 thousand dollars. The higher flow rate comes from the simulation of the simple air Brayton cycle with the compressor and turbine efficiencies of 85% and 90%, respectively. This is due to the high pressure drop. From this analysis, it showed that the compressor would have a cost nearing 865 thousand dollars, which surpasses Aspen HYSYS's approximation.
- 3. Roots Systems gave a rough estimate for the price of the compressor set-up. Their representative said for one compressor on a skid with the controller, piping, valves, and intercooler, would be approximately 1 to 2 million dollars. However, during a phone call with the representative, they recommended 2 million dollars plus or minus 20% as their reasonable estimate for the price of the compressor system. They specified that the compressor would be a 12-inch piping, 2 stage rotary lobe compressor with a nominal 350 HP motor.

	INL Equipment	INL Quoted Cost [USD]	INL Quoted [ACFM]	Needed [ACFM]	Adjusted Capital Cost [USD]	QTY	Estimated Capital Cost [USD]
Comp-01	25 hp Compressor	\$ 92,225.00	45	337.5	\$ 355,745.74	2	\$ 711,491.48
Comp-01	25 hp Compressor	\$ 92,225.00	45	478.9	\$ 449,738.76	2	\$ 899,477.52
Comp-01	25 hp Compressor	\$ 92,225.00	45	295.9	\$ 325,734.24	2	\$ 651,468.47
Comp-01	25 hp Compressor	\$ 92,225.00	45	1272	\$ 865,371.61	2	\$ 1,730,743.22

Table 3.18 Adjusted Compressor Capital Cost using ACFM

For these reasons, the total estimated cost for one compressor is 799 thousand dollars, which was Aspen HYSYS's estimate. This estimate was within the reasonable range that the vendors said the compressors would cost. However, the price may vary slightly as Roots System's estimate would include piping and an intercooler. This would remove chiller HX-03 from the breakdown. Their compressor set also used 12 inch piping, which would increase the estimated piping cost outside of what they would provide; however, the cost for increasing the pipe size would be minimal when compared to the other large components in the system. The pipe sizing would only need to be increased after the gas is expanded past CV-01. This would only marginally increase the piping cost. Therefore, the total estimated capital cost for the PCU simulator is 2.15 million dollars, see Table 3.15.

Chapter 4: Estimated Start Up Analysis for PCU using Aspen HYSYS

4.1 Introduction

A modular power conversion unit will be used to generate power from heat provided by microreactors. These PCUs are around 1-20 MW_e (Office of Nuclear Energy, 2018). The nuclear microreactor's PCU being investigated will be similar to an air breathing compressorturbine unit. It is noted that there are many different potential PCU configurations that could be utilized with nuclear microreactors. A detailed search was performed on actual compressorturbine units. These units could provide an accurate representation of the size and efficiencies that would be used for modular nuclear microreactors.

Knowing the sizing of a full scale modular PCU nuclear reactor will also aid in the development and versatility of the PCU simulator. A key factor for the PCU simulator is that it is capable of simulating state points in a power cycle. These state points do not have to come from steady-state operations of the power cycles. Understanding the start up procedure gives the three key data points discussed in the previous chapter. These three key points are the conditions of the working fluid entering and leaving the turbine and entering the reactor (vacuum chamber in the MAGNET). During the start up processes, these three key points for a non-recuperated Brayton cycle could be simulated. Similar steps described later in the chapter could be applied to a recuperated Brayton cycle.

4.2 Aspen HYSYS Analysis of Siemen's SGT-A05 KB7HE

Siemens Automation Company manufactures a small, portable, compressor-turbine unit, the SGT-A05 KB7HE, which produces around 5 MW_e. This power generation unit was selected to perform an analysis on, as it falls within the expected power range of the modular nuclear microreactors (1-20 MW). Analyzing the commercial unit provided representative efficiencies for the compressor and turbine. An Aspen HYSYS model was designed to replicate the Siemens' public data sheet for this unit. The unit's data sheet is shown in Table 4.1 and the Aspen HYSYS model is shown in Figure 4.1.

	SGT-A05 KB5S SGT-A05 KB7S			SGT-A05 KB7 HE			
Power Output	4.0 MWe	5.4 MWe		5.8 MWe			
Fuel	Natural gas, liqu automatic change	uid fuel, duel fu over from prima load	el; other fue ary to secon	els on rec dary fue	quest; l at any		
Frequency	50/60 Hz	50/60 Hz		50/60 Hz			
Gross Efficiency	29.70%	32.30%		33.209	%		
Heat Rate	12,137 kJ/kWh	11,152 kJ/kV	Vh 1	0,848 kJ	/kWh		
Turbine Speed	14,200 rpm	14,600 rpm	1	14,600 r	pm		
Pressure Ratio	10.3 : 1	13.9 : 1		14.0 :	1		
Exhaust mass flow	15.4 kg/s	21.3 kg/s		21.4 kg	g/s		
Exhaust Temperature	560°C (1,404°F)	484°C (921°	F) 5	522°C (972F)			
NOx emissions ≤ 25 ppmvd at 15% O2 on fuel gas (with DLE))		
	D6: Therr	mal Efficiency 0.3	3320				
	D5: Powe	er Out 6	645				
Ambient Air In Compressor Compressor Power Adiabatic Efficiency Adiabatic Efficiency Seactor Natural Gas Reactor Exhaust Hilet Turbine Power Turbine Adiabatic Efficiency Exhaust Adiabatic Efficiency Seactor Energy 14.88 MV							
Energy 8.2	32 MW						
	Material St	reams					
Amb	ient Air In Compressed A	Air Natural Gas	Turbine Inlet	Exhaust	Waste		
Temperature C	15.00 389	9.3 389.3	1098	522.0	1098		
Pressure kPa	101.3 14	19 1419	1419	101.3	1419		
Mass Flow kg/s	21.0 2	0.387	21.4	21.4	0.000		

Table 4.1 Siemens' SGT-A05 Public Data Sheet (Siemens, 2019)

Figure 4.1 SGT-A05 KB7HE Air Brayton Cycle Aspen HYSYS Model

The SGT-A05 KB7HE Aspen HYSYS model was created to determine the representative efficiencies for the compressor and turbine for a similarly sized PCU for nuclear microreactors. The compressor efficiencies are expected to be within the range of 70%-85% and turbine efficiencies are expected to be between 75%-90% (Wark, 1995). Through parametric studies

using the Aspen HYSYS model, a compressor efficiency of 83.1% and a turbine efficiency of 88.7% was obtained. It is shown that some of the values in the Aspen HYSYS model do not match the Siemens' data sheet. This is likely due to Siemens' data sheet being collected from a physical unit which includes losses in the system and the generator. The efficiencies found in Aspen HYSYS are, however, reasonable according to the traditional ranges presented by Wark. This data provided useful information that these smaller PCUs can still obtain high adiabatic efficiencies for compressors and turbines. Therefore, two cases were analyzed to give a range of data: a scenario assuming compressor and turbine efficiencies at 85% and 90% and a scenario assuming a compressor and turbine efficiencies of 70% and 80%, respectively.

An analysis was performed to compare the performance between the Siemen's SGT-A05 KB7HE unit and an optimized 85% compressor and 90% turbine efficiency heat pipe nuclear reactor PCU using 600°C turbine inlet temperature. This temperature is the expected temperature found in the MAGNET leaving the heat pipe section as well as within the range of normal operations for a heat pipe cooled reactor (Westinghouse, 2019). Both units were assumed to use dry air as the working fluid and were both an open air Brayton cycle. This comparison is shown in Table 4.2. It is shown that the heat pipe powered PCU does not produce as much power or have a high thermal efficiency compared to Siemens combustion powered PCU. This is expected due to the turbine inlet temperature and pressure ratios of the SGT-A05 being much greater. However, the thermal efficiency for the heat pipe powered Brayton cycle is still reasonable.

	Thermal Efficiency	Pressure Ratic	Power Out [MW]	Turb In Temp [°C]	Exhaust Temp [°C]	Mass Flow Rate [kg/s]	Comp Efficiency	Turb Efficiency	Carnot Efficiency	Second Law Efficiency
Heat Pipe Power Simple Air Brayton Cycle	23.4	7.38	2.34	600	280	28.7	85	90	66.3	35.3
Siemen's SGT- A05 KB7HE Natural Gas Combustion Brayton Cycle	33.2	14	6.65	1100	522	21.4	83.1	88.7	78.6	42.3

Table 4.2 Comparison Between a Heat Pipe Powered PCU and a Natural Gas Power PCU

4.3 Estimated Start Up Analysis for Heat Pipe Nuclear Reactor Operating at 650°C

A simplified air Brayton cycle was constructed in Aspen HYSYS to simulate the performance of the PCU. Figure 4.2 shows the Aspen HYSYS model for the Brayton cycle using the higher compressor and turbine efficiencies, the process flow diagram for both efficiency model is in Appendix M. The heat source used in the model could be representative of a gas combustion unit or some other heat source such as nuclear power. The "Air Compressor" and "Air Turbine" are both functioning from design curves presented above. For the dynamic analysis, an approximation of a quasi-steady-state process is assumed. This assumption implies that the PCU responds instantaneously to small incremental steps. This approach is valid for dynamic analysis as these systems do respond quickly. According to J. Kim et al., many mathematical models simulate start up of gas turbine engines with a quasi-steady-state assumption (Kim, Song, Kim, & Ro, 2002). Therefore, the start up analysis was performed using a quasi-steady-state assumption.



Figure 4.2 Air Brayton Cycle with 85% Compressor and 90% Turbine Adiabatic Efficiencies with a Turbine Inlet Temperature of 650°C

To perform an analysis on the start up of the simple air Brayton cycle, the start up process needs to be understood. The process of starting up a simple air Brayton cycle power conversion unit was described by a representative from Siemens for one of their larger power production plants (Siemens, 2019).

Kim et al. also described that during start up, "Turbine efficiencies must be high enough, at a speed approximately 40% to 85% of its design speed, in order for the engine to sustain itself without starter power" (Kim, Song, Kim, & Ro, 2002). They also describe that it is slightly different for each engine. Kim et al.'s data was comparable to Siemens' report.

Using guidance from both sources, the start up process used for this analysis was as follows:

- 1. A motor begins to turn the compressor. The motor can be a 480 V motor, or the unit can be started by reversing the power into the generator to act as a motor.
- 2. The motor drives the compressor to the shaft rotational speed range of 61 63% of the operating speed at which time the fuel is injected into the combustion chamber. At this point, the combustion is considered unstable.
- The generator continues to drive the compressor to about 83.33% of the operational speed when the combustion process is considered stable and the turbine can sustain the compression process.
- 4. The turbine drives the system at this point and the fuel rate is increased until the turbine speed reaches the system's operational speed.

These start up steps are used for a conventional natural gas powered PCU. They outline when the fuel would be added during the start up of the PCU. However, there was discussion on how a nuclear powered heat pipe reactor could start up. Sodium cooled heat pipes, as the ones used for the MAGNET, could take a considerable amount of time to get to their operating point (Reid, Sena, & Martinez, 2001) and could use a loop for cooling separated from the PCU. Once the heat pipes are at their operating point, the PCU could start up and the PCU working fluid could be directed through the heat pipe heat exchanger through a series of valving which would add heat to the PCU as well as continued cooling to the heat pipes. Making sure that the heat pipes always had sufficient mass flow rate for cooling while switching from the heat pipe primary cooling loop and the PCU would need to be considered. However, for the remained of this chapter, the start up analysis used the conventional natural gas PCU start up detailed above.

Generic compressor and turbine curves were obtained to help simulate the performance of the PCU during off design conditions. The generic curves were scaled to the operating points expected from the optimized heat pipe PCUs, such as the one in Figure 4.2. The curves have been scaled to fit a higher efficiency compressor and turbine case as well as a lower efficiency compressor and turbine scenario. These curves were generated for two separate simple Brayton cycles with a turbine inlet temperature of 650°C: one with an 85% compressor efficiency and 90% turbine efficiency and the other with a 70% compressor efficiency and 80% turbine efficiency. The curves also assume that 100% rotational speed is the same as Siemens' SGT-A05-KB7HE which is 14600 rpm. The curves are shown below in Figure 4.3 to Figure 4.6. The curves were entered into Aspen HYSYS to estimate the performance of the PCUs at different shaft rotation speeds and varying efficiencies.

An approximate mass flow rate equation was used during the quasi-steady-state analysis. Equation 4.1 relates the density of the inlet fluid, volume of the unit, and the rotational speed of the unit to the mass flow rate. The mass flow rate at a given speed is proportional to the compressor speed percentage multiplied by the design mass flow rate when the inlet density is considered constant, shown in Equation 4.2. This estimation was used to determine the mass flow rate at varying rotational speeds of the PCU.

Where:

$$\dot{m} = \frac{\rho V n}{60} \left(\frac{kg}{s}\right) \qquad Equation 4.1$$

$$\dot{m} = \frac{n}{n_{op}} \dot{m}_{op} \qquad Equation 4.2$$

$$\dot{m} \rightarrow mass flow rate\left(\frac{kg}{s}\right)$$

$$\rho \rightarrow Inlet mass density\left(\frac{kg}{m^3}\right)$$

$$V \rightarrow Unit volume (m^3)$$

$$n \rightarrow Unit's speed\left(\frac{rev}{min}\right)$$

$$\dot{m}_{op} \rightarrow Operational mass flow rate\left(\frac{kg}{s}\right)$$

$$n_{op} \rightarrow Unit's operational speed\left(\frac{rev}{min}\right)$$







Figure 4.3 Compressor Curves for the 85% Compressor and 90% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 650°C



Figure 4.4 Turbine Curves for the 85% Compressor and 90% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 650°C





Figure 4.5 Compressor Curves for 70% Compressor and 80% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 650°C



Figure 4.6 Turbine Curves for 70% Compressor and 80% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 650°C

During start up, it was assumed that the compressor drives the system in terms of rotational speed and mass flow rate due to the start up motor turning the compressor which is shafted to the turbine. The turbine then controls the system once the temperature and pressure reach the point where the turbine generates sufficient power to overcome the work of the compressor. It was assumed that the operating rotational speed was 14600 rpm, which mimics the operating rotational speed of Siemens' SGT-A05 KB7HE PCU. The results for the start up analysis for both the highest and lowest efficiencies for the compressor and turbine case scenarios are shown below in Table 4.3 to Table 4.4 and Figure 4.7 to Figure 4.10. It is assumed that the power out is the compressor power subtracted from the turbine power and it does not include inefficiencies in the generator unit.

Table 4.3 Results of Start Up Analysis for 85% Compressor and 95% Turbine Adiabatic Efficiencies with a Turbine Inlet Temperature of 650°C

RPM	Power Out (MW)	Compressor Power (MW)	Turbine Power (MW)	Turbine Inlet Temp (°C)	Comp Outlet Pres (MPa)	Exhaust Temp (°C)	Mass Flow Rate (kg/s)
0	0	0	0	21.1	0.101	21.1	0
61.64%	-1.34	1.71	0.362	125	0.251	103	16
86%	0.00846	4.85	4.86	512	0.524	313	22.4
100%	2.35	7.63	9.97	651	0.86	304	26
110%	2.24	10.1	12.4	674	1.17	283	28.6

Table 4.4 Results of Start Up Analysis for 70% Compressor and 80% Turbine Adiabatic Efficiencies with a Turbine Inlet Temperature of 650°C

RPM	Power Out (MW)	Comp Power (MW)	Turbine Power (MW)	Turbine Inlet Temp (°C)	Comp Outlet Pres (MPa)	Exhaust Temp (°C)	Mass Flow Rate (kg/s)
0	0	0	0	21.1	0.101	21.1	0
61.64%	-0.629	0.761	0.131	79.7	0.162	69.2	12.2
83%	0.00657	1.95	1.95	552	0.233	445	16.5
100%	0.791	3.4	4.2	649	0.333	460	19.8
110%	0.75	4.53	5.28	640	0.406	423	21.8



Figure 4.7 Power Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% with a Turbine Inlet Temperature of 650°C

Simple Brayton Cycle High Efficiency Start-up Temperatures and Pressure



Figure 4.8 Temperature and Pressure Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% with a Turbine Inlet Temperature of 650°C



Simple Brayton Cycle Low Efficiency Start-Up Power

Figure 4.9 Power Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% with a Turbine Inlet Temperature of 650°C

Simple Brayton Cycle Low Efficiency Start-up Temperatures and Pressure



Figure 4.10 Temperature and Pressure Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% with a Turbine Inlet Temperature of 650°C

The analysis shows that the higher efficiency case scenario has enough turbine power to self-sustain the system when the rotational speed is close to 86% of the operating speed. The lower efficiency case scenario showed the turbine generated enough power to self-sustain near 83% of the operating rotational speed. Both these values are within the range that Kim et al and Siemens described for start up. However, their data was based off natural gas combustion and required the combustion to be stable. The microreactor heat pipes could possibly start heating the air sooner, requiring less power input into the power conversion unit.

4.4 Estimated Start Up Analysis for Heat Pipe Nuclear Reactor Operating at 600°C

A similar analysis was performed on a heat pipe PCU assuming the working fluid was pure nitrogen, and the turbine inlet temperature was 600°C instead of 650°C. The other assumptions remained the same. This analysis is analogous to the fluid and turbine inlet temperature of the MAGNET. To be simulated in the PCU simulator, the pressures would only need to be adjusted to acquire the correct pressure ratio at each start up state point. This analysis required a new set of curves to be generated for the compressor and turbine at their different paired efficiencies: 70% and 80% compressor and turbine efficiencies respectively, and 85% and 90% compressor and turbine efficiencies, respectively. This was done because the operating temperature was adjusted. These models were optimized to obtain the highest possible thermal efficiency. The higher efficiency model is shown in Figure 4.11, the process flow diagram for both efficiency model is in Appendix M. The compressor and turbine curves are shown in Figure 4.12 to Figure 4.15 for the high and low efficiency cases. The results of the analyses are shown in Table 4.5 to Table 4.6 and Figure 4.16 to Figure 4.19.



Figure 4.11 Simple Nitrogen Brayton Cycle with 85% Compressor and 90% Turbine Adiabatic Efficiencies with a Turbine Inlet Temperature of 600°C



Figure 4.12 Compressor Curves for the 85% Compressor and 90% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 600°C





Figure 4.13 Turbine Curves for the 85% Compressor and 90% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 600°C





Figure 4.14 Compressor Curves for 70% Compressor and 80% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 600°C





Figure 4.15 Turbine Curves for 70% Compressor and 80% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 600°C

Table 4.5	Results of St	art Up Ana	lysis for 85%	Compresso	or and 95%	Turbine	Adiabatic
	Efficiencies	Case with a	Turbine Inle	et Temperat	ure of 600°	С	

RPM (%)	Pressure Ratio	Turbine Inlet Temp (°C)	Exhaust Temp (°C)	Comp Outlet Temp (°C)	Comp Outlet Pres (MPa)	Turbine Adiabatic Efficiency	Compressor Adiabatic Efficiency	Reactor Heat (MW)	Compressor Power (MW)	Turbine Power (MW)	Power Out (MW)	Mass Flow Rate (kg/s)
0	0	21.1	21.1	21.1	0.101	0	0	0	0	0	0	0
60	2.19	110	91	110	0.222	25	82.8	0	1.55	0.327	-1.23	16.7
86	4.58	471	287	213	0.464	74.5	81.8	6.8	4.88	4.89	0.00431	24
100	7.32	600	284	279	0.742	88.6	85	10	7.67	9.85	2.18	27.9

Table 4.6 Results of Start Up Analysis for 70% Compressor and 80% Turbine Adiabatic Efficiencies Case with a Turbine Inlet Temperature of 600°C

RPM (%)	Pressure Ratio	Turbine Inlet Temp (°C)	Exhaust Temp (°C)	Comp Outlet Temp (°C)	Comp Outlet Pres (MPa)	Turbine Adiabatic Efficiency	Compressor Adiabatic Efficiency	Reactor Heat (MW)	Compressor Power (MW)	Turbine Power (MW)	Power Out (MW)	Mass Flow Rate (kg/s)
0	0	21.1	21.1	21.1	0.101	0	0	0	0	0	0	0
60	1.48	71.8	63.1	71.8	0.15	25	68.2	0	0.667	0.113	-0.554	12.6
82.30	2.09	554	460	122	0.212	66.3	67.4	8.2	1.84	1.84	0.00334	17.3
100	2.93	600	434	170	0.297	78.7	70	10	3.3	3.95	0.655	21


Figure 4.16 Power Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% with a Turbine Inlet Temperature of 650°C

Simple Brayton Cycle High Efficiency Start-up Temperatures and Pressure



Figure 4.17 Temperature and Pressure Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% with a Turbine Inlet Temperature of 600°C



Figure 4.18 Power Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% with a Turbine Inlet Temperature of 600°C.

Simple Brayton Cycle Low Efficiency Start-up Temperatures and Pressure



Figure 4.19 Temperature and Pressure Profiles for Start Up Analysis of Air Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% with a Turbine Inlet Temperature of 600°C

The start up points between the two cycles are similar in terms of percent RPM when the unit is self-sustaining. The curves have a similar shape between the high and low efficiencies.

The power out is lower than the 650°C cases analyzed earlier, which is expected since the mass flow rate and the turbine inlet temperature is lower. However, the results follow a similar pattern.

A start up process could be simulated within the power conversion unit simulator by simulating the temperatures and pressure ratios found at the inlet and outlet of the turbine and the temperature entering the MAGNET vacuum chamber. As shown in the above tables and figures, four key rotation speeds simulate the start up process with the needed key points. Using similar analysis, the PCU simulator would be able to simulate different start up process of various power cycles as well as their shut down process.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

5.1.1 MAGNET Conclusions

The INL is developing the MAGNET to help test and prove various types of modular nuclear microreactors. Many Aspen HYSYS models were created to aid in this development. These models were designed after the equipment being placed within the MAGNET, including heat exchangers, piping, insulation, valving, pumps, and compressors. These models provide detailed process conditions at many state points within the MAGNET and several conclusions are drawn from the models.

- The MAGNET Aspen HYSYS models are rigorous models estimating many aspects throughout the loop. This makes them a great starting point for the expected process conditions until the equipment and heat exchanger models can be validated.
- Models for conditions that could be potentially dangerous if we pushed the system. Ensure safety while operations.
- The MAGNET models could be used to simulate potential experiments for the MAGNET. Running experiments can be costly due to labor and energy requirements. The HYSYS models could aid in the development of experiments to provide the most relevant information with the least amount of time and cost by eliminating experiments that provide little value.
- The MAGNET HYSYS models could be used to simulate off design conditions to determine safety parameters. The models could provide when the pressure or temperatures reach an extreme that could be potentially dangerous.
- The MAGNET was designed with the intent for using nitrogen as the main working fluid, but it was also considered to use helium. The MAGNET model estimated the performance of the heat exchangers and showed that helium will reach a higher temperature than nitrogen by approximately 34°C at similar heat pipe power. This puts the highest temperature in the system close to 634°C. The piping was designed for an operating temperature of 650°C which makes helium push near the design limit of the piping.

- The heat pipe heat exchanger designed showed that the desired temperature increase is possible.
- The models are a more rigorous analysis of the pressure drops throughout the MAGNET, estimating the pressure drop across the heat exchangers, piping, and valves. Using the designed 250 kW of heat pipe power with nitrogen, the total pressure drop through the MAGNET was approximately 146 kPa or a pressure ratio of 1.12. Approximately half of the pressure loss in the system was from the heat exchangers estimating close to 66 kPa. Similar cases using helium showed a pressure ratio across the MAGNET similar to nitrogen nearing 1.10.
- From the pressure ratio data, the MAGNET compressor being purchased should be able to handle the expected pressure ratios. However, there is some concern if the compressor can handle the higher flow rates required in the MAGNET. The required volumetric flow rate for nitrogen operating at 250 kW of heat pipe power is near 143 ACFM where the compressor is rated at 48 ACFM.
- The MAGNET models estimated the temperature drop and heat loss from the piping. Using the assumptions for the piping and insulation, the heat loss from the piping is minimal and could be neglected in the larger heat pipe power loads. The heat loss was less than 5% in the system with a heat pipe power load of at least 75 kW.

5.1.2 MAGNET with Different PCU Configurations Conclusions

A major feature of modular nuclear microreactors is the ability to generate power and as such, the MAGNET has been designed with a feature to connect a PCU or PCU simulator to it. A PCU attached to the MAGNET consists of a compressor and turbine set. The PCU simulator consists of a series of valves and heat exchangers to perform the simulation.

• The MAGNET Aspen HYSYS models were equipped with a compressor and a turbine for power generation. The configuration added was a closed-loop recuperated Brayton cycle. The pressure ratio was optimized across the turbine to achieve the highest thermal efficiency which was 8.57% for nitrogen as the working fluid and 15.5% for helium as the working fluid. The MAGNET could generate 21 kW of power with nitrogen and 39 kW of power with helium.

- Simple Brayton cycles and recuperated Brayton cycles can be uniquely identified by three state points if the pressure ratio is the same across the compressor and through the exhaust of the system. The three state points are the compressor exhaust, the turbine inlet, and the turbine exhaust.
- Power cycles are largely pressure ratio driven. Maintaining the optimized pressure ratio for the maximum thermal efficiency preserves the thermal efficiency with different working fluids, even at varying compressor inlet pressures. The analysis showed that maintaining the pressure ratio and the turbine inlet temperature, the Brayton cycles maintained the optimized thermal efficiencies using air or nitrogen at varying compressor inlet pressures.
- A physical PCU connected to the MAGNET has the advantage that it would be a physical PCU being tested. This would provide dynamic data for operating the unit while generating power at design conditions. It would also provide data for off design conditions, the start up process, and shutting down the unit. These tests would provide data that is not estimated. However, the tests would be limited to a single type of power cycle.
- The PCU simulator is advantageous as it allows for testing of many simple Brayton cycles and recuperated Brayton cycles of varying thermal efficiencies and compressor and turbine adiabatic efficiencies. This could all be done with a single unit. However, the simulation of the start up and shutdown for a PCU would be estimated from other analyses.
- The PCU simulator's major disadvantage is that it is expensive. It has been estimated to have a total capital cost nearing 2.15 million dollars. The estimate was performed by three different methods.

5.1.3 PCU Start Up Analysis Conclusions

An analysis was performed on the start up of a simple Brayton cycle. The start up provides information of how an actual system could start, as well as how the system could be simulated during start up.

• A Siemens' SGT-A05 was modeled in Aspen HYSYS based on their data sheet. This unit is a natural gas unit and was used to provide a baseline for information regarding

the adiabatic efficiencies of the compressor and turbine. From these models, it was determined that a high-end adiabatic efficiency for the compressor and turbine could be upwards of 85% and 90%, respectively.

- During the start up of a natural gas PCU, a motor turns the compressor turbine shaft until approximately 63% of the maximum speed at which point the fuel is added. The motor continues to turn the shaft until the combustion process is considered stable. Then the turbine would generate enough energy to offset the energy of compression. However, when nuclear power is used there is no issue of an unstable combustion. The full heat load of the reactor could be added at the beginning of the start up process instead of at 63% of maximum speed. Thus, the PCU could generate power sooner.
- Assuming that a nuclear powered PCU would start similar to a natural gas PCU, the three unique state points were collected. These three state points are the compressor exhaust, the turbine inlet, and the turbine exhaust. These points throughout the start up process could be simulated in the PCU simulator which would simulate the start up of the PCU.

5.2 Recommendations

The MAGNET Aspen HYSYS and the PCU simulator models provided a starting point for further analysis and process condition predictions. However, there is more work that needs to be performed for further validation of the models.

5.2.1 MAGNET Recommendations

- The MAGNET Aspen HYSYS models have not been validated by the physical MAGNET.
- Though the heat exchangers have been compared to other solvers, the heat exchangers models need to be validated by comparing their performance to the physical heat exchangers.
- The main chiller heat exchanger in the main MAGNET loop was not modeled. There were many unknowns about the heat transfer correlations to properly solve the heat exchanger models. The physical heat exchanger would need to be tested to create an accurate computer model of the heat exchanger for the Aspen HYSYS model.

- The MAGNET has a large chiller unit attached to it for cooling. This unit could be modeled to provide an accurate total energy consumption through the entire MAGNET system.
- The MAGNET compressor unit should be checked to ensure it can handle helium and the required flow rates for the system.
- If helium were to be used, the piping in the system may need to be redesigned to handle working temperatures around 650°C.
- The mass flow rate of helium throughout the system is a lot lower compared to nitrogen which produces lower velocities throughout the piping. The mass flow rate could be increased to use more capacity of the system. If this were to be done, larger heaters could be added for the heat pipes to still reach the desired outlet temperatures.
- Currently, the Aspen HYSYS models of the MAGNET are solved in a steady-state environment. The process of making the models work dynamically would provide useful information in the loop.

5.2.2 MAGNET PCU Simulator Recommendations

- The PCU simulator is at a point of building and constructing.
- The PCU simulator could benefit from being modeled dynamically, as well as being modeled dynamically while being attached to the MAGNET model.

5.2.3 PCU Start Up Recommendations

- Start up analyses of recuperated Brayton cycles were not performed. This would be valuable data for understanding how modular nuclear microreactors would operate under these PCU configurations. The point where the turbine provides enough energy to sustain the compression process could be found and these data points could be used in the PCU simulator.
- Shutdown analyses on both the simple and recuperated Brayton cycles were not performed. This data could be used for shutdown of the MAGNET attached to the PCU simulator.
- Development is needed on how a nuclear powered PCU would undergo the start up process. There would be a possibility of having two separate loops, one loop would be for the PCU and the second would be for the primary cooling system of the heat pipe

nuclear reactor. Once the heat pipes are at full operations, the PCU could start up and route the air through valving to cool the heat pipe heat exchanger. This would add the needed heat to the PCU for operations.

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Appendix A: Aspen HYSYS Models for the Microreactor AGile Non-nuclear Experimental Testbed

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Nitrogen Operating at 600°C and 250 kW of Heat Pipe Power



1			2440	Case	Name: detailed ini test	bed 250kw n2.hsc	
3	@aspentech	Bedford, MA	DAHO	Unit	Set: MAGNET		
4		USA		Date	Time: Wed Jun 03 14	:08:58 2020	
6 7	Worl	kbook: Ca	se (Main)				
8 9			N	lateri	al Streams	Fiuld	IPkg: All
10	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out
12	Temperature	(C)	2	83.2	17.78	6.667 *	20.00
13	Pressure	(bar_g)	1	1.15	3.726	3.987 *	11.04
14	Mass Flow	(kg/s)	0.9	9187	6.761	6.761 *	0.9187
15	Mass Density	(kg/m3)	7	.336	1068	1077	13.93
16	Mass Enthalpy	(kJ/kg)	2	74.5	-1.207e+004	-1.210e+004	-8.557
17	Mass Entropy	(KJ/Kg-C)	BHY 01 Cold In	.209	0.5631	0.4282	4.524
18	Temperature	(C)	RHX-01 Cold In	3.05	RHX-01 Cold Out	vacuum Champer In 358 1	vacuum Chamber Out
20	Pressure	(bar d)		1.78	11.67 *	11.65	11.40 '
21	Mass Flow	(kg/s)	0.	9187	0.9187	0.9187	0.9187
22	Mass Density	(kg/m3)	1	4.14	6.735	6.729	4.772
23	Mass Enthalpy	(kJ/kg)	5	5.130	357.6	356.8	629.0
24	Mass Entropy	(kJ/kg-C)	4	.552	5.337	5.336	5.707
25	Name		RHX-01 Hot In		RHX-01 Hot Out	Comp In	6
26	Temperature	(C)		98.5	283.5 *	19.94	19.97
27	Pressure Mass Flow	(bar_g)	1	1.34	11.16 *	10.74	10.87
28	Mass Flow Mass Density	(kg/s) (kg/m3)	0.	759	0.9107	0.9107 *	13.73
30	Mass Enthalov	(kg/lis) (k_l/ka)		27.2	274.8	-8.535	-8.543
31	Mass Entropy	(kJ/ko-C)	5	.706	5.210	4.532	4.528
32	Name		Chiller In		Chiller Out	CWS-04	CWR-01
33	Temperature	(C)	1	7.78	6.659	6.664	17.78
34	Pressure	(barq)	3	.820	3.724	3.841	3.502
35	Mass Flow	(kg/s)	6	.761	6.761	6.761	6.761
36	Mass Density	(kg/m3)		1068	1077	1077	1068
37	Mass Enthalpy	(KJ/Kg)	-1.207e-	+004	-1.210e+004	-1.210e+004	-1.207e+004
39	Name	(NJ/Ng-C)	CWR-05	3031	CWS-02	0.4202 CWS-03	CWS-06
40	Temperature	(C)	1	7.78	6.662	6.662	6.665
41	Pressure	(bar_g)	3	.822	4.189	4.187	3.835
42	Mass Flow	(kg/s)	e	.761	6.761	6.761	6.761
43	Mass Density	(kg/m3)		1068	1077	1077	1077
44	Mass Enthalpy	(kJ/kg)	-1.207e-	+004	-1.210e+004	-1.210e+004	-1.210e+004
45	Mass Entropy	(kJ/kg-C)	0.1	5631	0.4281	0.4281	0.4282
46	Name	(0)	13	2.47	14 22.05	15 22.06	10 10.07
48	Pressure	(bar o)		1.95	11.80	11 79	10.97
49	Mass Flow	(kg/s)	0.	9187	0.9187	0.9187	0.9187
50	Mass Density	(kg/m3)	1	4.32	14.15	14.15	13.73
51	Mass Enthalpy	(kJ/kg)	5	.221	5.137	5.137	-8.543
52	Mass Entropy	(kJ/kg-C)	4	.548	4.552	4.552	4.528
53	Name		Comp Out		4-2	CWR-02	CWR-03
54	Temperature	(C)	3	3.24	33.17	17.78	17.78
55	Marc Elew	(bar_g)	1	2.20 *	11.96	3.500	3.496
57	Mass Density	(KQ/S) /ko/m3)	0.	4.50	14 33	0./01	0./61
58	Mass Enthalov	(ku/ka)		.235	5.221	-1.207e+004	-1.207e+004
59	Mass Entropy	(kJ/kq-C)	4	.543	4.548	0.5631	0.5631
60 61 62							
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1			Case	Name: d	etailed ini test	bed 250kw n2.hsc		
3	(aspentech Bedford, MA	IDAHO	Units	Set: N	IAGNET			
4	USA		Date/	Time: V	Ved Jun 03 14:	08:58 2020		
6	Werkheek, G	ne (Mein)	1		n			
8	WORKDOOK. Ca	ase (main)	(00	ntinued	9			
9		Materia	I Stre	Streams (continued) Fluid Pkg:				
10 11	Name	CWR-04		CWS-05			-	
12	Temperature (C)	1	7.78		6.665			
13	Pressure (bar_g)	3	3.824		3.837			
14	Mass Flow (kg/s)	6	5.761		6.761			
15	Mass Density (kg/m3)	4 007-0	1068		1077			
16	Mass Entrapy (KJ/Kg) Mass Entropy (kJ/Kg/C)	-1.20/e	+004 5631	-	0.4282		_	
17	(Kong-C)	U.,	0001		0.4202		1	
19			Com	positions		Fit	id Pkg:	All
20	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot O	ut
21	Master Comp Mass Frac (Nitrogen)	1.0	0000 "					1.0000
22	Master Comp Mass Frac (EGlycol)				0.4461	0.4461		
23	Master Comp Mass Frac (H2O)	RHV 01 Cold In		PHY 01 Cold	0.5539	U.5539	Vocuum Cho	mbor Out
25	Master Comp Mass Frac (Nitrogen)	11	0000	RHA-01 GOK	1 0000	1 0000	vacuum cha	1 0000
26	Master Comp Mass Frac (EGivcol)	1.4				1.5555		
27	Master Comp Mass Frac (H2O)		•••				1	
28	Name	RHX-01 Hot In		RHX-01 Hot	Out	Comp In	6	
29	Master Comp Mass Frac (Nitrogen)	1.0	0000		1.0000	1.0000	-	1.0000
30	Master Comp Mass Frac (EGlycol)							
31	Master Comp Mass Frac (H2O)	Chilles In						
32	Name Master Comp Mass Erac (Nitrogen)	Chiller In		ChilerOut		CWS-04	CWR-01	
34	Master Comp Mass Frac (EGiven)		4461 *		0.4461	0 4461		0.4461
35	Master Comp Mass Frac (H2O)	0.6	5539 *		0.5539	0.5539		0.5539
36	Name	CWR-05		CWS-02		CWS-03	CWS-06	
37	Master Comp Mass Frac (Nitrogen)							
38	Master Comp Mass Frac (EGlycol)	0.4	4461		0.4461	0.4461		0.4461
39	Master Comp Mass Frac (H2O)	0.8	5539		0.5539	0.5539		0.5539
40	Name Master Comp Mass Erac (Nitrogen)	13	0000	14	1.0000	10	10	1 0000
42	Master Comp Mass Frac (EGivcol)					1.5555		
43	Master Comp Mass Frac (H2O)							
44	Name	Comp Out		4-2		CWS-01	CWR-02	
45	Master Comp Mass Frac (Nitrogen)	1.0	0000		1.0000			
46	Master Comp Mass Frac (EGlycol)					0.4461		0.4461
47	Master Comp Mass Frac (H2O)	OWB 03		0000 01		0.5539		0.5539
48 49	Name Master Comp Mass Erac (Nitrogen)	CWR-03		CWR-04		CWS-05		
50	Master Comp Mass Frac (EGivcol)	0,4	4461		0.4461	0.4461		
51	Master Comp Mass Frac (H2O)	0.8	5539		0.5539	0.5539		
52				v Stroome		El	id Dka:	A11
53			merg	y sueams			au ray.	~
54	Name	Heat Pipes		PIPE-RHX-0	1 Cold Out He	PIPE-RHX-01 Hot In Hea	t PIPE-RHX-0	1 Hot Out Hea
55 55	Name (KW)	DIDE-HV-03 Host	:50.0	DIDE HY OF	U.6881 Hot Heat	1.621 DIDE-HV-02 Heat	Comp Down	0.2641
57	Heat Flow (kW)	7.957e	-002	FIFE-TIX-01	6.769e-003	-6.661e-004	out prover	12.65
58	Name	Chiller Duty		PIPE-CWS-0	6 Heat	PIPE-CWS-03 Heat	PIPE-CWR-H	leat
59	Heat Flow (KW)	2	60.5	-	5.757e-003	-2.028e-002	-	7.013e-003
60	Name	PIPE-CWR-05 Heat	t	PIPE-CWS-0	1 Heat	PIPE-HV-01 Heat	PIPE-Comp I	Heat
61	Heat Flow (KW)	-2.425e	-003	-	1.032e-002	5.956e-003	9	9.596e-003
62	Asnes Technology Inc		on 192	eve ve-	.0		-	0.0.0
63	Aspen Technology Inc.	Asp	en HY	or 5 Version	8		- Pa	d by user

1	UNIVERSITY OF IDAHO			Case	Name: detailed ini test	bed 250kw n2.hsc		
3	(aspentech	UNIVERSITY OF Bedford, MA	IDAHO	Unit :	Set: MAGNET			
4		USA		Date	Time: Wed Jun 03 14	:08:58 2020		
6	14/		(11-1-)					
8	worl	KDOOK: Ca	ase (Main)	(co	ntinued)			
9 10			Energy	Stre	ams (continued)	Fluid Pkg:		
11	Name		Chiller Pump Power	r	PIPE-CWR-02 Heat	PIPE-CWR-03 Heat	PIPE-CW	S-04 Heat
12	Heat Flow	(kW)	0.3	3907	-6.124e-003	-4.830e-003		-2.605e-002
13 14				н	eaters	Fluid	d Pikg:	All
15	Name		Vacuum Chamber					
16	DUTY	(kW)	2	250.0				
17	Feed Temperature	(C)	3	358.1				
18	Product Temperature	(C)	6	500.0 *				
19	Mass Flow	(kg/s)	0.9	9187				
20 21				C	oolers	Fluid	1 Pkg:	All
22	Name		Chiller					
23	DUTY	(kW)	2	260.5				
24	Feed Temperature	(C)	1	7.78				
25	Product Temperature	(C)		5.659				
26	Mass Flow	(kq/s)	6	5.761				
27			н	leat E	xchangers	Fluk	1 Pkg:	All
29	Name		RHX-01		Chiller HX-01			
30	Duty	(KW)	3	323.8	260.0			
31	Tube Side Feed Mass Flow	(kg/s)	0.1	9187	0.9187			
32	Shell Side Feed Mass Flow	(kg/s)	0.9	9187	6.761 *			
33	Tube Inlet Temperature	(C)	5	598.5	283.2			
34	Tube Outlet Temperature	(C)	2	283.5 *	20.00 *			
35	Shell Inlet Temperature	(C)	3	33.05	6.667 *			
36	Shell Outlet Temperature	(C)	3	358.8	17.78			
38	UA	(W/C)		1321	3066			
39	Minimum Approach	(C)	2	239.7	13.33			
40						Eluiz	I Dko:	All
41				-	umps	T TON	a ring.	74
42	Name	0110	Chiller Pump	2007				
43	Food Drossure	(NVV)		3907				
45	Product Pressure	(bar_g)		190				
46	Product Temperature	(C)	6	5.662				
47	Feed Temperature	(C)	6	5.659				
48	Adiabatic Efficiency	(%)	7	75.00				
49	Pressure Ratio		1	1.099				
50	Mass Flow	(kg/s)	6	5.761				
51	Compressors Fluid Pkg: All							
53	Name		Comp-01					
54	Power	(KW)	1	2.65				
55	Feed Pressure	(bar_g)	1	0.74				
56	Product Pressure	(bar_g)	1	2.20 *				
57	Product Temperature	(C)	3	33.24				
58	Feed Temperature	(C)	1	19.94				
59	Adiabatic Efficiency			75 *				
60	Mass Flow	(header)	1	0187 *				
62	madd Fluw	(KQ/S)	0.	5107	1	I		
63	Aspen Technology Inc.		Asp	en HY	SYS Version 9			Page 3 of 4
	respectively respectively at the		130					

* Specified by user.

1				Case	Name: detailed ini ter	t bed 250kw n2.hsc	
3	(aspentech	UNIVERSITY OF I Bedford, MA	DAHO	Unit S	et: MAGNET		
4		USA		Date/	Time: Wed Jun 03 1	4:08:58 2020	
6				,			
8	worl	KDOOK: Ca	ase (Main)		ntinued)		
9 10				Exp	anders	Fluid	1 Pkg: All
11	Name						
12	Power	(KW)					
13	Feed Pressure	(bar_g)					
14	Product Pressure	(bar q)					
15	Product Temperature	(C)					
16	Feed Temperature	(C)					
17	Adiabatic Efficiency						
18	Mass Flow	(kg/s)					
19 20			F	ipe S	egments	Fluid	1 Pkg: All
21	Name		PIPE-Cold Out-RHX	-01 to	PIPE-Hot In-Vacum Char	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01
22	Feed Temperature	(C)	3	58.8	600.0	283.5 *	33.17
23	Feed Pressure	(bar_g)	1	1.67 *	11.40	11.16 *	11.95
24	Product Temperature	(C)	3	58.1	598.5	283.2	33.06
25	Product Pressure	(bar q)	1	1.65	11.34	11.15	11.80
26	Insulation Conductivity	(W/m-K)	6.826e-	002 *	8.439e-002	6.350e-002	4.856e-002 *
27	Name PIPE-HV-02 to			016	0.1016	0.1016	0.1016
28	Feed Temperature (C)			9	PIPE-RX-01 ID RV-02	PIPE-CWS-RV-003 to RA-	17.78
29	Feed Temperature	(C)	1	9.97	20.00	0.003	3 725
31	Product Temperature	(bal_g) (C)	10.00		19.97	6.667 '	17.78
32	Product Pressure	(bar g)	10	0.74	10.87	3.987 *	3,502
33	Insulation Conductivity	(W/m-K)	4.781e	002 *	4.782e-002	3.254e-002 *	3.328e-002 *
34	Insulation Thickness	(m)	0.1	016	0.1016	1.500	3.810e-002
35	Name		PIPE-CWR-HV-002	to Chil	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03	PIPE-CWS-Chiller to HV-0
36	Feed Temperature	(C)	17	7.78	33.06	33.24	6.662
37	Feed Pressure	(bar q)	3.	822	11.79	12.20 *	4.190
38	Product Temperature	(C)	1	7.78	33.05	33.17	6.662
39	Product Pressure	(bar_g)	3 2290	820	11.78	4 9570 000 +	4.109
40	Insulation Conductivity	(W/III-K) (m)	3.320	002 -	4.0500-002	4.0570-002	3.8106-002
42	Name	(11)	PIPE-CWR-HV-004	to Out	PIPE-CWR-Outside Wall	PIPE-CWS-HV-001 to Out	PIPE-CWS-Outside Wall to
43	Feed Temperature	(C)	1	7.78	17.78	6.662	6.664
44	Feed Pressure	(bar_g)	3.	500	3.496	4.187	3.841
45	Product Temperature	(C)	1	7.78	17.78	6.664	6.665
46	Product Pressure	(bar_g)	3.	496	3.824	3.841	3.837
47	Insulation Conductivity	(W/m-K)	3.328e-	002 *	3.328e-002	3.254e-002 *	3.254e-002 *
48	Insulation Thickness	(m)	3.810e-	002	3.810e-002	3.810e-002	3.810e-002
49							
50							
57							
53							
54							
55							
56							
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58							
59							
60							
61							
62	Asnan Technology Inc.		Arm	n HV	SVS Version 0		Page 4 of 4
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Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Helium Operating at 600°C and 250 kW of Heat Pipe Power



1			Case	Name: deta	iled ini test	bed 250kw HE.	hsc					
2	(aspentech	UNIVERSITY OF I Bedford, MA	DAHO	Unit	Set: MAG	GNET						
4		USA		Date	/Time: Wed	1 Jun 03 14	:13:03 2020					
6 7 8	Work	book: Ca	ase (Main)								
9 10				Materi	al Streams			Fluid	I Pkg:	All		
11	Name		HX-01 Hot In		CWR		CWS		HX-01 Hot Out			
12	Temperature	(C)		208.4		17.78		6.667 *		20.00 *		
13	Pressure	(bar_g)		11.19		3.726		3.987 *		11.07		
14	Mass Flow	(kg/s)		0.2741		6.983	Manual Obs	6.983 *	10000	0.2741		
15	Tomporature	(0)	RHX-01 Cold In	24.00	RHX-01 Cold O	425.1	Vacuum Char	nber in	vacuum cham	ber Out		
10	Pressure	(bar g)		11.78		11.67 *		11.65		11.40 *		
18	Mass Flow	(kg/s)		0.2741		0.2741		0.2741		0.2741		
19	Name		RHX-01 Hot In		RHX-01 Hot Ou	t	Comp In		6			
20	Temperature	(C)		598.9		208.5 *		20.01		20.00		
21	Pressure	(bar_g)		11.35		11.19 *		10.88		10.96		
22	Mass Flow	(kg/s)		0.2741		0.2741		0.2741 *		0.2741		
23	Name		Chiller In		Chiller Out		CWS-04		CWR-01			
24	Temperature	(C)		17.78		6.654		6.661		17.78		
25	Pressure Mass Firm	(bar q)		4.141		4.038		4.190		3.500		
26	Name	(KQ/S)	CWR-05	0.903	CWR-03	0.903	CWR-02	0.903	CWS-02	0.963		
28	Temperature	(C)	CHINES .	17.78	CHINES	17.78	CHICOL	17.78	0110-02	6 658		
29	Pressure	(bar g)		4.143		3.821		3.498		4.543		
30	Mass Flow	(kg/s)		6.983		6.983		6.983		6.983		
31	Name		CWS-03		CWS-06		13		14			
32	Temperature	(C)		6.658		6.664		34.95		34.88		
33	Pressure	(bar_g)		4.541		3.838		11.89		11.79		
34	Mass Flow	(kg/s)		6.983		6.983		0.2741		0.2741		
35	Name		15		16		Comp Out		4-2			
36	Temperature	(C)		34.88		20.00		34.96		34.95		
38	Mass Flow	(baiq) (ko/s)		0.2741		0.2741		0.2741		0.2741		
39	Name	(-2-)	CWS-01		CWR-04		CWS-05					
40	Temperature	(C)		6.658		17.78		6.664				
41	Pressure	(bar_g)		4.545		4.145		3.840				
42	Mass Flow	(kg/s)		6.983		6.983		6.983				
43				Com	positions			Fluid	Pka:	AI		
44 45	Name		HX-01 Hot In		CWR		CWS		HX-01 Hot Out			
46												
47	Name		RHX-01 Cold In		RHX-01 Cold O	ut	Vacuum Char	nber In	Vacuum Cham	ber Out		
48 49	Name		RHX-01 Hot In		RHX-01 Hot Ou	t	Comp In		6			
50												
51	Name		Chiller In		Chiller Out		CWS-04		CWR-01			
52	Namo	CWP-05		CWP.03		CWIR-02		CIME-02				
54	Name		CWR-05		CWR-05		GWR-02		CW3-02			
55	Name		CWS-03		CWS-06		13		14			
56	Name CWS-03											
57	Name 15			16		Comp Out		4-2				
59	Name		CWS-01		CWR-04		CWS-05					
60	D Traine CWS-U1											
61												
62	Asnen Technology Inc.		Δ.		SVS Version 0				Par	a 1 of 2		
92	ASPEN LEGITIOROUV INC.	Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 3										

1				Case	Name: detailed ini test	bed 250kw HE.hsc				
2	(aspentech	UNIVERSITY OF I Bedford, MA	IDAHO	Unit 9	Set: MAGNET					
4	0	USA		Date/	Time: Wed Jun 03 14:	13:03 2020				
6 7 8	Work	(book: Ca	ase (Main)	(co	ntinued)					
9 10			E	Energ	y Streams	Fluid	I Pkg:	AII		
11	Name		Heat Pipes		PIPE-RHX-01 Cold Out He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot C	Dut He		
12	Heat Flow	(KW)		250.0	0.8693	1.624	0.1	1769		
13	Name		PIPE-HV-03 Heat		PIPE-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power			
14	Heat Flow	(kW)	9.1916	+002	-6.632e-003	-6.404e-004	2	21.30		
15	Name		Chiller Duty		PIPE-CWS-06 Heat	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	t		
16	Heat Flow	(kW)		269.1	-2.866e-002	-4.640e-002	-1.096e	+002		
17	Name		PIPE-CWR-Heat		PIPE-CWR-05 Heat	PIPE-CWS-01 Heat	PIPE-HV-01 Heat			
18	Heat Flow	(KVV)	-/.U4be	+003	-2.425e-003	-1.0328-002	DIDE CIVIC 04 Hast	+003		
20	Heat Flow	(RMD)	PIPE-Compineat	-002	0.4382	-1 0050-002	PIPE-OWS-04 Heat	002		
21	rical flow	(877)	1.1025	-002	0.4002	-1.0506-002	4.0056	-002		
22				H	eaters	Fluid	Pkg:	All		
23	Name		Vacuum Chamber							
24	DUTY	(kW)	2	250.0						
25	Feed Temperature	(C)	4	424.5						
26	Product Temperature	(C)		500.0 *						
27	Mass Flow	(kg/s)	0:	2741						
28	Coolers Fluid Pkg: All									
29	Namo		Chillor				-			
30	DUTY	(RMD)	Chiller	060.1						
32	Feed Temperature	(C)		17.78						
33	Product Temperature	(C)	6	5.654						
34	Mass Flow	(kg/s)		5.983						
35			н	leat E	xchangers	Fluid	I Pkg:	AI		
36 37	Name		RHX-01		Chiller HX-01					
38	Duty	(KW)		556.1	268.5					
39	Tube Side Feed Mass Flow	(kg/s)	0.	2741	0.2741					
40	Shell Side Feed Mass Flow	(kg/s)	0.	2741	6.983 *					
41	Tube Inlet Temperature	(C)		598.9	208.4					
42	Tube Outlet Temperature	(C)	2	208.5 *	20.00 *					
43	Shell Inlet Temperature	(C)		34.88	6.667 *					
44	Shell Outlet Temperature	(C)	4	425.1	17.78					
45		(C)		2201	30.20					
47	Minimum Approach	(0.00)		173.7	13.33					
48		(0)			10.00					
49				P	umps	Fluid	Pkg:	Al		
50	Name		Chiller Pump							
51	Power	(kW)	0.	4382						
52	Feed Pressure	(bar_g)	4	4.038						
53	Product Pressure	(bar_g)	4	4.545						
54 66	Froduct Temperature	(C)		0.000						
20 56	Adjabatic Efficiency	(C)		2.004						
57	Pressure Ratio	(78)		1.100						
58	Mass Flow	(ka/s)		5.983						
59 60 61 62	Asnen Technology Inc		Á so	on HV	VSVS Varsion Q		Page 2	of 3		
92	Lisseed by UNIVERSITY OF IDA	но	ASD				1 Specified by up	010		

1	UNIVERSITY OF IDAHO			Case N	Name: detailed ini test	bed 250kw HE.hsc				
3	(aspentech	UNIVERSITY OF Bedford, MA	IDAHO -	Unit Se	et: MAGNET					
4		USA		Date/T	ime: Wed Jun 03 14	:13:03 2020				
6 7 8	Worl	kbook: Ca	ase (Main) (con	tinued)					
9			(Comp	ressors	Fluid	iPkg: Ali			
10	Name		Comp-01							
12	Power	(KW)	21	.30						
13	Feed Pressure	(bar_g)	10	.88						
14	Product Pressure	(barq)	12	.05 *						
15	Product Temperature	(C)	34	.96						
16	Feed Temperature	(C)	20	.01						
17	Adiababo Eniciency Dressure Rafio		11	108						
19	Mass Flow	(kg/s)	0.2	741 *						
20		(2-)		-		El tra	Share All			
21				Ехра	anders	Fluid	TPNg. Al			
22	Name									
23	Power	(KW)								
24	Feed Pressure	(bar_g)								
25	Product Pressure	(Dal Q)								
27	Feed Temperature	(C)								
28	Adiabatic Efficiency									
29	Mass Flow	(kg/s)								
30	Pine Segments Fluid Bkg: All									
31			-							
32	Name Ecod Tomporature	(***	PIPE-Cold Out-RHX-	01 to	PIPE-Hot In-Vacum Cham	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01			
34	Feed Pressure	(bar g)	42	67 *	11.40 *	11.19 *	11.89			
35	Product Temperature	(C)	42	4.5	598.9	208.4	34.88			
36	Product Pressure	(bar_g)	11	.65	11.36	11.19	11.79			
37	Insulation Conductivity	(W/m-K)	7.258e-	002 *	8.440e-002 *	5.888e-002 *	4.866e-002 *			
38	Insulation Thickness	(m)	0.1	016	0.1016	0.1016	0.1016			
39	Name Each Tomporature	(0)	PIPE-HV-02 to Comp)	PIPE-HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-			
40	Feed Temperature Food Drossuro	(bar d)	20	96	20.00 -	3,838	3 725			
42	Product Temperature	(C)	20	.01	20.00	6.667 *	17.78			
43	Product Pressure	(bar_g)	10	.88	10.96	3.987 *	3.500			
44	Insulation Conductivity	(W/m-K)	4.782e-	002 *	4.782e-002 *	3.254e-002 *	3.328e-002 *			
45	Insulation Thickness	(m)	0.1	016	0.1016	3.810e-002	3.810e-002			
46	Name		PIPE-CWR-HV-002 t	o Chli	PIPE-CWS-Chiller to HV-0	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03			
47	Feed Temperature	(C)	17	.78	6.658	34.88	34.96			
49	Product Temperature	(Dal Q) (C)	4.	78	4.040	34.88	34.95			
50	Product Pressure	(bar g)	4.	141	4.543	11.78	11.90			
51	Insulation Conductivity	(W/m-K)	3.328e-	002 *	3.254e-002 *	4.866e-002 *	4.867e-002 *			
52	Insulation Thickness	(m)	3.810e-	002	3.810e-002	0.1016	0.1016			
53	Name		PIPE-CWS-HV-001 t	o Outi	PIPE-CWS-Outside Wall to	PIPE-CWR-HV-004 to Out	PIPE-CWR-Outside Wall t			
54	Feed Temperature	(C)	6.	558	6.661	17.78	17.78			
55 56	Product Temperature	(par_g)	4.	561	4.190	3.498	3.821			
57	Product Pressure	(bar o)	4	190	3.840	3.821	4.145			
58	Insulation Conductivity	(W/m-K)	3.254e-	002 *	3.254e-002 *	3.328e-002 *	3.328e-002 *			
59	Insulation Thickness	(m)	3.810e-	002	3.810e-002	3.810e-002	3.810e-002			
60 61 62			Arno		VS Vortige 0		Page 2 of 2			
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Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Nitrogen Operating at 600°C and 75 kW of Heat Pipe Power



1			Case	Name: detailed ini test	bed 75kW n2.hsc					
3	@aspentech	UNIVERSITY OF I Bedford, MA	DAHO	Unit 9	Set: MAGNET					
4		USA		Date	Time: Wed Jun 03 14	:14:32 2020				
6 7 8	Work	(book: Ca	ase (Main)							
9			м	ateri	al Streams	Fluid	1 Pkg: Ali			
11	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out			
12	Temperature	(C)	2	33.0	17.78	6.667 *	20.00 *			
13	Pressure	(bar_g)	1	1.36	3.726	3.987 *	11.25			
14	Mass Flow	(kg/s)	0.3	3238	1.923	1.923 *	0.3238			
15	Mass Density Mass Enthainy	(kg/ms) (k.l/kg)	0	19.7	-1 207e+004	-1 210e+004	-8.614			
17	Mass Entropy	(kJ/ko-C)	5	.101	0.5631	0.4282	4.519			
18	Name		RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out			
19	Temperature	(C)	2	4.55	396.9	394.7	600.0 *			
20	Pressure	(bar_g)	1	1.67	11.65 *	11.65	11.40 *			
21	Mass Flow	(kg/s)	0.3	3238	0.3238	0.3238	0.3238			
22	Mass Density	(kg/m3)	1	4.43	6.342	6.361	4.772			
23	Mass Enthalpy	(kJ/kg)	-3	.882	399.8	397.3	629.0			
24	Name	(NJ/Ng-C)	RHX-01 Hot In	.525	5.402 RHX-01 Hot Out	Comp In	5.707			
26	Temperature	(C)	5	95.7	233.6 *	20.02	20.02			
27	Pressure	(bar_g)	1	1.39	11.36 *	11.21	11.23			
28	Mass Flow	(kg/s)	0.3	3238	0.3238	0.3238 *	0.3238			
29	Mass Density	(kg/m3)	4	.793	8.197	14.13	14.15			
30	Mass Enthalpy	(kJ/kg)	6	24.0	220.4	-8.579	-8.587			
31	Mass Entropy	(kJ/kg-C)	5	.701	5.102	4.520	4.519			
32	Temperature	(0)	Chiller In	7 78	Chiler Out	CWS-04 6.652	CWR-01 17.78			
34	Pressure	(bar g)	3	859	3 762	3 793	3 526			
35	Mass Flow	(kg/s)	1	923	1.923	1.923	1.923			
36	Mass Density	(kg/m3)	1	1068	1077	1077	1068			
37	Mass Enthalpy	(kJ/kg)	-1.207e+	-004	-1.210e+004	-1.210e+004	-1.207e+004			
38	Mass Entropy	(kJ/kg-C)	0.8	5631	0.4281	0.4282	0.5631			
39	Name	(0)	CWR-05	7 70	CWS-02	CWS-03	CWS-06			
40 41	Pressure	(bar g)	3	860	4 132	4 131	3.792			
42	Mass Flow	(kg/s)	1	.923	1.923	1.923	1.923			
43	Mass Density	(kg/m3)	1	1068	1077	1077	1077			
44	Mass Enthalpy	(kJ/kg)	-1.207e+	-004	-1.210e+004	-1.210e+004	-1.210e+004			
45	Mass Entropy	(kJ/kg-C)	0.5	5631	0.4281	0.4281	0.4282			
46	Name		13		14	15	16			
47 49	remperature Procesure	(C)	2	4.63	24.56	24.56	20.02			
40	Mass Finw	(bar q) (ko/s)		1.09	0 3238	0 3238	0.3238			
50	Mass Density	(kg/m3)	1	4.45	14.43	14.43	14.14			
51	Mass Enthalpy	(kJ/kg)	-3	809	-3.877	-3.877	-8.587			
52	Mass Entropy	(kJ/kg-C)	4	.525	4.525	4.525	4.519			
53	Name		Comp Out		4-2	CWR-02	CWR-03			
54	Temperature	(C)	2	4.65	24.63	17.78	17.78			
55 56	Mass Flow	(bar_g)	1	1.73	11.69	3.526	3.525			
57	Mass Density	(kg/s) (kg/m3)	1	4,49	14.45	1.923	1058			
58	Mass Enthalpy	(kJ/kg)	-3	797	-3.809	-1.207e+004	-1.207e+004			
59	Mass Entropy (kJ/kg) Mass Entropy (kJ/kg-C)			4.524 4.524 0.5631						
60 61 62										
63	Aspen Technology Inc.	HO	Asp	en HY	SYS Version 9		Page 1 of 4			

1			Case	Name: detailed ini tes	t bed 75kW n2.hsc	
3	()aspentech Bedford, MA	IDAHO	Unit	Set: MAGNET		
4	USA		Date	Time: Wed Jun 03 14	4:14:32 2020	
6 7	Workbook: Ca	ase (Main)	(co	ntinued)		
8		ace (main)	,00	intinuouj		
9		Materia	l Stre	ams (continued)	Fluid	d Pkg: All
11	Name	CWR-04		CWS-05	CWS-01	
12	Temperature (C)	1	17.78	6.666	6.657	
13	Pressure (bar_g)	3	3.860	3.792	4.132	
14	Mass Flow (kq/s)	1	.923	1.923	1.923	
15	Mass Density (kg/m3)		1068	1077	1077	
16	Mass Enthalpy (KJ/Kg)	-1.207e	+004	-1.210e+004	-1.210e+004	
12	Mass Endopy (Norkg-C)	0.	3031	0.4202	0.4201	
19			Com	positions	Fluid	d Pkg: All
20	Name	HX-01 Hot In		CWR	CWS	HX-01 Hot Out
21	Master Comp Mass Frac (Nitrogen)	1.1	0000 -			1.0000
22	Master Comp Mass Frac (EGlycol)			0.4461	0.4461	
23	Master Comp Mass Frac (H2O)			0.5539	0.5539	
24	Name Nactor Comp Macr. Erze (Nitrogen)	RHX-01 Cold In	0000	KHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
26	Master Comp Mass Frac (EGlycol)			1.0000	1.0000	1.0000
27	Master Comp Mass Frac (H2O)		•••	•••		
28	Name	RHX-01 Hot In		RHX-01 Hot Out	Comp In	6
29	Master Comp Mass Frac (Nitrogen)	1.	0000	1.0000	1.0000 *	1.0000
30	Master Comp Mass Frac (EGlycol)					
31	Master Comp Mass Frac (H2O)					
32	Name	Chiller In		Chiller Out	CWS-04	CWR-01
33	Master Comp Mass Frac (Nitrogen)		4461 *	0.4461	0.4451	0.4461
35	Master Comp Mass Frac (H2O)	0.5	5539 *	0.5539	0.5539	0.5539
36	Name	CWR-05		CWS-02	CWS-03	CWS-06
37	Master Comp Mass Frac (Nitrogen)					
38	Master Comp Mass Frac (EGlycol)	0.4	4461	0.4461	0.4461	0.4461
39	Master Comp Mass Frac (H2O)	0.9	5539	0.5539	0.5539	0.5539
40	Name	13	0000	14	15	16
41	Master Comp Mass Frac (EGlycol)			1.0000	1.0000	1.0000
43	Master Comp Mass Frac (H2O)					
44	Name	Comp Out		4-2	CWS-01	CWR-02
45	Master Comp Mass Frac (Nitrogen)	1.1	0000	1.0000		
46	Master Comp Mass Frac (EGlycol)				0.4461	0.4461
47	Master Comp Mass Frac (H2O)				0.5539	0.5539
48	Name	CWR-03		CWR-04	CWS-05	
49 60	Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGivcol)	0.	4461	0.4461	0.4461	
51	Master Comp Mass Frac (H2O)	0.1	5539	0.5539	0.5539	
52	1 1 E		nera	v Streams	Fluir	1 Pka: All
53			inerg	y streams		
54	Name Heat Flow (MAR)	Heat Pipes	15.00	PIPE-RHX-01 Cold Out H	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out He
55	Name (KW)	PIPE-HV-03 Heat	3.00	PIPE-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power
57	Heat Flow (kW)	2.280e	-002	-6.620e-003	-6.505e-004	1.548
58	Name	Chiller Duty		PIPE-CWS-06 Heat	PIPE-CWS-03 Heat	PIPE-CWR-Heat
59	Heat Flow (kW)	7	4.11	-5.726e-003	-2.076e-002	-7.174e-003
60	Name	PIPE-CWR-05 Heat	t	PIPE-CWS-01 Heat	PIPE-HV-01 Heat	PIPE-Comp Heat
61	Heat Flow (kW)	-2.421e	-003	-1.031e-002	1.698e-003	2.771e-003
62	Asnen Technology Inc	1	on LIV	CVC Version 0		Page 2 of 4
0.5	Aspen Technology Inc.	ASD	en Ař	STS VEISION 8		rade 2 of 4

" Specified by user.

1	UNIVERSITY OF IDAHO			Case	Name: detailed ini test	bed 75kW n2.hsc	
3	(aspentech	UNIVERSITY OF Bedford, MA	IDAHO	Unit :	Set: MAGNET		
4		USA		Date	/Time: Wed Jun 03 14	:14:32 2020	
6 7 8	Worl	kbook: Ca	ase (Main)	(co	ntinued)		
9 10			Energy	Stre	ams (continued)	Fluid	1 Pkg: All
11	Name		Chiller Pump Power	r	PIPE-CWR-02 Heat	PIPE-CWR-03 Heat	PIPE-CWS-04 Heat
12	Heat Flow	(kW)	8.805e	-002	-6.114e-003	-4.604e-003	-2.601e-002
13 14				н	eaters	Fluid	1 Pkg: All
15	Name		Vacuum Chamber				
16	DUTY	(kW)	7	5.00			
17	Feed Temperature	(C)	3	94.7			
18	Product Temperature	(C)	6	00.0 *			
19	Mass Flow	(kg/s)	0.3	3238			
20 21	20 Coolers Fluid Pkg: /						
22	Name		Chiller				
23	DUTY	(kW)	7	4.11			
24	Feed Temperature	(C)	1	7.78			
25	Product Temperature	(C)		654			
26	Mass Flow	(kq/s)	1	.923			
27			н	eat E	xchangers	Fluid	d Pkg: All
28	News		DUN DI		Oblige UV 04		-
29	Name	(840)	RHX-01	20.7	Chiler HX-01		
30	Tube Side Feed Mass Flow	(KVV)		2028	0 3238		
32	Shell Side Feed Mass Flow	(kg/s)	0.	3238	1.923 *		
33	Tube Inlet Temperature	(C)	5	95.7	233.0		
34	Tube Outlet Temperature	(C)	2	33.6 *	20.00 *		
35	Shell Inlet Temperature	(C)	2	4.55	6.667 *		
36	Shell Outlet Temperature	(C)	3	96.9	17.78		
37	LMTD	(C)	2	04.0	72.89		
38	UA	(W/C)	6	40.7	1014		
39	Minimum Approach	(C)	1	98.8	13.33		
40 41				P	umps	Fluid	1 Pkg: Ali
42	Name		Chiller Pump				
43	Power	(KW)	8.805e	-002			
44	Feed Pressure	(bar_g)	3	8.762			
45	Product Pressure	(bar_g)	4	.132			
40	Food Tomperature	(C)		654			
48	Adiabatic Efficiency	(%)	7	5.00			
49	Pressure Ratio		1	.077			
50	Mass Flow	(kg/s)	1	.923			
51				Com	pressors	Fluid	1 Pkg: All
52							
54	Power	(kW)	1	.548			
55	Feed Pressure	(bar_g)	1	1.21			
56	Product Pressure	(bar_g)	1	1.73 *			
57	Product Temperature	(C)	2	4.65			
58	Feed Temperature	(C)	2	0.02			
59	Adiabatic Efficiency			75 *			
60	Pressure Ratio		1	.042			
61	M355 F10W	(kq/s)	0.3	5238 *	I	I	I
62	Asnon Technology Inc.		A ===	on UV	SVS Version 0		Page 2 of 4
03	Aspen rechnology inc.		Aso	ell A î	o to version a		Page 3 of 4

Image: Spentice Unit Set: MAGE: Tropic Database Unit Set: Machine: Det Time: Wed Jun 03 41:14.32 0200 Image: Spentice Workbook: Case (Main) (continued) Det Time: Wed Jun 03 41:14.32 0200 Image: Spentice Workbook: Case (Main) (continued) Expanders Full Play: All Image: Spentice (Bar g) Image: Spentice	1		UNIVERSITY OF IDAHO			Name: d	etailed ini test	bed 75kW n2.hsc	
1 USA Description: Wedulan 03.14.11.6.32.0200 0 Expanders Phild Pag All 1 Name Expanders Phild Pag All 10 Expanders Phild Pag All 11 Name Interme Phild Pag All 12 Poser (MV) Interme Phild Pag All 13 Product Pressure (Dat of the state	3	(aspentech Bedfor	ERSITY OF 10, MA	DAHO	Unit S	Set: N	IAGNET		
Image: statute Plus Pkg: All 1 Name: 0 Expanders Plus Pkg: All 1 Name: 0 0 0 0 0 1 Product Pressure: 0/br gl 0/br gl 0 0 0 1 Product Pressure: 0/br gl 0/br gl 0 0 0 0 1 Mater Fore 0/br gl 0	4	USA			Date/	Time: V	/ed Jun 03 14:	14:32 2020	
Image: Second	6				,				
1 Expanders PUR Pig: Al 11 Name	7 8	Workboo	ok: Ca	ase (Main)	(co	ntinued)		
Name (W) (W) (Interpretation of the state of the	9				Exp	anders		Fluid	i Pkg: Ali
Dover (NV) Image: Control of the second of	11	Name							
Deck Display Construction Display Display 10 Product Temperature (C)	12	Power	(KW)						
Image: Product Pressure (Dec) Image: Product Pressure (Pipe Segments Find Prig: And 1 Name PIPE-Cod Out-RYK-016 PIPE-Hot In-Vacum Cham PIPE-Hot Out-RYK-0110 PIPE-Hot In-Vacue Pressure PIPE-Hot Pres	13	Feed Pressure	(bar_g)						
IP: Product Temperature (C) Image: Construct Temperature (C) 11 Addatable Efficiency Image: Construct Temperature (C) Image: Construct Temperature Im	14	Product Pressure	(bar q)						
Is Freed Temperature (C) Image of the second of the se	15	Product Temperature	(C)						
Instance Endersoy Image Now Ippe Pipe Segments Fuld Pkg All IN Mass Flow Ippe Pipe Peed Temperature Pipe	16	Feed Temperature	(C)						
Idia Mas Flow (bgs) Pipe Segments Fuid Pkg: All 23 Name PIPE-Cold CURRENCO 10 PIPE-Hot In-Vacum Cham PIPE-Hot 233.6 243.5 23 Feed Temperature (C) 396.5 600.0 233.6 243.5 24 Feed Temperature (C) 394.7 595.7 233.8 244.5 25 Freed Temperature (C) 394.7 595.7 233.8 2455 26 Freed Temperature (C) 394.7 595.7 233.8 2455 21 Freed Temperature (C) 394.7 595.7 233.8 2455 21 Instation Conductivity VMIm-K1 7.056.402 6.040-600.2 4.805-602 21 Instation Conductivity VMIm-K1 7.056.002 6.040-600.2 4.805-602 22 Feed Temperature (C) 20.02 20.02 6.666 7.77.8 23 Freed Temperature (D) 11.23 3.726 3.726 3.726 <t< th=""><th>17</th><th>Adiabatic Efficiency</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>	17	Adiabatic Efficiency							
Pipe Segments Flue Pig. Al 21 Name PIPE-Coid OutRHX-0116 PIPE-Hot OutRHX-0116 PIDE-Hot OutRHX-0116<	18	Mass Flow	(kg/s)						
Name PIPE-Cold Out-RIX-OI to PIPE-Hot Out-RIX-OI to	19			Pipe §	Segments		Fluid	Pkg: All	
Display Pred Temperature (C) 396.5 600.0° 233.6 24.63 21 Feed Temperature (D) 11.65 11.40 11.36 11.65 21 Feed Temperature (C) 394.7 595.7 223.0 24.55 21 Feed Temperature (D) 11.65 11.35 11.36 11.67 23 Insulation Conductivity (WIM-K) 7.0684-002 6.042-002 4.080-002 7 27 Insulation Conductivity (WIM-K) 7.0684-02 9.124-010 PIPE-CWR-HVC01 0.1016<	21	Name		PIPE-Cold Out-RH)	K-01 to	PIPE-Hot In-	Vacum Chaml	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01
Differ (bit g) 1165 11.40 11.36 11.69 22 Product Temperature (C) 394.7 595.7 233.0 24.56 24 Product Temperature (Dir q) 11.65 11.39 11.136 11.61 25 Insulation ConductWip (Wm-K) 7.0584-002 8.429e-002 6.6040-002 4.608e-002 21 Insulation Truckness (M) 0.1016 0.1016 0.1016 0.1016 23 Name PIPE-HV-02 to Comp PIPE-HX-01 to HV-02 PIPE-CWR-HX-01 to HV-02 PIPE-CWR-HX-02 to Conl HIPE-HX-01 to HX-01 PIPE-CWR-HX-01 to HX-02 PIPE-CWR-HX-02 to Conl HIPE-HX-01 to HX-01 PIPE-CWR-HX-02 to Conl HIPE-HX-01 PIPE-CWR	22	Feed Temperature	(C)	3	396.9		600.0 *	233.6 *	24.63
Product Temperature (C) 39-7 595.7 233.0 2456 Product Temperature (D) 116.5 11.33 11.36 11.57 Insulation Conductivity (Wim-K) 7.0688-502 * 8.429-002 * 6.0406-02 * 4.808e-02 * Insulation TheAnes (m) 0.1016 0.1016 0.1016 0.1016 0.1016 0.1016 21 Insulation TheAnes (m) 0.1016	23	Feed Pressure	(bar_g)	1	11.65 *		11.40 *	11.36 *	11.69
23 Product Pressure (bar q) 11.15 11.39 11.36 11.61 21 Insulation Conductivity (Wim+K) 7.058-002 5.029-002 5.009-002 4.608-002 21 Insulation Thickness (m) 0.1016 0.101	24	Product Temperature	(C)		394.7		595.7	233.0	24.55
Insulation Conductivity (Wim-K) 7.668-002 ' 6.429-002 ' 6.040e-002 ' 4.808-002 ' Insulation Conductivity (Wim-K) 0.1016 0.1016 0.1016 0.1016 Name PIPE-HV-02 to Comp PIPEHX-01 to HV-02 PIPE-CWB-HV-03 to HX. PIPE-CWR-HX-01 to HV-02 20 Feed Preserute (C) 20.02 20.00 ' 6.666 ' 17.78 31 Product Temperature (C) 20.02 ' 20.02 ' 6.667 ' 17.78 32 Product Pressure (Bar.g) 11121 ' 11.23 ' 3.987 ' 3.526 31 Insulation Conductivity (Wim-K) 4.782e-002 ' 4.782e-002 ' 3.328+002 ' 31 Insulation Conductivity (Wim-K) 4.782e-002 ' 4.782e-002 ' 3.328+002 ' 32 Insulation Conductivity (Wim-K) 4.782e-002 ' 4.782e-002 ' 3.254e-002 ' 3.328+002 ' 33 Name PIPE-CWR-HV-020 to Cml PIPE-HV-01 to RH×01 I PIPE-CWS-OUBIE to HV-01 To RH×01 I PIPE-CWS-OUBIE to HV-01 To RH×01 I PIPE-CWS-OUBIE to HV-01 To RH×01 I	25	Product Pressure	(bar q)	1	11.65		11.39	11.36	11.67
Insulation Thickness (m) 0.1016	26	Insulation Conductivity	(W/m-K)	7.0686	+002 *		8.429e-002 *	6.040e-002 *	4.808e-002 *
21 Name PIPE-tV-02 to Comp PIPE-tV-03 to HV-02 PIPE-CWR-HV-03 to HV-02 PIPE-CWR-HV-03 to HV-03 PIPE-CWR-HV-03 to HV-03 20 Feed Pressure (bar_g) 11.23 11.25 3.792 3.726 31 Product Temperature (C) 20.02 20.02 6.667 17.78 32 Product Temperature (D) 20.02 4.782+002 3.254+002 3.328+002 3.310+002 3.310+002 3.310+002	27	Insulation Thickness	(m)	0.	1016		0.1016	0.1016	0.1016
21 Peed Temperature (C) 20.02 20.00 ¹ 6.066 17.76 23 Feed Temperature (C) 20.02 20.02 6.667 17.78 23 Product Temperature (C) 20.02 20.02 6.667 17.78 23 Insulation Conductivity (Wim-K) 4.782e-002 4.782e-002 3.284e-002 3.284e-002 3.284e-002 3.284e-002 3.284e-002 3.284e-002 3.284e-002 3.810e-002 3.810e-002 3.810e-002 3.810e-002 3.810e-002 4.802e-002 4.802e-002 4.802e-002 4.802e-002 4.802e-002 4.802e-002 4.802e-002 3.84e-002 3.84e-002 3.84e-002 4.808e-002 3.84e-002 3.84e-002 4.808e-002 3.84e-002	28	Name		PIPE-HV-02 to Con	PE-HV-02 to Comp F		to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-0
Product Pressure (bar g) 11.23 11.24 3.742 3.742 3.742 3 Product Pressure (bar g) 11.21 11.23 3.987 3.328 31 Insulation Conductivity (Win-k) 4.782+002 4.782+002 3.254+002 3.328+002 3.328+002 31 Insulation Thickness (m) 0.016 0.1016 1.500 3.810e-002 32 Product Pressure (bar q) 3.866 1.17.7 1.17.3 4.132 31 Preduct Temperature (C) 1.7.78 24.56 24.55 6.577 32 Product Temperature (C) 1.7.78 24.55 24.453 6.558 32 Product Temperature (C) 1.7.78 24.55 24.453 6.558 32 Product Temperature (Da g) 3.526 3.252 4.308+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002 3.254+002	29	Feed Temperature	(C)		20.02		20.00 *	0.000	17.78
2 Product Prinstance (b) 20.02 0.007 11.21 2 Product Pressure (b) 1.121 1.123 3.3967 3.526 31 Insulation Conductivity (Wim-K) 4.782e-002 4.782e-002 3.254e-002 3.326e-002 21 Insulation Thickness (m) 0.1016 0.1016 1.500 3.310e-002 23 Insulation Thickness (m) 0.1016 0.1016 1.500 3.810e-002 24 Feed Temperature (C) 17.78 24.55 24.65 6.657 25 Product Pressure (bar.g) 3.866 11.67 11.73 4.132 26 Insulation Conductivity (Wim-K) 3.328e-002 4.808e-002 4.808e-002 3.254e-002 21 Insulation Thickness (m) 3.810e-002 0.1016 0.1016 3.810e-002 24 Name PIPE-CWR-HV-004 to Out PIPE-CWR-HV-001 to Out PIPE-CWR-HV-004 16.668 6.662 29 Product Pressure	24	Preduct Temperature	(bar_g)		20.02		20.02	3.792	3.720
Product Freedow (ws.g) 1121 1123 0.001 0.002 Insulation Conductivity (Wm-K) 4.782e-002 3.328e+002 4.55 6.657 27 Feed Temperature (C) 17.78 2.4.55 2.4.53 6.657 38 Product Temperature (C) 17.78 2.4.55 2.4.53 6.657 39 Product Temperature (C) 17.78 2.4.55 2.4.53 6.657 31 Insulation Conductivity (Wim-K) 3.328e+002 4.808e+002 4.808e+002 3.254e+002 4.132 30 Insulation Thickness (m) 3.810e+002 0.1016 0.1016 3.810e+002 4.808e+002 4.808e+002 4.808e+002 4.808e+002 4.808e+002 4.808e+	32	Product Temperature Droduct Drossure	(bar (t)		11.21		11.23	3.087 *	3 525
23 Insulation Thickness (m) 0.1016 0.1016 0.1016 1.500 3.810e-002 35 Name PIPE-CWR-HV-002 to Chil PIPE-CWR-1 PIPE-CWG-1 PIPE-CWG-Chiler to HV-02 36 Feed Temperature (C) 17.76 24.66 24.65 6.657 37 Feed Temperature (D) 17.76 24.65 24.63 6.657 38 Product Temperature (C) 17.77 24.255 24.63 6.652 39 Product Pressure (Dar.g) 3.859 11.67 11.73 4.132 41 Insulation Conductivity (Wim-K) 3.328e-002 4.808e-002 4.808e-002 3.254e-002 4.808e-002 3.254e-002 4.808e-002 4.808e-002 3.254e-002 3.254e-002 3.254e-002 3.254e-002 4.808e-002 3.525 4.131 3.793 41 Insulation Thickness (m) 3.526 3.525 4.131 3.793 42 Feed Temperature (C) 17.78 5.652 5	33	Insulation Conductivity	(W/m-K)	4,7826	+002 *		4.782e-002 *	3.254e-002 *	3.328e-002 *
125 Name PIPE-CWR-HV-002 to Chi PIPE-HV-01 to RHX-01 PIPE-Comp to HV-03 PIPE-CW3-Chiller to HV-03 126 Feed Temperature (C) 17.78 24.55 24.65 66.657 12 Feed Pressure (bar q) 3.860 11.67 11.73 4.132 28 Product Temperature (C) 17.78 24.55 24.63 6.658 39 Product Temperature (Dar q) 3.859 11.67 11.69 4.132 40 Insulation Thickness (m) 3.328+002 4.808+002 4.808+002 3.254+002 41 Insulation Thickness (m) 3.310+002 0.1016 0.810+002 42 Insulation Thickness (m) 3.810+002 1.778 1.778 6.658 6.662 43 Feed Temperature (C) 17.78 17.78 6.658 6.666 44 Feed Pressure (bar g) 3.525 3.310+002 3.328+002 3.254+002 3.254+002 3.254+002 3.254+002 3	34	Insulation Thickness	(m)	0.	1016		0.1016	1.500	3.810e-002
96 Feed Temperature (C) 17.78 24.56 24.65 6.657 37 Feed Pressure (bar q) 3.860 11.67 11.73 4.132 38 Product Pressure (bar q) 3.859 11.67 11.89 4.132 38 Product Pressure (bar q) 3.859 11.67 11.69 4.132 40 Insulation Conductivity (Wm-K) 3.328-002 * 4.808-002 * 4.808-002 * 3.254-002 * 41 Insulation Conductivity (Wm-K) 3.328-002 * 4.808-002 * 3.254-002 * 42 Insulation Thiokness (m) 3.810e-002 * 0.1016 0.1016 3.810e-002 * 41 Insulation Thiokness (m) 3.810e-002 * 0.1016 0.1016 6.658 6.662 42 Feed Temperature (C) 17.78 17.78 6.658 6.662 43 Product Pressure (bar q) 3.525 3.800 3.328+002 * 3.254+002 * 3.254+002 * 3.254+002 * 3.81	35	Name		PIPE-CWR-HV-002	to Chil	PIPE-HV-01	to RHX-01	PIPE-Comp to HV-03	PIPE-CWS-Chiller to HV-0
31 Feed Pressure (bar q) 3.860 11.67 11.73 4.132 32 Product Temperature (C) 17.78 24.55 24.63 6.658 32 Insulation Conductivity (Wim-K) 3.328e-002 · 4.808e-002 · 4.808e-002 · 3.254e-002 · 41 Insulation Thickness (m) 3.810e-002 0.1016 0.1016 3.810e-002 · 42 Insulation Thickness (m) 3.810e-002 · 4.808e-002 · 4.808e-002 · 3.254e-002 · 43 Insulation Thickness (m) 3.810e-002 · 0.1016 0.1016 · 3.810e-002 · 44 Feed Temperature (C) 17.78 · 17.78 · 6.658 6.662 · 45 Feed Temperature (C) 17.78 · 17.78 · 6.652 · 6.5666 · 46 Product Temperature (C) 17.78 · 17.78 · 3.254e-002 · 3.254e-002 · 45 Insulation Conductivity (Wm-K) · 3.328e-002 · 3.328e-002 · 3.254e-002 · 3.254e-002 · 46 Insulation Conductivity (Wm-K) · 3.328e-002 ·	36	Feed Temperature	(C)	1	17.78		24.56	24.65	6.657
38 Product Temperature (C) 17.78 24.55 24.63 6.658 39 Product Pressure (bar_g) 3.859 11.67 11.69 4.132 40 Insulation Conductivity (Wm+K) 3.328e-002 4.808e-002 4.808e-002 4.808e-002 41 Insulation Conductivity (Wm+K) 3.328e-002 0.1016 0.1016 3.810e-002 42 Name PIPE-CWR-HV-004 to Out PIPE-CWR-Outside Wall to PIPE-CWS-HV-001 to Out PIPE-CWS-HV-	37	Feed Pressure	(bar q)		3.860		11.67	11.73 *	4.132
32 Product Pressure (par. g) 3.859 11.67 11.69 4.132 10 Insulation Conductivity (Wim-K) 3.328e-002 * 4.808e-002 * 4.808e-002 * 3.254e-002 * 11 Insulation Thickness (m) 3.310e-002 0.1016 0.1016 3.810e-002 12 Name PIPE-CWR-HV-004 to Out PIPE-CWR-HV-001 to Out PIPE-CWS-HV-001 to Out PIPE-CWS-Outside Wall to 13 Freed Temperature (C) 17.78 17.78 6.658 6.662 14 Freed Pressure (bar. g) 3.526 3.525 4.131 3.793 15 Product Temperature (C) 17.78 17.78 6.662 6.666 16 Product Pressure (bar. g) 3.525 3.860 3.793 3.792 11 Insulation Thickness (m) 3.810e-002 3.328e-002 * 3.254e-002 * 3.254e-002 * 11 Insulation Thickness (m) 3.810e-002 3.810e-002 3.810e-002 3.810e-002 3.810e-002	38	Product Temperature	(C)	1	17.78		24.55	24.63	6.658
40 Insulation Conductity (Wm-k) 3.3280-002 * 4.808-002 * 4.808-002 * 3.2840-002 * 41 Insulation Thickness (m) 3.8100-002 0.1016 0.1016 3.8100-002 42 Name PIPE-CWR-HV-004 to Out PIPE-CWR-Outside Wall ty PIPE-CWS-Outside Wall ty PIPE-CW	39	Product Pressure	(bar_g)		3.859		11.67	11.69	4.132
41 Insulation Trickness (m) 3.810e-002 0.1016 0.1016 3.810e-002 42 Name PIPE-CWR-HV-004 to Out PIPE-CWR-HV-001 to Out PIPE-CWS-Putside Walt 43 Feed Temperature (C) 17.78 17.78 6.6558 6.662 44 Feed Temperature (D) 17.78 17.78 6.652 6.662 44 Feed Pressure (bar_g) 3.525 3.850 3.793 3.793 45 Product Temperature (D) 17.78 17.78 6.652 6.666 46 Product Pressure (bar_g) 3.525 3.860 3.793 3.792 47 Insulation Conductivity (Wim-K) 3.328e-002 3.328e-002 3.254e-002 3.810e-002 48 Insulation Thickness (m) 3.810e-002 3.810e-002 3.810e-002 3.810e-002 49 S <	40	Insulation Conductivity	(W/m-K)	3.3286	-002 ·		4.808e-002 *	4.808e-002 *	3.254e-002 *
Name Pre-CWR-Hvodu Bodi Pre-CWR-Hvodu Bodi <th>41</th> <th>Insulation Thickness</th> <th>(m)</th> <th>DIDE CWP HV 004</th> <th>Ho Out</th> <th>DIDE OWD /</th> <th>U.1016 Veteleto Moll M</th> <th>DIDE CIVE HV 001 to Out</th> <th>3.610E-002</th>	41	Insulation Thickness	(m)	DIDE CWP HV 004	Ho Out	DIDE OWD /	U.1016 Veteleto Moll M	DIDE CIVE HV 001 to Out	3.610E-002
Incompetition (b) (c) <	43	Feed Temperature	(C)	PIPE-OWR-NV-004	7 78	PIPEROWING	17.78	FIPE-OWS-HV-001 t0 Odd	FIFE-GWS-Outside Wall to 6 662
45 Product Temperature (cf) 17.78 17.78 6.662 6.666 45 Product Pressure (bar_q) 3.525 3.860 3.793 3.792 47 Insulation Conductivity (Wim-K) 3.328e-002 * 3.254e-002 * 3.254e-002 * 48 Insulation Conductivity (Wim-K) 3.328e-002 * 3.328e-002 * 3.810e-002 49 Insulation Thickness (m) 3.810e-002 3.810e-002 3.810e-002 50 51 52 53 54 55 56 57 51 52 54 55 56 57 58 59 56 52 56 57 58 59 59 59 59 50 56 57 56 57 58 59 56 57 58 59 56 56 57 58 59 50 56 56 57 58 56 56 57 58 59 50	44	Feed Pressure	(bar g)		3.526		3.525	4.131	3.793
46 Product Pressure (bar_g) 3.525 3.860 3.793 3.792 47 Insulation Conductivity (W/m-K) 3.328-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.254-002 * 3.810e-002	45	Product Temperature	(C)		17.78		17.78	6.662	6.666
47 Insulation Conductivity (Wim-K) 3.328e-002 * 3.328e-002 * 3.254e-002 * 3.254e-002 * 48 Insulation Thickness (m) 3.810e-002 3.810e-002 3.810e-002 3.810e-002 49 50 51 52 53 54 55 55 51 52 53 54 55 56 57 58 52 53 54 55 56 57 58 56 57 53 54 55 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 59 50 56 57 58 59 59 50 56 57 58 56 57 58 59 50 56 57 58 56 57 58 56 57 58 56 57 58 56 56 57 58 56 56 56 57 58 56 56 56 56<	46	Product Pressure	(bar g)	3	3.525		3.860	3.793	3.792
48 Insulation Thickness (m) 3.810e-002 3.810e-002 3.810e-002 49 50 51 52 53 54 55 56 51 56 57 58 59 56 57 58 56 50 56 57 58 56 57 58 56 57 58 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 58 59 56	47	Insulation Conductivity	(W/m-K)	3.3286	+002 °		3.328e-002 *	3.254e-002 *	3.254e-002 *
49 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53	48	Insulation Thickness	(m)	3.8106	-002		3.810e-002	3.810e-002	3.810e-002
50 51 52 53 54 55 56 57 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 Page 4 of 4	49								
51 52 53 56 57 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 64	50								
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61 62 63 Aspen Technology Inc. 63 Aspen HYSYS Version 9 Page 4 of 4	60								
62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 4 of 4	61								
63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 4 of 4	62				_		_		
	63	Aspen Technology Inc.		Asp	en HY	SYS Version	9		Page 4 of 4

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Helium Operating at 600°C and 75 kW of Heat Pipe Power



1			Case	Name: def	alled ini test	bed 75kW HE.hsc	
2	easpentech UNIVERSITY OF Bedford, MA	IDAHO ·	Unit	Set: MA	GNET		
4	USA		Date	Time: We	ed Jun 03 14	:16:46 2020	
6 7 8	Workbook: C	ase (Main)					
9 10		м	lateri	al Streams		Flu	id Pkg: Ali
11	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out
12	Temperature (C)	1	45.6		17.78	6.667	20.00 *
13	Pressure (bar_g)	1	1.34		3.726	3.987	11.23
14	Mass Flow (kg/s)	0.1	1170		1.986	1.986	0.1170
15	Name	RHX-01 Cold In		RHX-01 Cold (Out .	Vacuum Chamber In	Vacuum Chamber Out
15	Pressure (b)	2	1.60		4/0.3	4/0.0	11.40 *
18	Mass Flow (kg/s)	01	1170		0 1170	0 1170	0 1170
19	Name	RHX-01 Hot In		RHX-01 Hot O	ut	Comp In	6
20	Temperature (C)	5	97.3		145.8 *	20.01	20.01
21	Pressure (bar_g)	1	1.39		11.34 *	11.19	11.21
22	Mass Flow (kg/s)	0.1	1170		0.1170	0.1170	0.1170
23	Name	Chiller In		Chiller Out		CWS-04	CWR-01
24	Temperature (C)	1	7.78		6.651	6.659	17.78
25	Pressure (bar q)	3	.859		3.762	3.793	3.526
26	Mass Flow (Kg/s)	1	.986	CWP 03	1.986	1.986	1.986
27	Temperature (C)	CWR-05	7 78	CWR-05	17.78	17.78	6 655
29	Pressure (bar g)	3	859		3.525	3.525	4.132
30	Mass Flow (kg/s)	1	.986		1.986	1.986	1,986
31	Name	CWS-03		CWS-06		13	14
32	Temperature (C)	6	.655		6.663	26.91	26.85
33	Pressure (bar_g)	4	.132		3.792	11.71	11.69
34	Mass Flow (kg/s)	1	.986		1.986	0.1170	0.1170
35	Name	15		16		Comp Out	4-2
36	Temperature (C)	2	6.85		20.01	26.92	26.91
37	Pressure (bar q)	1	1.69		0.1120	11.74	11.71
38	Name (Ky/s)	CWS-01	11/0	CWR-04	0.1170	CWS-05	0.1170
40	Temperature (C)	6	654	- Children	17.78	6.663	
41	Pressure (bar q)	4	.132		3.859	3.793	
42	Mass Flow (kg/s)	1	.986		1.986	1.986	
43			Com	nositions		Elu	id Dka: All
44			com	positions		FIG	iurky. Ai
45	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out
46	Master Comp Mass Frac (Hellum)	1.0	0000				1.0000
47	Master Comp Mass Frac (F2O)				0.5539	0.5539	
49	Name	RHX-01 Cold In		RHX-01 Cold (0.4401 Dut	Vacuum Chamber In	Vacuum Chamber Out
50	Master Comp Mass Frac (Hellum)	1.0	0000	Tribeer cold (1.0000	1.0000	1.0000
51	Master Comp Mass Frac (H2O)						
52	Master Comp Mass Frac (EGlycol)						
53	Name	RHX-01 Hot In		RHX-01 Hot O	ut	Comp In	6
54	Master Comp Mass Frac (Hellum)	1.0	0000		1.0000	1.0000	1.0000
55	Master Comp Mass Frac (H2O)	ļ					
56	Master Comp Mass Frac (EGlycol)						
57	Name	Chiller In		Chiler Out		CWS-04	CWR-01
50	Master Comp Mass Frac (Hellum)				0.5520	0.5530	0.5530
60	Master Comp Mass Frac (FGlycol)	0.0	4461 *		0.0009	0.0009	0.0009
61	Company and the second second second					0,4401	
62							
63	Aspen Technology Inc.	Asp	en HY	SYS Version 8)		Page 1 of 4

^{*} Specified by user.

1	easpentech			Case Name: detailed ini test bed 75kW HE.hsc					
3				Unit Set: MAGNET					
4				te/Time: Wed Jun 03 14:16:46 2020					
6 7 8	Workbook: Case (Main) (continued)								
9	Compositions (continued) Fluid Pka:								All
11	Name	CWR-05		CWR-03		CWR-02		CWS-02	
12	Master Comp Mass Frac (Hellum)								
13	Master Comp Mass Frac (H2O)	0.	5539		0.5539		0.5539		0.5539
14	Master Comp Mass Frac (EGlycol)	0.	4461	0000 05	0.4461	12	0.4461		0.4461
15	Name Master Comp Mass Frac (Hellum)	CWS-03		CWS-06		13	1,0000	14	1 0000
17	Master Comp Mass Frac (H2O)	0	5539		0.5539				
18	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461				
19	Name	15		16		Comp Out		4-2	
20	Master Comp Mass Frac (Hellum)	1.	0000		1.0000		1.0000		1.0000
21	Master Comp Mass Frac (H2O)								
22	Master Comp Mass Frac (EGlycol)								
23	Name	CWS-01		CWR-04		CWS-05			
24	Master Comp Mass Frac (Hellum)		5520		0.5520		0.6620		
26	Master Comp Mass Frac (FGlycol)	0	4461		0.4461		0.4461		
27		-							
28			Energ	y Streams			Fluid	i Pkg:	Ali
29	Name	Heat Pipes		PIPE-RHX-	01 Cold Out He	PIPE-RHX-0	1 Hot In Heat	PIPE-RHX	-01 Hot Out Hea
30	Heat Flow (KW)		75.00		1.021		1.617		0.1108
31	Name	PIPE-HV-03 Heat		PIPE-HX-01	Hot Heat	PIPE-HV-02	Heat	Comp Pow	er
32	Heat Flow (KVV)	Chiller Duty	e-002	DIDE CWR	-6.6366-003	DIDE CIME D	6.584e-004	DIDE CWE	4.198
34	Heat Flow (KW)	Chiller Duty	76 61	PIPEROWO	-2.863e-002	PIPEROWORU	2 078e-002	PIPEROWI	-6.112e-003
35	Name	PIPE-CWR-Heat		PIPE-CWR	05 Heat	PIPE-CWS-0	1 Heat	PIPE-HV-0	1 Heat
36	Heat Flow (kW)	-7.229	e-003		-2.420e-003		1.031e-002		2.841e-003
37	Name	PIPE-Comp Heat		Chiller Pum	p Power	PIPE-CWR-0	3 Heat	PIPE-CWS	-04 Heat
38	Heat Flow (KW)	4.578	e-003		9.114e-002		4.595e-003		-2.602e-002
39 40			н	eaters			Fluid	i Pikg:	All
41	Name	Vacuum Chamber							
42	DUTY (kW)		75.00						
43	Feed Temperature (C)		476.6						
44	Product Temperature (C)		600.0 *						
45	Mass Flow (Kg/s)	U.	.11/0						
47	Coolers Fluid Pkg: All								All
48	Name	Chiller							
49	DUTY (KW)		76.61						
50	Feed Temperature (C)		17.78						
51	Mass Flow (kn/s)		1 086						
53	(igo)								
54									
55									
56									
57									
58									
60 60									
61									
62									
63	Aspen Technology Inc.	Asc	en Hì	SYS Versio	n 9				Page 2 of 4

* Specified by user.

1				Case Name: detailed initiation 75kW LIE her						
2	UNIVERSITY OF IDAHO			Case Name. Detailed ini test bed / Skivy HE.hisc						
3	(aspentech	Bedford, MA	Uni	Unit Set: MAGNET						
5		034	Dat	Date/Time: Wed Jun 03 14:16:46 2020						
6										
7	Workbook: Case (Main) (continued)									
8										
10			Heat	Exchangers	Flui	1 Pkg: All				
11	Name		RHX-01	Chiller HX-01						
12	Duty	(KW)	274.6	76.41						
13	Tube Side Feed Mass Flow	(kg/s)	0.1170	0.1170						
14	Shell Side Feed Mass Flow	(kg/s)	0.1170	1.986						
15	Tube Inlet Temperature	(C)	597.3	145.6						
15	Shell Inlet Temperature	(C)	140.0	20.00 ·						
17	Shell Outlet Temperature	(C)	478 3	17.78						
19	I MTD	(C)	4/0.3	43.92						
20	UA	(W/C)	2307	1740						
21	Minimum Approach	(C)	118.9	13.33						
22				_						
23				Pumps	Flue	IPKG: All				
24	Name		Chiller Pump							
25	Power	(KW)	9.114e-002							
26	Feed Pressure	(barq)	3.762							
27	Product Pressure	(bar_g)	4.132							
28	Product Temperature	(C)	6.654							
29	Feed Temperature	(C)	6.651							
30	Adiabatic Efficiency	(%)	/5.00							
32	Mass Finw	(kn/s)	1.070							
33	Maloo I Iow	(kgro)	1.500							
34			Cor	npressors	Flui	1 Pkg: All				
35	Name		Comp-01							
36	Power	(KW)	4.198							
37	Feed Pressure	(bar q)	11.19							
38	Product Pressure	(bar_g)	11.74	•						
39	Product Temperature	(C)	26.92							
40	Adjobatic Efficiency	(0)	20.01							
42	Pressure Ratio		1045							
43	Mass Flow	(ka/s)	0.1170							
44		(2-)	-							
45			E	panders	Flue	i Pikg: Ali				
46	Name									
47	Power	(kW)								
48	Feed Pressure	(bar q)								
49	Product Pressure	(barq)								
50	Product Temperature	(C)								
51	Adjabatic Efficiency	(0)								
53	Mass Flow	(ka/s)								
54		(190)								
55	Pipe Segments Fluid Pkg: A									
56	Name		PIPE-Cold Out-RHX-01 t	PIPE-Hot In-Vacum Cham	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01				
57	Feed Temperature	(C)	478.3	600.0 *	145.8 *	26.91				
58	Feed Pressure	(bar_g)	11.65	11.40	11.34 "	11.71				
59	Product Temperature	(C)	476.6	597.3	145.6	26.85				
60	Product Pressure	(bar q)	11.65	11.39	11.34	11.69				
61	Insulation Conductivity	(W/m-K)	7.607e-002	8.435e-002	5.5110-002 *	4.821e-002 *				
62	Aspen Technology Ice	Insulation Thickness (m) 0.1016 0.1016 0.1016 0.1016 0.10								
0.3	Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 4									

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1				Case Name: detailed ini test bed 75kW HE.hsc						
2	(aspentech UNIVERSITY OF IDAHO Bedford, MA USA			Unit Set: MAGNET						
4				Date/Time: Wed Jun 03 14:16:46 2020						
6										
7 8	Workbook: Case (Main) (continued)									
9 10			Pipe S	egme	nts (continued)	Fluid	1 Pkg: All			
11	Name		PIPE-HV-02 to Com	1p	PIPE-HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV			
12	Feed Temperature	(C)	2	0.01	20.00	6.663	17.78			
13	Feed Pressure	(bar_g)	1	1.21	11.23	3.792	3.726			
14	Product Temperature Product Pressure	(C)	2	1 10	20.01	6.667 *	17.78			
16	Insulation Conductivity	(W/m-K)	4.782e	-002 -	4.782e-002	3.254e-002 *	3.328e-002			
17	Insulation Thickness	(m)	0.1	1016	0.1016	3.810e-002	3.810e-002			
18	Name		PIPE-CWR-HV-002	to Chil	PIPE-CWS-Chiller to HV-	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03			
19	Feed Temperature	(C)	1	7.78	6.654	26.85	26.92			
20	Feed Pressure	(bar_g)	3	3.859	4.132	11.69	11.74			
21	Product Temperature	(C)	1	7.78	6.655	26.84	26.91			
22	Product Pressure	(bar_g)	3 2000	8.859	4.132	11.69	11.71			
23	Insulation Conductivity	(W/m-K)	3.3288	-002 -	3.2540-002	4.820e-002 *	4.821e-002			
25	Name	(11)	PIPE-CWS-HV-001	to Out	PIPE-CWS-Outside Wall	PIPE-CWR-HV-004 to Out	PIPE-CWR-Outside Wal			
26	Feed Temperature	(C)	6	655	6.659	17.78	17.78			
27	Feed Pressure	(bar_g)	4	.132	3.793	3.525	3.525			
28	Product Temperature	(C)	6	5.659	6.663	17.78	17.78			
29	Product Pressure	(bar_g)	3	3.793	3.793	3.525	3.859			
30	Insulation Conductivity	(W/m-K)	3.254e	-002 *	3.254e-002	3.328e-002 *	3.328e-002			
3 3 3 4 3 5 3 6 7 8 3 9 4 4 1 4 2 3 4 4 5 6 7 8 9 6 1 5 5 5 5 5 5 5 5 5 8 9 6 1										
61 62										

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Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Nitrogen Operating at 600°C and 2 kW of Heat Pipe Power



1	Aspentech UNIVERSITY OF IDAHO Bedford, MA USA			Case Name: detailed Ini Test bed 2kw n2.hsc					
3				Units	Jnit Set: MAGNET				
4				Date/	Time: Wed Jun 03 14	Wed Jun 03 14:18:24 2020			
6 7	Work	khook: Ca	ase (Main)						
8	WOINDON. Case (Mail)								
9 10	Material Streams Fluid Pkg: Al								
11	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out		
12	Temperature	(C)	1	15.5	17.78	6.667 *	20.00 *		
13	Pressure Mass Flow	(bar_g)	1	1.35	3.726	3.987 *	11.23		
14	Mass Flow Mass Density	(KQ/S) (kg/m3)	4.4599	0 70	1.154e-002	1.154e-002	4.4598-003		
16	Mass Enthalpy	(kJ/kg)	9	3.12	-1.240e+004	-1.244e+004	-8.610		
17	Mass Entropy	(kJ/kg-C)	4	.817	0.7740	0.6361	4.519		
18	Name		RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out		
19	Temperature	(C)	2	1.95	273.4	198.1	600.0 *		
20	Pressure	(bar_g)	1	1.65	11.65 *	11.65	11.40		
21	Mass Flow	(kg/s)	4.459e	-003	4.459e-003	4.459e-003	4.459e-003		
22	Mass Density	(kg/m3)	1	4.54	7.774	9.021	4.771		
23	Mass Entraipy Mass Entrony	(KJ/Kg) (k l/ko-C)		516	203.7	162.0	5 707		
25	Name	(no/ng-o)	RHX-01 Hot In		RHX-01 Hot Out	Comp In	6		
26	Temperature	(C)	3	81.1	133.0 "	20.77	20.73		
27	Pressure	(bar_g)	1	1.40 *	11.35 *	11.23	11.23		
28	Mass Flow	(kg/s)	4.459e	-003	4.459e-003	4.459e-003 *	4.459e-003		
29	Mass Density	(kg/m3)	6	.365	10.23	14.12	14.12		
30	Mass Enthalpy	(kJ/kg)	3	82.3	111.9	-7.789	-7.837		
31	Mass Entropy	(KJ/Kg-C)	Chiller in	.382	4.864 Chiller Out	4.522 CIMP-04	4.522 CWP-01		
33	Temperature	(C)	Conner III	8.19	4.578	5.361	17.93		
34	Pressure	(bar_g)	4	.197	4.093	3.789	3.529		
35	Mass Flow	(kg/s)	1.154e	-002	1.154e-002	1.154e-002	1.154e-002		
36	Mass Density	(kg/m3)		1063	1074	1073	1064		
37	Mass Enthalpy	(kJ/kq)	-1.240e	+004	-1.245e+004	-1.244e+004	-1.240e+004		
38	Mass Entropy	(KJ/Kg-C)	CWP.05	7789	0.6096	0.6196	0.7758		
39 40	Temperature	(C)	CWR-05	8 14	18.04	17.93	4 845		
41	Pressure	(barg)	4	.197	3.863	3.529	4.126		
42	Mass Flow	(kg/s)	1.154e	-002	1.154e-002	1.154e-002	1.154e-002		
43	Mass Density	(kg/m3)		1063	1063	1064	1074		
44	Mass Enthalpy	(kJ/kg)	-1.240e-	+004	-1.240e+004	-1.240e+004	-1.245e+004		
45	Mass Entropy	(kJ/kg-C)	0.1	7783	0.7771	0.7758	0.6130		
46	Temperature	(0)	CWS-06	008	13 24.05	14 22.03	10 22.03		
48	Pressure	(bar o)	3	.789	11.65	11,65	11,65		
49	Mass Flow	(kq/s)	1.154e	-002	4.459e-003	4.459e-003	4.459e-003		
50	Mass Density	(kg/m3)		1073	14.43	14.53	14.53		
51	Mass Enthalpy	(kJ/kg)	-1.244e	+004	-4.406	-6.569	-6.569		
52	Mass Entropy	(kJ/kg-C)	0.0	6276	4.524	4.516	4.516		
53	Name	(0)	16	0.72	Comp Out	4-2	CWS-01		
54 55	Pressure	(U) (har n)	2	1.23	24.54	24.06	4.5/8		
56	Mass Flow	(kg/s)	4,459e	-003	4,459e-003	4.459e-003	1.154e-002		
57	Mass Density	(kg/m3)	1	4.12	14.41	14.43	1074		
58	Mass Enthalpy	(kJ/kg)	-7	.837	-3.896	-4.406	-1.245e+004		
59	Mass Entropy	(kJ/kg-C)	4	.522	4.525	4.524	0.6096		
60 61 62									
63	3 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 4								
	LICENSES IN LINU/EDOITY OF IN	Let 1					The second se		
4									
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2	UNIVERSITY OF	IDAHO	Case	Name: di	etailed ini Test	t bed 2kw n2.hsc			
3	(aspentech Bedford, MA		Unit S	iet: M	AGNET				
4	654		Date/	Time: W	/ed Jun 03 14	18:24 2020			
6 7 8	Workbook: C	ase (Main)	(co	ntinued)				
9		Materia	al Stre	ams (conti	nued)	Flu	d Pkg: All		
10	Nama	CW9-02		CWR-04		CWS-05			
12	Temperature (C)	0110-02	4 845	0111104	18.14	5 998			
13	Pressure (bar g)		4 126		4 197	3 789			
14	Mass Flow (kg/s)	1.154	-002		1.154e-002	1,154e-002			
15	Mass Density (kg/m3)		1074		1063	1073			
16	Mass Enthalpy (kJ/kg)	-1.245e	+004	-1	.240e+004	-1.244e+004			
17	Mass Entropy (kJ/kg-C)	0.	6130		0.7783	0.6276			
18 19			Com	ositions		Flu	d Pkg: All		
20	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out		
21	Master Comp Mass Frac (Hellum)								
22	Master Comp Mass Frac (EGlycol)				0.4073	0.4073			
23	Master Comp Mass Frac (H2O)				0.5927	0.5927			
24	Name	RHX-01 Cold In		RHX-01 Cold	Out	Vacuum Chamber In	Vacuum Chamber Out		
25	Master Comp Mass Frac (Hellum)								
26	Master Comp Mass Frac (EGlycol)								
27	Master Comp Mass Frac (H2O)								
28	Name	RHX-01 Hot In		RHX-01 Hot	Out	Comp In	6		
29	Master Comp Mass Frac (Hellum)								
30	Master Comp Mass Frac (EGlycol)								
31	Master Comp Mass Frac (H2O)								
32	Name	Chiller In		Chiller Out		CWS-04	CWR-01		
33	Master Comp Mass Frac (Hellum)	-							
34	Master Comp Mass Frac (EGlycol)	0.	4073		0.4073	0.4073	0.4073		
35	Name	CWR-05	3927	CWR-03	0.0527	CWR-02	CWS-03		
37	Master Comp Mass Frac (Hellum)	0111100		0111100					
38	Master Comp Mass Frac (EGlycol)	0.	4073		0.4073	0.4073	0.4073		
39	Master Comp Mass Frac (H2O)	0.	5927		0.5927	0.5927	0.5927		
40	Name	CWS-06		13		14	15		
41	Master Comp Mass Frac (Hellum)								
42	Master Comp Mass Frac (EGlycol)	0.	4073						
43	Master Comp Mass Frac (H2O)	0.	5927	Orme Ord			0000.04		
44	Master Comp Mass Eran (Hellum)	10		Comp Out		4-2	CWS-01		
46	Master Comp Mass Frac (EGivcol)						0.4073		
47	Master Comp Mass Frac (H2O)						0.5927		
48	Name	CWS-02		CWR-04		CWS-05			
49	Master Comp Mass Frac (Hellum)								
50	Master Comp Mass Frac (EGlycol)	0.	4073		0.4073	0.4073			
51	Master Comp Mass Frac (H2O)	0.	5927		0.5927	0.5927			
52 53		Energ	y Streams		Flu	d Pkg: All			
54	Name	PIPE-RHX-01 Cold	Out He	PIPE-RHX-0	1 Hot In Heat	PIPE-RHX-01 Hot Out He	PIPE-HV-03 Heat		
55	Heat Flow (kW)	0.	3644		1.100	8.371e-002	9.656e-003		
56	Name	PIPE-HX-01 Hot H	eat	PIPE-HV-02	Heat	Comp Power	Chiller Duty		
57	Heat Flow (kW)	-3.4176	e-003	-	1.871e-004	1.736e-002	0.5557		
58	Name	PIPE-CWS-06 Hea	t	PIPE-CWS-0	3 Heat	PIPE-CWR-02 Heat	PIPE-CWR-Heat		
59 60	Heat Flow (KW)	-2.724	e-002	DIDE LINK CO	2.099e-002	-4.283e-003	-6.145e-003		
61	Heat Flow (PMD)	PIPE-CWR-US Hea	-003	PIPE-MV-01	164L 3 591e-004	2 250a.003	A 7320-005		
62	(NY)	-2.020	000		0.0010-004	2.2050-000	4.7020000		
63	Aspen Technology Inc.	Asc	en HY	SYS Version	9		Page 2 of 4		
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1	UNIVERSITY OF IDAHO			Case	Name: detailed ini T	est bed 2kw n2.hsc		
3	@aspentech	Bedford, MA	DAHO	Unit S	Set: MAGNET			
4		USA		Date/	Time: Wed Jun 03	14:18:24 2020		
6 7 8	Worl	kbook: Ca	ase (Main)	(co	ntinued)			
9 10			Energy	y Streams (continued) Fluid Pkg:				
11	Name		PIPE-CWS-01 Heat	t	PIPE-CWR-03 Heat	PIPE-CWS-04 Heat	Heat Pipe Power	
12	Heat Flow	(kW)	-1.0866	-002	-4.144e-003	-2.595e-002	1.993	
13				н	eaters	Flui	d Pkg: All	
14	Name		Vacuum Chamber				-	
16	DUTY	(KW)		.993				
17	Feed Temperature	(C)	1	98.1				
18	Product Temperature	(C)		00.0 -				
19	Mass Flow	(kg/s)	4.4596	-003				
20 21				Co	oolers	Flui	d Pkg: All	
22	Name		Chiller					
23	DUTY	(kW)	0.	5557				
24	Feed Temperature	(C)	1	8.19				
25	Product Temperature	(C)	1 1540	.578				
27	Midoo Flow	(\$4/8)	1.1346	-002				
28			н	leat Exchangers Fluid Pkg:				
29	Name		RHX-01		Chiller HX-01			
30	Duty	(kW)	1	.206	0.4536			
31	Tube Side Feed Mass Flow	(kg/s)	4.4596	-003	4.459e-003			
32	Shell Side Feed Mass Flow	(Kg/S)	4.4596	81.1	1.1540-002			
34	Tube Outlet Temperature	(C)		33.0 *	20.00	•		
35	Shell Inlet Temperature	(C)	2	1.95	6.667	•		
36	Shell Outlet Temperature	(C)	2	73.4	17.78			
37	LMTD	(C)	1	09.5	42.40			
38	UA Minimum Anoropoh	(W/C)	1	1.01	10.70			
39 40	Minimum Approach	(0)		ur.r	10.00			
41				P	umps	Flui	d Pkg: All	
42	Name		Chiller Pump					
43	Power	(kW)	4.7326	-005				
44	Feed Pressure	(bar_g)		1.093				
45	Product Pressure Droduct Temperature	(bar_g)		1578				
47	Feed Temperature	(C)		1.578				
48	Adiabatic Efficiency	(%)	1	5.00				
49	Pressure Ratio		1	.006				
50	Mass Flow	(kg/s)	1.1546	-002				
51 52	51 52				pressors	Flui	d Pkg: All	
53	Name		Comp-01					
54	Power	(kW)	1.7366	-002				
55	Feed Pressure	(bar_g)	1	1.23		1		
20 57	Product Pressure	(par_g)		1.05 1				
58	Feed Temperature	(C)		0.77				
59	Adiabatic Efficiency	(-)		75 *				
60	Pressure Ratio		1	.034				
61	Mass Flow	(kg/s)	4.4596	-003 *				
62	Anna Taskasland				CVC Version 0		Prove 0 of t	
63	Aspen Technology Inc.	HO	Asp	en HY	STS Version 8		Page 3 of 4	

1				Case	Name: detailed ini Tes	t bed 2kw n2.hsc			
3	(aspentech	UNIVERSITY OF I Bedford, MA	DAHO	Unit S	Set: MAGNET				
4		USA		Date/	Time: Wed Jun 03 14	:18:24 2020			
6 7	Work	book: Ca	ase (Main)	(co	ntinued)				
8 9									
10				Exp	anders	Fluid Pkg:			
11	Name								
12	Food Dressure	(NVV) (Dat. 0)							
14	Product Pressure	(bar q)							
15	Product Temperature	(C)							
16	Feed Temperature	(C)							
17	Adiabatic Efficiency								
18	Mass Flow	(kg/s)							
19 20				Pipe \$	Segments	Fluid	Pkg: All		
21	Name		PIPE-Cold Out-RH)	K-01 to	PIPE-Hot In-Vacum Cham	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01		
22	Feed Temperature	(C)	3	273.4	600.0 *	133.0 *	24.06		
23	Feed Pressure	(bar_g)	1	11.65 *	11.40	11.35 *	11.65		
24	Product Temperature	(C)	1	198.1	381.1	115.5	22.03		
25	Product Pressure	(bar q)	1	11.65	11.40	11.35	11.65		
26	Insulation Conductivity	(W/m-K) (m)	0.0556	1016	0.1016	5.364e-002 * 0.1016	4.7990-002		
28	Name	(11)	PIPE-HV-02 to Con		PIPE-HX-01 to HV-02	PIPE-CWS-HV-001 to HV-	PIPE-CWS-HV-003 to HX-		
29	Feed Temperature	(C)		20.73	20.00 *	4.845	5.998		
30	Feed Pressure	(bar_g)	1	11.23	11.23	4.126	3.789		
31	Product Temperature	(C)		20.77	20.73	5.361	6.667 *		
32	Product Pressure	(bar_g)	1	11.23	11.23	3.789	3.987 *		
33	Insulation Conductivity	(W/m-K)	4.7866	+002 *	4.784e-002 *	3.244e-002 *	3.252e-002 *		
34	Insulation Linickness	(m)	DIDE-CWR-HY-01	1016 HV-0	U.1016 DIDE-CWR-HV-004 to Out	3.810E-002 DIDE-CWR-HV-002 to Chil	3.810E-002		
36	Feed Temperature	(C)	PIPE-OWICH A-OT	17.78	17.93	18.14	22.03		
37	Feed Pressure	(bar g)		3.726	3.529	4.197	11.65		
38	Product Temperature	(C)	1	17.93	18.04	18.19	21.95		
39	Product Pressure	(bar_g)	3	3.529	3.863	4.197	11.65		
40	Insulation Conductivity	(W/m-K)	3.3286	+002 *	3.329e-002 *	3.330e-002 *	4.793e-002 *		
41	Insulation Thickness	(m)	3.8106	+002	3.810e-002	3.810E-002	0.1016 DIDE CWR Outside Wall M		
43	Feed Temperature	(C)	PIPE-Compile HV4	00 04 54	4.578	18.04	5 361		
44	Feed Pressure	(barg)	1	11.65 *	4.126	3.863	3.789		
45	Product Temperature	(C)	2	24.06	4.845	18.14	5.998		
46	Product Pressure	(bar_g)	1	11.65	4.126	4.197	3.789		
47	Insulation Conductivity	(W/m-K)	4.8066	+002 *	3.241e-002 *	3.330e-002 *	3.248e-002 *		
48	Insulation Thickness	(m)	0.	1016	3.810e-002	3.810e-002	3.810e-002		
43									
51									
52									
53									
54									
55									
56									
58									
59									
60									
61									
62							_		
63	Aspen Technology Inc.	0	Aso	en HY	SYS Version 9		Page 4 of 4		

Appendix B: Aspen HYSYS Models for the Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger

Aspen HYSYS process model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Nitrogen Operating at 600°C and 250 kW of Heat Pipe Power



1			DAHO	Case	Name: detailed ini test	bed 250kw n2 v2.hsc	
3	@aspentech	Bedford, MA	DAHO	Units	Set: MAGNET		
4		JSA		Date/	Time: Wed Jun 03 14	:20:34 2020	
6	Workt		nce (Main)				
8	WOIN.	000K. Ca	ase (main)				
9 10			N	lateri	al Streams	Fluid	1 Pkg: All
11	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out
12	Temperature	(C)	2	283.2	17.78	6.667 *	20.00 *
13	Pressure Mass Flaw	(bar_g)	1	11.15	3.726	3.987	11.03
14	Mass Plow Mass Density	(kq/s) (kq/m3)		7.334	1068	0./01	13.92
16	Mass Enthalpy	(kJ/ka)	2	274.5	-1.207e+004	-1.210e+004	-8.556
17	Mass Entropy	(kJ/kg-C)	5	5.209	0.5631	0.4282	4.524
18	Name		RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
19	Temperature	(C)	3	33.08	358.8	358.1	600.0 *
20	Pressure	(bar_g)	1	11.78	11.67 *	11.65	11.40 *
21	Mass Flow	(kg/s)	0.9	9187	0.9187	0.9187	0.9187
22	Mass Density	(kg/m3)	1	14.14	6.734	6.729	4.770
23	Mass Entrapy Mass Entrapy	(ku/kg) (k l/kg-C)		1.552	5 337	300.0 5 336	5 707
25	Name	(Noring-C)	RHX-01 Hot In		RHX-01 Hot Out	Comp In	6
26	Temperature	(C)	5	598.5	283.5 *	19.94	19.97
27	Pressure	(bar_g)	1	11.34	11.16 *	10.73	10.87
28	Mass Flow	(kg/s)	0.9	9187	0.9187	0.9187 *	0.9187
29	Mass Density	(kg/m3)	4	4.757	7.336	13.58	13.73
30	Mass Enthalpy	(kJ/kg)	6	527.2	274.8	-8.535	-8.542
31	Mass Entropy	(KJ/Kg-C)	Chiller In	5.706	5.210 Chiller Out	4.532	4.528 CWP-01
33	Temperature	(C)	1	17.78	6 659	6 664	17.78
34	Pressure	(bar q)	3	3.820	3.724	3.838	3.502
35	Mass Flow	(kg/s)	6	5.761	6.761	6.761	6.761
36	Mass Density	(kg/m3)		1068	1077	1077	1058
37	Mass Enthalpy	(kJ/kg)	-1.207e-	+004	-1.210e+004	-1.210e+004	-1.207e+004
38	Mass Entropy	(kJ/kg-C)	0.9	5631	0.4281	0.4282	0.5631
39	Temperature	(0)	CWR-05	17.78	17.78	UWR-02	GW3-02 6.652
41	Pressure	(bar q)	3	3.822	3.496	3.500	4,185
42	Mass Flow	(kg/s)	6	5.761	6.761	6.761	6.761
43	Mass Density	(kg/m3)		1068	1068	1068	1077
44	Mass Enthalpy	(kJ/kg)	-1.207e-	+004	-1.207e+004	-1.207e+004	-1.210e+004
45	Mass Entropy	(kJ/kg-C)	0.9	5631	0.5631	0.5631	0.4281
46	Name	(0)	CWS-03		CWS-06	13	14 33.00
48	Pressure	(bar d)		1183	3,835	33.21	33.09
49	Mass Flow	(kg/s)	6	5.761	6.761	0.9187	0.9187
50	Mass Density	(kg/m3)		1077	1077	14.32	14.15
51	Mass Enthalpy	(kJ/kg)	-1.210e	+004	-1.210e+004	5.257	5.173
52	Mass Entropy	(kJ/kg-C)	0.4	4281	0.4282	4.549	4.552
53	Name		15		16	Comp Out	4-2
54 55	Pressure	(C) (bar a)	3	11.70	19.97	33.28	33.21
56	Mass Flow	(ka/s)	0.0	9187	0.9187	0.9187	0.9187
57	Mass Density	(kg/m3)	1	14.15	13.72	14.59	14.33
58	Mass Enthalpy	(kJ/kg)	5	5.173	-8.542	5.271	5.257
59	Mass Entropy	(kJ/kg-C)	4	4.552	4.529	4.543	4.548
60 61 62							
63	Aspen Technology Inc.		Asp	en HY	SYS Version 9		Page 1 of 5
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1		10410	Case	Name: de	etailed ini test	bed 250kw n2 v2.hsc		
3	(easpentech Bedford, MA	IDAHO	Unit S	Set: M	IAGNET			
4	USA		Date/	Time: W	/ed Jun 03 14	20:34 2020		
6	Warkbook: C	ana (Main)	100	ntinued	n.			
8	WORKDOOK. C	ase (main)	(00)	nunuea)			
9		Materia	al Stre	I Streams (continued) Fluid Pkg:				
11	Name	CWS-01		Heat Pipe Ev	aporator	Heat Pipe Condensor	CWS-05	
12	Temperature (C)		5.662		650.0 *	650.0	6.664	
13	Pressure (bar_g)		4.187		-0.9475	-0.9475	3.837	
14	Mass Plow (KQ/s) Mass Density (kg/m3)	· · ·	1077		1.972e-002	6.082e-002 799.6	6./61	
16	Mass Enthalpy (kg/kg)	-1.210e	+004		-1791	-5902	-1.210e+004	
17	Mass Entropy (kJ/kg-C)	0.	4281		58.21	53.39	0.4282	
18	Name	CWR-04						
19	Temperature (C)		17.78					
20	Pressure (bar_g)		3.824					
21	Mass Flow (kg/s)		5.761					
22	Mass Density (Kg/m3)	-1 207e	1068					
24	Mass Entropy (kJ/kg-C)	-1.2076	5631					
25	(10.12 0)					-		
26			Com	positions		Flui	d Pkg: Al	
27	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out	
28	Master Comp Mass Frac (Nitrogen)	1.	• 0000				1.0000	
29	Master Comp Mass Frac (H2O)				0.5539	0.5539		
30	Master Comp Mass Frac (EGlycol)				0.4461	0.4461		
32	Name	RHX-01 Cold In		RHX-01 Cold	Out	Vacuum Chamber In	Vacuum Chamber Out	
33	Master Comp Mass Frac (Nitrogen)	1.	0000	1000	1.0000	1.0000	1.0000	
34	Master Comp Mass Frac (H2O)							
35	Master Comp Mass Frac (EGlycol)							
36	Master Comp Mass Frac (Sodium*)							
37	Name	RHX-01 Hot In		RHX-01 Hot	Out	Comp In	6	
38	Master Comp Mass Frac (Nitrogen)	1.			1.0000	1.0000 -	1.0000	
40	Master Comp Mass Frac (EGIvcol)							
41	Master Comp Mass Frac (Sodium*)	1						
42	Name	Chiller In		Chiller Out		CWS-04	CWR-01	
43	Master Comp Mass Frac (Ntrogen)							
44	Master Comp Mass Frac (H2O)	0.	5539 *		0.5539	0.5539	0.5539	
45	Master Comp Mass Frac (EGlycol)	0.	4461 *		0.4461	0.4461	0.4461	
40	Name	CWB-05		CWR-03		CWR-02	CWS-02	
48	Master Comp Mass Frac (Nitrogen)							
49	Master Comp Mass Frac (H2O)	0.	5539		0.5539	0.5539	0.5539	
50	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461	0.4461	0.4461	
51	Master Comp Mass Frac (Sodium*)							
52	Name Master Comp Mass Erro (Mitmoor)	CWS-03		CWS-06		13	14	
54	Master Comp Mass Frac (Httogen)	0	5539		0.5539	1.000	1.0000	
55	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461			
56	Master Comp Mass Frac (Sodium")							
57	Name	15		16		Comp Out	4-2	
58	Master Comp Mass Frac (Ntrogen)	1.	0000		1.0000	1.0000	1.0000	
59	Master Comp Mass Frac (H2O)							
60	Master Comp Mass Frac (Ediycol)							
62	master Comp mass Frac (Sodium)	1						
63	Aspen Technology Inc.	Asc	en HY	SYS Version	9		Page 2 of 5	
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1	UNIVERSITY OF IDAHO			e Name: detailed ini test	bed 250kw n2 v2.hsc	
3	(aspentech Bedford, M	TY OF IDAHO A	Uni	Set: MAGNET		
4	USA		Dat	e/Time: Wed Jun 03 14	:20:34 2020	
6	Mandaha a la	0	(1.1			
8	WORKDOOK:	Case	(Main) (co	ontinuea)		
9 10			Composit	ions (continued)	Fluid	i Pkg: Ali
11	Name	CWS	-01	Heat Pipe Evaporator	CWS-05	CWR-04
12	Master Comp Mass Frac (Nitrogen)					
13	Master Comp Mass Frac (H2O)		0.5539		0.5539	0.5539
14	Master Comp Mass Frac (EGiycol)		0.4461		0.4461	0.4461
15	Master Comp Mass Frac (Sodium*)	line	Dire Condenses	1.0000 *		
16	Name Master Comp Mass Erze (Nitronon)	Hear	Pipe Condensor			
17	Master Comp Mass Frac (H2O)					
19	Master Comp Mass Frac (FGIvcol)					
20	Master Comp Mass Frac (Sodium*)		1.0000			
21			-			Direct 17
22			Ener	gy Streams	Fluid	I Pikg: All
23	Name	PIPE	-RHX-01 Cold Out H	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 Heat
24	Heat Flow	(KW)	0.6882	1.621	0.2642	7.990e-002
25	Name	PIPE	E-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power	Chiller Duty
26	Heat Flow	(KW)	-6.769e-003	-6.661e-004	12.68	260.5
27	Name	PIPE	-CWS-06 Heat	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	PIPE-CWR-Heat
28	Heat How	(KW)	-2.8668-002	-2.028e-002	-6.1246-003	-7.0138-003
29	Name Heat Flow	PIPE	-CWR-05 Heat	-1.032e-002	5 0730-003	PIPE-Comp Heat
31	Name	(KVV) Chill	er Pump Power	Flectric Heater Power	PIPE-CWS-04 Heat	PIPE-CWR-03 Heat
32	Heat Flow	0KW0	0.3877	250.0	-4.038e-003	-4.830e-003
33					El tra	Share all
34				leaters	Fluid	TPNg. All
35	Name	Elec	tric Heaters			
36	DUTY	(KW)	250.0			
37	Feed Temperature	(C)	650.0			
30	Mass Flow	(C) kn/s)	6.0820-002			
40		ngro/	0.0020-002			
41			0	Coolers	Fluid	i Pikg: Ali
42	Name	Chill	er			
43	DUTY	(KW)	260.5			
44	Feed Temperature	(C)	17.78			
45	Product Temperature	(C)	6.659			
46	Mass Flow	kg/s)	6.761			
47			Heat	Exchangers	Fluid	i Pkg: All
49	Name	RHX	-01	Chiller HX-01	Vacuum Chamber	
50	Duty	(KW)	323.8	260.0	250.0	
51	Tube Side Feed Mass Flow	kg/s)	0.9187	0.9187	6.082e-002	
52	Shell Side Feed Mass Flow (kg/s)	0.9187	6.761 *	0.9187	
53	Tube Inlet Temperature	(C)	598.5	283.2	650.0	
54	Shell Inlet Temperature	(C)	203.5	20.00 -	358.1	
56	Shell Outlet Temperature	(C)	358.8	17.78	500.0	
57	LMTD	(C)	245.1	168.2	136.5	
58			1321	0.0000	1832	
	UA (W/C)	1021			
59	UA (Minimum Approach	(C)	239.7	168.2	49.99	
59 60	UA (Minimum Approach	(C)	239.7	168.2	49.99	
59 60 61	UA () Minimum Approach	(C)	239.7	168.2	49.99	
59 60 61 62	UA () Minimum Approach	(C)	239.7	168.2	49.99	

1				Case Na	ame: detailed ini test	bed 250kw n2 v2.hsc	
3	(aspentech	Bedford, MA	DAHO	Unit Set	: MAGNET		
4		USA		Date/Tir	me: Wed Jun 03 14	:20:34 2020	
6 7 8	Worl	kbook: Ca	ase (Main)	(con	tinued)		
9				Pur	mps	Fluid	I Pikg: All
10	Name		Chiller Pump		-		
12	Power	(KW)	0.3	877			
13	Feed Pressure	(bar g)	3	724			
14	Product Pressure	(bar q)	4	187			
15	Product Temperature	(C)	6	.662			
16	Feed Temperature	(C)	6	.659			
17	Adiabatic Efficiency	(%)	7	5.00			
18	Pressure Ratio		1	890.			
19	Mass Flow	(kg/s)	6	.761			
20				Compr	ressors	Fluid	I Pkg: All
22	Name		Comp-01				
23	Power	(kW)	1	2.68			
24	Feed Pressure	(bar_g)	1	0.73			
25	Product Pressure	(bar q)	1	2.20 *			
26	Product Temperature	(C)	3	3.28			
27	Feed Temperature	(C)	1	9.94			
28	Adiabatic Efficiency			105			
30	Mass Finw	(ka/s)		120			
31	Indoo 1 Iow	(kgro)	0.3	107			
32				Expa	nders	Fluid	I Pikg: All
33	Name						
34	Power	(kW)					
35	Feed Pressure	(bar_g)					
36	Product Pressure	(bar_g)					
38	Feed Temperature	(C)					
39	Adiabatic Efficiency	(0)					
40	Mass Flow	(kg/s)					
41						El tra	Dhay bi
42			· · · · · · · · · · · · · · · · · · ·	'ipe Se	gments	Fluid	i Phg. Ali
43	Name		PIPE-Cold Out-RHX	-01 to	PIPE-Hot In-Vacum Cham	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01
44	Feed Temperature	(C)	3	58.8	600.0 *	283.5 *	33.21
45	Peed Pressure	(bar_g)	1	1.67	11.40 -	11.16	11.95
40	Product Temperature Droduct Drassura	(bar d)		1.65	590.5 11 34	203.2	33.09
48	Insulation Conductivity	(W/m-K)	6.826e	-002 *	8,439e-002 *	6.350e-002 '	4.856e-002 *
49	Insulation Thickness	(m)	0.1	016	0.1016	0.1016	0.1016
50	Name		PIPE-HV-02 to Com	P I	PIPE-HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-0
51	Feed Temperature	(C)	1	9.97	20.00 *	6.664	17.78
52	Feed Pressure	(bar_g)	1	0.86	11.03	3.835	3.726
53	Product Temperature	(C)	1	9.94	19.97	6.667 '	17.78
54	Product Pressure	(bar_g)	1	002 *	10.87	3.987 *	3.502
56	Insulation Conductivity	(w/m-K) (m)	4.7010	002	4.702002	3.2540-002	3.810-002
57 58 59 60 61 62							
	Annual Tradition 1			1.0.000	1011-1-0		P 4 4 7

1				Case Name: detailed Ini test bed 250kw n2 v2.hsc					
3	(aspentech	Bedford, MA	DAHO	Unit Set:	MAGNET				
4		USA		Date/Time:	Wed Jun 03 14	:20:34 2020			
6									
7	Wor	kbook: Ca	ase (Main) (contin	ued)				
9			Pipe Se	gments (o	ontinued)	Fluid	Pkg: All		
11	Name		PIPE-CWR-HV-002 to	Chil PIPE	-CWS-Chiller to HV-D	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03		
12	Feed Temperature	(C)	17.	78	6.662	33.09	33.28		
13	Feed Pressure	(bar_g)	3.8	22	4.187	11.79	12.20		
14	Product Temperature	(C)	17.	78	6.662	33.08	33.21		
15	Product Pressure	(bar_g)	3.3280.0	20	4.100	4 8550,002 +	4 8570-002		
10	Insulation Thickness	(wini-K) (m)	3.810=0	02	3.810e-002	4.0000-002	4.0576-002		
18	Name	(11)	PIPE-CWR-Outside V	Vali to PIPE-	CWR-HV-004 to Out	PIPE-CWS-HV-001 to Out	PIPE-CWS-Outside Wall		
19	Feed Temperature	(C)	17.	78	17.78	6.662	6.664		
20	Feed Pressure	(bar_g)	3.5	00	3.496	4.183	3.838		
21	Product Temperature	(C)	17.	78	17.78	6.664	6.664		
22	Product Pressure	(bar_g)	3.4	96	3.824	3.838	3.837		
23	Insulation Conductivity	(W/m-K)	3.328e-0	02 *	3.328e-002 *	3.254e-002 *	3.254e-002		
24	Insulation Thickness	(m)	3.810e-0	02	3.810e-002	3.810e-002	3.810e-002		
27 28 29 30 31 32 33 44 55 65 7 83 9 40 41 42 43 44 54 47 48 9 55 55 55 55 55 55 55 56 50 50 50 50 50 50 50 50 50 50 50 50 50									

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" Specified by user.

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Helium Operating at 600°C and 250 kW of Heat Pipe Power



1	1 LINIVERSITY OF IDAHO			Case	Name: detailed ini te	st bed 250kw He v2.hsc	
3	@aspentech	Bedford, MA	DANO	Unit S	Set: MAGNET		
4 5		USA		Date/	Time: Wed Jun 03 1	4:22:25 2020	
6 7	Work	khook: Ca	se (Main)				
8			ise (main)				
9 10			M	lateri	al Streams	Flui	d Pkg: All
11	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out
12	Temperature	(C)	2	14.7	17.78	6.667 *	20.00 *
13	Pressure Macs Flow	(bar_g)	1	1.19	3.726	3.987	11.08
15	Mass Density	(kq/s) (kq/m3)	1	2035	1068	1077	1.985
16	Mass Enthalpy	(kJ/kg)	9	85.5	-1.207e+004	-1.210e+004	-26.82
17	Mass Entropy	(kJ/kg-C)	1	8.40	0.5631	0.4282	15.77
18	Name		RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
19	Temperature	(C)	3	4.32	452.4	451.7	634.3 '
20	Pressure	(bar_g)	1	1.78	11.67	11.65	11.40 *
21	Mass Flow	(kg/s)	0.0	2635	0.2635	0.2635	0.2635
22	Mass Density Mass Esthalow	(Kg/m3)	2	7.61	0.8409	0.8406	0.6583
24	Mass Entrany Mass Entrany	(kJ/kg-C)		5.90	2221	2217	21.59
25	Name	(normg-c)	RHX-01 Hot In	0.50	RHX-01 Hot Out	Comp In	6
26	Temperature	(C)	6	33.0	214.8	20.01	20.00
27	Pressure	(bar_g)	1	1.36	11.19	• 10.90	10.98
28	Mass Flow	(kg/s)	0.3	2635	0.2635	0.2635 *	0.2635
29	Mass Density	(kg/m3)	0.6	5573	1.204	1.956	1.969
30	Mass Enthalpy	(kJ/kg)		3160	986.2	-26.78	-26.79
31	Mass Entropy	(KJ/Kg-C)	Chiller In	1.59	Chiller Out	15.80	15.79 CWR-01
33	Temperature	(C)	1	7.78	6.658	6.663	17.78
34	Pressure	(bar_g)	3	.818	3.721	3.844	3.500
35	Mass Flow	(kg/s)	6	.937	6.937	6.937	6.937
36	Mass Density	(kg/m3)	1	1068	1077	1077	1068
37	Mass Enthalpy	(kJ/kq)	-1.207e	+004	-1.210e+004	-1.210e+004	-1.207e+004
38	Mass Entropy	(KJ/Kg-C)	CWP.05	5631	0.4281 CWP-03	0.4282	0.5531 CWR-02
39 40	Temperature	(C)	1	7.78	17.78	17.78	6 661
41	Pressure	(barg)	3	.820	3.494	3.498	4.192
42	Mass Flow	(kg/s)	6	.937	6.937	6.937	6.937
43	Mass Density	(kg/m3)		1068	1068	1068	1077
44	Mass Enthalpy	(kJ/kg)	-1.207e+	+004	-1.207e+004	-1.207e+004	-1.210e+004
45	Mass Entropy	(kJ/kg-C)	0.5	5631	0.5631	0.5631	0.4281
46	Name	(0)	CWS-03	661	CWS-06 6.664	3/ 30	34 32
48	Pressure	(bar o)	4	.190	3,837	11.88	11.78
49	Mass Flow	(kq/s)	6	.937	6.937	0.2635	0.2635
50	Mass Density	(kg/m3)	1	1077	1077	2.018	2.003
51	Mass Enthalpy	(kJ/kg)	-1.210e	+004	-1.210e+004	47.97	47.64
52	Mass Entropy	(kJ/kg-C)	0.4	4281	0.4282	15.89	15.90
53	Name	100	15	4 3 9	16	Comp Out	4-2
55	Pressure	(C) (bar o)	3	1.78	20.00	12 03 *	34.39
56	Mass Flow	(kg/s)	0.3	2635	0.2635	0.2635	0.2635
57	Mass Density	(kg/m3)	2	.003	1.968	2.041	2.018
58	Mass Enthalpy	(kJ/kg)	4	7.64	-26.79	48.01	47.97
59	Mass Entropy	(kJ/kg-C)	1	5.90	15.79	15.86	15.89
60 61 62							
63	Aspen Technology Inc.		Asp	en HY	SYS Version 9		Page 1 of 5

1	LINIVERSITY OF		Case	Name: d	etailed ini test	bed 250kw He v2.hsc	
3	@aspentech Bedford, MA	IDAHO	Unit	Set: N	IAGNET		
4	USA		Date	Time: W	/ed Jun 03 14:	22:25 2020	
6	Warkhaak. C	ana (Main)	1		n.		
8	WORKDOOK: C	ase (Main)	(CO	ntinued)		
9		Materia	al Stre	ams (conti	nued)	Flui	d Pkg: All
10	Name	CWS-01		Heat Pipe Ev	aporator	Heat Pipe Condensor	CWR-04
12	Temperature (C)		6.661		650.0 *	650.0	17.78
13	Pressure (bar_g)		4.194		-0.9475	-0.9475	3.822
14	Mass Flow (kq/s)		6.937		6.082e-002	6.082e-002	6.937
15	Mass Density (Kg/m3)	1 2100	1077		1.9726-002	/99.6	1068
15	Mass Entropy (KJ/Kg) Mass Entropy (kJ/Kg_C)	-1.2100	4281		58.21	-5902	-1.20/04
18	Name (Norigital)	CWS-05	4201		00.21	00.05	0.0001
19	Temperature (C)	0.000	6.664				
20	Pressure (bar_g)		3.840				
21	Mass Flow (kg/s)	(6.937				
22	Mass Density (kg/m3)		1077				
23	Mass Enthalpy (kJ/kg)	-1.210e	+004				
24	Mass Entropy (kJ/kg-C)	0.	4282				
25			Com	positions		Flui	d Pkg: All
26 27	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out
28	Master Comp Mass Frac (Hellum)	1	0000				1.0000
29	Master Comp Mass Frac (H2O)	1	•••		0.5539	0.5539	
30	Master Comp Mass Frac (EGlycol)		•••		0.4461	0.4461	
31	Master Comp Mass Frac (Sodium*)						
32	Name	RHX-01 Cold In		RHX-01 Cold	Out	Vacuum Chamber In	Vacuum Chamber Out
33	Master Comp Mass Frac (Hellum)	1.	0000		1.0000	1.0000	1.0000
34	Master Comp Mass Frac (H2O)						
35	Master Comp Mass Frac (EGlycol)						
37	Name	RHX-01 Hot In		RHX-01 Hot	Out	Como In	6
38	Master Comp Mass Frac (Hellum)	1.	0000	THE OTHER	1.0000	1.0000 *	1.0000
39	Master Comp Mass Frac (H2O)						
40	Master Comp Mass Frac (EGlycol)						
41	Master Comp Mass Frac (Sodium*)						
42	Name	Chiller In		Chiller Out		CWS-04	CWR-01
43	Master Comp Mass Frac (Hellum)						
44 45	Master Comp Mass Frac (H2O)	0.	5539 *		0.5539	0.5539	0.5539
45	Master Comp Mass Frac (Sodium*)	0.			0.4461	0.4461	U.4461
47	Name	CWR-05		CWR-03		CWR-02	CWS-02
48	Master Comp Mass Frac (Hellum)		•••				
49	Master Comp Mass Frac (H2O)	0.	5539		0.5539	0.5539	0.5539
50	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461	0.4461	0.4461
51	Master Comp Mass Frac (Sodium*)						
52	Name	CWS-03		CWS-06		13	14
53 54	Master Comp Mass Frac (Heilum)		5570		0.5530	1.0000	1.0000
55	Master Comp Mass Frac (EG/vcol)	0	4461		0.4461		
56	Master Comp Mass Frac (Sodium*)						
57	Name	15		16		Comp Out	4-2
58	Master Comp Mass Frac (Hellum)	1	0000		1.0000	1.0000	1.0000
59	Master Comp Mass Frac (H2O)		•••		•••		
60	Master Comp Mass Frac (EGlycol)						
61	Master Comp Mass Frac (Sodium*)						
62	Asnen Technology Inc.	Are		SVS Version	0		Page 2 of 5
03	Licensed to: UNIVERSITY OF IDAHO	Asc	en n'i	or o version	0		*ade 2 of 5 *Specified by user.

1			Case I	Name: detailed ini test	bed 250kw He v2.hsc	
2	(easpentech UNIVERSITY OF Bedford, MA	FIDAHO	Unit S	et: MAGNET		
4	USA		Date/T	Time: Wed Jun 03 14	:22:25 2020	
6						
7 8	Workbook: C	ase (Main) (cor	ntinued)		
9		Compo	sitio	ns (continued)	Fluid	Pkg: All
10	Name	CWS-01		Heat Pine Evaporator	Heat Pine Condensor	CWR-04
12	Master Comp Mass Frac (Hellum)	00001		meat Pipe Evaporator	meat Pipe Condensor	
13	Master Comp Mass Frac (H2O)	0.55	39			0.5539
14	Master Comp Mass Frac (EGlycol)	0.44	61		•••	0.4461
15	Master Comp Mass Frac (Sodium*)			1.0000 *	1.0000	
16	Name	CWS-05				
17	Master Comp Mass Frac (Hellum)					
18	Master Comp Mass Frac (H2O)	0.55	39			
19	Master Comp Mass Frac (EGlycol)	0.44	61			
20	Master Comp Mass Frac (Sodium)					
22		En	nergy	/ Streams	Fluid	Pkg: All
23	Name	PIPE-RHX-01 Cold Or	ut He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 Heat
24	Heat Flow (kW)	0.94	76	1.761	0.1839	8.814e-002
25	Name	PIPE-HX-01 Hot Heat	t	PIPE-HV-02 Heat	Comp Power	Chiller Duty
26	Heat Flow (kW)	-6.666e-0	03	-6.401e-004	19.71	267.2
27	Name	PIPE-CWS-06 Heat		PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	PIPE-CWR-Heat
28	Heat Flow (KW)	-2.866e-0	02	-2.032e-002	-6.129e-003	-7.043e-003
29	Name	PIPE-CWR-05 Heat		PIPE-CWS-01 Heat	PIPE-HV-01 Heat	PIPE-Comp Heat
30	Heat Flow (kW)	-2.427e-0	03	-1.032e-002	6.604e-003	1.057e-002
31	Name (MAR)	Chiller Pump Power	-	Electric Heater Power	PIPE-CWR-03 Heat	PIPE-CWS-04 Heat
33	neat now (kw)	0.40	04	250.0	-4.0346-003	-2.0000-002
34			He	aters	Fluid	Pkg: All
35	Name	Electric Heaters				
36	DUTY (KW)	250	0.0			
37	Feed Temperature (C)	650	0.0			
38	Product Temperature (C)	650	0.0 *			
39	Mass Flow (kg/s)	6.082e-0	02			
40			Co	olers	Fluid	Pkg: All
42	Name	Chiller				
43	DUTY (kW)	267	7.2			
44	Feed Temperature (C)	17.	.78			
45	Product Temperature (C)	6.6	58			
46	Mass Flow (kg/s)	6.9	37			
47 48		Hea	at Ex	cchangers	Fluid	Pkg: All
49	Name	RHX-01		Chiller HX-01	Vacuum Chamber	
50	Duty (KW)	572	2.6	266.7	250.0	
51	Tube Side Feed Mass Flow (kg/s)	0.26	35	0.2635	6.082e-002	
52	Shell Side Feed Mass Flow (kg/s)	0.26	35	6.937 *	0.2635	
53	Tube Inlet Temperature (C)	633	3.0	214.7	650.0 *	
54 65	Tube Outlet Temperature (C)	214	4.8 *	20.00 *	650.0	
55	Shell Outlet Temperature (C)	34.	24	0.00/ 17.79	401.7	
57	LMTD (C)	402	0.6	125.7	72.02	
58	UA (W/C)	31	71	0.0000	3471	
59	Minimum Approach (C)	180	0.5	125.7	15.71	
60						
61						
62						
63	Aspen Technology Inc.	Aspen	n HYS	SYS Version 9		Page 3 of 5
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1	UNIVERSITY OF IDAHO			se Name: detailed ini	test bed 250kw He v2.hsc	
3	(aspentech	UNIVERSITY OF Bedford, MA	IDAHO Ur	It Set: MAGNET		
4		USA	Da	te/Time: Wed Jun 0	3 14:22:25 2020	
6 7 8	Worl	kbook: Ca	ase (Main) (c	ontinued)		
9				Pumps	Flui	d Pkg: All
11	Name		Chiller Pump			
12	Power	(kW)	0.4054			
13	Feed Pressure	(bar_g)	3.721			
14	Product Pressure	(bar q)	4.194			
15	Product Temperature	(C)	6.661			
16	Feed Temperature	(C)	6.658			
17	Adiabatic Efficiency	(%)	75.00			
18	Mass Flow	(ka/s)	6.937			
20		(1910)	0.50			
21			Co	mpressors	Flui	d Pkg: All
22	Name		Comp-01			
23	Power	(KW)	19.71			
24	Feed Pressure	(bar_g)	10.90			
25	Product Pressure	(bar q)	12.03	•		
26	Product Temperature	(C)	34.40			
27	Adjabatic Efficiency	(0)	20.01	•		
20	Pressure Ratio		1.095			
30	Mass Flow	(kg/s)	0.2635	•		
31			-			
32			E	xpanders	Fiu	a Pilg: Ali
33	Name					
34	Power	(kW)				
35	Peed Pressure	(bar_g)				
37	Product Pressure	(bal_g) (C)				
38	Feed Temperature	(C)				
39	Adiabatic Efficiency					
40	Mass Flow	(kg/s)				
41			Pip	Segments	Flui	d Pkg: All
42	Mana		DIDE Only Out DUX DA	DIDE Hat Is Vasure Of	DIDE List Out DUV 04 to 1	
43	Feed Temperature	(C)	PIPE-Cold Out-RHX-01 452.4	634	3 * 214.8 *	24.39
45	Feed Pressure	(bar q)	11.67	114	0 11.19	11.88
46	Product Temperature	(C)	451.7	633	0 214.7	34.32
47	Product Pressure	(bar_g)	11.65	11.3	6 11.19	11.78
48	Insulation Conductivity	(W/m-K)	7.438e-002	* 8.680e-00	2 * 5.927e-002 *	4.863e-002 *
49	Insulation Thickness	(m)	0.1016	0.101	6 0.1016	0.1016
50	Name		PIPE-HV-02 to Comp	PIPE-HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-0
51	Feed Temperature	(C)	20.00	20.0	0 0.664	17.78
52	Pred Plessure Droduct Temperature	(bal_g)	20.01	20.0	0 3.037	3.720
54	Product Pressure	(bar g)	10.90	10.9	8 3.987 *	3.500
55	Insulation Conductivity	(W/m-K)	4.782e-002	* 4.782e-00	2 * 3.254e-002 *	3.328e-002 *
56	Insulation Thickness	(m)	0.1016	0.101	6 3.810e-002	3.810e-002
57 58 59 60 61 62						
63	Aspen Technology Inc.		Aspen I	TYSYS Version 9		Page 4 of 5

1	1		Case	Case Name: detailed ini test bed 250kw He v2.hsc				
3	(aspentech	UNIVERSITY OF Bedford, MA	DAHO	Unit S	Set: MAGNET			
4	USA			Date/Time: Wed Jun 03 14:22:25 2020				
6	Maria 1	like alter Or	(Main)		u time all			
8	vvor	KDOOK: Ca	ase (main)	(co	ntinuea)			
9 10			Pipe S	egme	ents (continued)	Fluid	d Pkg: All	
11	Name		PIPE-CWR-HV-002	to Chil	PIPE-CWS-Chiller to HV-	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03	
12	Feed Temperature	(C)	1	17.78	6.661	34.32	34.40	
13	Feed Pressure	(bar_g)		3.820	4.194	11.78	12.03 "	
14	Product Temperature	(C)	1	17.78	6.661	34.32	34.39	
15	Product Pressure	(bar_g)		3.818	4.192	11.78	11.88	
16	Insulation Conductivity	(W/m-K)	3.3286	+002 ·	3.254e-002	4.863e-002	4.863e-002 *	
17	Insulation Thickness	(m)	3.8106	+002	3.810e-002	0.1016	0.1016	
18	Name Eacd Tomporature	(***	PIPE-CWS-HV-001		PIPE-CWS-Outside Wall	PIPE-CWR-HV-004 to Out	PIPE-CWR-Outside Wall 1	
20	Feed Temperature	(C) (bar d)		1 100	3.844	3,498	3.494	
21	Product Temperature	(bal_g) (C)		5.663	5.644	17.78	17.78	
22	Product Pressure	(bar g)		3 844	3.840	3.494	3.822	
23	Insulation Conductivity	(W/m-K)	3.2546	-002 *	3.254e-002	3.328e-002 *	3.328e-002 *	
24	Insulation Thickness	(m)	3.8106	+002	3.810e-002	3.810e-002	3.810e-002	
25						•	•	
26								
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62	Asnen Technology Inc.		Aco	en HV	SVS Version 0		Page 5 of 5	
0.5	Aspen recondicavinc.		ASD	el Dî	STS VEISION 8		Page 5 of 5	

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* Specified by user.

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Nitrogen Operating at 600°C and 75 kW of Heat Pipe Power



1		c	ase Name: detailed ini tes	st bed 75kw n2 v2.hsc	
3	(aspentech Bedford, MA	F IDAHO U	Init Set: MAGNET		
4	USA		ate/Time: Wed Jun 03 1	4:25:51 2020	
6 7	Workbook: C	ase (Main)			
9		Mat	erial Streams	Flui	d Pikg: All
10 11	Name	HX-01 Hot In	CWR	CWS	HX-01 Hot Out
12	Temperature (C)	232	1 17.78	6.667 *	20.00 *
13	Pressure (bar_g)	11.3	6 3.726	3.987 *	11.25
14	Mass Flow (kg/s)	0.325	3 1.923	1.923 *	0.3253
15	Mass Density (kg/m3)	8.21	9 1068	1077	14.17
16	Mass Entrapy (KJ/Kg) Mass Entrapy (KJ/Kg/C)	218	8 -1.20/04	-1.2100+004	-8.614
17	Name (KJ/Kg=C)	BHX-01 Cold In	BHX-01 Cold Out	Vacuum Chamber In	4.519 Vacuum Chamber Out
19	Temperature (C)	24.5	6 394.4	392.2	596.7 *
20	Pressure (bar_g)	11.6	7 11.65	11.65	11.40 *
21	Mass Flow (kg/s)	0.325	3 0.3253	0.3253	0.3253
22	Mass Density (kg/m3)	14.4	3 6.366	6.384	4.790
23	Mass Enthalpy (kJ/kg)	-3.87	3 397.0	394.6	625.2
24	Mass Entropy (kJ/kg-C)	4.52	5 5.398	5.394	5.702
25	Name (C)	RHX-01 Hot In	RHX-01 Hot Out	Comp In 00.00	0.00
20	Pressure (bar o)	11.3	9 11.35	11.21	11.23
28	Mass Flow (kg/s)	0.325	3 0.3253	0.3253 *	0.3253
29	Mass Density (kg/m3)	4.81	1 8.211	14.13	14.14
30	Mass Enthalpy (kJ/kg)	620	3 219.4	-8.579	-8.587
31	Mass Entropy (kJ/kg-C)	5.69	7 5.100	4.520	4.519
32	Name	Chiller In	Chiller Out	CWS-04	CWR-01
33	Temperature (C)	17.7	8 6.654	6.662	17.78
34	Mass Flow (kn/s)	3.03	3 1023	1.023	3.520
36	Mass Density (kg/m3)	106	8 1077	1077	1068
37	Mass Enthalpy (kJ/kg)	-1.207e+00	4 -1.210e+004	-1.210e+004	-1.207e+004
38	Mass Entropy (kJ/kg-C)	0.563	1 0.4281	0.4282	0.5631
39	Name	CWR-05	CWR-03	CWR-02	CWS-02
40	Temperature (C)	17.7	8 17.78	17.78	6.658
41	Pressure (bar_g)	3.86	0 3.525	3.526	4.131
43	Mass Density (kg/s)	1.92	3 1.923	1.923	1.923
44	Mass Enthalpy (kJ/kg)	-1.207e+00	4 -1.207e+004	-1.207e+004	-1.210e+004
45	Mass Entropy (kJ/kg-C)	0.563	1 0.5631	0.5631	0.4281
46	Name	CWS-03	CWS-06	13	14
47	Temperature (C)	6.65	8 6.663	24.64	24.57
48	Pressure (bar q)	4.13	1 3.792	11.69	11.67
49 50	Mass Flow (kg/s) Mass Density //com31	1.92	7 1.923	0.3253	0.3253
51	Mass Enthaloy (kg/ma)	-1.210e+00	4 -1.210e+004	-3,800	-3,858
52	Mass Entropy (kJ/kq-C)	0.428	1 0.4282	4.525	4.525
53	Name	15	16	Comp Out	4-2
54	Temperature (C)	24.5	7 20.02	24.66	24.64
55	Pressure (bar_g)	11.6	7 11.23	11.73 *	11.70
56	Mass Flow (kg/s)	0.325	3 0.3253	0.3253	0.3253
57 50	Mass Density (kg/m3)	14.4	3 14.14	14.49	14.45
59	Mass Entropy (KJ/Kg) Mass Entropy (k J/kg/C)	-3.86	5 4 510	-3.768	-3.000
60 61 62					
63	Aspen Technology Inc.	Aspen	HYSYS Version 9		Page 1 of 5
	LICEDSED IN: UNIVERSITY OF IDAHO				STREETING IN USER

1			Case	Name: de	stalled ini test	bed 75kw n2 v2.hs	c	
3	(aspentech Bedford, MA	IDAHO	Unit S	Set: M	AGNET			
4	USA		Date/	Time: W	ed Jun 03 14	:25:51 2020		
6								
7 8	WORKDOOK: C	ase (Main)	(coi	ntinued)			
9		Materia	al Stre	ams (contir	nued)		Fluid	1 Pkg: All
10 11	Name CWS-01			Heat Pipe Eva	aporator	Heat Pipe Conde	nsor	CWS-05
12	Temperature (C)		6.657		650.0 *		650.0	6.663
13	Pressure (bar_g)		4.131		-0.9475		-0.9475	3.792
14	Mass Flow (kq/s)		1.923	1	.825e-002	1.82	5e-002	1.923
15	Mass Density (kg/m3)		1077	1	.972e-002		799.6	1077
16	Mass Enthalpy (kJ/kg)	-1.210e	+004		-1791		-5902	-1.210e+004
17	Mass Entropy (kJ/kg-C)	0.	4281		58.21		53.39	0.4282
18	Name	CWR-04						
19	Temperature (C)		17.78					
20	Pressure (bar_g)		3.860					
21	Mass Flow (Kg/s)		1.923					
72	Mass Density (Agritis)	1 2070	1000					
24	Mass Entrony (k (kn-C)	-1.2076	5631					
25	(Norkgro)		0001					
26			Comp	positions			Fluid	1 Pkg: All
27	Name	HX-01 Hot In		CWR		CWS		HX-01 Hot Out
28	Master Comp Mass Frac (Ntrogen)	1.	0000 -					1.0000
29	Master Comp Mass Frac (H2O)				0.5539		0.5539	
30	Master Comp Mass Frac (EGlycol)				0.4461		0.4461	
31	Master Comp Mass Frac (Sodium*)							
32	Name	RHX-01 Cold In		RHX-01 Cold	Out	Vacuum Chambe	erin	Vacuum Chamber Out
33	Master Comp Mass Frac (Nitrogen)	1.	0000		1.0000		1.0000	1.0000
34	Master Comp Mass Frac (H2O)							
35	Master Comp Mass Frac (EGlycol)							
36	Master Comp Mass Frac (Sodium*)	DUN DI Uni In		DUD OF USE		On ma la		
30	Master Comp Mass Frac (Ntrogen)	1	0000	RHA-01 HOLD	1 0000	Comp in	1 0000 -	1 0000
39	Master Comp Mass Frac (H2O)							
40	Master Comp Mass Frac (EGlycol)							
41	Master Comp Mass Frac (Sodium*)							
42	Name	Chiller In		Chiller Out		CWS-04		CWR-01
43	Master Comp Mass Frac (Nitrogen)							
44	Master Comp Mass Frac (H2O)	0.	5539 *		0.5539		0.5539	0.5539
45	Master Comp Mass Frac (EGlycol)	0.	4461 *		0.4461		0.4461	0.4461
46	Master Comp Mass Frac (Sodium")							
47	Name	CWR-05		CWR-03		CWR-02		CWS-02
48	Master Comp Mass Frac (Nitrogen)	-						
49	Master Comp Mass Frac (H2O)	0.	5539		0.5539		0.5539	0.5539
50	Master Comp Mass Frac (Ediyodi)	U.			0.4401		0.4401	0.4401
57	Name	CWS-03		CWS-06		13		14
53	Master Comp Mass Frac (Nitrogen)	0.000		0.110 0.0			1.0000	1.0000
54	Master Comp Mass Frac (H2O)	0.	5539		0.5539			
55	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461			
56	Master Comp Mass Frac (Sodium*)							•••
57	Name	15		16		Comp Out		4-2
58	Master Comp Mass Frac (Nitrogen)	1	0000		1.0000		1.0000	1.0000
59	Master Comp Mass Frac (H2O)							
60	Master Comp Mass Frac (EGlycol)							
61	Master Comp Mass Frac (Sodium*)							
62	Anne Technology (1.02	eve v	0			D A C
63	Aspen Technology Inc.	Asc	en HY	SYS Version	8			Page 2 of 5

1			Case Name: detailed ini test bed 75kw n2 v2.hsc							
2	(Decementach UNIVERSITY OF	IDAHO								
3	USA Bedford, MA		Jhit Set: MAGNET							
5		C	Date/Time: Wed Jun 03 14	:25:51 2020						
6	Warkheak: C	ana (Main) (ontinued)							
8	WORKDOOK. C	ase (Main) (G	continuea)							
9		Compos	sitions (continued)	Fluir	1 Pka: All					
10		compos	iter Star	Hard Star Gradeness						
11	Name Master Comp Mass Frac (Ntrogen)	CWS-01	Heat Pipe Evaporator	Heat Pipe Condensor	CWS-05					
13	Master Comp Mass Frac (H2O)	0.55	39		0.5539					
14	Master Comp Mass Frac (EGlycol)	0.44	51 ***		0.4461					
15	Master Comp Mass Frac (Sodium*)		1.0000 *	1.0000						
16	Name	CWR-04								
17	Master Comp Mass Frac (Ntrogen)	0.55	20							
18	Master Comp Mass Frac (F2O)	0.55	51							
20	Master Comp Mass Frac (Sodium*)	0.44								
21		-		-						
22		En	ergy Streams	Fluid	1 PKg: Ali					
23	Name	PIPE-RHX-01 Cold Ou	t He PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 Heat					
24	Heat Flow (kW)	0.77	56 1.593	0.2026	2.286e-002					
25	Name	PIPE-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power	Chiller Duty					
26	Heat Flow (KVV)	-6.621e-00 DIDE-CWS-06 Heat	DIDE-CWS-03 Heat	DIDE-CWR-02 Heat	/4.14 DIDE-CWR-Heat					
28	Heat Flow (KW)	-2.901e-0	-2.076e-002	-6.114e-003	-7.175e-003					
29	Name	PIPE-CWR-05 Heat	PIPE-CWS-01 Heat	PIPE-HV-01 Heat	PIPE-Comp Heat					
30	Heat Flow (kW)	-2.421e-0	03 -1.031e-002	1.703e-003	2.778e-003					
31	Name	Chiller Pump Power	Electric Heater Power	PIPE-CWS-04 Heat	PIPE-CWR-03 Heat					
32	Heat Flow (kW)	8.799e-0	02 75.00	-4.033e-003	-4.604e-003					
33			Heaters	Fluid	1 Pkg: All					
35	Name	Electric Heaters								
36	DUTY (kW)	75.0	00							
37	Feed Temperature (C)	650	.0							
38	Product Temperature (C)	650	.0 *							
39	Mass Flow (kg/s)	1.825 e -0	02							
40		3 Mass Fluw (Kg/s) 1.0250-002								
			Coolers	Fluid	d Pkg: All					
42	Name	Chiller	Coolers	Fluid	d Pkg: All					
42 43	Name DUTY (KW)	Chiller 74.	Coolers	Fluid	1 Pkg: Ali					
42 43 44	Name DUTY (KW) Feed Temperature (C)	Chiller 74.	Coolers	Fluid	d Pkg: All					
42 43 44	Name DUTY (KW) Feed Temperature (C) Product Temperature (C)	Chiller 74. 17.1 6.61	Coolers	Fluid	d Pkg: Ali					
42 43 44 45 46	Name DUTY (kW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s)	Chiller 74. 17. 6.6 1.90	Coolers 14 78 54 23	Fluid	I Pkg: Ali					
42 43 44 45 45 47 48	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s)	Chiller 74. 17. 6.63 1.93 Hea	Coolers 14 78 54 23 at Exchangers	Fluid	1 Pkg: Ali					
42 43 44 45 45 47 48 49	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chilier 74. 17. 6.6 1.9 Hea RHX-01	Coolers 14 78 54 23 at Exchangers Chiller HX-01	Fluid	d Pkg: All					
42 43 44 45 45 47 48 49 50	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name Duty (KW)	Chilier 74. 17. 6.64 1.92 Hea RHX-01 130	Coolers 14 78 54 23 at Exchangers Chiller HX-01 14 73.97	Fluid Fluid Fluid Vacuum Chamber 75.00	d Pkg: All					
42 43 44 45 46 47 48 49 50 51	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chiller 74. 17. 6.64 1.92 He a RHX-01 130 0.325	Coolers	Fluic Fluic Vacuum Chamber 75.00 1.825e-002	d Pkg: All					
42 43 44 45 46 47 48 49 50 51 52 52	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name Duty Duty (kW) Tube Side Feed Mass Flow (kg/s) Shell Side Feed Mass Flow (kg/s)	Chillier 74. 17. 6.6 1.9 He : RHX-01 130 0.32 0.32	Coolers 14 78 54 23 at Exchangers Chiler HX-01 1.4 73.97 53 0.3253 1.923 .4 .4 .4 .4 .4 .4 .4 .4 .4 .	Fluic Fluic Vacuum Chamber 75.00 1.825e-002 0.3253	1 Pkg: All					
42 43 44 45 45 45 45 48 49 50 51 52 53 52 53	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name Duty Duty (kW) Tube Side Feed Mass Flow (kg/s) Shell Side Feed Mass Flow (kg/s) Tube United Temperature (C)	Chillier 74. 17. 6.6 1.9 He: RHX-01 0.32 0.32 0.32 0.32	Coolers	Fluic Fluic Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 *	1 Pkg: All					
42 43 44 45 45 45 47 48 49 50 51 52 53 54 55	Name DUTY (kW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name Duty Duty (kW) Tube Side Feed Mass Flow (kg/s) Shell Side Feed Mass Flow (kg/s) Tube Inlet Temperature (C) Tube Outlet Temperature (C)	Chillier 74. 17. 6.6 1.9 He : RHX-01 130 0.32 0.32 592 233 234	Coolers	Fluic Fluic Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 392 2	1 Pkg: All					
42 43 44 45 45 47 48 49 50 51 52 53 54 55 55	Name DUTY (kW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name 0 Duty (kW) Tube Side Feed Mass Flow (kg/s) Shell Side Feed Mass Flow (kg/s) Tube Inlet Temperature (C) Tube Outlet Temperature (C) Shell Inlet Temperature (C) Shell Outlet Temperature (C)	Chillier 74. 17. 6.6 1.9 He : RHX-01 130 0.32 0.32 592 232 232 24 394	Coolers	Fluic Fluic Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 392.2 596.7 °	1 Pkg: All					
42 43 44 45 45 45 45 45 50 51 52 53 55 55 55 55 57	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chillier 74. 17. 6.6 1.9 He : RHX-01 130 0.32 0.32 0.32 232 232 233 24. 394 203	Coolers	Fluid Fluid Vacuum Chamber Vacuum Chamber 0.3253 650.0 ° 650.0 ° 650.0 392.2 596.7 ° 129.3	1 Pkg: All					
42 43 44 45 45 45 47 48 49 50 51 52 53 54 55 55 55 57 58	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chillier 74.: 17.: 6.6: 1.9: He : RHX-01 130 0.32: 0.32: 0.32: 592 233 24.: 394 203 24.: 394 203 641	Coolers	Fluid Fluid Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 ° 650.0 392.2 596.7 ° 129.3 580.2	1 Pkg: All					
42 43 44 45 45 45 47 48 49 50 51 52 53 54 55 55 55 55 55 55 55 55 55 55 55 55	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chillier 74.: 17.: 6.6: 1.9: He : RHX-01 130 0.32: 0.32: 0.32: 592 232 24.: 394 203 24.: 394 203 641 198	Coolers	Fluid Fluid Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 392.2 596.7 ° 129.3 580.2 53.29	I Pkg: All					
42 43 44 45 45 45 47 48 49 50 51 52 53 54 55 55 56 57 58 59 60 51	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chillier 74: 17: 6.6: 1.9: He : RHX-01 130 0.32: 0.32: 592 232 232 24: 394 203 641 198	Coolers	Fluid Fluid Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 ° 650.0 392.2 596.7 ° 129.3 580.2 53.29	1 Pkg: All					
42 43 44 45 46 47 48 49 50 51 52 53 54 55 55 57 58 59 60 61 62	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chiller 74. 17. 16.64 1.99 He a RHX-01 130 0.324 0.324 0.324 232 232 24. 394 203 641 198	Coolers	Fluid Fluid Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 ° 650.0 ° 129.3 596.7 ° 129.3 580.2 53.29	I Pkg: All					
42 43 44 45 45 46 47 48 49 50 51 52 53 54 55 55 55 55 57 58 59 60 61 62 63	Name DUTY (KW) Feed Temperature (C) Product Temperature (C) Mass Flow (kg/s) Name	Chillier 74.: 17.: 6.6: 1.9: He : RHX-01 130 0.32: 0.32: 592 232 24.: 24: 394 203 641 198	Coolers	Fluid Fluid Vacuum Chamber 75.00 1.825e-002 0.3253 650.0 ° 650.0 ° 650.0 392.2 596.7 ° 129.3 580.2 53.29	I Pkg: All					

1			Case Name:	detailed ini test	bed 75kw n2 v2.hsc				
3	(aspentech Bedford, MA	FIDAHO	Unit Set:	MAGNET					
4	USA		Date/Time:	Wed Jun 03 14	:25:51 2020				
6									
7 8	Workbook: (ase (Main)	(continued)						
9			Pumps		Fluid	Fluid Pkg: All			
10	Name	Chiller Pump	-						
12	Power (kW	8.799e	-002						
13	Feed Pressure (bar o	3	3.762						
14	Product Pressure (bar o	4	4.131						
15	Product Temperature (C	• •	5.657						
16	Feed Temperature (C	6	5.654						
17	Adiabatic Efficiency (%	7	75.00						
18	Pressure Ratio	1	1.077						
19	Mass Flow (kg/s	1	1.923						
20			Compresso	ors	Fluid	i Pkg: All			
22	Name	Comp-01							
23	Power (kW	1	1.558						
24	Feed Pressure (bar_g	1	11.21						
25	Product Pressure (bar g	1	11.73 *						
26	Product Temperature (C	2	24.66						
27	Feed Temperature (C) 2	20.02						
28	Adiabatic Efficiency		75 •						
29	Pressure Ratio	1	1.042						
30	Mass Flow (Kg/s	0.	3253 1						
32			Expander	5	Fluid	i Pkg: All			
33	Name								
34	Power (kW)							
	Eard Descenter (here a								
25	reed Pressure (bar_g								
36	Product Pressure (bar_g								
36 37 30	Pred Pressure (bar g Product Pressure (bar g Product Temperature (C								
36 37 38	Prede Pressure (bar g Product Pressure (bar g Product Temperature (C Feed Temperature (C Adiabatic Efficiency								
36 37 38 39 40	Preduct Pressure (bar g Product Pressure (bar g Product Temperature (C Feed Temperature (C Adiabatic Efficiency Mass Flow (kols								
35 36 37 38 39 40 41	Prede Pressure (bar g Product Pressure (bar g Product Temperature (C Feed Temperature (C Adiabatic Efficiency Mass Flow (kg/s								
36 37 38 39 40 41 42	Preduct Pressure (bar g Product Pressure (bar g Product Temperature (C Feed Temperature (C Adiabatic Efficiency Mass Flow (kg/s		Pipe Segme	nts	Fluid	1 Pkg: All			
36 37 38 39 40 41 42 43	Preduct Pressure (bar_g Product Pressure (bar_g Product Temperature (C Feed Temperature (C Adiabato Efficiency Mass Flow (kg/s Name	PIPE-Cold Out-RH2	Pipe Segme	nts Hot In-Vacum Cham	Fluid PIPE-Hot Out-RHX-01 to H	1 Pkg: All PIPE-HV-03 to HV-01			
36 37 38 39 40 41 42 43 44	Preduct Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name Feed Temperature (C	PIPE-Cold Out-RHD	Pipe Segme K-01 to PIPE-1 394.4	nts Hot In-Vacum Cham 596.7 *	Fluid PIPE-Hot Out-RHX-01 to H 232.7 *	1 Pkg: All PIPE-HV-03 to HV-01 24.64			
36 37 38 39 40 41 42 43 44 45	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (Feed Temperature Feed Temperature (C Feed Temperature (C Feed Temperature (C	PIPE-Cold Out-RH2	Pipe Segme K-01 to PIPE-1 394.4 11.65	nts Hot In-Vacum Cham 596.7 ° 11.40 °	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 *	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69			
35 36 37 38 39 40 41 42 43 44 45 45	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (kg/s) Feed Temperature (C Feed Temperature (C Feed Temperature (C Product Temperature (C Product Temperature (C Product Temperature (C	PIPE-Cold Out-RH)	Pipe Segme K-01 to PIPE-1 394.4 11.65	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57			
35 36 37 38 39 40 41 42 43 44 45 45 45 47 48	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (Pred Temperature) Feed Temperature (C Feed Temperature (C Product Temperature (Dar_g)	PIPE-Cold Out-RH) PIPE-Cold Out-RH) PIPE-Cold Out-RH)	Pipe Segme K-01 to PIPE-1 394.4 11.65 ' 392.2 11.65	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8 405 000 °	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1 11.36 5 034 opp.1	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67			
35 36 37 38 39 40 41 42 43 44 45 45 45 45 49	Preduct Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (kg/s) Feed Temperature (C Feed Temperature (C Feed Temperature (C Product Temperature (C Product Temperature (C Product Temperature (C Insulation Conductivity (Wim-K	PIPE-Cold Out-RHD	Pipe Segme K-01 to PIPE-1 394.4 11.65 ' 392.2 11.65 -002 '	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 °	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1015	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002			
35 36 37 38 39 40 41 42 43 44 45 45 45 49 50	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (kg/s) Product Temperature (C Feed Temperature (C Feed Temperature (C Product Temperature (C Product Temperature (C Insulation Conductivity (Wim-K Insulation Thickness (m	PIPE-Cold Out-RH2	Pipe Segme K-01 to PIPE-1 394.4 11.65 ' 392.2 11.65 +002 ' 1016 100 PIPE-1	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX-	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0			
35 36 37 38 39 40 41 42 43 44 45 45 45 45 50 51	Preduct Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (Kg/s) Mass Flow (kg/s) Product Temperature (C Feed Temperature (Dar_g) Product Temperature (C Insulation Conductivity (Wim-K Insulation Thickness (m Name (m Feed Temperature (C	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 1 1 1 1 1 1 1 1 1 1 1 1 1	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 1992.2 11.65 +002 ' 1016 -002 PIPE-1 20.02	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 °	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX- 6.663	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78			
35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Adiabatic Efficiency (C Mass Flow (kg/s) Name (C Feed Temperature (C Feed Temperature (C Product Efficiency (kg/s) Name (D Feed Temperature (C Product Temperature (C Product Temperature (C Insulation Conductivity (Wim-K Insulation Thickness (m Name (C Feed Temperature (C Product Temperature (Dar_g) Insulation Conductivity (Wim-K Insulation Thickness (m Name (C Feed Temperature (C Feed Temperature (C Feed Temperature (C Feed Temperature (Dar_g) Feed Temperature (Dar_g)	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-HV-02 to Con PIPE-HV-02 t	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 392.2 11.65 	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25	Fluid PIPE-Hot Out-RHX-01 to H 232.7 ° 11.36 ° 232.1 11.36 6.034e-002 ° 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726			
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Preduct Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (C Feed Temperature (C Product Temperature (C Pred Pressure (bar_g) Insulation Thickness (m Name (C Feed Pressure (bar_g) Product Temperature (C	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 1 1 1 1 1 1 1 1 1 1 1 1 1	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 1992.2 11.65 +002 ' 1016 -002 ' 1016 1017 1018 1018 1018 1018 1018 1018 1018	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25 20.02	Fluid PIPE-Hot Out-RHX-01 to H 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 *	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78			
36 37 38 39 40 41 42 43 44 45 45 46 47 48 50 51 52 53	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Adiabatic Efficiency (C Mass Flow (kg/s) Name (C Feed Temperature (C Feed Temperature (C Product Efficiency (kg/s) Name (bar_g) Product Temperature (C Product Temperature (C Product Pressure (bar_g) Insulation Conductivity (Wim-K) Insulation Thickness (m Name (C Feed Temperature (C Product Temperature (C Product Temperature (C Pred Temperature (C Product Temperature (C Product Temperature (Dar_g)	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-HV-02 to Con PIPE-HV-02 t	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 392.2 11.65 -002 ' 1016 -002 ' 1016 -002 ' 11.23 20.02 11.21	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25 20.02 11.23	Fluid PIPE-Hot Out-RHX-01 to H 232.7 ° 11.36 ° 232.1 11.36 6.034e-002 ° 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 ° 3.987 °	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78 3.526			
36 37 38 39 40 41 42 43 44 45 46 47 48 49 51 52 53 54	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Adiabatic Efficiency (C Mass Flow (kg/s) Name (C Feed Temperature (C Product Temperature (Dar_g) Insulation Conductivity (Wim-K Insulation Thickness (m Name (C Feed Pressure (Dar_g) Insulation Thickness (m Product Temperature (C Feed Pressure (Dar_g) Insulation Conductivity (Wim-K Insulation Conductivity (Wim-K Product Temperature (C Product Temperature (Dar_g) Insulation Conductivity (Wim-K	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-HV-02 to Con PIPE-HV-02 t	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 392.2 11.65 -002 ' 1016 -002 ' 11.23 20.02 11.21 +002 '	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25 20.02 11.23 4.782e-002 °	Fluid PIPE-Hot Out-RHX-01 to H 232.7 ° 11.36 ° 232.1 11.36 6.034e-002 ° 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 ° 3.987 ° 3.254e-002 °	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78 3.526 3.328e-002 *			
36 37 38 39 40 41 42 43 44 45 50 51 51 52 52 53 54 55 55 56	Prede Pressure (bar_g) Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg)s Mass Flow (kg)s Product Temperature (C Feed Temperature (C Product Temperature (C Prede Pressure (bar_g) Product Temperature (C Product Pressure (bar_g) Insulation Conductivity (Wim-K) Insulation Thickness (m) Name (C Pred Temperature (C Pred Temperature (C Pred Temperature (C Pred Temperature (C Product Temperature (Dar_g) Insulation Conductivity (Wim-K) Insulation Conductivity (Wim-K)	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-HV-02 to Corr	Pipe Segme (-01 to PIPE- 394.4 11.65 	nts Hot In-Vacum Cham 596.7 * 11.40 * 592.4 11.20 8.406e-002 * 0.1016 HX-01 to HV-02 20.00 * 11.25 20.02 11.23 4.782e-002 * 0.1016	Fluic PIPE-Hot Out-RHX-01 to F 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 * 3.987 * 3.254e-002 * 3.810e-002	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 ° 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78 3.526 3.328e-002 ° 3.810e-002			
36 37 38 39 40 41 42 43 44 45 51 52 53 54 55 57 58 59 60 61 62	Preduct Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Mass Flow (kg/s) Product Temperature (C Feed Temperature (C Feed Temperature (C Feed Temperature (C Feed Temperature (C Product Temperature (Dar_g) Insulation Conductivity (Wim-K Insulation Thickness (m Name (C Feed Pressure (Dar_g) Insulation Thickness (m Product Temperature (C Feed Pressure (Dar_g) Insulation Conductivity (Wim-K Insulation Conductivity (Wim-K Insulation Thickness (m	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 1 7.052e 0 PIPE-HV-02 to Com PIPE-HV-02 to Com 2 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 1092.2 11.65 -002 ' 1016 1016 11.23 20.02 11.21 -002 ' 1016 1016	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25 20.02 11.23 4.782e-002 ° 0.1016	Fluid PIPE-Hot Out-RHX-01 to F 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 * 3.987 * 3.254e-002 *	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78 3.526 3.328e-002 * 3.810e-002			
35 36 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 55 57 58 59 60 61 62 63	Product Pressure (bar_g) Product Temperature (C Feed Temperature (C Adiabatic Efficiency (kg/s) Name (C Feed Temperature (C Product Temperature (C Product Temperature (C Insulation Conductivity (Wim-K Insulation Thickness (m Name (D Product Temperature (C Feed Pressure (bar_g) Insulation Conductivity (Wim-K Insulation Conductivity (Wim-K Insulation Conductivity (Wim-K Insulation Thickness (m Aspen Technology Inc. (m	PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-Cold Out-RH2 PIPE-HV-02 to Con PIPE-HV-02 to Con PIPE-HV-02 to Con PIPE-HV-02 to Con Asso	Pipe Segme K-01 to PIPE-1 194.4 11.65 ' 1092.2 11.65 1016 1016 1017 1016 11.23 10.02 11.23 10.02 11.21 10.02 11.21 10.02 11.21 10.02 10.02 11.21 10.02 10.	nts Hot In-Vacum Cham 596.7 ° 11.40 ° 592.4 11.39 8.406e-002 ° 0.1016 HX-01 to HV-02 20.00 ° 11.25 20.02 11.23 4.782e-002 ° 0.1016	Fluid PIPE-Hot Out-RHX-01 to F 232.7 * 11.36 * 232.1 11.36 6.034e-002 * 0.1016 PIPE-CWS-HV-003 to HX- 6.663 3.792 6.667 * 3.987 * 3.254e-002 *	1 Pkg: All PIPE-HV-03 to HV-01 24.64 11.69 24.57 11.67 4.808e-002 * 0.1016 PIPE-CWR-HX-01 to HV-0 17.78 3.726 17.78 3.526 3.328e-002 * 3.810e-002			

1			Car	se Name: detailed ini test	bed 75kw n2 v2.hsc	
3	(aspentech	Bedford, MA	Uni	t Set: MAGNET		
4		USA	Dat	e/Time: Wed Jun 03 14	:25:51 2020	
6						
7	Wor	kbook: Ca	ase (Main) (co	ontinued)		
9			Pipe Segn	ents (continued)	Fluid	i Pikg: Ali
11	Name		PIPE-CWR-HV-002 to CI	PIPE-CWS-Chiller to HV-0	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03
12	Feed Temperature	(C)	17.78	6.657	24.57	24.65
13	Feed Pressure	(bar_g)	3.860	4.131	11.67	11.73
14	Product Temperature	(C)	17.78	6.658	24.56	24.64
15	Product Pressure	(bar_g) (Wm-K)	3.859	4.131	11.07	4 8080-002
10	Insulation Thickness	(Willer) (m)	3.810+002	3.810e-002	0.1016	4.000E-002 0.1016
18	Name	()	PIPE-CWR-Outside Wall	to PIPE-CWR-HV-004 to Out	PIPE-CWS-HV-001 to Out	PIPE-CWS-Outside Wall
19	Feed Temperature	(C)	17.78	17.78	6.658	6.662
20	Feed Pressure	(bar_g)	3.526	3.525	4.131	3.792
21	Product Temperature	(C)	17.78	17.78	6.662	6.663
22	Product Pressure	(bar_g)	3.525	3.860	3.792	3.792
23	Insulation Conductivity	(W/m-K)	3.328e-002	3.328e-002 *	3.254e-002 *	3.254e-002
24	Insulation Thickness	(m)	3.810e-002	3.810e-002	3.810e-002	3.810e-002
27 28 29 30						
31 32 33 34						
35 36 37						
39 40 41						
43 44 45						
46 47 48 49						
50 51 52 53						
54 55 56						
58 59 60						
61						

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Aspen HYSYS Version 9

Page 5 of 5 Specified by user.

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Helium Operating at 600°C and 75 kW of Heat Pipe Power



1				Case	Name: dei	tailed ini test	bed 75kw He v2.hsc		
3	(1) aspentech	Bedford, MA	DAHO	Unit S	Set: MA	GNET			
4		USA		Date/Time: Wed Jun 03 14:30:19 2020					
6 7	Wor	kbook: Ca	ase (Main)						
8 9			M	latori	al Streams		FI	id Pkg: All	
10 11	Name		HX-01 Hot In	lateri	CWR		CWS	HX-01 Hot Out	
12	Temperature	(C)	1	48.9		17.78	6.667	20.00 *	
13	Pressure	(bar_g)	1	1.34		3.726	3.987	11.23	
14	Mass Flow	(kq/s)	0.1	1134		1.977	1.977	0.1134	
15	Mass Density	(kg/m3)	1	.409		1068	1077	2.010	
16	Mass Entraipy	(KJ/Kg) (kJ/kg.C)		43.5	-1.	20/e+004	-1.210e+004	-20.83	
12	Name	(NJ/Ng-C)	RHX-01 Cold In	1.02	RHX-01 Cold	Dut	Vacuum Chamber In	Vacuum Chamber Out	
19	Temperature	(C)	2	6.78	11111010010	508.5	506.6	633.9 '	
20	Pressure	(bar_g)	1	1.69		11.65 *	11.65	11.40 '	
21	Mass Flow	(kg/s)	0.1	1134		0.1134	0.1134	0.1134	
22	Mass Density	(kg/m3)	2	2.038		0.7798	0.7815	0.6586	
23	Mass Enthalpy	(kJ/kg)	8	3.391		2513	2503	3164	
24	Mass Entropy	(kJ/kg-C)	1	5.79	DUN DU UN D	20.77	20.76	21.59	
25	Temperature	(0)	RHX-01 Hot In	30.0	RHX-01 Hot O	140.1.1	Comp In 20.01	0 00.01	
27	Pressure	(bar g)	0	1.39		11.34 *	11.20	11.21	
28	Mass Flow	(kg/s)	0.1	1134		0.1134	0.1134	0.1134	
29	Mass Density	(kg/m3)	0.6	6604		1.408	2.005	2.007	
30	Mass Enthalpy	(kJ/kg)		3149		644.5	-26.76	-26.77	
31	Mass Entropy	(kJ/kg-C)	2	1.57		17.62	15.75	15.75	
32	Name		Chiller In		Chiller Out		CWS-04	CWR-01	
33	Temperature	(C)	1	7.78		6.651	6.659	17.78	
35	Mass Flow	(bai <u>g</u>) (ko/s)	1	977		1 977	3.793	1 977	
36	Mass Density	(kg/m3)		1068		1077	1077	1068	
37	Mass Enthalpy	(kJ/kg)	-1.207e	+004	-13	210e+004	-1.210e+004	-1.207e+004	
38	Mass Entropy	(kJ/kg-C)	0.5	5631		0.4280	0.4281	0.5631	
39	Name		CWR-05		CWR-03		CWR-02	CWS-02	
40	Temperature	(C)	1	7.78		17.78	17.78	6.655	
41 42	Pressure Mass Elow	(bar_g)	3	077		3.525	3.525	4.132	
43	Mass Density	(kg/o) (kg/m3)		1068		1068	1058	1077	
44	Mass Enthalpy	(kJ/kg)	-1.207e-	+004	-13	207e+004	-1.207e+004	-1.210e+004	
45	Mass Entropy	(kJ/kg-C)	0.8	5631		0.5631	0.5631	0.4280	
46	Name		CWS-03		CWS-06		13	14	
47	Temperature	(C)	6	655		6.663	26.85	26.78	
48	Pressure	(bar q)	4	.132		3.792	11.71	11.69	
49 50	Mass Flow Mass Density	(KQ/S) (kg/m3)	1	.9// 1077		1.977	2.041	2 039	
51	Mass Enthalpy	(kJ/kg)	-1.210e	+004	-1.3	210e+004	8.745	8.416	
52	Mass Entropy	(kJ/kg-C)	0.4	4280		0.4282	15.78	15.79	
53	Name		15		16		Comp Out	4-2	
54	Temperature	(C)	2	6.78		20.01	26.85	26.85	
55	Pressure	(bar_g)	1	1.69		11.21	11.74	11.71	
56 67	Mass Flow	(kg/s)	0.1	1134		0.1134	0.1134	0.1134	
57 58	Mass Density Mass Enthality	(Kg/m3) (KJ/kg)	2	416		-26.77	2.046	2.041	
59	Mass Entropy	(kJ/ka-C)	1	5.79		15.75	15.78	15.78	
60								•	
61 62									

1		IDAHO.	Case	Name: de	etailed ini test	bed 75kw He v	2.hsc		
3	@aspentech Bedford, MA	IDAHO	Unit :	Set: M	AGNET				
4	USA		Date/	Time: W	led Jun 03 14	:30:19 2020			
6	Warkback: C	100	ntinued	,					
8	WOIKDOOK. C	ase (main)	(00)	nunuea)				
9 10		Materia	al Stre	ams (contir	nued)		Fluid	i Pkg:	All
11	Name	CWS-01		Heat Pipe Eva	aporator	Heat Pipe Co	ndensor	CWR-04	
12	Temperature (C)		6.654		650.0 *		650.0		17.78
13	Pressure (bar_g)		4.132		-0.9475		-0.9475		3.859
14	Mass Flow (KQ/S) Mass Density (kg/m3)		1077	1	0726-002		1.825e-002 799.6		1.977
16	Mass Enthalpy (kJ/kg)	-1.210e	+004		-1791		-5902	-1.20	7e+004
17	Mass Entropy (kJ/kg-C)	0.	4280		58.21		53.39		0.5631
18	Name	CWS-05							
19	Temperature (C)	(6.663						
20	Pressure (bar_g)	;	3.793						
21	Mass Flow (kg/s)	1	1.977						
22	Mass Density (kg/m3)		1077						
23	Mass Enthalpy (kJ/kg)	-1.210e	+004						
24	Mass Entropy (KJ/Kg-C)	0.	4282						
25			Com	positions			Fluid	i Pkg:	All
27	Name	HX-01 Hot In		CWR		CWS		HX-01 Hot Out	
28	Master Comp Mass Frac (Hellum)	1.	0000						1.0000
29	Master Comp Mass Frac (H2O)		•••		0.5539		0.5539		
30	Master Comp Mass Frac (EGlycol)				0.4461		0.4461		
31	Master Comp Mass Frac (Sodium*)								
32	Name	RHX-01 Cold In		RHX-01 Cold	Out	Vacuum Cha	mber in	Vacuum Chambe	er Out
33	Master Comp Mass Frac (Hellum)	1.	0000		1.0000		1.0000		1.0000
34	Master Comp Mass Frac (H2O)								
35	Master Comp Mass Frac (EGlycol)								
37	Name	RHX-01 Hot In		RHX-01 Hot (Dut	Comp In		6	
38	Master Comp Mass Frac (Hellum)	1.	0000		1.0000		1.0000 *		1.0000
39	Master Comp Mass Frac (H2O)		•••						
40	Master Comp Mass Frac (EGlycol)		•••						
41	Master Comp Mass Frac (Sodium*)								
42	Name	Chiller In		Chiller Out		CWS-04		CWR-01	
43	Master Comp Mass Frac (Hellum)	-							
44 45	Master Comp Mass Frac (H2O) Master Comp Mass Frac (EChronit	0.	A464 1		0.5539		0.5539		0.0039
46	Master Comp Mass Frac (Sodium')	U.			0.4401		0.4401		0.4401
47	Name	CWR-05		CWR-03		CWR-02		CWS-02	
48	Master Comp Mass Frac (Hellum)		•••						•••
49	Master Comp Mass Frac (H2O)	0.	5539		0.5539		0.5539		0.5539
50	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461		0.4461		0.4461
51	Master Comp Mass Frac (Sodium*)								
52	Name	CWS-03		CWS-06		13	4 6 6 6 6	14	4 0000
53	Master Comp Mass Frac (Hellum)		5530		0.5530		1.0000		1.0000
55	Master Comp Mass Frac (F2O) Master Comp Mass Frac (FC/wool)	0.	4461		0.5559				
56	Master Comp Mass Frac (Sodium')	U.			0.4401				
57	Name	15		16		Comp Out		4-2	
58	Master Comp Mass Frac (Hellum)	1.	0000		1.0000		1.0000		1.0000
59	Master Comp Mass Frac (H2O)								
60	Master Comp Mass Frac (EGlycol)		••••		•••				
61	Master Comp Mass Frac (Sodium*)		•••						
62								_	
63	Aspen Technology Inc.	Aso	en HY	SYS Version	8			Page	2 of 5

1		Case	Name: detailed ini test	bed 75kw He v2.hsc	
3	(easpentech Bedford, MA	IDAHO Unit	Set: MAGNET		
4	USA	Date	Time: Wed Jun 03 14	:30:19 2020	
6	Washing also 0				
8	WORKDOOK: C	ase (Main) (co	ntinuea)		
9 10		Compositi	ons (continued)	Fluid	i Pikg: Ali
11	Name	CWS-01	Heat Pipe Evaporator	Heat Pipe Condensor	CWR-04
12	Master Comp Mass Frac (Hellum)				
13	Master Comp Mass Frac (H2O)	0.5539			0.5539
14	Master Comp Mass Frac (EGlycol)	0.4461			0.4461
15	Master Comp Mass Frac (Sodium*)		1.0000 *	1.0000	
16	Name	CWS-05			
17	Master Comp Mass Frac (Hellum)	0.5530			
18	Master Comp Mass Frac (F2O)	0.5559			
20	Master Comp Mass Frac (Sodium')	0.4401			
21		1			
22		Energ	jy Streams	Fluid	i Pkg: Ali
23	Name	PIPE-RHX-01 Cold Out He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 Heat
24	Heat Flow (kW)	1.113	1.752	0.1141	3.758e-002
25	Name	PIPE-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power	Chiller Duty
26	Heat Flow (KW)	-6.635e-003	-6.582e-004	4.031	76.22
27	Name	PIPE-CWS-06 Heat	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	PIPE-CWR-Heat
28	Heat Flow (kW)	-2.863e-002	-2.078e-002	-6.115e-003	-7.223e-003
29	Name	PIPE-CWR-05 Heat	PIPE-CWS-01 Heat	PIPE-HV-01 Heat	PIPE-Comp Heat
30	Heat Flow (KW)	-2.421e-003	-1.031e-002	2.807e-003	4.526e-003
31	Name Heat Flow (MID	Chiller Pump Power	Electric Heater Power	PIPE-CWR-U3 Heat	PIPE-CWS-04 Heat
33	neatriow (kw)	5.0076-002	73.01	-4.3506-003	-2.0026-002
34		н	eaters	1 Pkg: All	
35	Name	Electric Heaters			
36	DUTY (KW)	75.01			
37	Feed Temperature (C) Product Temperature (C)	650.0			
30	Mass Flow (kn/s)	1 8250-002			
40	(kgo)	1.0200-002			
41		с	oolers	Fluid	i Pkg: All
42	Name	Chiller			
43	DUTY (kW)	76.22			
44	Feed Temperature (C)	17.78			
45	Product Temperature (C)	6.651			
46	Mass Flow (kg/s)	1.977			
47 48		Heat E	xchangers	Fluid	i Pkg: All
49	Name	RHX-01	Chiller HX-01	Vacuum Chamber	
50	Duty (kW)	284.0	76.02	75.01	
51	Tube Side Feed Mass Flow (kg/s)	0.1134	0.1134	1.825e-002	
52	Shell Side Feed Mass Flow (kg/s)	0.1134	1.977 *	0.1134	
53	Tube Inlet Temperature (C)	630.9	148.9	650.0 *	
54 66	rube Outlet Temperature (C) Shell Inlet Temperature (C)	149.1 '	20.00 *	650.0 606 6	
		20.70	0.00/	533.0 ⁺	
56	Shell Outlet Temperature (C)	508.5			
56 57	Shell Outlet Temperature (C) Shell Outlet Temperature (C) LMTD (C)	508.5	86.22	58,24	
56 57 58	Shell Outlet Temperature (C) Shell Outlet Temperature (C) LMTD (C) UA (W/C)	508.5 122.4 2321	86.22	58.24 1288	
56 57 58 59	Shell Outlet Temperature (C) Shell Outlet Temperature (C) LMTD (C) UA (W/C) Minimum Approach (C)	508.5 122.4 2321 122.3	86.22 0.0000 86.22	58.24 1288 16.12	
56 57 58 59 60 61	Shell Outlet Temperature (C) LMTD (C) UA (W/C) Minimum Approach (C)	508.5 122.4 2321 122.3	86.22 0.0000 86.22	58.24 1288 16.12	
56 57 58 59 60 61 62	Shell Outlet Temperature (C) Shell Outlet Temperature (C) LMTD (C) UA (W/C) Minimum Approach (C)	508.5 122.4 2321 122.3	86.22 0.0000 86.22	58.24 1288 16.12	

1				Case Name:	detailed ini test	bed 75kw He v2.hsc	
3	@aspentech	Bedford, MA	DAHO	Unit Set:	MAGNET		
4		USA		Date/Time:	Wed Jun 03 14:	30:19 2020	
6 7 8	Worl	kbook: Ca	ase (Main) (contin	ued)		
9 40		Fluid	i Pikg: Ali				
11	Name		Chiller Pump				
12	Power	(KW)	9.067e-0	02			
13	Feed Pressure	(bar_g)	3.1	62			
14	Product Pressure	(bar q)	4.	32			
15	Product Temperature	(C)	6.6	54			
16	Feed Temperature	(C)	6.0	51			
17	Adiabatic Efficiency	(%)	75	.00			
18	Pressure Ratio	(here)	1.0	178			
19	Mass Flow	(Kg/S)	1.3	977			
21			(Compresso	ors	Fluid	I Pkg: All
22	Name		Comp-01				
23	Power	(KW)	4.0	31			
24	Feed Pressure	(bar_g)	11	.20			
25	Product Pressure	(bar q)	11	.74 *			
26	Product Temperature	(C)	26	.85			
27	Adiabatia Efficiency	(C)	20	.01			
20	Dressure Ratio		11	10 -			
30	Mass Flow	(kg/s)	0.1	34 '			
31		(
32				Expander	5	Fluid	i Pkg: Ali
33	Name						
34	Power	(kW)					
35	Peed Pressure	(bar_g)					
30	Product Pressure	(bar_g)					
38	Feed Temperature	(C)					
39	Adiabatic Efficiency						
40	Mass Flow	(kg/s)					
41			P	ine Seame	nts	Fluid	Pka: All
42	Mana		DIDE OVIA OVA DUIX		latin Manual Obard	DIDE Unit Out DUIX Of the L	
43 44	Name Eood Tomporature	(0)	PIPE-Cold OUT-RHX-		Hot In-Vacum Cham	PIPE-HOLOUT-RHX-01 to H	PIPE-HV-03 to HV-01
45	Feed Pressure	(bar d)	11	65 '	11.40 *	143.1	11.71
46	Product Temperature	(C)	50	6.6	630.9	148.9	26.78
47	Product Pressure	(bar_g)	11	.65	11.39	11.34	11.69
48	Insulation Conductivity	(W/m-K)	7.809e-0	02 *	8.671e-002 *	5.530e-002 *	4.820e-002 *
49	Insulation Thickness	(m)	0.10	16	0.1016	0.1016	0.1016
50	Name		PIPE-HV-02 to Comp	PIPE-	HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-
51	Feed Temperature	(C)	20	.01	20.00 *	6.663	17.78
52	Feed Pressure	(bar_g)	11	.21	11.23	3.792	3.726
53	Product Temperature	(C)	20	.01	20.01	6.667 *	17.78
55	Insulation Conductivity	(Ual <u>-g)</u> (W/m-K)	4 7820-1	102 *	4 7826-002 *	3 2546-002 *	3 3280-002 *
56	Insulation Thickness	(m)	0.10	016	0.1016	3.810e-002	3.810e-002
57 58 59 60							
62							

1			DANO	Case	Name: detailed ini test	bed 75kw He v2.hsc	
3	@aspentech	Bedford, MA	DAHO	Unit S	et: MAGNET		
4		USA		Date/	Time: Wed Jun 03 14:	30:19 2020	
6							
7	Wor	kbook: Ca	ase (Main)	(coi	ntinued)		
9			Pipe S	eame	nts (continued)	Fluid	I Pika: Ali
10 11	Name		PIPE-CWR-HV-002	to Chil	PIPE-CWS-Chiller to HV-0	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03
12	Feed Temperature	(C)	1	7.78	6.654	26.78	26.85
13	Feed Pressure	(bar_g)		.859	4.132	11.69	11.74 '
14	Product Temperature	(C)	1	7.78	6.655	26.78	26.85
15	Product Pressure	(bar_g)	2 200	.859	4.132	11.69	11.71
16	Insulation Conductivity	(W/m-к) (m)	3.3286	-002 *	3.2540-002 *	4.820e-002 *	4.8210-002 -
18	Name	(iii)	PIPE-CWS-HV-001	to Outs	PIPE-CWS-Outside Wall to	PIPE-CWR-HV-004 to Out	PIPE-CWR-Outside Wall 1
19	Feed Temperature	(C)		.655	6.659	17.78	17.78
20	Feed Pressure	(bar_g)	4	.132	3.793	3.525	3.525
21	Product Temperature	(C)	6	6.659	6.663	17.78	17.78
22	Product Pressure	(bar_g)	3	.793	3.793	3.525	3.859
23	Insulation Conductivity	(W/m-K)	3.2546	-002 *	3.254e-002 *	3.328e-002 *	3.328e-002 '
24	Insulation Thickness	(m)	3.810e	-002	3.810e-002	3.810e-002	3.810e-002
25							
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63	Aspen Technology Inc.		Asn	en HY	SYS Version 9		Page 5 of 5

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* Specified by user.

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Nitrogen Operating at 600°C and 27 kW of Heat Pipe Power



1				Case	Name: detailed ini t	est bed 27kw n2 v2.hsc	
3	(e)aspentech	Bedford, MA	DAHO	Unit S	et: MAGNET		
4		USA		Date/	Time: Wed Jun 03	14:33:39 2020	
6	14/1		(14.1.1)				
8	work	(DOOK: Ca	ase (Main)				
9			м	ateria	al Streams	FI	uld Pkg: All
10	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out
12	Temperature	(C)	1	77.9	17.7	8 6.667	· 20.00 *
13	Pressure	(bar_g)	1	1.39	3.72	5 3.987	11.28
14	Mass Flow	(kg/s)	0.1	474	0.647	0.6471	0.1474
15	Mass Density	(kg/m3)	9.	234	106	8 1077	14.20
16	Mass Entrapy Mass Entropy	(KJ/Kg) (KJ/Kg.C)	10	076	-1.20/e+004	4 -1.210e+004	-6.622
10	Name	(No/Ng=C)	RHX-01 Cold In	.3/0	RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
19	Temperature	(C)	2	3.52	447.1	442.3	604.1 *
20	Pressure	(bar g)	1	1.66	11.65	5 11.65	11.40 '
21	Mass Flow	(kg/s)	0.1	474	0.1474	4 0.1474	0.1474
22	Mass Density	(kg/m3)	14	4.47	5.893	3 5.938	4.750
23	Mass Enthalpy	(kJ/kg)	-4.	.979	456.3	7 450.5	633.6
24	Mass Entropy	(kJ/kg-C)	4	.521	5.484	4 5.475	5.712
25	Name		RHX-01 Hot In		RHX-01 Hot Out	Comp In	6
26	Temperature	(C)	5	94.6	178.0	8 20.06	20.05
27	Pressure	(bar_g)	1	1.40	11.3	9 11.27	11.27
28	Mass Flow	(Kg/S)	0.1	4/4	0.14/4	4 0.14/4	. 0.14/4
29	Mass Density Mass Enthalow	(kg/m3)	4.	22.8	9.21	14.19	14.20
31	Mass Entrany Mass Entrany	(ku/kg) (ku/kg-C)	5	22.0	4 97	4 518	-0.5/1
32	Name	(10.19 0)	Chiller In		Chiller Out	CWS-04	CWR-01
33	Temperature	(C)	1	7.79	6.63	6.653	17.78
34	Pressure	(bar_g)	3.	.863	3.76	5 3.788	3.528
35	Mass Flow	(kg/s)	0.6	471	0.647	0.6471	0.6471
36	Mass Density	(kg/m3)	1	068	107	7 1077	1068
37	Mass Enthalpy	(kJ/kq)	-1.207e+	004	-1.210e+004	4 -1.210e+004	-1.207e+004
38	Mass Entropy	(KJ/Kg-C)	OWP OF	632	0.427	0.4280	0.5632
39	Temperature	(0)	CWR-05	7 70	GWR-03	CWR-02	CW3-02 6.643
40	Pressure	(bar g)	3	863	3.52	3 3 528	4 127
42	Mass Flow	(kg/s)	0.6	471	0.647	0.6471	0.6471
43	Mass Density	(kg/m3)	1	068	106	8 1068	1077
44	Mass Enthalpy	(k.J/kg)	-1.207e+	004	-1.207e+004	4 -1.207e+004	-1.210e+004
45	Mass Entropy	(kJ/kg-C)	0.5	632	0.563	2 0.5632	0.4279
46	Name		CWS-03		CWS-06	13	14
47	Temperature	(C)	6.	.643	6.65	4 23.63	23.53
48	Pressure	(bar q)	4.	.127	3.78	8 11.66	11.66
49 50	Mass Plow Mass Density	(kq/s)	0.6	471	0.647	0.1474	0.1474
50	Mass Enthainy	(kg/ma) (k_l/kg)	-1 210-4	004	-1 210+00/	14.47	-4 971
52	Mass Entropy	(kJ/ko-C)	0.4	279	0.428	4.522	4.521
53	Name	(15		16	Comp Out	4-2
54	Temperature	(C)	2	3.53	20.0	5 23.65	23.63
55	Pressure	(bar_g)	1	1.66	11.2	7 11.67	11.66
56	Mass Flow	(kg/s)	0.1	474	0.1474	4 0.1474	0.1474
57	Mass Density	(kg/m3)	14	4.47	14.20	14.47	14.47
58	Mass Enthalpy	(kJ/kg)	-4.	.971	-8.57	1 -4.847	-4.864
59 60	Mass Entropy	(kJ/kg-C)	4.	.521	4.51	5 4.522	4.522
60 61 62							
63	Aspen Technology Inc.		Aspe	en HY	SYS Version 9		Page 1 of 4
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1			Case	Name: detailed	i ini test	bed 27kw n2 v2.ha	sc		
3	@aspentech Bedford, MA	DAHO	Unit S	Unit Set: MAGNET					
4	USA		Date/1	Time: Wed Ju	n 03 14	:33:39 2020			
6	Warkhaaki Ci	oo (Moin)	1000	ation (ad)					
8	WOIKDOOK. Ca	ase (main)	(00)	iunueu)					
9 10		Materia	I Strea	ams (continued)		Fluid	d Pkg:	All
11	Name	CWS-01		Heat Pipe Evaporat	tor	Heat Pipe Cond	ensor	CWS-05	
12	Temperature (C)		5.639	6	550.0 *		650.0		6.654
13	Pressure (bar_g)		4.127	-0.	9475		-0.9475		3.788
14	Mass Flow (Kq/s)	0.	1077	6.5696	+003	6.5	59e-003 700.6		0.6471
15	Mass Enthalpy (kL/kg)	-1.210e	+004	1.9726	1791		-5902	-12	10e+004
17	Mass Entropy (kJ/kq-C)	0.	4278	6	58.21		53.39		0.4281
18	Name	CWR-04							
19	Temperature (C)	1	17.79						
20	Pressure (bar_g)	:	3.863						
21	Mass Flow (kg/s)	0.	6471						
22	Mass Density (kg/m3)	4 007-0	1068						
23	Mass Entrapy (KJ/Kg)	-1.20/e	+004						
25	Mass Endopy (Norkg-C)	<u>.</u>	3032						
26			Comp	ositions			Fluid	d Pkg:	All
27	Name	HX-01 Hot In		CWR		CWS		HX-01 Hot Out	
28	Master Comp Mass Frac (Ntrogen)	1.	- 0000						1.0000
29	Master Comp Mass Frac (H2O)		•••	0.	5539		0.5539		
30	Master Comp Mass Frac (EGlycol)			0.	4461		0.4461		
31	Name	RHX-01 Cold In	0000	RHX-01 Cold Out	0000	Vacuum Chamb	er in	Vacuum Chamb	er Out
33	Master Comp Mass Frac (H2O)			1.			1.0000		1.0000
34	Master Comp Mass Frac (EGivcol)								
35	Name	RHX-01 Hot In		RHX-01 Hot Out		Comp In		6	
36	Master Comp Mass Frac (Nitrogen)	1.	0000	1.	0000		1.0000 *		1.0000
37	Master Comp Mass Frac (H2O)		•••						
38	Master Comp Mass Frac (EGlycol)	Obiliar in		Oblige Out		0000.04		0000 04	
39 40	Master Comp Mass Frac (Nitrogen)	Chiller In		Chiller Out		CW5-04		CWR-01	
41	Master Comp Mass Frac (H2O)	0.	5539 -	0.	5539		0.5539		0.5539
42	Master Comp Mass Frac (EGlycol)	0.	4461 *	0.	4461		0.4461		0.4461
43	Name	CWR-05		CWR-03		CWR-02		CWS-02	
44	Master Comp Mass Frac (Nitrogen)		•••						
45	Master Comp Mass Frac (H2O)	0.	5539	0.	5539		0.5539		0.5539
46	Master Comp Mass Frac (EGlycol)	0.	4461	0.	4461	12	0.4461		0.4461
48	Master Comp Mass Frac (Nitrogen)	CW3-03		011/0-00		13	1 0000	14	1 0000
49	Master Comp Mass Frac (H2O)	0.	5539	0.	5539				
50	Master Comp Mass Frac (EGlycol)	0.	4461	0.	4461				
51	Name	15		16		Comp Out		4-2	
52	Master Comp Mass Frac (Nitrogen)	1.	0000	1.	0000		1.0000		1.0000
53	Master Comp Mass Frac (H2O)								
54 60	Master Comp Mass Frac (EGlycol)	CWS-01		Heat Dine Evaneral	tor	Heat Dise Coord	ansor	CWS-05	
56	Master Comp Mass Frac (Nitrogen)	000-01		meat Pipe Evaporal		neat Pipe Cond		0113-05	
57	Master Comp Mass Frac (H2O)	0.	5539						0.5539
58	Master Comp Mass Frac (EGlycol)	0.	4461						0.4461
59	Name	CWR-04							
60	Master Comp Mass Frac (Nitrogen)								
61	Master Comp Mass Frac (H2O)	0.	5539						
62	Master Comp Mass Frac (EGIycol)	0.	4461	CVC Marriage O					- 2 - 6 4
63	Aspent Technology Inc.	Aso	en HY	STS Version 9				Page Specified b	e 2 014

1				Case	Name: detailed ini test	bed 27kw n2 v2.hsc		
2	(aspentech	UNIVERSITY OF I Bedford, MA	DAHO	Unit S	Set: MAGNET			
4		USA		Date/	Time: Wed Jun 03 14	:33:39 2020		
6 7 8	Worl	kbook: Ca	ase (Main)	(co	ntinued)			
9 10			I	Energ	y Streams	Fluid	I Pkg:	All
11	Name		PIPE-RHX-01 Cold	Out He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 H	leat
12	Heat Flow	(kW)	0.	9128	1.596	0.1424	1	.604e-002
13	Name		PIPE-HX-01 Hot He	at	PIPE-HV-02 Heat	Comp Power	Chiller Duty	
14	Heat Flow	(KW)	-6.5046	-003	-6.308e-004	0.5474		25.00
15	Name	0.00	PIPE-CWS-06 Hea	1	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	PIPE-CWR-H	eat
15	Name	(KVV)	PIPE-CWR-05 Heat		-2.021e-002 DIDE_CWS_01 Heat	-0.000E-003	DIDE-Comp H	.360e-003
18	Heat Flow	(KWO)	-2 3086-003		-9.927e-003	1 182e-003	riec-compt	9786-003
19	Name	()	Chiller Pump Powe	r	Electric Heater Power	PIPE-CWS-04 Heat	PIPE-CWR-0	3 Heat
20	Heat Flow	(kW)	2.8936	+002	27.00	-3.882e-003	4	.408e-003
21				He	eaters	Fluid	I Pkg:	All
23	Name		Electric Heaters					
24	DUTY	(KW)	License	27.00				
25	Feed Temperature	(C)		50.0				
26	Product Temperature	(C)		50.0 *				
27	Mass Flow	(kg/s)	6.5696	+003				
28 29				Co	oolers	Fluid	I Pkg:	All
30	Name		Chiller					
31	DUTY	(kW)	:	25.00				
32	Feed Temperature	(C)		7.79				
33	Product Temperature	(C)		5.636				
34	Mass Flow	(kg/s)	0.	6471				
36			H	leat E	xchangers	Fluid	Pkg:	All
37	Name	(RMD)	RHX-01	9.06	Chiller HX-01	Vacuum Chamber		
38	Tube Side Feed Mass Flow	(ko/s)		1474	0 1474	6 569-003		
40	Shell Side Feed Mass Flow	(kg/s)	0.	1474	0.6471 *	0.1474		
41	Tube Inlet Temperature	(C)		594.6	177.9	650.0 *		
42	Tube Outlet Temperature	(C)		178.8 *	20.00 *	650.0		
43	Shell Inlet Temperature	(C)	:	23.52	6.667 *	442.3		
44	Shell Outlet Temperature	(C)		47.8	17.78	604.1 *		
45	LMTD	(C)	1	151.1	59.21	106.9		
46	UA Minimum Annroach	(W/C)		450.4	420.3	252.5		
48	Minimum Approach	(0)		40.0	13.33	40.54		
49				P	umps	Fluid	i Pkg:	Ali
50	Name		Chiller Pump					
51	Power	(kW)	2.8936	+002				
52	Feed Pressure	(bar_g)		3.765				
53	Product Pressure	(bar_g)		4.127				
54	Product Temperature	(C)		0.039				
56	Adiabatic Efficiency	(6)		75.00				
57	Pressure Ratio	(~)		1.076				
58	Mass Flow	(kg/s)	0.	6471				
59 60 61 62 63	Aspen Technology Inc.		Asp	en HY	SYS Version 9		Pa	ae 3 of 4

1 2 LINIVERSITY OF IDAHO		Case N	Case Name: detailed Ini test bed 27kw n2 v2.hsc						
3	3 (aspentech Bedford, MA			Unit Set	t: MAGNET				
4		USA		Date/Tir	me: Wed Jun 03 1	4:33:39 2020			
6 7 8	Workt	book: C	ase (Main)	(con	tinued)				
9				Compr	ressors	Flui	d Pikg: All		
11	Name		Comp-01						
12	Power	(kW)	0.	5474					
13	Feed Pressure	(bar_g)	1	1.27					
14	Product Pressure	(bar q)	1	1.67 *					
15	Product Temperature	(C)		3.65					
16	Feed Temperature	(C)		0.06					
17	Adiabatic Efficiency			75 .					
18	Mass Flow	(kn/s)	0	1474 *					
20	Mado I low	(100)	0.	4/4					
21				Expa	nders	Flui	d Pkg: All		
22	Name								
23	Power	(KW)							
24	Feed Pressure	(bar_g)							
25	Product Pressure	(parq)							
20	Feed Temperature	(C)							
28	Adiabatic Efficiency	(0)							
29	Mass Flow	(kg/s)							
30				Pine Se	amonte	Elui	d Dka: All		
31				tipe se	rgineirus	T IG	arky. A		
32	Name		PIPE-Cold Out-RH)	(-01 to	PIPE-Hot In-Vacum Char	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01		
33	Feed Temperature	(C)		47.8	604.1	1/8.8	23.63		
35	Product Temperature	(0al_g) (C)		42.3	594.6	177.9	23.53		
36	Product Pressure	(bar q)	1	1.65	11.40	11.39	11.66		
37	Insulation Conductivity	(W/m-K)	7.3916	-002 *	8.440e-002	5.706e-002 '	4.802e-002 *		
38	Insulation Thickness	(m)	0.	1016	0.1016	0.1016	0.1016		
39	Name		PIPE-HV-02 to Con	IP I	PIPE-HX-01 to HV-02	PIPE-CWR-HX-01 to HV-0	PIPE-CWR-HV-002 to Chi		
40	Feed Temperature	(C)		0.05	20.00	17.78	17.79		
41	Feed Pressure	(bar_g)	1	1.27	11.28	3.726	3.863		
43	Product Temperature Droduct Dressure	(bar o)		1.27	20.05	3.528	3.853		
44	Insulation Conductivity	(W/m-K)	4.7826	-002 *	4.782e-002	3.328e-002 *	3.328e-002 *		
45	Insulation Thickness	(m)	0.	1016	0.1016	3.810e-002	3.810e-002		
46	Name		PIPE-CWS-Chiller	o HV-0	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03	PIPE-CWR-Outside Wall t		
47	Feed Temperature	(C)		639	23.53	23.65	17.78		
48	Feed Pressure	(barq)	4	.127	11.66	11.67 '	3.528		
49	Product Temperature	(C)		.643	23.52	23.63	17.78		
50	Insulation Conductivity	(Ual_g) (W/m-K)	3 2546	-002 *	4.802-002	4 802-002 *	3.328-002 *		
52	Insulation Thickness	(m)	3.810	-002	0.1016	0.1016	3.810e-002		
53	Name		PIPE-CWR-HV-004	to Out	PIPE-CWS-HV-001 to Ou	t PIPE-CWS-Outside Wall t	PIPE-CWS-HV-003 to HX-		
54	Feed Temperature	(C)	1	7.78	6.643	6.653	6.654		
55	Feed Pressure	(bar_g)	3	.528	4.127	3.788	3.788		
56	Product Temperature	(C)	1	7.79	6.653	6.654	6.667 *		
57	Product Pressure	(bar_g)		.863	3.788	3.788	3.987		
58 59	Insulation Conductivity	(W/m-K)	3.3286	-002 *	3.2540-002	3.2540-002 *	3.2540-002 *		
60 61	Insulation mickness	(m)	3.0106	-002	5.6 TUE-002	3.0104-002	3.010 0 02		
62									
63	Aspen Technology Inc.		Asp	en HYS	YS Version 9		Page 4 of 4		
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Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with Heat Pipe Heat Exchanger using Nitrogen Operating at 600°C and 2 kW of Heat Pipe Power



1				Case	Name:	detailed ini test bed 2kw n2 v2.hsc			
3	()aspentech	dford, MA	DAHO	Unit s	Set:	MAGNET			
4 5	US	SA		Date/	erTime: Wed Jun 03 14:35:50 2020				
6 7	Workbo	ook: Ca	ase (Main)						
8									
9 10			N	lateri	al Streams	5	Flu	id Pkg: All	
11	Name		HX-01 Hot In		CWR		CWS	HX-01 Hot Out	
12	Vapour Fraction		1.	0000		0.0000	0.0000	1.0000	
13	Temperature	(C)		116.7		17.78	6.667	20.00	
14	Pressure	(bar q)		11.34		3.726	3.987	11.22	
15	Mass Flow	(kg/s)	4.6996	E-003		1.232e-002	1.2326-002	4.699e-003	
16	Mass Density	(Kg/m3)		10.66		1064	10/2	14.14	
17	Mass Entraipy	(KJ/Kg)		94.47 1 921		-1.240e+004	-1.2440+004	-0.000	
18	Name	(KJ/Ng-C)	RHX-01 Cold In	+.021	RHX-01 Cr	U.7739	Vacuum Chamber In	Vacuum Chamber Out	
20	Vapour Fraction		1	0000	NHA-01 G	1 0000	1 0000	1 0000	
21	Temperature	(C)		22.02		272.0	200.5	583.5 *	
22	Pressure	(bar g)		11.65		11.65 *	11.65	11.40 *	
23	Mass Flow	(kg/s)	4.6996	-003		4.699e-003	4.699e-003	4.699e-003	
24	Mass Density	(kg/m3)	1	14.53		7.794	8.976	4.862	
25	Mass Enthalpy	(kJ/kg)	4	5.569		262.2	184.5	610.1	
26	Mass Entropy	(kJ/kq-C)		4.516		5.175	5.022	5.685	
27	Name		RHX-01 Hot In		RHX-01 Ho	ot Out	Comp In	6	
28	Vapour Fraction		1.	0000		1.0000	1.0000	1.0000	
29	Temperature	(C)	;	380.2		133.5 *	20.76	20.71	
30	Pressure	(bar_g)		11.40		11.34 *	11.23	11.22	
31	Mass Flow	(kg/s)	4.6996	+003		4.699e-003	4.699e-003	4.699e-003	
32	Mass Density	(kg/m3)		5.373		10.21	14.11	14.11	
33	Mass Entraipy	(KJ/Kg)		581.2		112.5	-7.803	-7.852	
35	Name	(NJ/NG-C)	Chiller In	5.300	Chiller Out	4.000	4.522 CWS-04	4.022 CWR-01	
36	Vapour Fraction		0	0000	onner out	0.0000	0,000	0 0000	
37	Temperature	(C)	-	18.16		4,718	5.447	17.92	
38	Pressure	(bar_g)	4	4.197		4.093	3.789	3.529	
39	Mass Flow	(kg/s)	1.2326	+002		1.232e-002	1.232e-002	1.232e-002	
40	Mass Density	(kg/m3)		1063		1074	1073	1064	
41	Mass Enthalpy	(kJ/kg)	-1.240e	+004		-1.245e+004	-1.244e+004	-1.240e+004	
42	Mass Entropy	(kJ/kg-C)	0.	7785		0.6114	0.6207	0.7757	
43	Name		CWR-05		CWR-03		CWR-02	CWS-03	
44	Vapour Fraction		0.	0000		0.0000	0.0000	0.0000	
45	remperature	(C)		10.11		18.02	17.92	4.966	
47	Mass Flow	(kn/s)	1 222	+.19/ 		1.2326-002	1 2326-002	1 2326-002	
48	Mass Density	(kg/m3)	1.2.328	1063		1064	1064	1074	
49	Mass Enthalpy	(kJ/ka)	-1.240e	+004		-1.240e+004	-1.240e+004	-1.244e+004	
50	Mass Entropy	(kJ/kg-C)	0.	7780		0.7768	0.7757	0.6145	
51	Name		CWS-06		13		14	15	
52	Vapour Fraction		0.	0000		1.0000	1.0000	1.0000	
53	Temperature	(C)		5.041		24.13	22.10	22.10	
54	Pressure	(bar_g)	;	3.789		11.65	11.65	11.65	
55	Mass Flow	(kg/s)	1.2326	+002		4.699e-003	4.699e-003	4.699e-003	
56	Mass Density	(kg/m3)		1073		14.43	14.53	14.53	
57	Mass Enthalpy	(kJ/kg)	-1.244e	+004		-4.327	-6.486	-6.486	
58	Mass Entropy	(KJ/Kg-C)	U.	6282		4.524	4.516	4.516	
60 61 62									
63	Aspen Technology Inc.		Ase	en HY	SYS Versio	on 9		Page 1 of 5	

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* Specified by user.

1			Case N	Name: detailed ini te	st bed 2kw n2 v2.hsc			
3	@aspentech Bedford, MA	FIDARO	Unit Se	et: MAGNET				
4	USA		Date/T	Time: Wed Jun 03	14:35:50 2020			
6	Warkhaaku		1000	tinue d)				
8	WORKDOOK: (ase (main)	(cor	itinuea)				
9 10		Materia	al Strea	ams (continued)	Flu	d Pkg: All		
11	Name	16		Comp Out	4-2	Heat Pipe Condensor		
12	Vapour Fraction	1.	0000	1.0000	1.0000	0.0000		
13	Temperature (C		20.71	24.60	24.13	650.0		
14	Pressure (bar q		11.22	11.65	11.65	-0.9475		
15	Mass Flow (kg/s	4.6996	e-003	4.699e-003	4.6996-003	4.8656-004		
16	Mass Density (Kg/m3 Mass Editation (Kg/m3		14.11	14.40	14.43	/99.0		
17	Mass Entrapy (NJ/Ng Mass Entropy (k l/ko.C	-	1.002	-3.031	-4.327	-0902		
10	Name (Kong-o	CWS-01	4.022	4.525 CWS-02	CWR-04	CWS-05		
20	Vanour Fraction	011001	0000	0.0000	0.0000	0,000		
21	Temperature (C		4.718	4,965	18.11	6.041		
22	Pressure (bar o		4.126	4.126	4.197	3.789		
23	Mass Flow (ko/s	1.232	-002	1,232e-002	1.2320-002	1.232e-002		
24	Mass Density (kg/m3)		1074	1074	1063	1073		
25	Mass Enthaloy (kJ/kg	-1.245e	+004	-1.244e+004	-1.240e+004	-1.244e+004		
26	Mass Entropy (kJ/ko-C	0	6114	0.6145	0.7780	0.6282		
27	Name	Heat Pipe Evapora	tor					
28	Vapour Fraction	1.	0000 -					
29	Temperature (C	(650.0 *					
30	Pressure (bar_g	-0.	9475					
31	Mass Flow (kg/s	4.866	e-004					
32	Mass Density (kg/m3	1.972	e-002					
33	Mass Enthalpy (kJ/kg		1791					
34	Mass Entropy (kJ/kg-C		58.21					
35 36			Comp	ositions	Flu	d Pkg: All		
37	Name	HX-01 Hot In		CWR	CWS	HX-01 Hot Out		
38	Master Comp Mass Frac (Nitrogen)	1.	- 0000	•••		1.0000		
39	Master Comp Mass Frac (EGlycol)			0.4073	0.4073			
40	Master Comp Mass Frac (H2O)							
41		_		0.5927	0.5927			
47	Master Comp Mass Frac (Sodium*)			0.5927	0.5927			
	Master Comp Mass Frac (Sodium") Name	RHX-01 Cold In		0.5927 RHX-01 Cold Out	0.5927	Vacuum Chamber Out		
43	Master Comp Mass Frac (Sodium") Name Master Comp Mass Frac (Nitrogen)	RHX-01 Cold In		0.5927 RHX-01 Cold Out 1.0000	0.5927 Vacuum Chamber In 1.0000	Vacuum Chamber Out 1.0000		
43 44	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol)	RHX-01 Cold In 1.	0000	0.5927 RHX-01 Cold Out 1.0000	0.5927 Vacuum Chamber In 1.0000	Vacuum Chamber Out		
43 44 45	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (H2O)	RHX-01 Cold In	0000	0.5927 RHX-01 Cold Out 1.0000	0.5927 Vacuum Chamber In 1.0000 	Vacuum Chamber Out 1.0000		
43 44 45 46	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium')	RHX-01 Cold In 1.	0000	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Cot	0.5927 Vacuum Chamber In 1.0000	Vacuum Chamber Out 1.0000 		
43 44 45 46 47	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitropp)	RHX-01 Cold In 1. RHX-01 Hot In	0000 	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out	0.5927 Vacuum Chamber In 1.0000 Comp In	Vacuum Chamber Out 1.0000 6 1.0000		
43 44 45 45 47 48 49	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (FGlycol)	RHX-01 Cold In 1. RHX-01 Hot In 1.	 0000 0000	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000	Vacuum Chamber Out 1.0000 6 1.0000 		
43 44 45 46 47 48 49 50	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol)	RHX-01 Cold In 1. RHX-01 Hot In 1.	 0000 0000 	RHX-01 Cold Out RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000 Comp In	Vacuum Chamber Out 1.0000 6 1.0000 6 		
43 44 45 46 47 48 49 50 51	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium')	RHX-01 Cold In 1. RHX-01 Hot In 1.	0 0000 0 0 0 0000 0 0 0	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000	Vacuum Chamber Out 1.0000 6 1.0000 6 		
43 44 45 46 47 48 49 50 51 51	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Hot In 1. Chiller In	0000 0000 	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 RHX-01 Hot Out Chiller Out	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000 Comp In CWS-04	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01		
43 44 45 46 47 48 49 50 51 52 53	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen)	RHX-01 Cold In 1. RHX-01 Hot In 1. Chiller In	0000 0000 0000 	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 RHX-01 Hot Out Chiller Out	0.5927 Vacuum Chamber In 1.0000 Comp In	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01		
44 43 44 45 46 47 48 49 50 51 52 53 54	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Hot In 1. Chiller In 0.	0000 0000 0000 4073 ⁻	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 RHX-01 Hot Out Chiller Out 0.4073 0.4073	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 0.4073	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-D1 0.4073		
43 44 45 45 45 47 48 49 50 51 52 53 54 55	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Hot In 1. Chillier In 0. 0.	00000 00000 -	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 RHX-01 Hot Out Chiller Out 0.4073 0.5927	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 CWS-04 0.4073 0.5927	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-D1 0.4073 0.5927		
44 44 45 46 47 48 49 50 51 52 53 54 55 55	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium')	RHX-01 Cold In 1. RHX-01 Hot In 1. Chillier In 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	00000 00000 4073 ' 5927 '	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out 1.0000 RHX-01 Hot Out Chiller Out 0.4073 0.5927	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 CWS-04 0.4073 0.5927	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01 0.4073 0.5927 		
44 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (H2O) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium) Master Comp Mass Frac (Sodium)	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In 1. Chillier In Chillier In 0. CWR-05	0000 0000 0000 4073 ' 5927 ' 	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out RHX-01 Hot Out Chiller Out Chiller Out CWR-03	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 CWS-04 CWS-04 CWS-04 CWR-02 CWR-02	Vacuum Chamber Out 1.0000 6 1.0000 6 6 CWR-01 0.4073 0.5927 CWS-03		
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Colycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In 1. Chillier In 0 Chillier In 0 CWR-05	0000 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out RHX-01 Hot Out Chiller Out 0.4073 0.5927 CWR-03	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 0.4073 0.5927 CWR-02	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01 0.4073 0.5927 CWS-03 		
44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In 1. Chillier In Chillier In Chillier School Colored CWR-05 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	4073	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out RHX-01 Hot Out Chiller Out 0.4073 0.5927 CWR-03	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 CWS-04 CWS-04 CWS-04 CWR-02 CWR-02	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01 CWR-01 CWS-03 0.4073 0.4073 0.4073		
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Colycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In Chilier In Chilier In CWR-05 CWR-05 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	 0000 0000 0000 4073 ' 5927 ' 	0.5927 RHX-01 Cold Out 1.0000 RHX-01 Hot Out RHX-01 Hot Out Chiller Out Chiller Out Chiller Out CWR-03 0.4073 0.5927	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000 CWS-04 CWS-04 CWS-04 CWR-02 CWR-02 0.4073 0.5927 0.4073 0.5927	Vacuum Chamber Out 1.0000 6 0.10000 6 CWR-01 0.4073 0.5927 0.4073 0.4073 0.4073		
43 44 45 46 47 48 49 50 51 52 53 54 55 55 57 58 59 60 61	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Codium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In Chiller In Chiller In CWR-05 CWR-05 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	4073 5927 4073 5927 	0.5927 RHX-01 Cold Out 1.0000	0.5927 Vacuum Chamber In 1.0000 Comp In 1.0000 CWS-04 CWS-04 CWS-04 CWR-02 CWR-02 CWR-02 0.4073 0.5927	Vacuum Chamber Out 1.0000 6 0.10000 6 CWR-01 0.4073 0.5927 0.4073 0.4073		
43 44 45 46 47 48 49 51 52 53 54 55 56 57 58 59 60 61 62	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Codium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium')	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In Chiller In Chiller In CWR-05 CWR-05 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.	0000 0000 4073 ' 5927 ' 4073 5927 - 	0.5927 RHX-01 Cold Out 1.0000	0.5927 Vacuum Chamber In 1.0000 Comp In Comp In CWS-04 CWS-04 CWR-02	Vacuum Chamber Out 1.0000 6 CWR-01 CWS-03 CWS-03 0.4073 0.5927 		
43 44 45 46 47 48 49 50 51 52 53 54 55 55 56 57 58 59 60 61 62 63	Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (H2O) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (EGlycol) Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Nitrogen) Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Name Master Comp Mass Frac (Sodium') Master Comp Mass Frac (Sodium')	RHX-01 Cold In 1. RHX-01 Cold In 1. RHX-01 Hot In Chiller In Chiller In CWR-05 CWR-05 CWR-05 Asc	0000 	0.5927 RHX-01 Cold Out 1.0000	0.5927	Vacuum Chamber Out 1.0000 6 1.0000 6 CWR-01 CWR-01 CWS-03 CWS-03 CWS-03 CWS-03 		
1		DAHO	Case	Name: detailed ini test	bed 2kw n2 v2.hsc			
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3	@aspentech Bedford, MA	IDANO	Unit S	Set: MAGNET				
4	USA		Date/	Time: Wed Jun 03 14	:35:50 2020			
6	Warkback: C	nen (Mein)	100	ntinued)				
8	WORKDOOK. Ca	ase (main)	(00)	nunuea)				
9 10		Comp	ositio	ons (continued)	Fluid	Fluid Pkg: All		
11	Name	CWS-06		13	14	15		
12	Master Comp Mass Frac (Nitrogen)			1.0000	1.0000	1.0000		
13	Master Comp Mass Frac (EGlycol)	0.	4073					
14	Master Comp Mass Frac (H2O)	0.	5927					
15	Master Comp Mass Frac (Sodium*)	45		Come Out	10	Heat Dise Europerator		
16	Name Master Comp Mass Erze (Nitrogen)	10	0000	Comp Out	4-2	Heat Pipe Evaporator		
17	Master Comp Mass Frac (Nillogen)			1.0000	1.0000			
19	Master Comp Mass Frac (EGycol)							
20	Master Comp Mass Frac (Sodium")					1 0000 '		
21	Name	Heat Pipe Condens	or	CWS-01	CWS-02	CWR-04		
22	Master Comp Mass Frac (Nitrogen)							
23	Master Comp Mass Frac (EGlycol)			0.4073	0.4073	0.4073		
24	Master Comp Mass Frac (H2O)		•••	0.5927	0.5927	0.5927		
25	Master Comp Mass Frac (Sodium*)	1.	0000					
26	Name	CWS-05						
27	Master Comp Mass Frac (Nitrogen)							
28	Master Comp Mass Frac (EGlycol)	0.	4073					
29	Master Comp Mass Frac (H2O)	0.	5927					
30	Master Comp Mass Frac (Sodium*)							
31 32		E	Energ	y Streams	Fluid	d Pkg: All		
33	Name	PIPE-RHX-01 Cold	Out He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out Hea	PIPE-HV-03 Heat		
34	Heat Flow (kW)	0.	3652	1.075	8.453e-002	1.016e-002		
35	Name	PIPE-HX-01 Hot He	at	PIPE-HV-02 Heat	Comp Power	Chiller Duty		
36	Heat Flow (kW)	-3.5226	-003	-1.972e-004	1.867e-002	0.5863		
37	Name	PIPE-CWS-06 Heat	t .	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat	PIPE-CWR-Heat		
38	Heat Flow (KW)	-2.723e	-002	-2.087e-002	-4.301e-003	-6.177e-003		
39	Name	PIPE-CWR-05 Heat	t	PIPE-HV-01 Heat	PIPE-Comp Heat	Chiller Pump Power		
40	Heat Flow (KW)	-2.0436	-003	3.933 0 -004	2.313 0 -003	5.050e-005		
41	Name Heat Flow	Electric Heater Pow	er	PIPE-CWS-01 Heat	PIPE-CWR-03 Heat	PIPE-CWS-04 Heat		
42	Heat Flow (KW)		2.000	-1.076e-002	-4.1696-003	-2.5658-002		
44			He	eaters	Fluid	1 Pkg: All		
45	Name	Electric Heaters						
46	DUTY (KW)	2	2.000					
47	Feed Temperature (C)		50.0					
48	Product Temperature (C)	6	50.0 *					
49 50			Co	oolers	Fluid	d Pkg: All		
51	Name	Chiller						
52	DUTY (KW)	0.	5863					
53	Feed Temperature (C)	1	8.16					
54	Product Temperature (C)	4	.718					
55 57 58 59 60 61 62								
63	Aspen Technology Inc.	Asp	en HY	SYS Version 9		Page 3 of 5		

1				Case	Name: deta	illed ini test	bed 2kw n2 v2.hsc		
2	(aspentech	UNIVERSITY OF Bedford, MA	IDAHO	Unit s	Set: MA	GNET			
4		USA		Date/	Time: We	1 Jun 03 14	:35:50 2020		
6	More	the alter C	and (Main)	1					
8	work	KDOOK: Ca	ase (main)	(co	ntinuea)				
9			н	leat E	xchangers		Flui	d Pikg:	All
11	Name		RHX-01		Chiller HX-01		Vacuum Chamber		
12	Duty	(kW)	1	.263		0.4844	2.000		
13	Tube Side Feed Mass Flow	(kg/s)	4.699e	+ 00 3	4.6	99e-003	4.866e-004		
14	Shell Side Feed Mass Flow	(kq/s)	4.699e	-003	1.2	32e-002 *	4.699e-003		
15	Tube Inlet Temperature	(C)	3	80.2		116.7	650.0 *		
16	Tube Outlet Temperature	(C)	1	33.5 *		20.00 *	650.0		
17	Shell Inlet Temperature	(C)		2.02		6.66/*	200.5		
18	Shell Outer Temperature	(C)		10.0		42.75	108.0		
20		(C)		1.49		42.70	190.9		
21	Minimum Approach	(C)		08.2		13.33	66.54		
22		(0)							
23				P	umps		Flui	d Pkg:	Ali
24	Name		Chiller Pump						
25	Power	(kW)	5.050e	-005					
26	Feed Pressure	(bar q)	4	1.093					
27	Product Pressure	(bar_g)	4	.126					
28	Product Temperature	(C)	4	1.718					
29	Adiabatic Efficiency	(%)	7	5.00					
30	Pressure Ratio	(here)	1	.006					
31	Mass Flow	(Kg/S)	1.2328	-002					
33				Com	pressors		Flui	d Pkg:	All
34	Name		Comp-01						
35	Power	(kW)	1.867e	-002					
36	Feed Pressure	(bar_g)	1	1.23					
37	Product Pressure	(barq)	1	1.65 *					
38	Product Temperature	(C)	2	24.60					
39	Feed Temperature	(C)	1	0.76					
40	Adiabatic Efficiency			75 •					
41	Pressure Ratio	(here)	1	.035					
42	Md55 FIOW	(kg/s)	4.0336	-005					
44				Exp	anders		Flui	d Pkg:	All
45	Name								
46	Power	(kW)							
47	Feed Pressure	(bar_g)							
48	Product Pressure	(barq)							
49	Product Temperature	(C)							
50	Feed Temperature	(C)							
51	Adiabatic Efficiency								
52 53			1	Pipe \$	Segments		Flui	d Pikg:	All
54	Name		PIPE-Cold Out-RH)	(-01 to	PIPE-Hot In-Va	cum Chami	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03	to HV-01
55	Feed Temperature	(C)	2	272.0		583.5 *	133.5 *		24.13
56	Feed Pressure	(bar_g)	1	1.65 *		11.40 *	11.34 "		11.65
57	Product Temperature	(C)	2	200.5		380.2	116.7		22.10
58	Product Pressure	(bar_g)	1	1.65		11.40	11.34		11.65
59	Insulation Conductivity	(W/m-K)	6.058e	+002 *	7.6	36e-002 *	5.389e-002 *	4	4.799e-002 '
60	Insulation Thickness	(m)	0.	1016		0.1016	0.1016		0.1016
67									
63	Aspen Technology Inc		Asn	en HV	SYS Version 9			Pa	age 4 of 5
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1		UNIVERSITY OF		Case N	lame: deta	iled ini test	bed 2kw n2 v2.hsc	
3	@aspentech	Bedford, MA	DAHO	Unit Se	et: MAG	SNET		
4		USA		Date/Ti	ime: Wed	I Jun 03 14:	35:50 2020	
6 7 8	Worl	kbook: Ca	ase (Main)	(con	tinued)			
9			Pipe S	egmen	I Pikg: All			
10	Nama		PIPE-HV-02 to Com		DIDE-HY-01 to I	HV-02	DIDE-CWS-HV-001 to HV-	DIDE-CWS-HV-003 to H
12	Feed Temperature	(C)	2	0.71	PIPEHIANTIN	20.00 *	4 955	6.041
13	Feed Pressure	(bar g)	1	1.22		11.22	4.126	3.789
14	Product Temperature	(C)	2	0.76		20.71	5.447	6.667
15	Product Pressure	(bar_g)	1	1.23		11.22	3.789	3.987
16	Insulation Conductivity	(W/m-K)	4.786e	-002 *	4.7	84e-002 *	3.244e-002 *	3.252e-002
17	Insulation Thickness	(m)	0.1	1016		0.1016	3.810e-002	3.810e-002
18	Name		PIPE-CWR-HX-01 t	o HV-D	PIPE-CWR-HV-	004 to Out	PIPE-CWR-HV-002 to Chil	PIPE-HV-01 to RHX-01
19	Feed Temperature	(C)	1	7.78		17.92	18.11	22.10
20	Feed Pressure	(bar_g)	3	.726		3.529	4.197	11.65
21	Product Temperature	(C)	1	7.92		18.02	18.16	22.02
22	Product Pressure	(bar_g)	3	.529		3.863	4.197	11.65
23	Insulation Conductivity	(W/m-K)	3.328e	-002 *	3.3	29e-002 *	3.330e-002 *	4.793e-002
24	Insulation Thickness	(m)	3.810e	-002	3.8	10e-002	3.810e-002	0.1016
25	Name		PIPE-Comp to HV-0	3	PIPE-CWS-Chil	ler to HV-0	PIPE-CWR-Outside Wall to	PIPE-CWS-Outside Wall
26	Feed Temperature	(C)	2	4.60		4.718	18.02	5.447
27	Feed Pressure	(bar_g)	1	1.65 *		4.126	3.863	3.789
28	Product Temperature	(C)	2	4.13		4.966	18.11	6.041
29	Product Pressure	(bar_g)	1	1.65		4.126	4.197	3.789
30	Insulation Conductivity	(W/m-K)	4.8068	-002	3.2	42e-002 *	3.3308-002	3.2488-002
3 3 3 5 5 7 8 9 4 4 4 4 4 4 9 5								

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Appendix C: Aspen HYSYS Models for the Microreactor AGile Non-nuclear Experimental Testbed PCU Units

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with PCU using Nitrogen Operating at 600°C and 250 kW of Heat Pipe Power



1			DAHO	Case	Name: detailed ini test	bed 250kw n2 PCU Pressure	es.hsc
3	@aspentech	Bedford, MA	IUANO	Unit :	Set: MAGNET		
4		USA		Date	Time: Wed Jun 03 14	:38:48 2020	
6 7	Work	khook: Cr	see (Main)				
8	••••	NDOOK. CO	ase (main)				
9 10			Ν	lateri	al Streams	Fluid Pkg: All	
11	Name		HX-01 Hot In		CWR	CWS	HX-01 Hot Out
12	Temperature	(C)		277.2	17.78	6.667 *	20.00 *
13	Pressure Mass Elem	(bar_g)		5.214	3.726	3.987 *	5.100
15	Mass Density	(kg/m3)		3.804	1068	1077	7.047
16	Mass Enthalpy	(kJ/kg)		268.1	-1.207e+004	-1.210e+004	-6.919
17	Mass Entropy	(kJ/kg-C)		5.397	0.5631	0.4282	4.730
18	Name		RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
19	Temperature	(C)	1	125.7	328.7	328.0	600.0 *
20	Pressure	(bar_g)	1	11.76	11.67 *	11.65	11.40 *
21	Mass Flow	(kg/s)	0.	8187	0.8187	0.8187	0.8187
22	Mass Density Mass Enthalow	(Kg/m3) (K l/kg)		10.77	7.068	7.000	4.770
24	Mass Entrony	(kJ/kg-C)		1835	5 283	5 282	5 707
25	Name	(RHX-01 Hot In		RHX-01 Hot Out	Comp In	6
26	Temperature	(C)	4	476.6	277.5 *	19.89	19.94
27	Pressure	(bar_g)		5.487 *	5.228 *	4.613	4.832
28	Mass Flow	(kg/s)	0.	8187	0.8187	0.8187 *	0.8187
29	Mass Density	(kg/m3)	1	2.915	3.811	6.486	6.738
30	Mass Enthalpy	(kJ/kg)	4	488.8	268.4	-6.896	-6.903
32	Name	(KJ/NG-C)	Chiller In	0.720	Chiller Out	4./55 CWR-01	4./44 CWR-05
33	Temperature	(C)	1	17.78	6.658	17.78	17.78
34	Pressure	(bar_g)		3.831	3.734	3.508	3.832
35	Mass Flow	(kg/s)		5.855	5.855	5.855	5.855
36	Mass Density	(kg/m3)		1068	1077	1058	1068
37	Mass Enthalpy	(kJ/kq)	-1.207e	+004	-1.210e+004	-1.207e+004	-1.207e+004
38	Name	(KJ/Kg-C)	CWR-03	5631	0.4201 CWR-02	0.5631 CWS-02	0.5031
40	Temperature	(C)	000000	17.78	17.78	6.661	6.661
41	Pressure	(bar q)		3.503	3.507	4.174	4.172
42	Mass Flow	(kg/s)		5.855	5.855	5.855	5.855
43	Mass Density	(kg/m3)		1068	1068	1077	1077
44	Mass Enthalpy	(kJ/kg)	-1.207e	+004	-1.207e+004	-1.210e+004	-1.210e+004
45	Mass Entropy	(kJ/kg-C)	0.	5631	0.5631	0.4281	0.4281
46	Temperature	(0)	CWS-06	665	13 125.5	14 125.7	10 125.7
48	Pressure	(bar g)		3.824	11.94	11.78	11.77
49	Mass Flow	(kq/s)	5	5.855	0.8187	0.8187	0.8187
50	Mass Density	(kg/m3)		1077	10.90	10.78	10.78
51	Mass Enthalpy	(kJ/kg)	-1.210e	+004	105.0	104.1	104.1
52	Mass Entropy	(kJ/kg-C)	0,	4282	4.833	4.834	4.835
53	Name	(0)	16	0.04	Comp Out	4 405.5	Turbine Inlet
55	Pressure	(bar o)		1822	12.00	120.0	090.3 11 35
56	Mass Flow	(ka/s)	0	8187	0.8187	0.8187	0.8187
57	Mass Density	(kg/m3)		5.727	11.11	10.90	4.763
58	Mass Enthalpy	(kJ/kg)	-	5.903	105.1	105.0	627.0
59	Mass Entropy	(kJ/kg-C)	4	4.744	4.827	4.833	5.706
60 61 62							
63	Aspen Technology Inc.		Aso	en HY	SYS Version 9		Page 1 of 4
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1		IDA HO	Case	Name: detai	led ini test	bed 250kw n2 PCU Pressu	es.hsc
3	@aspentech Bedford, MA	IDAHO	Unit :	Set: MAG	NET		
4	USA		Date/	Time: Wed	Jun 03 14:	38:48 2020	
6	Warkback: C	ana (Main)	100	ntinued)			
8	WORKDOOK. Ca	ase (main)	(00	nunuea)			
9		Materia	l Stre	ams (continu	ed)	Flu	d Pkg: All
11	Name	CWS-01		CWS-05		CWR-04	CWS-04
12	Temperature (C)		5.661		6.665	17.78	6.663
13	Pressure (bar_g)	4	4.175		3.825	3.833	3.829
14	Mass Flow (kq/s)		5.855		5.855	5.855	5.855
15	Mass Density (Kg/m3)	4 040-	1077		1077	1058	1077
16	Mass Entrapy (KJ/Kg)	-1.210e	+004	-1.21	0.4292	-1.20/0+004	-1.2100+004
17	Mass Entropy (Kokg-C)	U.	4201		0.4202	0.5631	0.4202
19			Com	positions		Flu	d Pkg: All
20	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out
21	Master Comp Mass Frac (Nitrogen)	1.	0000 *				1.0000
22	Master Comp Mass Frac (EGlycol)				0.4461	0.4461	
23	Master Comp Mass Frac (H2O)				0.5539	0.5539	
24	Name	RHX-01 Cold In		RHX-01 Cold Ou	rt	Vacuum Chamber In	Vacuum Chamber Out
25	Master Comp Mass Frac (Nitrogen)	1.	0000		1.0000	1.0000	1.0000
20	Master Comp Mass Frac (EGIVCOI)						
28	Name	RHX-01 Hot In		RHX-01 Hot Out		Comp In	6
29	Master Comp Mass Frac (Nitrogen)	1.	0000		1.0000	1.0000	1.0000
30	Master Comp Mass Frac (EGlycol)						
31	Master Comp Mass Frac (H2O)					•••	
32	Name	Chiller In		Chiller Out		CWS-04	CWR-01
33	Master Comp Mass Frac (Nitrogen)		••••			•••	
34	Master Comp Mass Frac (EGlycol)	0.	4461 "		0.4461	0.4461	0.4461
35	Master Comp Mass Frac (H2O)	0.	5539 *		0.5539	0.5539	0.5539
36	Name	CWR-05		CWR-03		CWR-02	CWS-02
37	Master Comp Mass Frac (Nitrogen)		4461		0.4461	0.4461	0.4461
38	Master Comp Mass Frac (EGiyoti)	0.	5530		0.5530	0.4401	0.4401
40	Name	CWS-03	0005	CWS-06	0.0005	13	14
41	Master Comp Mass Frac (Nitrogen)					1.0000	1.0000
42	Master Comp Mass Frac (EGlycol)	0.	4461		0.4461	•••	
43	Master Comp Mass Frac (H2O)	0.	5539		0.5539		
44	Name	15		16		Comp Out	4
45	Master Comp Mass Frac (Nitrogen)	1.	0000		1.0000	1.0000	1.0000
46	Master Comp Mass Frac (EGlycol)						
47	Master Comp Mass Frac (H2O)			0000 51			
48	Name	Turbine Inlet		CWS-01		CWS-05	CWR-04
49	Master Comp Mass Frac (Nitrogen)	1.			0.4461	0.4461	0.4461
51	Master Comp Mass Frac (H2O)				0.5539	0.5539	0.5539
52							
53 Energy Streams Fluid Pkg:					d Pkg: All		
54	Name	Heat Pipes		PIPE-RHX-01 C	old Out He	PIPE-RHX-01 Hot In Heat	PIPE-RHX-01 Hot Out He
55	Heat Flow (KW)		250.0		0.6111	1.620	0.2567
57	Heat Flow AND	PIPE-HV-US Heat	7672	PIPE-HX-UT HOU	neat	-6 870a 004	Comp Power
58	Name (KVV)	Chiller Duty	1012	PIPE-CWS-06 H	eat	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat
59	Heat Flow (kW)	Since Only	225.6	-2.8	32e-002	-2.002e-002	-6.124e-003
60	Name	PIPE-CWR Heat		PIPE-CWR-05 H	leat	PIPE-CWS-01 Heat	PIPE-HV-01 Heat
61	Heat Flow (kW)	-6.9026	+003	-1.1	47e-002	-1.032e-002	5.734e-002
62							
63	Aspen Technology Inc.	Aso	en HY	SYS Version 9			Page 2 of 4
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1			0440	Case	Name: detail	ied ini test	bed 250kw n2 PCU Pressure	es.hsc	
3	(1) aspentech	Bedford, MA	IDAHO	Unit S	Set: MAG	NET			
4		USA		Date/	Time: Wed	Jun 03 14	:38:48 2020		
6	Wor	khook: Cr	ee (Main)	(00)	ntinued)				
8	WOI	NDOOK. CO	ase (Maili)		nunueuj				
9 10			Energy	/ Strea	ams (continue	d)	Fluid	d Pkg:	Ali
11	Name		PIPE-Comp Heat		Turbine Power		Chiller Pump Power	PIPE-CWS-04	Heat
12	Heat Flow	(kW)	9.2406	÷002		113.1	0.3198	-2	.605e-002
13	Name		PIPE-CWR-03 Hea	t					
14	Heat Flow	(KVV)	-2.2008	-002					
16	5			He	eaters		Fluid	d Pikg:	All
17	Name		Vacuum Chamber						
18	DUTY	(kW)		250.0					
19 20	Pred Temperature	(C)		528.0 500.0 *					
21	Mass Flow	(kg/s)	0.	8187					
22				C	oolers		Fluid	d Pkg:	All
23	Name		Chiller					-	
25	DUTY	(KW)	- Chiller	225.6					
26	Feed Temperature	(C)	1	17.78					
27	Product Temperature	(C)		5.658					
28	Mass Flow	(kg/s)		5.855					
29 30			н	leat E	xchangers		Fluid	d Pkg:	All
31	Name		RHX-01		Chiller HX-01				
32	Duty	(kW)	1	180.4		225.2			
33	Tube Side Feed Mass Flow	(kg/s)	0.	8187		0.8187			
34	Tube Inlet Temperature	(Kg/S) (C)	0.	8187 476.6		277.2			
36	Tube Outlet Temperature	(C)		277.5 *		20.00 *			
37	Shell Inlet Temperature	(C)	1	125.7		6.667 *			
38	Shell Outlet Temperature	(C)		328.7		17.78			
39		(C)	1	149.9		83.58			
40	Minimum Approach	(C)		1203		13.33			
42				D			Eluiz	i Dka:	
43				F	umps		Fluk	a Pilig.	~
44	Name		Chiller Pump	2400					
45	Power Feed Pressure	(kvv) (bar.g)		3 7 3 4					
47	Product Pressure	(bar_g)		4.175					
48	Product Temperature	(C)		5.661					
49	Feed Temperature	(C)		5.658					
50	Adiabatic Efficiency Pressure Ratio	(%)		1 003					
52	Mass Flow	(ka/s)		5.855					
53									
54									
55									
57									
58									
59									
60									
61 62									
63	Aspen Technology Inc.		Asn	en HY	SYS Version 9			Pa	ae 3 of 4
	Licensed to: UNIVERSITY OF ID	AHO.	1126					1 Onechied	by upor

1			Са	se Name:	detailed ini test	bed 250kw n2 PCU Pressure	es.hsc	
3	@aspentech	Bedford, MA	Un	it Set:	MAGNET			
4		USA	Da	te/Time:	Wed Jun 03 14:	38:48 2020		
6 7 8	Wor	kbook: Ca	ase (Main) (c	ontinue	d)			
9			Co	mpressors		Fluid	1 Pkg: All	
11	Name		Comp-01					
12	Power	(KW)	91.71					
13	Feed Pressure	(bar_g)	4.613					
14	Product Pressure	(barq)	12.20	•				
15	Product Temperature	(C)	126.8					
16	Adiabatic Efficiency	(C)	19.89					
12	Pressure Ratio		2 349					
19	Mass Flow	(ka/s)	0.8187	•				
20			-			First	Dhay All	
21		Fluk	i Pilg: Ali					
22	Name		Turbine					
23	Power	(kW)	113.1					
24	Feed Pressure	(bar_g)	11.35					
25	Product Pressure Droduct Temperature	(bar q)	0.407					
27	Feed Temperature	(C)	598.3					
28	Adiabatic Efficiency		90	•				
29	Mass Flow	(kg/s)	0.8187					
30			Pine	Segments		Fluir	1 Pkg: All	
31								
32	Name Eacod Tomporature	(0)	PIPE-Cold Out-RHX-01	to PIPE-Hot I	n-Vacum Cham	PIPE-Hot Out-RHX-01 to F	PIPE-HV-03 to HV-01	
34	Feed Pressure	(bar 0)	11.67	•	11.40 *	5 228 *	11.94	
35	Product Temperature	(C)	328.0		598.3	277.2	125.7	
36	Product Pressure	(bar_g)	11.65		11.35	5.214	11.78	
37	Insulation Conductivity	(W/m-K)	6.634e-002	•	8.438e-002 *	6.313e-002 *	5.395e-002 '	
38	Insulation Thickness	(m)	0.1016		0.1016	0.1016	0.1016	
39	Name Eaco Tomo craturo	(0)	PIPE-HV-02 to Comp	PIPE-HX-0	01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-0	
40	Feed Temperature	(bar d)	19.94		20.00 -	0.000	3 725	
42	Product Temperature	(C)	19.89		19.94	6.667 *	17.78	
43	Product Pressure	(bar_g)	4.613		4.832	3.987 *	3.508	
44	Insulation Conductivity	(W/m-K)	4.781e-002	•	4.782e-002 *	3.254e-002 *	3.328e-002 *	
45	Insulation Thickness	(m)	0.1016		0.1016	3.810e-002	3.810e-002	
46	Name		PIPE-CWR-HV-002 to C	hil PIPE-CWS	S-Chiller to HV-D	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03	
47	Feed Temperature	(C)	17.78		6.661	125.7	126.8	
49	Product Temperature	(ball q) (C)	3.032		4.175	125.7	12.20	
50	Product Pressure	(bar g)	3.831		4.174	11.76	11.95	
51	Insulation Conductivity	(W/m-K)	3.328e-002	•	3.254e-002 *	5.392e-002 *	5.398e-002 *	
52	Insulation Thickness	(m)	3.810e-002		3.810e-002	0.1016	0.1016	
53	Name		PIPE-CWS-HV-001 to O	ut PIPE-CWS	S-Outside Wall to	PIPE-CWR-HV-004 to Out	PIPE-CWR-Outside Wall t	
54	Feed Temperature	(C)	6.661		6.663	17.78	17.78	
55 55	Preduct Temperature	(par_g)	4.172		3.829	3.507	3.503	
57	Product Pressure	(bar o)	3 829		3.825	3.503	3.833	
58	Insulation Conductivity	(W/m-K)	3.254e-002	•	3.254e-002 *	3.328e-002 *	3.328e-002 *	
59	Insulation Thickness	(m)	3.810e-002		3.810e-002	3.810e-002	3.810e-002	
60 61 62 63	Aspen Technology Inc							
	Licensed to: UNIVERSITY OF ID						Specified by user	

Aspen HYSYS Process Model of Microreactor AGile Non-nuclear Experimental Testbed with PCU using Helium Operating at 600°C and 250 kW of Heat Pipe Power



1			Case N	ame: detailed	d ini test i	bed 250 kw He PCU Pressur	res.hsc
2	(easpentech Bedford, MA	OF IDAHO	Unit Set	t: MAGNE	ET		
4	USA		Date/Tir	me: Wed Ju	un 03 14:	41:37 2020	
6 7 8	Workbook:	Case (Main)					
9 10			laterial	Streams		Fluid	1 Pkg: All
11	Name	HX-01 Hot In		CWR		CWS	HX-01 Hot Out
12	Temperature	C)	225.6		17.78	6.667 *	20.00 *
13	Pressure (bar	g)	5.567		3.726	3.987 *	5.454
14	Mass Flow (kg	(S) 0	1943		5.398	5.398 *	0.1943
15	Mass Density (Kgm Mass Enthaloy (kgm	3) U	1042	-1 207e	1066	-1 2100+004	-25.44
17	Mass Entropy (kJ/ko-	g) C)	19.80	-1.20/6	.5631	0.4282	17.07
18	Name	RHX-01 Cold In		RHX-01 Cold Out		Vacuum Chamber In	Vacuum Chamber Out
19	Temperature	C)	149.7	:	353.1	352.4	600.0 *
20	Pressure (bar	g)	11.73		11.66 *	11.65	11.40 *
21	Mass Flow (kg	s) 0	1943	0.	.1943	0.1943	0.1943
22	Mass Density (kg/n	3)	1.450	0	.9736	0.9741	0.6841
23	Mass Enthalpy (KJ/	g)	647.5		1705	1701	2988
25	Name (KJ/Kg	BHX-01 Hot In	17.57	RHX-01 Hot Out	19.02	Comp in	6
26	Temperature	C)	429.2	and of the out	225.8 *	20.01	20.01
27	Pressure (bar	g)	5.737 *		5.572 *	5.271	5.350
28	Mass Flow (kg	(S) 0	1943	0.	.1943	0.1943 *	0.1943
29	Mass Density (kg/n	3) 0	4626	0	.6353	1.032	1.045
30	Mass Enthalpy (kJ/l	g)	2100		1043	-26.39	-26.40
31	Mass Entropy (KJ/Kg-	C) Chiller In	21.52	Chiller Out	19.80	17.13	17.11
33	Temperature	Cililei III	17.78	onlier out	6 658	6.663	17.78
34	Pressure (bar	g)	3.832		3.736	3.823	3.511
35	Mass Flow (kg	5)	5.398	-	5.398	5.398	5.398
36	Mass Density (kg/n	3)	1068		1077	1077	1068
37	Mass Enthalpy (kJ/	q) -1.207e	+004	-1.210e	2+004	-1.210e+004	-1.207e+004
38	Mass Entropy (KJ/Kg-	C) 0.	5631	CMR 03	.4281	0.4282 CIMP 02	0.5631
39 40	Temperature	CWR-05	17.78	CWR-05	17.78	17.78	6 661
41	Pressure (bar	a)	3.834		3.507	3.510	4.167
42	Mass Flow (kg	5)	5.398	-	5.398	5.398	5.398
43	Mass Density (kg/n	3)	1068		1068	1068	1077
44	Mass Enthalpy (KJ/	g) -1.207e	+004	-1.207e	2+004	-1.207e+004	-1.210e+004
45	Mass Entropy (kJ/kg-	C) 0	5631	0.	.5631	0.5631	0.4281
46	Name	CWS-03	5.661	CWS-06		13	14 140.8
48	Pressure (bar	a)	4.165		3.818	11,81	11.74
49	Mass Flow (kg	(5)	5.398		5.398	0.1943	0.1943
50	Mass Density (kg/n	3)	1077		1077	1.456	1.451
51	Mass Enthalpy (kJ/	g) -1.210e	+004	-1.210e	2+004	652.8	647.9
52	Mass Entropy (kJ/kg-	C) 0.	4281	0.	.4282	17.57	17.57
53	Name	15	140.8	16	20.01	Comp Out	4-2
55	Pressure (har	a)	11.73		5.347	11 92 *	100.7
56	Mass Flow (kg	s) 0	1943	0	.1943	0.1943	0.1943
57	Mass Density (kg/n	3)	1.450		1.044	1.458	1.456
58	Mass Enthalpy (kJ/	g)	647.9	-	26.40	653.4	652.8
59	Mass Entropy (kJ/kg-	C)	17.57		17.11	17.55	17.57
60 61 62							
63	Aspen Technology Inc.	Asc	en HYS	YS Version 9			Page 1 of 4

1	UNIVERSITY OF	DANO.	Case	Name: detailed ini tes	t bed 250 kw He PCU Pressu	res.hsc
3	(e)aspentech Bedford, MA	IDANO	Unit S	et: MAGNET		
4	USA		Date/1	Time: Wed Jun 03 14	4:41:37 2020	
6 7 8	Workbook: Ca	ase (Main) (cor	ntinued)		
9 10		Material	Strea	ams (continued)	Flui	1 Pkg: All
11	Name	CWS-01		Turbine In	CWR-04	CWS-05
12	Temperature (C)	6.0	661	598.4	17.78	6.665
13	Pressure (bar_g)	4.	168	11.38	3.835	3.820
14	Mass Flow (kg/s)	5.	398	0.1943	5.398	5.398
15	Mass Density (Kg/m3) Mass Enthalow (k l/kg)	-1 210eu	0//	0.6843	1068	10//
10	Mass Entropy (kJ/kg-C)	0.4	281	21.38	0.5631	0.4282
18	(and ching c)			acitions		Dhay All
19			omp	ositions	Fius	a Pilg: All
20	Name	HX-01 Hot In		CWR	CWS	HX-01 Hot Out
21	Master Comp Mass Frac (Heilum)	1.0		0.4461	0.4451	1.0000
23	Master Comp Mass Frac (EGIycol)			0.5539	0.5539	
24	Name	RHX-01 Cold In		RHX-01 Cold Out	Vacuum Chamber In	Vacuum Chamber Out
25	Master Comp Mass Frac (Hellum)	1.0	000	1.0000	1.0000	1.0000
26	Master Comp Mass Frac (EGlycol)					•••
27	Master Comp Mass Frac (H2O)					
28	Name Master Comp Mass Etap (Hollum)	RHX-01 Hot In	000	RHX-01 Hot Out	Comp In	1 0000
30	Master Comp Mass Frac (Felum)	1.0		1.0000	1.0000	1.0000
31	Master Comp Mass Frac (H2O)					
32	Name	Chiller In		Chiller Out	CWS-04	CWR-01
33	Master Comp Mass Frac (Hellum)					
34	Master Comp Mass Frac (EGlycol)	0.4	461 *	0.4461	0.4461	0.4461
35	Master Comp Mass Frac (H2O)	0.5	539 *	0.5539	0.5539 CWIR 02	0.5539
37	Name Master Comp Mass Frac (Helium)	CWR-05		CWR-03	CWR-02	CWS-02
38	Master Comp Mass Frac (EGlycol)	0.4	461	0.4461	0.4461	0.4461
39	Master Comp Mass Frac (H2O)	0.5	539	0.5539	0.5539	0.5539
40	Name	CWS-03		CWS-06	13	14
41	Master Comp Mass Frac (Hellum)				1.0000	1.0000
42 43	Master Comp Mass Frac (EGIycol)	0.4	461	0.4461		
44	Name	15		16	Comp Out	4-2
45	Master Comp Mass Frac (Hellum)	1.0	000	1.0000	1.0000	1.0000
46	Master Comp Mass Frac (EGlycol)					
47	Master Comp Mass Frac (H2O)					
48	Name	CWS-01		Turbine in	CWR-04	CWS-05
49 50	Master Comp Mass Frac (Heilum) Master Comp Mass Frac (EGivcol)	0.4	461	1.0000	0.4451	0.4461
51	Master Comp Mass Frac (H2O)	0.5	539		0.5539	0.5539
52				. Stroome	Eluk	Dkn: All
53	Mama	El Mant Dince	nerg)			
54	Name Heat Flow (MA)	Heat Pipes		PIPE-RHX-U1 Cold OUT H	PIPE-RHX-01 Hot in Heat	PIPE-RHX-01 Hot Out Hei
56	Name	PIPE-HV-03 Heat	0.0	PIPE-HX-01 Hot Heat	PIPE-HV-02 Heat	Comp Power
57	Heat Flow (kW)	0.9	656	-6.659e-003	-6.391e-004	132.1
58	Name	Chiller Duty		PIPE-CWS-06 Heat	PIPE-CWS-03 Heat	PIPE-CWR-02 Heat
59	Heat Flow (kW)	20	8.0	-2.867e-002	-1.989e-002	-6.123e-003
60	Name	PIPE-CWR-Heat		PIPE-CWR-05 Heat	PIPE-CWS-01 Heat	PIPE-HV-01 Heat
61 62	Heat Flow (KW)	-7.578e-	003	-2.424e-003	-1.032e-002	7.222 e -002
63	Aspen Technology Inc.	Aspe	n HYS	SYS Version 9		Page 2 of 4
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1				Case	Name: detailed ini test	bed 250 kw He PCU Pressu	res.hsc	
3	@aspentech	Bedford, MA	IUANO	Unit	Set: MAGNET			
4		USA		Date	Time: Wed Jun 03 14	:41:37 2020		
6 7	Wor	khook: C	ace (Main)	100	ntinued)			
8	4401	NDOOK. CO	ase (main)	(00	ininueuj			
9 10			Energy	/ Stre	ams (continued)	Flui	d Pkg:	All
11	Name		PIPE-Comp Heat		Chiller Pump Power	Turbine Power	PIPE-CWS-04 He	at
12	Heat Flow	(kW)	0.	1162	0.2889	170.8	-2.605	5e-002
13	Name Heat Flow	0000	PIPE-CWR-03 Hea	t 				
15	THEAT THE W	(811)	1.001	ц.	esters	Fini	1 Pka:	All
16	Nama		Varian Chamber				<u>-</u> -	
17	Name	0000	vacuum chamber	250.0				
19	Feed Temperature	(C)		352.4				
20	Product Temperature	(C)		500.0 *				
21	Mass Flow	(kg/s)	0.	1943				
22				C	oolers	Flui	d Pkg:	All
24	Name		Chiller					
25	DUTY	(KW)		208.0				
26	Feed Temperature	(C)		17.78				
27	Product Temperature	(C)	(5.658				
28	Mass Flow	(kg/s)		5.398				
29 30			H	leat E	xchangers	Flui	d Pkg:	All
31	Name		RHX-01		Chiller HX-01			
32	Duty	(kW)	:	205.4	207.6			
33	Tube Side Feed Mass Flow	(kg/s)	0.	1943	0.1943			
34	Shell Side Feed Mass Flow	(kg/s)	0.	1943	5.398 *			
36	Tube Outlet Temperature	(C)		+29.2 225.8 *	225.0			
37	Shell Inlet Temperature	(C)		149.7	6.667 *			
38	Shell Outlet Temperature	(C)	;	353.1	17.78			
39	LMTD	(C)		76.11	62.01			
40	UA	(W/C)		2699	3348			
41 42	Minimum Approach	(C)	1	76.08	13.33			
43				P	umps	Flui	d Pkg:	All
44	Name		Chiller Pump					
45	Power	(KW)	0.	2889				
46	Feed Pressure	(bar_g)		3.736				
47 49	Product Pressure	(bar_g)		4.168				
49	Feed Temperature	(C)		5.658				
50	Adiabatic Efficiency	(%)		75.00				
51	Pressure Ratio			1.091				
52	Mass Flow	(kg/s)		5.398				
53								
54								
56								
57								
58								
59								
60 64								
61 62								
63	Aspen Technology Inc.		Asp	en HY	SYS Version 9		Page	3 of 4
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1			Ca	se Name: detailed ini tes	t bed 250 kw He PCU Pressu	res.hsc		
3	(aspentech	UNIVERSITY OF Bedford, MA	Un	t Set: MAGNET				
4		USA	Da	e/Time: Wed Jun 03 14	4:41:37 2020			
6 7 8	Work	(book: Ca	ase (Main) (co	ontinued)				
9			Co	npressors	Fluid	1 Pkg: All		
11	Name		Comp-01					
12	Power	(KW)	132.1					
13	Feed Pressure	(bar g)	5.271					
14	Product Pressure	(bar q)	11.92	•				
15	Product Temperature	(C)	150.8					
16	Feed Temperature	(C)	20.01					
17	Adiabatic Efficiency		75	•				
18	Pressure Ratio		2.059					
19	Mass Flow	(kg/s)	0.1943	•				
20 21	Expanders Fluid Pkg: All							
22	Name		Turbine					
23	Power	(KW)	170.8					
24	Feed Pressure	(bar_g)	11.38					
25	Product Pressure	(bar q)	5.737	•				
26	Product Temperature	(C)	429.2					
27	Feed Temperature	(C)	598.4					
28	Adiabatic Efficiency	(h-h-)	90	•				
29	Mass Flow	(Kg/S)	0.1943					
30			Pipe	Segments	Fluid	1 Pkg: All		
32	Name		PIPE-Cold Out-RHX-01	p PIPE-Hot In-Vacum Cham	PIPE-Hot Out-RHX-01 to H	PIPE-HV-03 to HV-01		
33	Feed Temperature	(C)	353.1	600.0	225.8 *	150.7		
34	Feed Pressure	(bar_g)	11.66	11.40	5.572 *	11.81		
35	Product Temperature	(C)	352.4	598.4	225.6	149.8		
36	Product Pressure	(bar_g)	11.65	11.38	5.567	11.74		
37	Insulation Conductivity	(W/m-K)	6.790e-002	* 8.439e-002 *	5.993e-002 *	5.538e-002 *		
38	Insulation Thickness	(m)	0.1016	0.1016	0.1016	0.1016		
39	Name Each Tomporphise	(0)	PIPE-HV-02 to Comp	PIPE-HX-01 to HV-02	PIPE-CWS-HV-003 to HX-	PIPE-CWR-HX-01 to HV-0		
40	Feed Temperature	(0)	20.01	20.00	0.000	3 725		
42	Product Temperature	(0al_g) (C)	20.01	20.01	6.667 *	17.78		
43	Product Pressure	(bar q)	5.271	5.350	3.987 *	3.511		
44	Insulation Conductivity	(W/m-K)	4.782e-002	4.782e-002	3.254e-002 *	3.328e-002 *		
45	Insulation Thickness	(m)	0.1016	0.1016	3.810e-002	3.810e-002		
46	Name		PIPE-CWR-HV-002 to C	NI PIPE-CWS-Chiller to HV-0	PIPE-HV-01 to RHX-01	PIPE-Comp to HV-03		
47	Feed Temperature	(C)	17.78	6.661	149.8	150.8		
48	Feed Pressure	(bar q)	3.834	4.168	11.73	11.92 '		
49	Product Temperature	(C)	17.78	6.661	149.7	150.7		
50	Product Pressure	(bar_g)	3.832	4.16/	5 5350 000 -	11.81 5.5410 000 r		
51	Insulation Thickness	(w///HK) (m)	3.810=002	3.8106-002	0.000-002	0.0416-002		
53	Name	(0)	PIPE-CWR-HV-004 to O	ut PIPE-CWR-Outside Wall t	PIPE-CWS-HV-001 to Out	PIPE-CWS-Outside Wall t		
54	Feed Temperature	(C)	17.78	17.78	6.661	6.663		
55	Feed Pressure	(bar_g)	3.510	3.507	4.165	3.823		
56	Product Temperature	(C)	17.78	17.78	6.663	6.665		
57	Product Pressure	(bar_g)	3.507	3.835	3.823	3.820		
58	Insulation Conductivity	(W/m-K)	3.328e-002	* 3.328e-002 *	3.254e-002 *	3.254e-002 '		
59	Insulation Thickness	(m)	3.810e-002	3.810e-002	3.810e-002	3.810e-002		
60 61 62								
63	Aspen Technology Inc.		Aspen H	YSYS Version 9		Page 4 of 4		

Appendix D: Pipe Insulation Data Sheet

MAGNET Gas Pipe Insulation Data Sheet (Johns Manville, 2019)



INDUSTRIAL INSULATION

THERMO-1200[™] Calcium Silicate Pipe & Block Insulation

DATA SHEET

THERMO-1200™

Thermo-1200[™] is a water resistant, Type I calcium silicate pipe and block insulation, designed for applications that operate at temperatures up to 1200°F (650°C).

BENEFITS

Water Resistant*: Thermo-1200[™] is the only North American calcium silicate insulation available that is water resistant. The insulation is engineered to withstand a heavy rainfall (114" of rain/ hour) for up to 20 minutes without absorbing more than 15% of its weight in water. This will allow contractors to install the insulation without immediately applying the jacketing afterward, offering more time and flexibility in the installation process than has traditionally been available.

Inhibits Corrosion: A proprietary corrosion inhibitor, called XOX Corrosion Inhibitor®, is integral to the chemical makeup of Thermo-1200TM. XOX Corrosion Inhibitor helps protect against corrosion under insulation (CUI) and makes Thermo-1200TM one of the least corrosive thermal insulations available.

Durable: Thermo-1200[™] is a cementitious insulation with exceptional compressive strength (>100 psi/690kPa), making it ideal for applications where mechanical abuse is likely. The inorganic binder will hold its shape and maintain the physical integrity of the insulation, even past 450°F, the point at which most organic binders burn off.

Extended Life Cycle: When properly installed and maintained, Thermo-1200's superior physical strength and inorganic binders can provide an insulation lifespan of up to 25 years or more.

FEATURES

- Non-combustible, cementitious insulation
- Temperature range: Ambient to 1200°F
- Asbestos, lead, and mercury-free

APPLICATIONS

In addition to water resistance, Thermo-1200^m offers superior durability and compressive strength. This is coupled with high-temperature, corrosion-inhibiting performance, making it ideal for the following applications:

Pipe and Equipment:

- Chemical Processing
- Power Generation
 Petroleum Refining
- 5

QUALITY STATEMENT

Johns Manville industrial products are designed, manufactured and tested to strict quality standards in our own facilities. This, along with third party auditing is your assurance that this product delivers consistently high quality.



FIRE SAFETY

Surface Burning Characteristics. When tested in accordance with ASTM E84 and UL 723, Thermo-1200[™] has flame spread/smoke developed ratings of 0/0.

Non-Combustible. When tested in accordance with ASTM E136 as defined by NFPA 101.

ISO 9000 CERTIFICATION

Thermo-1200[™] is manufactured and tested in our own facilities under implemented Quality Management Systems which are certified to be in accordance with ISO 9001quality standards. This certification, along with regular, independent third-party auditing of our plant and records for compliance, is your assurance that this product consistently delivers high quality performance.

PRODUCT CERTIFICATION

When ordering material to comply with any government specification or any other listed specification, a statement of that fact must appear on the purchase order. Government regulations and other listed specifications require specific lot testing, and prohibit the certification of compliance after shipment has been made. There may be additional charges associated with specification compliance testing. Please refer to JM-IND-CSP-3 for Certification Procedures and Charges. Call customer service for more information (1-800-866-3234).

*Thermo-1200™ water resistant calcium silicate is not hydrophobic. Thermo-1200 ™ is designed to be able to withstand short periods of rainfail without absorbing water in excess. The volume of water absorption depends on the duration of exposure and the amount of rainfail. The insulation is not meant to withstand extreme weather conditions without jacketing. While this new water resistant testure can be helpful during protonged field installations, it is nevertheless recommended that an installer weatherproof and jacket the thermal insulation as soon as it is feasibly possible. Should water enter the system, the corrosion inhibitors will still activate to continue to help combat corrosion at a chemical level, and once the system reaches operating temperatures, the water will vaporize and leave the system.

IND- 303 10/16/19 (Replaces IND-300 05/28/19)

INDUSTRIAL INSULATION

THERMO-1200™

CALCIUM SILICATE PIPE & BLOCK INSULATION

DATA SHEET

THERMAL CONDUCTIVITY



 ASTM C335 (Pipe)
 Btu *in/(hr + ft⁰ * F)
 344
 389
 4.47
 4.86
 5.38
 5.91
 6.47

 W/m * C
 .050
 .056
 .063
 .070
 .078
 .085
 .093

 ASTM C518
 Btu *in/(hr * ft⁰ * F)
 .355
 .373
 .397
 .428
 .405
 .509
 .559

 (Flat)
 W/m * C
 .051
 .054
 .057
 .082
 .067
 .073
 .081

* Thermo-1200 Insulation is tested in accordance with ASTM C518 and ASTM C335.

AVAILABLE FORMS & SIZES

Insulation Form: Round Surfaces	Pipe Size (in)	Pipe Size (mm)
Pipe Insulation	1/2-24	15-600
Quad Segments	20-37	500-925
Hex Pipe Covering (Ruston Plant Only)	38-52	950-1300
3-V Scored Block Width: 12"/305mm Length: 36"/914mm	30 minimum	750 minimum
Curved Segments	30-126	762 - 3200
Beveled Lags	126 and higher	3200 and higher
Insulation Form: Flat Surfaces	Insulation Size (in)	Insulation Size (mm)
Flat Block	Width: 6 and 12 Length: 36	Width: 152 and 305 Length: 914

SPECIFICATION COMPLIANCE

ASTM C165 Compressive Strength	>100psi (690kPa) 5% compression
ASTM C203 Flexural Strength	>50psi (450kPa)
ASTM C302 Density (Dry) Average	<15pcf (240kg/m ²)
ASTM C356 Linear Shrinkage	<2.0% after 24hr Soaking period at 1200°F (650°C)
ASTM C421 Abrasion Resistance Weight Loss by Tumbling	After the first 10min <20% After the second 10min<40%
ASTM C447 Maximum Service Temperature	1200°F (650°C)
ASTM C533, Type I Material Specification	Passes
ASTM C665 Corrosivity to Steel	Passes
ASTM C795/C871/C692 Corrosion: Austenitic Stainless Steel	Passes
ASTM C1338 Fungi Resistant	Passes
ASTM C1617 Corrosion	Passes (<di td="" water)<=""></di>
ASTM EB4 Surface Burning Characteristics	Flame Spread: 0 Smoke Developed: 0
ASTM E136 Non-Combustible	Passes
NRC Reg. Guide 1.36	Passes
MIL-1-24244	Passes
MIL-I-2781 1200°F (650°C) [Pipe] Military Specification	Passes
MIL-PRF-2819 Class 2 to 1200°F (650°C) [Block] Military Specification	Passes

3-V SCORED BLOCK APPLICATION GUIDE

Minimum Diameter									
	Insulation	n Thickness	Triple Sc	ored					
	in	mm	in	mm					
	1½	38	30	762					
	2	51	40	1016					
	21/2	64	50	1270					
	3	76	60	1524					



717 17th St. Denver, CO 80202 (800) 866-3234 JM.com Technical specifications as shown in this literature are intended to be used as general guidelines only. Please refer to the Safety Data Sheet and product label prior to using this product. The physical and chemical properties of the Thermo-1200[™] listed herein represent typical, average values obtained in accordance with accepted test methods and are subject to normal manufacturing variations. They are supplied as a technical service and are subject to change without notice. Any references to numerical flame spread or smoke developed ratings are not intended to reflect hazards presented by these or any other materials under actual fire conditions. Check with the Regional Sales Office nearest you for current information.

All Johns Manville products are sold subject to Johns Manville's standard Terms and Conditions, which includes a Limited Warranty and Limitation of Remedy. For a copy of the Johns Manville standard Terms and Conditions or for information on other Johns Manville thermal insulation and systems, visit www.jm.com/terms-conditions or call (800)654-3103.

IND- 303 10/16/19 (Replaces IND-300 05/28/19)

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MAGNET Outside Chiller Loop Pipe Insulation Data Sheet (Owen Corning, 2017)



SSL II" WITH ASJ MAX FIBERGLAS" PIPE INSULATION FIBERGLASS INSULATION



Description

Owens Corning* SSL II* with ASJ Max Fiberglas™ Pipe Insulation is molded of heavy density resin bonded inorganic glass fibers that come in one-piece, 36° (914mm) long, hinged sections. The insulation is tailored to fit for copper and iron pipe applications.

Features

- ASJ Max is an all-service-jacket with a polymer film exterior surface that is smooth, durable, cleanable, wrinkle-resistant, resists water staining and doesn't support mold or mildew growth¹
- ASJ Max can resist short durations of water exposure that may occur during construction
- SSL II* Positive Closure System is an advanced double adhesion that fastens and installs with no need for staples or mastic
- Insulation is tailored to fit with:
- FlexCore technology to compress over copper and some small-bore iron pipes and fittings, saving time by eliminating the need to fillet
 RigidCore technology for fast and easy
- fabrication on larger pipes

 The product has a maximum operating
- temperature of 1,000°F (538°C) (with heat-up schedule)
- The product does not contain Polybromodiphenyl ethers (PBDE) (penta-, octa-, or deca-brominated diphenyl)

1. ASJ Max jacket does not support mold growth as tested in accordance with ASTM C1338.



Physical Properties

PROPERTY	TEST METHOD	VALUE
Density (size dependent)	ASTM C302	3.5 to 5.5 pcf
Operating Temperature Range ²	ASTM C411	0°F to 1,000°F (-18°C to 538°C)
Water Vapor Sorption	ASTM C1104	Less than 5% by weight
Corrosion	ASTM C665	Pass - steel, copper, and aluminum
Corrosion	ASTM C1617	Pass - steel
Jacket Temperature Limitation	ASTM C1136	-20°F to 150°F (-29°C to 66°C)
Jacket Permeance	ASTM E96, Proc. A	0.01 perm
Burst Strength, min	ASTM D774/D774M	100 psi
Composite Surface Burning Characteristics ^a	UL 723, ASTM EB4 or CAN/ULC-S201	Flame Spread 25 Smoke Developed 50

With heat-up schedule when operating temperatures between 850^{opt} and 1,000^{opt}.
 The surface burning characteristics of these products tervis team determined in accordance with UI, 723, ASTM E84 or CAVULCE-000, Walass are sponted to the measure 5 reling.

Standards, Codes Compliance

- ASTM C547, Mineral Fiber Pipe Insulation: Type I, Grade A; and Type IV, Grade B
- ASTM C585, Inner and Outer Diameters of Thermal Insulation for Nominal Sizes of Pipe and Tubing
- ASTM C1136, Flexible Low Permeance Vapor Retarders for Thermal Insulation: Types I, II, III, IV, X
- UL Labeled for Flame Spread Index of 25 or less and Smoke Developed Index of 50 and is fully building code compliant
- UL Listed and Labeled for use over PVC and other polymer pipes UL Category BSMP
- ASTM C795, Thermal Insulation for Use in Contact with Austenitic Stainless Steel⁴
- Nuclear Regulatory Commission Guide 1.36, Non-Metallic Thermal Insulation⁴
- MIL-PRF-22344E, Insulation, Pipe, Thermal, Fibrous Glass
- MIL-DTL-32585, Type I, Form 4, Facing A
- MIL-DTL-24244D (Ships) Insulation Material with Special Corrosion, Chloride, and Fluoride Requirements⁴
- NFPA 90A and 90B

4. Preproduction qualification testing complete and on file. Chemical analysis of each production lot required for total conformance. Certification needs to be specified at time of order.

Applications

- Used to insulate iron, copper, PVC and other polymer pipes with operating temperatures between 0°F (-18°C) to 1,000°F (538°C) in commercial & institutional buildings, and industrial facilities
- When temperatures are above 650°F (454°C), maximum installed insulation thickness shall be no greater than 6' as a single layer or nested
- Rated per ASTM C547, Type I, Grade A Pipe insulation can be installed on in-service/hot pipes with an operating temperature up to 850°F (454°C)
- Rated per ASTM C547, Type IV, Grade B When operating temperatures will be between 850°F (454°C) to a 1,000°F (538°C) a heat-up schedule needs to be followed per the Installation Instructions, Pub No. 10021355
- When installed outdoors, an additional weather-protective jacket is required

Thermal Conductivity

	_		
MEAN TEMP °F	K BTU•IN/HR•FT ² * ⁰ F	MEAN TEMP °C	λ ₩/M•°C
50	0.22	10	0.032
75	0.23	25	0.034
100	0.24	50	0.037
150	0.27	100	0.043
200	0.29	125	0.047
250	0.32	150	0.051
300	0.35	175	0.056
350	0.39	200	0.062
400	0.43	225	0.068
450	0.48	250	0.075
500	0.54	275	0.082
			-

Apparent thermal conductivity values determined in accordance with ASTM practice C1045 with data obtained by ASTM Test Method C335. Values are nominal, subject to normal testing and manufacturing tolerances.

Thickness to Prevent Surface Condensation

.

Owens Corning* ASJ Max Jacket for up to 16" NPS (400mm DN), in. (mm)56

AMBIENT TEMP		RELATIVE	SYSTEM OPERATING TEMPERATURES							
oF	(°C)	HUMIDITY	35°F	(2°C)	45°F	(7°C)	55°F	(13°C)		
110	(43)	70%	1	(25)	1	(25)	1	(25)		
		80%	11/2	(38)	11/2	(38)	11/2	(38)		
		90%	31/2	(89)	31/2	(89)	3	(76)		
100	(38)	70%	1	(25)	1	(25)	1	(25)		
		80%	11/2	(38)	11/2	(38)	1	(25)		
		90%	31/2	(89)	3	(76)	21/2	(64)		
90	(32)	70%	1	(25)	1	(25)	1	(25)		
		80%	11/2	(38)	1	(25)	1	(25)		
		90%	31/2	(89)	3	(76)	21/2	(64)		
80	(27)	80%	11/2	(38)	1	(25)	1	(25)		
		90%	3	(76)	21/2	(64)	2	(51)		
70	(21)	80%	1	(25)	1	(25)	1	(25)		
		90%	21/2	(64)	2	(51)	1	(25)		
		90%	21/2	(64)	2	(51)	1			

"Calculations estimated using NAIMA 3E Plus version 4.0 software. Fixed design conditions: Steel Horizontal Piping 16" NPS, 0 mph wind speed, Oxfer Surface Jacket Emittence of 0.9. "Nermal conductivity values used in these calculations are subject to normal manufacturing tolerances.

Availability

Our Fiberglas[™] Pipe Insulation portfolio is available in thicknesses up to 5". Contact your local Owens Corning Area Sales Manager for product availability.

Refer to Pipe Insulation Sizing Manual for more information: Pub. No. 10018078.

Installation

Ambient application temperatures are from 25°F (-4°C) to 110°F (43°C).

For complete installation instructions and recommendations see 'Fiberglas™ Pipe Insulation Installation Instructions' (Pub. No. 10021355).

Environmental and Sustainability

Owens Corning is a worldwide leader in building material systems, insulation and composite solutions, delivering a broad range of high-quality products and services. Owens Corning is committed to driving sustainability by delivering solutions, transforming markets and enhancing lives. More information can be found at www.owenscorning.com.

Certifications and Sustainable Features

- Certified by SCS Global Services to contain an average of 53% recycled glass content, 31% pre-consumer and 22% post-consumer
- For faced products: GREENGUARD Certified products are certified to GREENGUARD standards for low chemical emissions into indoor air during product usage. For more information, visit ul.com/gg
 Environmental Product Declaration (EPD) has been
- Environmental Product Declaration (EPD) has been certified by UL Environment
- Material Health Certificate from Cradle to Cradle Products Innovation Institute or Health Product Declarations available



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OWENS CORNING INSULATING SYSTEMS, LLC ONE OWENS CORNING PARKWAY TOLEDO, OHIO, USA 43659

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PRODUCT DATA SHEET

Fiberglas^{**} OWENS VaporWick[®] Pipe Insulation CORNING



Description

Owens Corning* VaporWick* Pipe Insulation is an innovative insulation product designed specifically for below-ambient temperature applications in severe hot/humid operating environments. The heart of the system is a wick material that transports condensed water to the outside of the system for evaporation to the atmosphere. The wick keeps the fiberglass insulation dry, preventing dripping and allowing the insulation to perform effectively over the life of the project.

VaporWick* Pipe Insulation's one-piece, 36" (914mm) long molded sections come in standard sizes and are composed of heavy density fiberglass insulation with an organic binder. The synthetic wicking material is factory-installed on the inner surface of the assembly. The sections are opened, placed over the pipe, closed and secured with a pressuresensitive adhesive closure. The insulation is factory-jacketed with a resilient, tough, soil-resistant polymer facing that matches standard PVC fitting covers. Auxiliary items include rolls of wick material for wrapping elbows and valves; VaporWick* Pipe Insulation evaporation skirt (hula skirt) for verticals; and matching butt joint sealing tape for system closure

Availability

VaporWick® Pipe Insulations are available in thickness and for pipe sizes as follows.										
insulation T	hickness	Nominal P	ipe Sizes							
Inches	(mm)	NPS, Inches	(DN, mm)							
1	(25)	¥₂-24	(15-600)							
11/2	(38)	V2-24	(15-600)							
2	(51)	Va-30	(15-762)							
21/2	(64)	2-30	(50-762)							
3	(76)	3-30	(75-762)							

For additional sizes, check with your Owens Coming repres

Physical Properties

Property	Test Method	Value
Operating Temperature Range		32°F to 220°F (0°C to 104°C)
Jacket Permeance	ASTM E96, Desicant method	< 0.15 perm
Jacket Temperature Limitation	ASTM C1136	225°F (107°C)
Burst Strength, min	ASTM D774/ D774M	55 psi
Corrosion Resistance	ASTM C665	Meets requirements
Fungi Resistance	ASTM C1338	Meets requirements
Composite Surface Burning Characteristics ¹ Flame Spread Smoke Developed	ASTM E94, UL 723, and CAN/ULC-S102	< 25 < 50

 The surface butting characteristics of these products have been determined in accordance with ASTM EB4, UL 723, and CAN/ULC-S102. These standards should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment, which takes into account all of the factors, which are pertinent to an assessment of the fire hazard of a particular end use. Values are reported to the nearest 5 rating.

Features

- Keeps insulation dry by incorporating a specially designed wicking material that absorbs condensed water from the pipe surface and wicks it to the outside, keeping the insulation dry and minimizing any loss in insulating capability. This prevents dripping and the associated staining of ceiling tiles and damage to the building contents
- VaporWick* Pipe Insulation is rated for operating temperatures which range from 32°F to 220°F, making it ideal for dual temperature installations
- UL Classified for Surface Burning Characteristics. Flame spread rating of 25 or less, and smoke development rating of 50 or less means that VaporWick* Pipe Insulation will be granted immediate building code approval for use in air plenums and other critical locations
- Low thermal conductivity contributes to lower operating costs at a favorable installed cost/performance ratio
- Self-drying feature allows product to be installed on wet pipes. Systems do not need to be shut down during installation of the VaporWick* System
- Positive closure is fast, neat, and foolproof. No need for staples or mastic
- VaporWick* Pipe Insulation provides no sustenance for mold to propagate and meets the standard ASTM test for fungi resistance

Thermal Conductivity

Mean Temp. "F	k Btu-in/ hr-ft²-°F	Mean Temp. °C	λ.W/m∗°C
50	0.22	10	0.032
75	0.23	25	0.034
100	0.24	50	0.037
150	0.27	100	0.043
200	0.29	125	0.047

Note: Values are nominal, subject to normal testing and manufacturing tolerances.

Technical Information

- The VaporWick* System was developed for piping systems that operate at below ambient temperatures, which present special considerations due to the possibility of water vapor migration to the cold pipe surface. If the operating temperature of the piping system is below the dew point of the ambient air, moisture will condense on the cold pipe surface. With time, the condensed water will accumulate, reducing the R-value of the insulation, and possibly resulting in dripping, which can stain ceiling tiles and damage building contents below
- The problem is not limited to open cell insulation materials. Many closed cell insulations have low water vapor permeability, yet water buildup is a serious problem due to incomplete sealing at longitudinal seams and butt joints
- Traditionally, designers have relied on vapor retarders and mastics or other sealants to slow the ingress of moisture. This approach is highly dependent on the skill and experience of the installers. In contrast, VaporWick* Pipe Insulation incorporates a patented concept that utilizes a unique wicking material to remove condensed water from the system, keeping the insulation dry. Water vapor that enters the system and condenses on the cold pipe surface is removed to the outer surface by capillary action, where it then evaporates to the ambient air.

Applications

- VaporWick* Pipe Insulation is engineered for insulation of cold piping and dual temperature piping operating at temperatures from 32°F (0°C) to 220°F (104°C) in buildings and industrial facilities
- Installation of VaporWick* Pipe Insulation is similar to regular fiberglass pipe covering. See VaporWick* Pipe Insulation Installation Instructions for complete details (Publication No. 44645)

Installation

- The VaporWick* System can be applied on new and retrofit jobs. Unlike traditional insulation, this system may readily be installed on operating systems even if the pipes are wet and slightly corroded. Caution is needed on severely corroded sections as pipe diameters may exceed those listed in ASTM C585. This may cause an improper pipe fit and result in overloading of the system and/or failure of the closure tape resulting in system failure. For severely corroded pipes, rust and scale should be removed before installation. Ensure that the recommended thickness has been specified to prevent surface condensation
- The VaporWick* System is not recommended for outdoors or exposed piping where additional jacket finish is required. Application should be at temperatures between 25°F (-4°C) and 110°F (44°C)
- The evaporation holes must remain uncovered and unpainted at all times after installation. Painting or covering over the evaporation holes will defeat the function of the system. Use of stickers, labels, or colored tape is recommended for pipe service identification

Standards, Codes Compliance

- ASTM C547, Mineral Fiber Pre-Formed Pipe Insulation, Type 1²
- ASTM C795, Thermal Insulation for Use Over austenitic Stainless Steel³
- ASTM C585, Inner and Outer Diameters of Rigid Thermal Insulation for Pipe and Tubing
- Nuclear Regulatory Commission Guide 1.36, Non-Metallic Thermal Insulation³
- NFPA 90A
- NYC MEA No. 349-02M
 Exception required for max use temp.
- Preproduction qualification testing complete and on file. Chemical analysis of each production lot required for total conformance.

Thickness To Prevent Surface Condensation

VaporWick[®] Pipe insulation does not prevent surface condensation. Sufficient thickness must be selected to minimize condensation on the outer surface. Use the following table for guidance.

Fluid Temperature 35"F										
Ambient	Delative				Pipe	Size,	NPS			
Temp. "F	Humidity %				2"	4*	6"	8"	10 ^a	12"
	70	1	1	1	1	1	1	1	1	1
80	80	1	1	1	1	1	1	1	11/2	11/2
	90	11/2	11/2	2	2	2	2	21/2	21/2	21/2
	70	1	1	1	1	1	1	1	1	1
90	80	1	1	1	1	1	11/2	11/2	11/2	11/2
	90	2	2	2	21/2	3	3	3	3	31/2
Fluid Temperature 45*F										
Amblent	Delative				Pipe	Size,	NPS			
Temp. "F	Humidity %				2"	4*	6"	8"	10ª	12"
	70	1	1	1	1	1	1	1	1	1
80	80	1	1	1	1	1	1	1	1	1
	90	1	11/2	11/2	11/2	11/2	2	2	2	2
	70	1	1	1	1	1	1	1	1	1
90	80	1	1	1	1	1	1	1	1	1
	90	11/2	2	2	2	21/2	21/2	21/2	21/2	3
		Flu	id Ter	nperat	ure 55	FF.				
Amblent	Relative				Pipe	Size,	NPS			
Temp. "F	Humidity %	¥5*		1%	2"	4*	6"	8"	10°	12"
	70	1	1	1	1	1	1	1	1	1
80	80	1	1	1	1	1	1	1	1	1
	90	1	1	1	1	11/2	11/2	11/2	1½	11/2
	70	1	1	1	1	1	1	1	1	1
90	80	1	1	1	1	1	1	1	1	1
	90	11/2	11/2	11/2	11/2	2	2	2	2	2

Note: All thicknesses are in inches rounded up to the nearest available VaporWick® Pipe Insulation size.

Recommendations were developed using the NAIMA SE Plus® computer program, assuming wind speed of 0 mph and outer jacket emittance of 0.9.

Certifications and Sustainable Features

- · Certified by SCS Global Services to contain a minimum of 53% recycled glass content, 31% pre-consumer and 22% post-consumer
- GREENGUARD Certified products are certified to GREENGUARD standards for low chemical emissions into indoor air during product usage. For more information, visit ul.com/gg
- Environmental Product Declaration (EPD) has been certified by UL Environment
- Material Health Certificate from Cradle to Cradle Products Innovation Institute

Environmental and Sustainability

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Appendix E: Recuperating Heat Exchanger Data

PCHE Recuperating Heat Exchanger Process Specifications

Microreactor Recuperative HX Salient Features List 11/27/2019

A compact platelet heat exchanger with the following design parameters:

316L stainless steel
Cold Side Parameters

Compressed N2
Mass flow rate
0.938 kg/s
MAWP
22 barg
Nominal inlet pressure
12.0 barg
Nominal Δp
0.375 parg
0.375 parg
0.000 C
38 ° C
29-5an - 2020

We have the state of t

CES estimates Tout = 290°C For a heart balance of R = 0.32 MW



Recuperating Heat Exchanger Outer Dimensions

Ð					Spreadsheet	: SPRDSHT-RHX-01	Sizing				_ _ ×
Connections Parameters Formulas Spreadsheet Calculation Order User Variables Notes											
Current Cell Exportable Exportable Angles in:					Edit Rows/Columns]					
	A	В	с	D	E	F	G	н	1	J	к
1		Hot			Cold			Channel			
2		In	Out	Avg	In	Out	Avg	D	2.000 mm	2.000e-003 m	
3	m dot	0.9166 kg/s			0.9166 kg/s			Dh	1.222 mm	1.222e-003 m	
4	Temperature	598.5 C	282.7 C	440.6 C	31.66 C	358.3 C	195.0 C	P	24.60 mm	2.460e-002 m	
5	Pressure	1241 kPa	1223 kPa	1232 kPa	1285 kPa	1274 kPa	1280 kPa	Theta (Degrees)	6.430		
6	Viscosity	4.187e-002 cP	2.884e-002 cP	3.521e-002 cP	1.882e-002 cP	3.185e-002 cP	2.544e-002 cP	Theta (Rad)	0.1122		
7	Density	4.780 kg/m3	7.384 kg/m3	5.793 kg/m3	14.27 kg/m3	6.770 kg/m3	9.178 kg/m3	Lp (length per pitc	24.76 mm	2.476e-002 m	
8	Thermal Conducti	5.906e-002 W/m-K	4.222e-002 W/m-K	5.086e-002 W/m-K	2.686e-002 W/m-K	4.644e-002 W/m-K	3.716e-002 W/m-K	Af per Channel	1.571 mm2	1.571e-006 m2	
9	Mass Specific Heat	1.144 kJ/kg-C	1.093 kJ/kg-C	1.119 kJ/kg-C	1.065 kJ/kg-C	1.106 kJ/kg-C	1.080 kJ/kg-C	Channels per Sheet	65.00		
10	Pr	0.8112	0.7468	0.7746	0.7463	0.7583	0.7395	Number of Sheets	112.0	112.9	
11	Re hot	5563	а	9.126e-003	Re cold	7702		Af Cold	5.718e-003 m2		
12	f*Re	62.88	b	0.9913	f*Re	80.80		Af Hot	5.718e-003 m2		
13	dP hot	18.28 kPa	c	1.255e-003	dP cold	10.71 kPa		Perimeter	5.142e-003 m	Number of Pitch	9.086
14	Nu hot	15.58	d	1.058	Nu cold	20.30		As per Pitch	1.273e-004 m2	Number of Pitch	9.000
15	h hot	648.3 W/m2-C			h cold	617.2 W/m2-C		As Cold per Channel	1.146e-003		
16								As Hot per Channel	1.146e-003		
17	U	316.2 W/m2-C		Thickness of metal	0.7620 mm	7.620e-004 m		Total As Cold	4.170 m		
18	AU	1318 W/C		Metal K value	14.00 W/m-K			Total As Hot	4.170 m		
19	۸	4.170 m2		R for SS material	5.443e-005	1.837e+004 W/m2-C					
20	A actual	4.170 m2	UA actual	1318 W/C							
Delete Function Help Spreadsheet Only										🔲 Ignored	

Aspen HYSYS Spreadsheet of Recuperating Heat Exchanger Design Parameters







SPECIFICATIONS						
models	Inner tube design	outer tube design	Inner tube material	outer tube material	heat transfer area	weight
DTC-CUB/CUC-8-1-1	1250 psi at 300°F (86 bar at 148°C)	700 psi at 300°F (48 bar at 148°C)	1/2 in OD copper	1 in OD copper	2.52 ft ² (0.23 m ²)	30 lb (13.6 kg)
DTC-SSB/CUC-8-1-1	2400 psi at 1000°F (165 bar at 537°C)	700 psi at 300°F (48 bar at 148°C)	1/2 in OD 316 SS	1 in OD copper	2.52 ft ² (0.23 m ²)	30 lb (13.6 kg)
DTC-IN7/CUC-8-1-1	4000 psi at 900°F (276 bar at 482°C)	700 psi at 300°F (48 bar at 148°C)	1/2 in OD Inconel®	1 in OD copper	2.52 ft ² (0.23 m ²)	30 lb (13.6 kg)
DTC-SSB/SSD-8-1-1	2400 psi at 1000°F (165 bar at 537°C)	2300 psi at 1000°F (158 bar at 537°C)	1/2 in OD 316 SS	1 in OD 316 SS	2.52 ft ² (0.23 m ²)	30 lb (13.6 kg)
DTC-IN7/SSD-8-1-1	4000 psi at 900°F (276 bar at 482°C)	2300 psi at 1000°F (158 bar at 537°C)	1/2 in OD Inconel®	1 in OD 316 SS	2.52 ft ² (0.23 m ²)	30 lb (13.6 kg)

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Appendix F: Chiller Heat Exchanger Data

Chiller Heat Exchanger Process Specifications



REFERENCE

Thermal Calculation

Customer					
Project	COMPRESSED	NITROGEN COO	LER		
Item					
PROCESS		S	ERVICE	PR	ODUCT
Fluid			EG50	Nitrogen @	11 barg
Channel		She	llside	Tub	eside
Inlet temperature	[*F]		44.000	52	7.000
Outlet temperature	[*F]		64.000	6	68.000
Mass flow	[lb/h]	55 3	90.555	7 95	52.515
Volumetric flow	[gow]	1	03.155	2 16	0.840
Velocity	[ft/s]		3.791	5	6.659
Pressure loss	[psi]		3.7875	1	.6444
HEAT EXCHANGER		XLG@ I-SERIES			
Number of units / Model HEX	1	XLG8 I-6"/19x	1"-60"-304/30	4-X	
Nominal length of units	[ft]	4,92			
Flow arrangement		Counterflow			
PERFORMANCE					
Heat load	[BTU/h]		912	613.665	
Effective temperature difference	[*F]			203.408	
K-value (clean)	[BTU/h-ft1.*)	6		168.422	
Fouled K-value	(BTU/h-ft1.4)			168.422	
Fitted heat transfer area	[ft]			24.094	
Overdesign	[96]			17.431	
GEOMETRY AND DESIGN DATA		SHELL	SIDE	TUBES	IDE
No. Units parallel/series flow		1	1	1	1
Diameter / wall thickness	[1n]	6.63	0.11	0.98	0.04
No. Tubes per channel / passes		1	1	19	1
Working pressure (max/min)	[psi]	72.52	FV	174.05	FV
Working temperature (max/min)	[°F]	212.00	32.00	550.00	32,00
Design pressure	[psi]	150	.00	320.0	00
Volume	[USgal]	1.3	20	11.8	34
PxV - PED	-	Not app)	licable	Not appl	icable
Category 97/23/EC		Not app)	licable	Not appl	icable
Metal Temp (average)	[*F]	54.	00	117.	47
Netal material		AISI	-304	AISI-	304
Connection type		ANSI#15	0 RFS0	ANS1#300	RFSO
Gasket material		-	Second Second	-	
Shellside baffles		8 segment	tal 045%		
FLUID DATA	STRUCT	EGS	50	Nitrogen @	11 barg
Channel		Shell	side	Tubes	ide
Density (in/out)	[16/ft']	66.946	66.582	0.45884	0.86452
Specific heat (in/out)	[BTU/1b·°F]	0.820	0.828	0.25359	0.24780
Latent heat	[B7U/1b]	-		1.201	12
Thermal conductivity (in/out)	[BTU/h·ft·*F]	0.240	0.241	0,02392	0.01410
Consistency index (in/out)	[<p]< td=""><td>5.997</td><td>4.099</td><td>1,00000</td><td>1.00000</td></p]<>	5.997	4.099	1,00000	1.00000
Flow behaviour		1.000	1.000	1,00000	1.00000
Apparent viscosity (in/out)	{cP}	5.997	4.099	0.02733	0.01734
Fouling resistance	[h.fex.*F/BT	0.	000000	0.0	00000
Reynolds No.		2 1	94.081	132 92	7.584
Prandtl No.			40.267		0.716



XLG I-Series - Summary

Reference HEAT EXCHANGER No.Units x Model XLG® I-SERIES XLG I-6"/19x1"-60"-304/304-X

GEOMETRY & FEATURES		
Channels	Shellside	Tubeside
Fluids	EG50	Nitrogen @11 barg
No.Parallel flow lines	1	1
No.Units in series per line	1	1
No.Passes	1	1
Shell & Tubes/Nominal length	6.63x0.11 inch / 4.92 ft	19 tubes 0.98x0.04" / 4.92 ft
Tube(s) pattern	Not corrugated	Corrugated
Material wetted areas	AISI-304	AISI-304
Inlet & outlet connections	ANSI#150 RFSO 3"	ANSI#300 RFSO 6"
Interconnections		
Bonnets/Reducers/Bends	107	
Gaskets	2 - C	
Inlet & outlet manifolds		
Finish external / product side	Matt	Nill finish
Shellside baffles	8 segmental @45%	
Bellows	Included	
Mounting position	As	wished
Supports for installation	Not	included
Thermal insulation	Not	included
Side protection sheets	Not	included
Weight empty/full		
Footprint		15

DESTON CONDITIONS	Shellside	Tubeside
Operating/Design temperature	/212°F	/550°F
Operating/Design pressure	/150 Psi	/320 Psi
Fluid classification 97/23/EC	Not applicable	Not applicable
PED Category 2014/68/EU	Not applicab	le outside EU
Design code	PED EN134	145 Part 3

Appendix G: Aspen HYSYS Power Cycle Models for the Development of PCU Test Loop for Micro-Reactor Testbed

Aspen HYSYS Process Model of Micro AGile Non-nuclear Experimental Testbed with

Nitrogen Operating at 600°C



1				Case Name:	Ini test bed n2.hsc		
2				Unit Set	NuScale3a		
4	0.	USA		Date/Time:	Fri Jan 31 15:09:09 202	0	
6 7 8	Wor	kbook	: Case (Mai	n)			
9				Material Stream	IS	Fluid Pkg	;: All
10	Nama		Cold Air In	Cold Alt Out	Hot air in	Hot als Out	1
12	Temperature	(C)	56.10	360.0 *	508.8	30/1 0	304.6
13	Draccura	(U) (kDa)	1295	1084	1047	1001 *	0.400
14	Mass Finw	(knis)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063
15	Mass Density	(kg/m3)	13 287901	5 7448009	4 0314146	5.8169219	5 7819625
16	Mass Enthainy	(k l/ka)	29.65	358.9	627.5	298.2	298.0
17	Mass Entrony	(k.l/kn-C)	4 625	5 386	5 756	5 309	5 311
18	Name	(Narkg-O)	3	4	12	13	2
19	Temperature	(C)	600.0.°	350.4	20.00.1	55.47	304.6.1
20	Draccura	(kDa)	1051 *	1073	051.3 *	1301 *	0.400
21	Mass Finw	(kn/s)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063 *
22	Mass Density	(kg/0) (kg/m3)	4.0436817	5.6929869	10 982355	13 326666	5 7819625
	Mass Enthalow	(k l/ka)	628.0	359.0	7.951	30.03	0.7019020
20	Mass Entropy	(ku/kg-C)	5 755	5 399	4 505	4.625	5 311
24	wass chuopy	(hang-o)	0.700	0.000	4.050	4.020	0.011
25				Compositions	1	Fluid Pkg	r All
20	Name		Cold Air in	Cold Air Out	Hot air in	Hot alr Out	1
29	Comp Mole Erac (Nitrogen)		1 0000	1 0000	1 0000	1 0000	1 0000
29	Comp Mole Frac (CO2)		0.0000	0,0000	0.0000	0.0000	0.0000
30	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	0.0000
21	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	0.0000
22	Comp Mole Frae (H2O)		0.0000	0.0000	0.0000	0.0000	0.0000
33	Name		3	4	12	13	2
34	Comp Mole Erac (Nifrogen)		1 0000	1 0000	1,0000	1 0000	1 0000 *
35	Comp Mole Frac (CO2)		0.0000	0,0000	0.0000	0.0000	0.0000 *
36	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	0.0000 *
37	Comp Mole Frac (Oxygen)		0.0000	0,0000	0.0000	0.0000	0.0000 *
38	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	0.0000 *
39	comp mole r ruo (rizo)		0.0000	0.0000	0.0000	0.0000	0.0000
40				Energy Stream	s	Fluid Pkg	r: All
41	Name		Heat	Heat Loss Ex Pipe	Heat Loss In Pipe	Heat Loss Into Chamb	Heat Loss Out Chamb
42	Heat Flow	(MW)	0.2500	2.432e-004	3.564e-004	1.282e-003	6.120e-004
43	Name		Chiller Duty	Blower Power			
44	Heat Flow	(MW)	0.2825	3.500e-002			
45 46				Heaters		Fluid Pkg	c All
47	Name		Test Article Chamber				
48	DUTY	(MW)	0.2500				
49	Feed Temperature	(C)	359.4				
50	Product Temperature	(C)	600.0 *				
51	Mass Flow	(ka/s)	0.9238				
52		(
53	Coolers Fluid Pkg: All						i: All
54	Name		Chiller				
55	DUTY	(MW)	0.2825				
56	Feed Temperature	(C)	304.6 *				
57	Product Temperature	(C)	20.00 *				
58	Mass Flow	(kg/s)	0.9238 *				
59					-		
60							
61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
	Licensed to: UNIVERSITY OF ID/	но					* Specified by user.

1			Case Name:	Case Name: Ini test bed n2.hsc				
2	etion (MA UNIVERSITY OF IDAHO Bedford, MA USA			Unit Set	NuScale3a			
4				Date/Time:	Fri Jan 31 15:09:09 2020			
6 7	Worl	Case (Mair	n) (continue	(continued)				
9				Heat Exchange	rs	Fiuld Pk	a: All	
10	Name		BUY				-	
12	Duty	(5.654)	0 3042					
13	Tube Side Feed Mass Flow	(ka/s)	0.0042					
14	Shell Side Feed Mass Flow	(kg/s)	0.9238					
15	Tube Inlet Temperature	(C)	56.10					
16	Tube Outlet Temperature	(C)	360.0 *					
17	Shell Inlet Temperature	(C)	598.8					
18	Shell Outlet Temperature	(C)	304.9					
19	LMTD	(C)	243.9					
20	UA	(kJ/C-h)	4490					
21	Minimum Approach	(C)	238.8					
22				Compressore		Fluid Dk	. All	
23				compressors			y. 74	
24	Name		Blower					
25	Power	(MW)	3.500e-002					
26	Feed Pressure	(kPa)	951.3 *					
27	Product Pressure	(kPa)	1301 *					
28	Product Temperature	(C)	56.47					
29	Feed Temperature	(C)	20.00 *					
30	Adiabatic Efficiency		/5 *					
31	Mess Flew	(heriz)	1.300					
22	MIDSS FILW	(NU/S)	0.9230					
33						1		
33 34				Expanders	1	Fluid Pkg	g: All	
33 34 35	Name			Expanders		Fiuld Pkg	g: All	
33 34 35 36	Name	(MW)		Expanders		Fluid Pk	g: All	
33 34 35 36 37	Name Power Feed Pressure	(MW) (kPa)		Expanders		Fluid Pk	g: All	
33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)		Expanders		Fluid Pk	g: All	
33 34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)		Expanders		Fluid Pk	g: All	
33 34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)		Expanders		Fluid Pk	g: All	
33 34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency	(MW) (kPa) (kPa) (C) (C)		Expanders		Fluid Pk		
33 34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pk		
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pk		
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (C) (kg/s)		Expanders		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kg/s)		Expanders		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Exect Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa)		Expanders		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Pressure Press	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (kPa)		Expanders		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Pre	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cq	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 53	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)		Valves		Fluid Pky	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kPa)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)		Valves		Fluid Pkg	g: All	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Fred Temperature Product Pressure Product Pressure Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Fredet Temperature Product Pressure Product Pressure Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 54 55 57 58 59 60	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Pressure Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Pressure Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)		Valves		Fluid Pkg		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 50 51 52 53 54 55 56 57 58 59 60 61 62 63	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)		Expanders Valves	ion 9	Fluid Pkg	g: All	

Air Brayton Open Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



1	1			Case Name:	Case Name: simple brayton cycle 600 best case.hsc			
2			Unit Set:	Unit Set: NuScale3a				
4		USA		Date/Time:	Tue Nov 26 12:31:09 20)19		
6	Wor	khooku	Cooo (Mai	n)				
8	won	KDOOK.	Case (Ivial	n)				
9 10				Material Stream	IS	Fluid Pkg	i: All	
11	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet		
12	Temperature	(C)	280.5	600.0 *	21.11 *	279.9		
13	Pressure	(kPa)	751.8	736.8	101.3 *	101.3 *		
14	Mass Flow	(kg/s)	52.306453	52.306453	52.306453 *	52.306453		
15	Mass Density	(kg/m3)	4.6986368	2.9198486	1.1948843	0.63505947		
16	Mass Enthalpy	(kJ/kg)	157.8	508.6	-111.2	157.5		
17	Mass Entropy	(kJ/kg-C)	5.359	5.864	5.283	5.936		
19				Compositions		Fluid Pkg	i: All	
20	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet		
21	Comp Mole Frac (Nitrogen)		0.7713	0.7713	0.7713	0.7713		
22	Comp Mole Frac (Oxygen)		0.2069	0.2069	0.2069	0.2069		
23	Comp Mole Frac (Argon)		0.0092	0.0092	0.0092	0.0092		
24	Comp Mole Frac (CO2)		0.0003	0.0003	0.0003	0.0003		
25	Comp Mole Frac (H2O)		0.0123	0.0123	0.0123	0.0123		
26				Energy Stream:	s	Fluid Pkg	i: All	
28	Name		Comp Pwr	Reactor Heat	Turb Pwr			
29	Heat Flow	(MW)	14.07	18.35	18.36			
30 31				Heaters		Fluid Pkg	: All	
32	Name		Reactor					
33	DUTY	(MW)	18.35					
34	Feed Temperature	(C)	280.5					
35	Product Temperature	(C)	600.0 *					
36	Mass Flow	(kg/s)	52.31					
37				Coolere		Eluid Dia		
38				Coolers		Fidio P Ng		
39	Name							
40	DUTY	(MW)						
41	Feed Temperature	(C)						
42	Product Temperature	(C)						
43	Mass Flow	(kg/s)						
44 45				Heat Exchanger	s	Fluid Pkg	i: All	
46	Name							
47	Duty	(MW)						
48	Tube Side Feed Mass Flow	(kg/s)						
49	Shell Side Feed Mass Flow	(kg/s)						
50	Tube Inlet Temperature	(C)						
51	Tube Outlet Temperature	(C)						
52	Shell Inlet Temperature	(C)						
55	I MTD	(0)						
55	UA	(k.l/C-h)						
56	Minimum Approach	(C)						
57 58 59 60 61 62								
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2	
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1	UNIVERSITY OF IDAHO Bedford, MA			Case Name: simple brayton cycle 600 best case.hsc			
3				Unit Set:	it: NuScale3a		
4	<u> </u>	USA		Date/Time:	Tue Nov 26 12:31:09 2	019	
6							
7	Wor	kbook:	Case (Main) (continue	ed)		
9				Compressors	s	Fluid Pk	g: All
10	Name		Air Compressor				
12	Power	(MW)	14.07				
13	Feed Pressure	(kPa)	101.3 *				
14	Product Pressure	(kPa)	751.8				
15	Product Temperature	(C)	280.5				
16	Feed Temperature	(C)	21.11				
17	Adiabatic Efficiency		85 *				
18	Pressure Ratio		7.420 *				
19	Mass Flow	(kg/s)	52.31 *				
20				Expanders		Fluid Pk	a: All
21							-
22	Name		Air Turbine				
23	Power	(MW)	18.36				
24	Peed Pressure	(kPa)	/ 30.8		-		
20	Product Pressure	(KPa)	101.3				
20	Froduct Temperature	(C)	2/9.9				
27	Adiabatic Efficiency	(0)	0.00				
29	Mass Flow	(ka/s)	52.31				
30	mass rion	(13/3)	02.01				
31				Valves		Fluid Pkg	g: All
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(kPa)					
37	Product Temperature	(C)					
38	Mass Flow	(kg/s)					
39	Cg						
40	Resistance (Cv or K)						
41							
42							
40							
44							
45							
47							
48							
49							
50							
51							
52							
53							
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1000							
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60 61							
60 61 62 63	Aspen Technology Inc.		٨		sion 9		Page 2 of 2

Nitrogen Brayton Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%





1	UNIVERSITY OF IDAHO Bedford, MA			Case Name:	Case Name: nitrogen brayton cycle 600 best case.hsc			
2				Unit Set:	Unit Set: NuScale3a			
4		USA		Date/Time:	Tue Nov 26 12:50:10 20)19		
6								
7 8	Worl	kbook:	Case (Mai	n)				
9				Material Stream	IS	Fluid Pkg	: All	
10	Name		Comp Out	Turbine Inlet	Nitrogen	Turbine Outlet		
12	Temperature	(C)	281.6	600.0 *	21.11 *	277.3		
13	Pressure	(kPa)	1073	1051 *	144.6 *	144.6 *		
14	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000 *	1.0000000		
15	Mass Density	(kg/m3)	6.4918092	4.0436817	1.6565694	0.88454671		
16	Mass Enthalpy	(kJ/kg)	272.8	628.9	-4.450	268.3		
17	Mass Entropy	(kJ/kg-C)	5.244	5.756	5.166	5.831		
19				Compositions		Fluid Pkg	: All	
20	Name		Comp Out	Turbine Inlet	Nitrogen	Turbine Outlet		
21	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000 *	1.0000		
22	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000 *	0.0000		
23	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000 *	0.0000		
24	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000 *	0.0000		
25	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000 *	0.0000		
26				Energy Stream	s	Fluid Pkg	: All	
28	Name		Comp Pwr	Reactor Heat	Turb Pwr			
29	Heat Flow	(MW)	0.2772	0.3561	0.3605			
30				Heaters		EL: A DIA		
31				Heaters		Fiuld Pkg	: All	
32	Name		Reactor					
33	DUTY	(MW)	0.3561					
34	Feed Temperature	(C)	281.6					
30	Product Temperature	(C)	600.0					
37	Mass Flow	(Ng/S)	1.000					
38				Coolers		Fluid Pkg	: All	
39	Name							
40	DUTY	(MW)						
41	Feed Temperature	(C)						
42	Product Temperature	(C)						
43	Mass Flow	(kg/s)						
44				Heat Exchanger	rs	Fluid Pkg	: All	
46	Name							
47	Duty	(MW)				i		
48	Tube Side Feed Mass Flow	(kg/s)						
49	Shell Side Feed Mass Flow	(kg/s)						
50	Tube Inlet Temperature	(C)						
51	Tube Outlet Temperature	(C)						
52	Shell Inlet Temperature	(C)						
53	Shell Outlet Temperature	(C)						
55	UA	(kJ/C-h)						
56	Minimum Approach	(C)						
57		1-1				I		
58								
59								
60								
61								
62	Aspen Technology Inc.			Aenen HVSVS Vorsi	on 9		Dage 1 of 2	
03	Licensed to: UNIVERSITY OF IDA	HO		Aspentition oversi	011-0		Page For Z	
1				Case Name:	nitrogen brayton cycle (000 best case.hsc		
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3	(e)aspented	b Bedford, M	IA DAHO	Unit Set:	NuScale3a			
4		USA		Date/Time:	Tue Nov 26 12:50:10 2	019		
6								
7 8	v	orkbook:	Case (Mai	n) (continue	ed)			
9				Compressors	i	Fluid Pk	g: All	
11	Name		Compressor					
12	Power	(MW)	0.2772					
13	Feed Pressure	(kPa)	144.6 *					
14	Product Pressure	(kPa)	1073					
15	Product Temperature	(C)	281.6					
16	Feed Temperature	(C)	21.11 *					
17	Adiabatic Efficiency		85 *					
18	Pressure Ratio		7.420					
19	Mass Flow	(kg/s)	1.000 *					
20				Expanders		Fluid Pk	g: All	
22	Name		Turbine					
23	Power	(MW)	0.3605					
24	Feed Pressure	(kPa)	1051 *					
25	Product Pressure	(kPa)	144.6					
26	Product Temperature	(C)	277.3					
27	Feed Temperature	(C)	600.0 *					
28	Adiabatic Efficiency		90 -					
29	Mass Flow	(kg/s)	1.000					
30 31				Valves		Fluid Pk	g: All	
32	Name							
33	Pressure Drop	(kPa)						
34	Feed Pressure	(kPa)						
35	Feed Temperature	(C)						
36	Product Pressure	(kPa)						
37	Product Temperature	(C)						
38	Mass Flow	(kg/s)						
39	Cg							
40	Resistance (Cv or K)							
41								
42								
43								
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63	Aspen rechnology	ITIC.		Aspen HTSYS Vers	1011 9		Page 2 of 2	
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Air Brayton Open Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine

Adiabatic Efficiencies of 70% and 80%



Image Unit Set: Nudscalada Image	1				Case Name:	simple brayton cycle 60	0 worst case.hsc	
d USA DearTime: Tax New 26 12.35:18.2019 0 Workbook: Case (Main) 0 Material Streams Fluid Plg. All 1 Taxme Comp Out Turbine Inter Turbine Outer All 1 Mana Comp Out Turbine Inter Hund Air Turbine Outer All 1 Mana Operation Operation Fluid Plg. All 1 Mana Comp Out Turbine Inter Hund Air Turbine Outer All 1 Mana Enhalty (L/lkg.) 4.22.8 Operation 1.0000000 1.0000000 1.0000000 Inter All Mana Enhalty (L/lkg.) 6.322 0.131 Comp Out Turbine Outer Operation Operatio	2	(e)aspentech	UNIVERSIT Bedford, MA	Y OF IDAHO A	Unit Set:	NuScale3a		
Image Comp Out Material Streams Fuid Phg: All Image Comp Out Turbine Inite Turbine Outer All Image Comp Out 21111 431.6	4 5		USA		Date/Time:	Tue Nov 26 12:35:18 20)19	
Image: Second	6	Wor	khooki	Caso (Mai	a)			
θ Full Play All 11 Amme Comp Out Turbine Inlet Humid Air Turbine Oute All 13 Amme (Pr.2) Comp Out Turbine Inlet Humid Air Turbine Oute All 14 Mass Eritory (Pr.2) 2.02.0 101.0 1.000000 1.000000 1.000000 16 Mass Eritory (Pr.2) 2.337081 1.112.02344 1.94843 0.463207 - 16 Mass Eritory (Pr.2) 5.322 6.108 -	8	won	KDOOK.	Case (Mail	1)			
Name Comp Out Turbine Intel Hundi Air Turbine Quilt 13 Preparator (C) 77.8 900.01 21.11 413.6 14 Mass Frow (Aga) 1.0000000 1.0000000 1.0000000 14 Mass Frow (Aga) 2.333761 1.1622244 1.164843 0.44825067 16 Mass Enhaly (UAlkg) 42.28 0.064 -111.2 2.21.4 17 Mass Enhaly (UAlkg) 42.28 0.064 -111.2 2.21.4 18 Stency (UAlkg) 42.28 0.064 -111.2 2.21.4 18 Stency UAlkg 42.85 0.064 -111.2 2.21.4 18 Stency UAlkg 2.23.7651 Turbine Intel Turbine UAlkg 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 <	9 10				Material Stream	IS	Fluid Pkg	g: All
Image CO 170.8 00.00 21.11 411.6 Presure (PA) 288.9 222.9 10.13 101.3 101.3 Mass Envin (Qay) 1.000000 1.000000 1.000000 10.00000 Mass Enthely (Qukg) 2.337511 1.112.2344 0.4633067 111.2 Mass Enthely (Qukg) 2.337511 1.112.2344 0.4133 0.413 Mass Enthely (Qukg) 2.322 0.321 0.233 0.102 Comp Mole Fac (Ntrogen) 0.7713 0.7773 0.7773 0.7773 0.7773 Comp Mole Fac (Ntrogen) 0.0002 0.0002 0.0002 0.0002 0.0002 Comp Mole Fac (Nogen) 0.0002 0.0002 0.0002 0.0002 0.0002 Comp Mole Fac (Nogen) 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123	11	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	
19 Presure (0; P) 2020 101.3 101.3 4 Mass Forw (0; p) 1.000000 1.000000 1.000000 5 Mass Entropy (1; M) 2.233781 1.192244 1.194845 0.4933007 10 Mass Entropy (1; M) 2.23 0.130 0.2033 0.108 10 Mass Entropy (1; M) 3.222 0.130 0.2033 0.108 10 Mass Entropy (1; M) 0.2713 0.27713 0.27713 0.27713 0.27713 0.27713 0.27713 0.27713 0.2776 0.0002 0.0002 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0013 0.0121 0.1713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.7713 0.0714 0.0003 0.0003 0.0003 0.0003 0.0003 0.0013 0.0013 0.0013	12	Temperature	(C)	170.8	600.0 *	21.11 *	431.6	
14 Mass Flow (tig/ti) 1.000000 1.000000 1.000000 15 Mass Entholy (til/tig) 2.333761 1.1123484 0.4935007 16 Mass Entholy (til/tig) 2.333761 1.1022344 1.141848 0.4935007 17 Mass Entholy (til/tig) 2.33761 1.1022344 1.141848 0.4935007 18 Sentholy (til/tig) 5.392 6.130 5.283 6.190 19 Name Comp Out Tuthine Inlat Hunid Air Tuthine Outlet 1 10 Comp Mole Frac (Narogen) 0.0020 0.0020 0.0020 0.0020 20 Comp Mole Frac (A20) 0.0123 0.0123 0.0123 0.0123 20 Comp Mole Frac (M20) 0.0123 0.4022 0.1011 1 21 Mare Comp Pur Reactor Fluid Pkg All 21 Mare Comp Pur Reactor 1 1 23 Mare Comp Pur Reactor 1 1 <td>13</td> <td>Pressure</td> <td>(kPa)</td> <td>298.9</td> <td>292.9</td> <td>101.3 *</td> <td>101.3 *</td> <td></td>	13	Pressure	(kPa)	298.9	292.9	101.3 *	101.3 *	
Mass Density (kg/m3) 2.33781 1.1023244 1.1144843 0.4835007 Mass Entropy (kl/kg-C) 5.382 6130 5.283 6180	14	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000 *	1.0000000	
Mass Entholy (k.lkgC) 42.25 00.94 -111.2 021.4 Mass Entholy (k.lkgC) 5.392 6.130 5.283 6.180 Mass Entholy (k.lkgC) 5.392 6.130 5.283 6.180 Mass Entholy (k.lkgC) 5.392 6.181 Mund Air Tution Unit Mund Air Tution Outet All Mass Entholy Comp Mole Frac (Nongen) 0.001 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0773 0.0793 0.0002 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0013 Mass Entholy All	15	Mass Density	(kg/m3)	2.3337681	1.1623244	1.1948843	0.49835067	
Image Entropy (µklg-C) 5.92 6.10 5.223 6.169 30 Compositions Fuid Pkg: All 31 Ame Comp Mole Frac (Ningen) 0.7713 0.7713 0.7713 0.7713 21 Comp Mole Frac (Ningen) 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0002 0.0003 0.0013 0.0123 0.0173 0.0173 Mare N	16	Mass Enthalpy	(kJ/kg)	42.25	508.4	-111.2	321.4	
Bit Compositions Fuid Pkg: All 20 Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) 0.07713 0.0773 0.0723 0.0002 0.0002 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0003 0.0013 0.0123 <td< td=""><td>17</td><td>Mass Entropy</td><td>(kJ/kg-C)</td><td>5.392</td><td>6.130</td><td>5.283</td><td>6.198</td><td></td></td<>	17	Mass Entropy	(kJ/kg-C)	5.392	6.130	5.283	6.198	
20 Name Comp Out Turbine Outer Nume Air Turbine Outer 21 Comp Mole Frac (Mrogen) 0.7713 0.0002 0.0003 0.0003 0.0013 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0123 0.0133 0.0173 0.0133 0.0173 0.0133 0.0173 0.0133 0.0173	18 19				Compositions	•	Fluid Pkg	g: All
21 Comp Mole Frac (Ningen) 0.711 0.713 0.713 0.713 21 Comp Mole Frac (Nagen) 0.0002 0.0002 0.0002 0.0002 23 Comp Mole Frac (Nagen) 0.0002 0.0003 0.0003 0.0003 24 Comp Mole Frac (Nagen) 0.0022 0.0023 0.0123 0.0123 26 Comp Mole Frac (Nagen) 0.0123 0.0123 0.0123 0.0123 27 Tenerry Streams Fluid Pkg: All 28 Name Comp Pwr Reactor Heat Turb Pwr Product 29 Heat Flow (MW) 0.4062 0.1371 Comp Mole Frac (Nagen) All 31 Terre Flow Fluid Pkg: All Stars Flow All 33 DUTY (MW) 0.4062 0.000 Comp Mole Frac (Nagen) All 34 Feed Temperature (C) 1000 Comp Mole Frac (Nagen) All 35 Product Temperature (C) 6000.0.1 Comp Mole Frac (Nagen)	20	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	
22 Comp Mole Frac (Argen) 0.2080 0.2080 0.2080 0.2080 0.2080 0.2080 24 Comp Mole Frac (A2O) 0.0033 0.0033 0.0033 0.0033 25 Comp Mole Frac (A2O) 0.0123 0.0123 0.0123 0.0123 27 Image: Comp Mole Frac (A2O) 0.0133 0.0492 0.0123 0.0123 28 Name Comp Mole Frac (A2O) 0.1133 0.4992 0.1871 Image: Comp Mole Frac (A2O) All 29 Heat Flow (MW) 0.1533 0.4992 0.1871 Image: Comp Mole Frac (C) All 31 Image: Comp Part Reactor	21	Comp Mole Frac (Nitrogen)		0.7713	0.7713	0.7713	0.7713	
21 Comp Mole Frac (Agon) 0.0022 0.0092 0.0092 0.0092 24 Comp Mole Frac (C2) 0.0023 0.0023 0.0023 0.0023 28 Comp Mole Frac (C2) 0.0123 0.0123 0.0123 0.0123 29 The Frac (C2) 0.0123 0.0123 0.0123 0.0123 29 Amme Comp Mole Frac (H2O) 0.0123 0.0123 0.0123 20 Heat Frac (M2O) 0.0135 0.4662 0.1871 Image 20 Heat Frac (M2O) 0.4662 0.1871 Image All 31 The frac Temperature (C) 0.4062 Image Image All 32 Name Reactor Image Image Image All 33 DUTY (MV) 0.4662 Image Image Image All 34 Feed Temperature (C) 000.0 Image Image Image Image Image Image Image Image Image Ima	22	Comp Mole Frac (Oxygen)		0.2069	0.2069	0.2069	0.2069	
24 Comp Mole Frac (CO2) 0.003 0.003 0.003 27 Comp Mole Frac (H2O) 0.0123 0.0123 0.0123 0.0123 0.0123 0.0133 0.0133 27 Name Comp Pwr Reador Heat Turb Pwr Fluid Pkg: All 28 Mame Comp Pwr Reador Heat Turb Pwr Fluid Pkg: All 29 Mame Reador 0.4602 0.1871 31 Heaters Fluid Pkg: All 32 Name Reador Image: All 33 Reador Image: All 34 Feed Temperature (C) 170.8 Image: All 35 Product Temperature (C) 0000 Image: All 37 Mame Image: All Image: All 38 Name Image: All Image: All 39 Name Image: <thi< td=""><td>23</td><td>Comp Mole Frac (Argon)</td><td></td><td>0.0092</td><td>0.0092</td><td>0.0092</td><td>0.0092</td><td></td></thi<>	23	Comp Mole Frac (Argon)		0.0092	0.0092	0.0092	0.0092	
B Comp Mole Frac (H2C) 0.0123 0.0123 0.0123 0.0123 P Image: Provide Frac (H2C) Comp Pwr Reactor Heast Turb Pwr Image: Provide Frac (H2C) 0.1871 Image: Provide Frac (H2C)	24	Comp Mole Frac (CO2)		0.0003	0.0003	0.0003	0.0003	
Bit Fluid Pkg: All 10 Name Comp Pur Reactor Heat Turb Pur Out Pur Name Name Name Name Name Reactor Name	25	Comp Mole Frac (H2O)		0.0123	0.0123	0.0123	0.0123	
27 Name Comp Pwr Reactor Heat Turb Pwr Image 29 Heat Flow (MW) 0.1535 0.4682 0.1871 Image All 30 Image Reactor Heat Turb Pwr Image All 31 Name Reactor Heat Image All 32 Name Reactor Heat Image All 33 DUTY (MW) All Image Image Image 34 Feed Temperature (C) 600.0 Image Image </td <td>26</td> <td></td> <td></td> <td></td> <td>Energy Stream</td> <td>s</td> <td>Fluid Pkg</td> <td>a: All</td>	26				Energy Stream	s	Fluid Pkg	a: All
Name Comp Vmt Neador Heat Turb Vmt Comp Vmt 31 Heat Flow (MW) 0.1535 0.4662 0.1871 33 Name Reactor All 33 DUTY (MW) 0.4662 34 Feed Temperature (C) 000.0 35 Product Temperature (C) 000.0 36 Product Temperature (C) 000.0	27					-		
Instruction Color Color Color Color Color All 31 Image instruction Reactor Image instruction Fluid Pkg: All 32 Name instruction Reactor Image instruction Image instructinstresem instruction Image instructinstr	28	Name Heat Flow	(1404/5	Comp Pwr 0.1525	Reactor Heat	10rb PWr 0.1971		
Heaters Fluid Pkg: All Name Reactor Image: Reactor	30	nearnow	(101337)	0.1000	0.4002	0.1071		
Name Reactor Image: Constraint of the sector of the secto	31				Heaters		Fluid Pkg	g: All
33 DUTY (MW) 0.4862 Image: Constraint of the second	32	Name		Reactor				
34 Feed Temperature (C) 170.8 Image: Coolers Image: Coolers Image: Coolers Fluid Rg: All 38 Forduct Temperature (C) 000.0° Image: Coolers Fluid Rg: All 39 Name Image: Coolers Fluid Rg: Coolers All 39 Name Image: Coolers Fluid Rg: Coolers All 30 Name Image: Coolers Fluid Rg: Coolers All 30 Name Image: Coolers Fluid Rg: Coolers All 30 Name Image: Coolers Fluid Rg: Coolers All 41 Feed Temperature (C) Image: Coolers All 42 Product Temperature (C) Image: Coolers All 43 Mass Flow (kg/s) Image: Coolers All 44 Product Temperature (C) Image: Coolers All 45 Name Image: Coolers Fluid Rg: Coolers All 46 Image: Coolers Fluid Rg: Coolers All 47 Duty (MW) Image: Coolers Image: Coolers	33	DUTY	(MW)	0.4662				
38 Product Temperature (C) 600.0 ° Image: Coolers Fluid Pkg:: All 39 Name Coolers Fluid Pkg:: All 30 Name Image: Coolers Fluid Pkg:: All 30 Name Image: Coolers Fluid Pkg:: All 30 Name Image: Coolers Fluid Pkg:: All 40 DUTY (MW) Image: Coolers Fluid Pkg:: All 41 Feed Temperature (C) Image: Coolers Fluid Pkg:: All 42 Product Temperature (C) Image: Coolers Fluid Pkg:: All 43 Mass Flow (kg/s) Image: Coolers Fluid Pkg:: All 44 Product Temperature (C) Image: Coolers Fluid Pkg:: All 45 Name Image: Coolers Fluid Pkg:: All All 46 Name Image: Coolers Fluid Pkg:: All 47 Dufy (MW) Image: Coolers Fluid Pkg:: All 48 Site Feed Mass Flow <t< td=""><td>34</td><td>Feed Temperature</td><td>(C)</td><td>170.8</td><td></td><td></td><td></td><td></td></t<>	34	Feed Temperature	(C)	170.8				
38 Mass Flow (kg/s) 1.000 Image: Coolers Fluid Pkg: All 39	35	Product Temperature	(C)	600.0 *				
37 37 Fluid Pkg: All 38 Name Image: All Fluid Pkg: All 40 DUTY (MW) Image: All Image: All Image: All 41 Feed Temperature (C) Image: All Ima	36	Mass Flow	(kg/s)	1.000				
38 Coord Name Internet Name 39 Name	37				Coolers		Fluid Pkr	n All
30 Name Image Ima	38				000013			
40 DOTY (MW)	39	Name						
Image Image <th< td=""><td>40</td><td>DUTY</td><td>(MW)</td><td></td><td></td><td></td><td></td><td></td></th<>	40	DUTY	(MW)					
42 Product Temperature (C) Image: Constraint of the second of the se	41	Feed Temperature	(0)					
Mass Flow (kg/s) Image of the second	42	Product Temperature	(0)					
Heat Exchangers Fluid Pkg: All 46 Name Image: State S	43	Mass Flow	(kg/s)					
46 Name Image: Constraint of the state	45				Heat Exchange	rs	Fluid Pkg	g: All
47 Duty (MW) Image: Constraint of the state of t	46	Name						
44 Tube Side Feed Mass Flow (kg/s) Image: Constraint of the symbol	47	Duty	(MW)					
49 Shell Side Feed Mass Flow (kg/s) Image: Constraint of the symbol of	48	Tube Side Feed Mass Flow	(kg/s)					
80 Tube Inlet Temperature (C) Image: Constraint of the state	49	Shell Side Feed Mass Flow	(kg/s)					
51 Tube Outlet Temperature (C) Image: Constraint of the constr	50	Tube Inlet Temperature	(C)					
82 Shell Inlet Temperature (C) Image: Constraint of the symbol of th	51	Tube Outlet Temperature	(C)					
Shell Outlet Temperature (C) Image: Constraint of the state of th	52	Shell Inlet Temperature	(C)					
54 LMTD (C) Image: Constraint of the state of th	53	Shell Outlet Temperature	(C)					
55 UA (kJ/C-h) <td>54</td> <td>LMTD</td> <td>(C)</td> <td></td> <td></td> <td></td> <td></td> <td></td>	54	LMTD	(C)					
Iminum Approach (C) Minimum Approach (C)	55	UA .	(kJ/C-h)					
Bit 58 59 60 61 62 63 Aspen Technology Inc. Aspen Technology Inc. Page 1 of 2	56	Minimum Approach	(C)					
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2	57 58 59							
61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2	60							
62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2	61							
63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2	62							
	63	Aspen Technology Inc.		1	Aspen HYSYS Versi	on 9		Page 1 of 2

1				Case Name:	simple brayton cycle 60	0 worst case.hsc	
2	(aspentech	UNIVERSIT Bedford, MA	Y OF IDAHO A	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:35:18 2	019	
6							
7	Wor	kbook:	Case (Mair	n) (continue	ed)		
9				Compressors		Fluid Pk	a: All
10	Name		Air Compressor				-
12	Power	(MW)	0.1535				
13	Feed Pressure	(kPa)	101.3 *				
14	Product Pressure	(kPa)	298.9				
15	Product Temperature	(C)	170.8				
16	Feed Temperature	(C)	21.11 *				
17	Adiabatic Efficiency		70 *				
18	Pressure Ratio		2.950 *				
19	Mass Flow	(ka/s)	1.000 *				
20				- ·	•		
21				Expanders		Fluid Pk	g: All
22	Name		Air Turbine				
23	Power	(MW)	0.1871				
24	Feed Pressure	(kPa)	292.9				
25	Product Pressure	(kPa)	101.3 *				
26	Product Temperature	(C)	431.6				
27	Feed Temperature	(C)	600.0 *				
28	Adiabatic Efficiency		80 *				
29	Mass Flow	(kg/s)	1.000				
30				Values		ELVI DL	
31				valves		Fluid PK	g: Ali
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(kPa)					
37	Product Temperature	(C)					
38	Mass Flow	(kg/s)					
39	Cg						
40	Resistance (Cv or K)						
41							
42							
43							
44							
45							
40							
47							
40							
50							
51							
52							
53							
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63	Aspen Technology Inc.		1	Aspen HYSYS Vers	ion 9		Page 2 of 2
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Nitrogen Brayton Open Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



—								
1					Case Name:	nitrogen brayton cycle 6	00 worst case.hsc	
3	(aspentech	Bedford, M	TY OF IDAHO A		Unit Set:	NuScale3a		
4		USA			Date/Time:	Tue Nov 26 12:49:34 20)19	
6 7 8	Wor	kbook:	Case (N	lain)				
9					Material Stream	s	Fluid Pkg	j: All
10	Name		Comp Out	1	Curbine Inlet	Nitrogon	Turbine Outlet	
12	Temperature	(C)	17	11	600.0 *	21.11 *	420.8	
13	Pressure	(kPa)	10	073	1051 *	363.7 *	363.7 *	
14	Mass Flow	(kg/s)	1.0000	000	1.0000000	1.0000000 *	1.0000000	
15	Mass Density	(kg/m3)	8.11496	817	4.0436817	4.1709780	1.7407278	
16	Mass Enthalpy	(kJ/kg)	15	3.0	628.9	-5.063	436.4	
17	Mass Entropy	(kJ/kg-C)	5.0	003	5.756	4.890	5.827	
18					Compositions		Eluid Dia	
19					compositions		Fluid Pkg	j. All
20	Name		Comp Out	T	Furbine Inlet	Nitrogen	Turbine Outlet	
21	Comp Mole Frac (Nitrogen)		1.00	000	1.0000	1.0000 *	1.0000	
22	Comp Mole Frac (Oxygen)		0.00	000	0.0000	0.0000 *	0.0000	
23	Comp Mole Frac (Argon)		0.00	000	0.0000	• 0.0000	0.0000	
24	Comp Mole Frac (CO2)		0.00	000	0.0000	• 0.0000	0.0000	
25	Comp Mole Frac (H2O)		0.00	000	0.0000	0.0000 *	0.0000	
26					Energy Streams	s	Fluid Pkg	a: All
27								-
28	Name	(1.640)	Comp Pwr	- F	Reactor Heat	Turb Pwr		
29	Heat Flow	(MVV)	0.10	080	0.4709	0.1925		
31					Heaters		Fluid Pkg	g: All
32	Name		Reactor					
33	DUTY	(MW)	0.47	759				
34	Feed Temperature	(C)	17	1.1				
35	Product Temperature	(C)	60	0.0 *				
36	Mass Flow	(kg/s)	1.0	000				
37					Coolers		Fluid Pkg	r All
38					0001013			
39	Name							
40	DUTY	(MW)						
41	Feed Temperature	(C)						
42	Product Temperature	(C)						
43	Mass Flow	(Kg/S)						
44				1	Heat Exchanger	s	Fluid Pkg	g: All
46	Name							
47	Duty	(MW)						
48	Tube Side Feed Mass Flow	(kg/s)						
49	Shell Side Feed Mass Flow	(kg/s)						
50	Tube Inlet Temperature	(C)						
51	Tube Outlet Temperature	(C)						
52	Shell Inlet Temperature	(C)						
53	Shell Outlet Temperature	(C)						
54	LMTD	(C)						
55	UA	(kJ/C-h)						
56	Minimum Approach	(C)						
57 58 59 60 61 62								
63	Aspen Technology Inc.			As	pen HYSYS Versid	on 9		Page 1 of 2
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1				Case Name:	nitrogen brayton cycle	600 worst case.hsc	
3	(aspentech	UNIVERSIT Bedford, MA	Y OF IDAHO A	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:49:34 2	019	
6							
7 8	Wor	kbook:	Case (Main	i) (continue	ed)		
9				Compressors	•	Fluid Pk	g: All
10	Name		Compressor	-			
12	Power	(MW)	0.1580				
13	Feed Pressure	(kPa)	363.7 *				
14	Product Pressure	(kPa)	1073				
15	Product Temperature	(C)	171.1				
16	Feed Temperature	(C)	21.11				
17	Adiabatic Efficiency		70 *				
18	Pressure Ratio		2.950				
19	Mass Flow	(kg/s)	1.000 *				
20			· · · · ·	5	•		
21				Expanders		Fluid Pk	g: All
22	Name		Turbine				
23	Power	(MW)	0.1925				
24	Feed Pressure	(kPa)	1051 *				
25	Product Pressure	(kPa)	363.7 *				
26	Product Temperature	(C)	429.8				
27	Feed Temperature	(C)	600.0 *				
28	Adiabatic Efficiency		80 -				
29	Mass Flow	(kg/s)	1.000				
30				Values		Eluid Blo	
31				valves	_		j. Ali
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(kPa)					
37	Product Temperature	(C)					
38	Mass Flow	(kg/s)					
39	Cg						
40	Resistance (Cv or K)						
41							
42							
43							
44							
45							
46							
47							
48							
49							
50							
51							
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63	Aspen Technology Inc.		A	spen HYSYS Vers	ion 9		Page 2 of 2
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Recuperated Air Brayton Open Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%

1				Case Name:	recuperated air brayton	cycle 600 best.hsc	
3	(e)aspentech	Bedford, M	IY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:48:39 20	019	
6	Wor	khooki	Caco (Mai	n)			
8	WOI	KDOOK.	Case (Mai	n)			
9				Material Stream	IS	Fluid Pk	g: All
10	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	Air Exhaust
12	Temperature	(C)	103.3	600.0 *	21.11	471.3	129.7
13	Pressure	(kPa)	214.8	206.3	101.3 *	103.4	101.3 *
14	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000 *	1.0000000	1.0000000
15	Mass Density	(kg/m3)	1.9790138	0.81879352	1.1948843	0.48143211	0.87203183
16	Mass Enthalpy	(kJ/kg)	-27.62	508.4	-111.2	364.9	-0.1229
17	Mass Entropy	(kJ/kg-C)	5.317	6.231	5.283	6.252	5.604
18	Name	(Reactor Inlet				
19	Temperature	(C)	446.3				
20	Pressure	(kPa)	210.5				
21	Mass Flow	(ka/s)	1.0000000				
22	Mass Density	(ka/m3)	1.0139446				
23	Mass Enthaloy	(k,1/kg)	337.5				
24	Mass Entropy	(kJ/kg-C)	6 010				
25		(1011)	0.010				
26				Compositions	1	Fluid Pk	g: All
27	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	Air Exhaust
28	Comp Mole Frac (Nitrogen)		0 7713	0 7713	0 7713	0.7713	0 7713
29	Comp Mole Frac (Oxygen)		0.2069	0.2069	0.2089	0.2069	0.2089
30	Comp Mole Frac (Argon)		0.0092	0.0092	0.0002	0.0092	0.0092
31	Comp Mole Frac (Argon)		0.0002	0.0082	0.0082	0.0002	0.0082
32	Comp Mole Frac (CO2)		0.0003	0.0003	0.0003	0.0003	0.0003
33	Name		Reactor Inlet	0.0125	0.0123	0.0120	0.0123
34	Comp Mole Erac (Nitrogen)		0.7713				
35	Comp Mole Frac (Oxugen)		0.2080				
36	Comp Mole Frac (Oxygen)		0.0002				
37	Comp Mole Frac (CO2)		0.0002				
38	Comp Mole Frac (H2O)		0.0123				
39	Comp Mole Plac (120)		0.0123				
40				Energy Stream	s	Fluid Pk	g: All
41	Name		Comp Pwr	Reactor Heat	Turb Pwr		
42	Heat Flow	(MW)	8.360e-002	0.1709	0.1435		
43		()					
44				Heaters		Fluid Pk	g: All
45	Name		Reactor				
46	DUTY	(MW)	0.1709				
47	Feed Temperature	(C)	446.3				
48	Product Temperature	(C)	600.0 *				
49	Mass Flow	(ka/s)	1.000				
50							
51				Coolers		Fluid Pk	g: All
52	Name						
53	DUTY	(MW)					
54	Feed Temperature	(C)					
55	Product Temperature	(C)					
56	Mass Flow	(kg/s)					
57 58 59 60 61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
	Licensed to: UNIVERSITY OF IDA	AHO					* Specified by user.

1				Case Name:	recuperated air brayton	cycle 600 best.hsc	
3	(e)aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:48:39 2	019	
6 7 8	Worl	kbook:	Case (Main) (continue	ed)		
9				Heat Exchange	rs	Fluid Pk	g: All
10	Name		Recuperating Heat Ex				
12	Duty	(MW)	0.3651				
13	Tube Side Feed Mass Flow	(kg/s)	1.000				
14	Shell Side Feed Mass Flow	(kg/s)	1.000				
15	Tube Inlet Temperature	(C)	103.3				
16	Tube Outlet Temperature	(C)	446.3				
17	Shell Inlet Temperature	(C)	471.3				
18	Shell Outlet Temperature	(C)	129.7				
19	LMTD	(C)	25.71				
20	UA	(kJ/C-h)	5.112e+004				
21	Minimum Approach	(C)	25.00				
22				Compressors		Fluid Pk	g: All
24	Name		Air Compressor				
25	Power	(MW)	8.360e-002				
26	Feed Pressure	(kPa)	101.3				
27	Product Pressure	(kPa)	214.8				
28	Product Temperature	(C)	103.3				
29	Feed Temperature	(C)	21.11				
30	Adiabatic Efficiency		85 *				
31	Pressure Ratio		2.120 *				
32	Mass Flow	(kg/s)	1.000 *				
33				Expanders	•	Fluid Pk	a: All
33 34				Expanders		Fluid Pk	g: All
33 34 35	Name		Air Turbine	Expanders		Fluid Pk	g: All
33 34 35 36	Name Power	(MW)	Air Turbine 0.1435 208.3	Expanders		Fluid Pk	g: All
33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa)	Air Turbine 0.1435 206.3 103.4	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)	Air Turbine 0.1435 206.3 103.4 471.3	Expanders		Fluid Pkg	g: All
33 34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 °	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency	(MW) (kPa) (kPa) (C) (C)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 ° 90 °	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 ° 90 ° 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 ° 90 ° 1.000	Expanders		Fluid Pk	
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 ° 90 ° 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 ° 90 ° 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 ° 90 ° 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 45 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Pressure Product Pressure Pressu	(MW) (kPa) (kPa) (C) (C) (kg/s) (kg/s) (kPa) (C) (kPa)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Product Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 45 45 45 50 51 52	Name Power Feed Pressure Product Pressure Product Pressure Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Co	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 * 90 * 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Temperature Product Pressure Pred Temperature Product Temperature Mass Flow Cg	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 600.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pred Pressure Pred Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pred Pressure Pred Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Pred Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Pred Temperature Product Pressure Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 9 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 56 57 58 59 59	Name Poduct Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Temperature Product Temperature Product Temperature Product Temperature Out Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 1	Name Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Temperature Product Temperature Product Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Expanders		Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 90 1.000	Valves		Fluid Pk	
33 34 35 36 37 38 39 40 41 42 43 44 45 50 51 52 53 54 55 56 57 58 59 60 61 62 63 63	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Temperature Product Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1435 206.3 103.4 471.3 800.0 ° 90 ° 1.000	Expanders Valves	ion 9	Fluid Pk	g: All

Recuperated Nitrogen Brayton Open Cycle at 600°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



1				Case Name:	recuperated N2 brayton	cycle 600 best case.hsc	
3	(aspentech	Bedford, M	IY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:50:54 20	019	
6 7 8	Wor	kbook:	Case (Mai	n)			
9				Material Stream	s	Fluid Pk	g: All
10	Name		Comp Out	Turbine Inlet	Nitrogen	Turbine Outlet	Reactor Inlet
12	Temperature	(C)	103.5	600.0 *	21.11 *	469.8	444.8
13	Pressure	(kPa)	1095	1051 *	516.4 *	526.9	1073
14	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000 *	1.0000000	1.0000000
15	Mass Density	(kg/m3)	9.7837189	4.0436817	5.9265298	2.3852321	5.0162010
16	Mass Enthalpy	(kJ/kg)	80.53	628.9	-5.487	481.1	453.2
17	Mass Entropy	(kJ/kg-C)	4.820	5.756	4.785	5.778	5.529
18	Name		Exhaust				
19	Temperature	(C)	128.9				
20	Pressure	(kPa)	516.4 *				
21	Mass Flow	(kg/s)	1.0000000				
22	Mass Density	(kg/m3)	4.3238300				
23	Mass Enthalpy	(kJ/kg)	108.4				
24	Mass Entropy	(kJ/kg-C)	5.115				
25				Compositions		Fluid Pk	
26	Name		Comp Out	Turbine Inlet	Nitrogen	Turbine Outlet	Reactor Inlet
28	Comp Mole Frac (Nitrogen)		1 0000	1 0000	1 0000 *	1 0000	1 0000
29	Comp Mole Frac (Oxygen)		0.0000	0 0000	0 0000 *	0.0000	0.0000
30	Comp Mole Frac (Arron)		0.0000	0.0000	0.0000 *	0.0000	0.0000
31	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000 *	0.0000	0.0000
32	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000 *	0.0000	0.0000
33	Name		Exhaust				
34	Comp Mole Frac (Nitrogen)		1.0000				
35	Comp Mole Frac (Oxygen)		0.0000				
36	Comp Mole Frac (Argon)		0.0000				
37	Comp Mole Frac (CO2)		0.0000				
38	Comp Mole Frac (H2O)		0.0000				
39				Energy Stream:	s	Fluid Pk	g: All
40	Name		Comp Pwr	Reactor Heat	Turb Pwr		
42	Heat Flow	(MW)	8.602e-002	0.1758	0 1478		
43	Treat How	(000)	0.0020-002	0.1700	0.1470		
44				Heaters		Fluid Pk	g: All
45	Name		Reactor				
46	DUTY	(MW)	0.1756				
47	Feed Temperature	(C)	444.8				
48	Product Temperature	(C)	600.0 *				
49	Mass Flow	(kg/s)	1.000				
50				Coolere		Electric Di	
51				Coolers		Fluid Pk	g: All
52	Name						
53	DUTY	(MW)					
54	Feed Temperature	(C)					
55	Product Temperature	(C)					
56	Mass Flow	(kg/s)					
57 58 59 60 61 62	Appp Technology /				on 0.		Porce 1 of 2
63	Aspen Technology Inc.	40		Aspen HYSYS Versi	on 9		Page 1 of 2
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1				Core Norma	and the barries of the second	and 200 best sees has	
2	0	UNIVERSI	TY OF IDAHO	Gase Name.	recuperated N2 braytor	r cycle dou best case.risc	•
3	(e)aspentech	Bedford, M	IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:50:54 2	019	
6							
7	Worl	kbook:	Case (Main) (continue	ed)		
8			•		-		
10				Heat Exchange	rs	Fluid Pkg	g: All
11	Name		Recuperating Heat Ex				
12	Duty	(MW)	0.3727				
13	Tube Side Feed Mass Flow	(kg/s)	1.000				
14	Shell Side Feed Mass Flow	(kg/s)	1.000				
15	Tube Inlet Temperature	(C)	103.5				
16	Tube Outlet Temperature	(C)	444.8				
17	Shell Inlet Temperature	(C)	469.8				
18	Shell Outlet Temperature	(C)	128.9				
19	LMID	(C)	25.33				
20	UA	(kJ/C-h)	5.298e+004				
21	Minimum Approach	(C)	25.00				
22				Compressors		Fluid Pkg	g: All
23	News		0	-			
24	Name	(5454/)	Compressor				
20	Power	(MVV) (ND-)	8.002e-002				
20	Preduct Processor	(KFa)	510.4				
21	Product Pressure Product Tomporature	(KPa) (C)	1090				
20	Froduct remperature	(0)	21.11				
30	Adiabatic Efficiency	(0)	21.11				
31	Pressure Ratio		2 120				
32	Mass Flow	(ka/s)	1.000 *				
33	indos r ion	("8")	1.000				
				Evnandore		Eluid Dka	n· ΔII
34				Expanders		Fidia Fik	. <u> </u>
34 35	Name		Turbine	Expanders		Fidia Fik	y. All
34 35 36	Name Power	(MW)	Turbine 0.1478	Expanders			y. 74
34 35 36 37	Name Power Feed Pressure	(MW) (kPa)	Turbine 0.1478 1051 *	Expanders			g. 240
34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)	Turbine 0.1478 1051 * 528.9	Expanders			g. 240
34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)	Turbine 0.1478 1051 * 528.9 489.8	Expanders			
34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)	Turbine 0.1478 1051 * 526.9 469.8 600.0 *	Expanders			
34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency	(MW) (kPa) (kPa) (C) (C)	Turbine 0.1478 1051 ° 526.9 469.8 600.0 ° 90 °	Expanders			
34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 526.9 469.8 600.0 90 1.000	Expanders			
34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pic	y All
34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 526.9 469.8 600.0 90 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 * 528.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 * 528.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 45 45 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pk	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Feed Temperature	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (c) (kPa) (C)	Turbine 0.1478 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Feed Temperature Product Pressure Pred Temperature Product Pressure Product Pressure Product Temperature Product Temperature	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa)	Turbine 0.1478 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 52 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Besidence (Current/D)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Pred Temperature Product Temperature Product Temperature Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Out Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 45 45 45 51 52 53 54 55 55	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 45 45 45 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 51 52 53 54 55 56 57 58 59	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 57 58 59 60	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 526.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Name Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 528.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 55 51 52 53 54 55 56 57 58 59 60 61 62	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Temperature Product Temperature Product Temperature Q Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 528.9 469.8 600.0 * 90 * 1.000	Valves		Fluid Pkg	g: All
34 35 36 37 38 39 40 41 42 43 44 45 55 51 52 53 54 55 56 57 58 59 60 61 62 63	Name Power Feed Pressure Product Temperature Preduct Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Temperature Pressure Drop Feed Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1478 1051 * 528.9 469.8 800.0 * 90 * 1.000 1.000 1.000	Valves	ion 9	Fluid Pkg	p. 74





1				0			-
2	0	UNIVERSI	TY OF IDAHO	Case Name:	recuperated air brayton	cycle ouu worst case.ns	c
3	(e)aspentech	Bedford, M	IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:21:47 20	019	
6							
7	Worl	kbook:	Case (Mai	n)			
9				Material Stream	-	Eluid Dh	
10				Material Stream	s	Fluid PK	g: All
11	Name	(0)	Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	Reactor Inlet
12	Deserves	(6)	101.9	000.0	21.11	00.0	481.0
14	Mass Flow	(kr/c)	1 000000	1 0000000	1 0000000 *	1 0000000	1 0000000
15	Mass Density	(kg/s) (kg/m3)	1 7426073	0.71842720	1 1048843	0 45000735	0.84874289
16	Mass Enthaloy	(kg/110)	-28.97	508.4	-111.2	403.3	375.7
17	Mass Entrony	(k l/kg-C)	5 351	8 260	5 283	6 303	6 000
18	Name	(NU/Ng-O)	Air Exhaust	0.200	0.200	0.000	0.000
19	Temperature	(C)	128.6				
20	Pressure	(kPa)	101.3 *				
21	Mass Flow	(ka/s)	1 0000000				
22	Mass Density	(kg/m3)	0.87454412				
23	Mass Enthaloy	(k,1/kg)	-1.318				
24	Mass Entropy	(kJ/kg-C)	5.601				
25		(a			
26				Compositions		Fluid Pk	g: All
27	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet	Reactor Inlet
28	Comp Mole Frac (Nitrogen)		0.7713	0.7713	0.7713	0.7713	0.7713
29	Comp Mole Frac (Oxygen)		0.2069	0.2069	0.2069	0.2069	0.2069
30	Comp Mole Frac (Argon)		0.0092	0.0092	0.0092	0.0092	0.0092
31	Comp Mole Frac (CO2)		0.0003	0.0003	0.0003	0.0003	0.0003
32	Comp Mole Frac (H2O)		0.0123	0.0123	0.0123	0.0123	0.0123
33	Name		Air Exhaust				
34	Comp Mole Frac (Nitrogen)		0.7713				
35	Comp Mole Frac (Oxygen)		0.2069				
36	Comp Mole Frac (Argon)		0.0092				
37	Comp Mole Frac (CO2)		0.0003				
38	Comp Mole Frac (H2O)		0.0123				
39				Energy Stream	s	Fluid Pk	g: All
41	Name		Comp Pwr	Reactor Heat	Turb Pwr		
42	Heat Flow	(MW)	8 225e-002	0 1327	0 1051		
43	Theat Thom	(and)	0.2200-002	0.1027	0.1001		
44				Heaters		Fluid Pk	g: All
45	Name		Reactor				
46	DUTY	(MW)	0.1327				
47	Feed Temperature	(C)	481.0				
48	Product Temperature	(C)	600.0 *				
49	Mass Flow	(kg/s)	1.000				
50				Cardan			
51				Coolers		Fluid Pk	g: All
52	Name						
53	DUTY	(MW)					
54	Feed Temperature	(C)					
55	Product Temperature	(C)					
56	Mass Flow	(kg/s)					
57							
58							
59							
60							
61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
	Licensed to: UNIVERSITY OF ID/	nnu					specified by user.

Image: Separation Unit REGITY OF IDAHO USA Case Name Transported at https/mysle 800 workt case No Unit Set: Nutrocale3a Image: Nutrocale3a Image: Nutrocale3a Image: Nutrocale3a Image: Nutrocale3a	111							
Image: Sepented biology of the second seco	2				Case Name:	recuperated air brayton	cycle 600 worst case.hso	C
4 USA Date/Time: Tue Nov 26 12:21:47:2019 6 7 Workbook: Case (Main) (continued) 10 Name Recogniting Heat Eq. All 11 Name Recogniting Heat Eq. All 12 Duty See Mass Flow Agay 1.000 All 13 Tue Side Feed Mass Flow Agay 1.000 All 14 Shell Net Temperature (C) 1.000 All 15 Tue Net Preperature (C) 1.000 All 15 Tue Net Preperature (C) 1.28.6 All 16 Tue Net Preperature (C) 2.28.0 All 11 Shell Net Temperature (C) 2.28.0 All 12 Marine Marcolant Color Ar Compressors Plud Pag. All 14 Mare Ar Compressors Plud Pag. All 15 Product Temperature (C) 2.111 All 14 Mare Ar Turbine Al	3	(aspentech	Bedford, M	A	Unit Set:	NuScale3a		
Image: Second	4		USA		Date/Time:	Tue Nov 26 12:21:47 2	019	
Image: state in the set of the s	6							
Image Heat Exchangers Fuid Pig: All 11 Name Recupering Heat Exchangers Fuid Pig: All 12 Duty (MW) 0.4046 Image: State St	7	Worl	kbook:	Case (Main) (continue	ed)		
Bill Heat Exchangers Puid Pag: All 11 Name Recoverating Heat Edit 12 Duty Outy 0.0494 13 Tube Side Feed Mass Flow (kg/s) 1.000 13 Tube Side Feed Mass Flow (kg/s) 1.000 14 Shell Side Feed Mass Flow (kg/s) 1.000	8				/			
Image Recuperating Heat Ex Image Image <thimage< th=""> <thimage< th=""> <thimage< th=""></thimage<></thimage<></thimage<>	9				Heat Exchange	rs	Fluid Pkg	g: All
Initian Description Description Description Description 13 Tube Side Feed Mass Flow (MV) 0.4946	10	Name		Peouperating Heat Ex				
Time Side Field Mass Flow (kg/s) 1.000	12	Duty	(MW)	0 4046				
14 Bit Side Field Mass Flow (0, gps) 1000 Image: Side Field Mass Flow (0, gps) 15 Tube helf Temperature (C) 481.0 Image: Side Field Mass Flow (D) 17 Shell Outer Temperature (C) 481.0 Image: Side Field Mass Flow (D) 18 Shell Outer Temperature (C) 28.6 Image: Side Field Mass Flow (D) 21 Marine (C) 28.60 Image: Side Field Mass Flow (D) 23 Compressors Fluid Pkg: All 23 Compressors Fluid Pkg: All 24 Name Ar Compressor Fluid Pkg: All 25 Feed Pressure (IPA) 188.5 Image: Side Field Mass Field	13	Tube Side Feed Mass Flow	(ka/s)	1.000				
Is Tube (bit Resperature (C) 1010 Image (bit Resperature) (C) 1010 Image (bit Resperature) (C) 1010 Image (bit Resperature) Image (bit Resperature) <thimage (bit="" resperature)<="" th=""></thimage>	14	Shell Side Feed Mass Flow	(kg/s)	1.000				
Ise Unit Contract Temperature (C) 481.0	15	Tube Inlet Temperature	(C)	101.9				
11 Shel lott Temperature (C) 50.0	16	Tube Outlet Temperature	(C)	481.0				
18 Shall Outlet Temperature (C) 128.6	17	Shell Inlet Temperature	(C)	506.0				
19 LNTD (C) 28.80	18	Shell Outlet Temperature	(C)	128.6				
10 UA (LIC-h) 5.448e-004 Immum Approach Immum Appr	19	LMTD	(C)	25.80				
I Minimum Approach (C) 26 Compressors Fluid Pkg: All 23 Name Ar Compressor Fluid Pkg: All 24 Name Ar Compressor Fluid Pkg: All 25 Power (MW) 8.226+002 26 Product Pressure (KPa) 101.3 * 27 Product Pressure (KPa) 188.6 27 Poduct Emperature (C) 11.1 * 28 Feed Temperature (C) 10.00 *	20	UA	(kJ/C-h)	5.646e+004				
Page All 24 Name Ar Compressors Fluid Pkg: All 24 Name Ar Compressor Image: Compressor Compressor Compressor Image: Compres	21	Minimum Approach	(C)	25.00				
21 Name Air Compressor	22				Compressors		Fluid Pkg	g: All
Image Image Image Image Image Prover (MV) 8.225-002 Image Image <td< td=""><td>23</td><td>News</td><td></td><td>Als Commence</td><td></td><td></td><td></td><td></td></td<>	23	News		Als Commence				
Image: Construct of the second seco	24	Rower	(M0A()	Air Compressor				
International (int a) (int a) (int a) 21 Product Temperature (C) 101.3 (C) 20 23 Product Temperature (C) 101.9 (C) 21.11 (C) (C) 21.11 (C) (C) 21.11 (C) (C) 21.11 (C)	26	Fower Food Processo	(MVV) (kPp)	101.2 *				
Indext Temperature (C) 1000 1000 20 Fred Temperature (C) 21.11 1 1 21 Adiabatic Efficiency 70 · 1 1 1 21 Mass Flow (kg/s) 1.000 · 1 1 1 22 Mass Flow (kg/s) 1.000 · 1	27	Product Pressure	(kPa)	188.5				
Image: Second	28	Product Temperature	(C)	101.9				
30 Adiabatic Efficiency 0 70 ° 1 31 Pressure Ratio 1.800 ° 1 1 33 Mass Flow (kg/s) 1.000 ° 1 1 33 Mass Flow (kg/s) 1.000 ° 1 1 34 Expanders Fluid Pkg: All 35 Name Air Turbine 1 1 36 Power (MW) 0.1051 1 1 37 Feed Pressure (IPa) 103.4 1 1 1 38 Product Temperature (C) 506.0 1 1 1 39 Product Temperature (C) 600.0 ° 1 1 1 41 Adiabatic Efficiency 80 ° 1 1 1 1 42 Mass Flow (kg/s) 1.000 1 1 1 1 1 1 1 1 1 1 1 1 1 1	29	Feed Temperature	(C)	21.11				
I Pressure Ratio 1.880 * Image: Constraint of the set of t	30	Adiabatic Efficiency	(-/	70 *				
32 Mass Flow (kg/s) 1.000 ⁻¹ Expanders Fluid Pkg: All 33 34 Expanders Fluid Pkg: All 34 Air Turbine All 35 Preed Pressure (kPa) 181.0 All All	31	Pressure Ratio		1.860 *				
Bit Stress Fluid Pkg: All 34 Air Turbine Image: Stress Fluid Pkg: All 35 Name Air Turbine Image: Stress All 36 Power (MW) 0.1051 Image: Stress All 37 Feed Pressure (kPa) 181.0 Image: Stress Image: Stress 38 Product Temperature (C) 606.0 Image: Stress Image: Stress 40 Feed Temperature (C) 600.0 Image: Stress Image: Stress 41 Adiabatic Efficiency 80° Image: Stress Image: Stress Image: Stress 43 Valves Fluid Pkg: All 44 Valves Fluid Pkg: All 45 Name Image: Stress Image: Stress All 46 Pressure Drop (kPa) Image: Stress Image: Stress 47 Feed Temperature (C) Image: Stress Image: Stress 48 Product Pressure (kPa) Image: Stress Image: Stress 50 Product Pressure (kPa) Image: Stress Image: Stress 51 Mass Flow (kg/s) Image: Stress Image: Stress	32	Mass Flow	(ka/s)	1.000 *				
34 CEXPANDERS PUID PAGE All 35 Name Air Turbine All 35 Power (MV) 0.1051 <t< td=""><td>33</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	33							
35 Name Air Turbine Image: Constraint of the state of the s					E			
36 Power (MW) 0.1051 Image: constraint of the state of th	34				Expanders		Fluid Pkg	g: All
37 Feed Pressure (kPa) 181.0 Image: constraint of the source of t	34 35	Name		Air Turbine	Expanders		Fluid Pkg	g: All
38 Product Pressure (KPa) 103.4 Image: Constraint of the second s	34 35 36	Name Power	(MW)	Air Turbine 0.1051	Expanders		Fluid Pkg	g: All
39 Product Temperature (C) 606.0	34 35 36 37	Name Power Feed Pressure	(MW) (kPa)	Air Turbine 0.1051 181.0	Expanders		Fluid Pkg	g: All
40 Freed Temperature (C) 000.0° 000	34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)	Air Turbine 0.1051 181.0 103.4	Expanders		Fluid Pkg	j: All
41 Adiabatic Emciency 80°	34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)	Air Turbine 0.1051 181.0 103.4 506.0	Expanders		Fluid Pkg	;: All
42 Mass Flow (kg/s) 1.000 Fluid Fluid Pkg: All 43 Valves Fluid Pkg: All 44 Valves Fluid Pkg: All 45 Name 46 Pressure Drop (kPa) 47 Feed Temperature (C) 47 Feed Temperature (C) 48 Feed Temperature (C)	34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)	Air Turbine 0.1051 181.0 103.4 506.0 600.0	Expanders		Fluid Pkg	
41 Valves Fluid Pkg: All 45 Name All 46 Pressure Drop (kPa)	34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency	(MW) (kPa) (kPa) (C) (C)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 ° 80 °	Expanders		Fluid Pkg	
44 Name Ame Ame 45 Name Image: Stress of the stress of	34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 * 80 * 1.000	Expanders		Fluid Pkg	
Name Name <th< td=""><td>34 35 36 37 38 39 40 41 42 43 44</td><td>Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow</td><td>(MW) (kPa) (kPa) (C) (C) (kg/s)</td><td>Air Turbine 0.1051 181.0 103.4 506.0 600.0 * 80 * 1.000</td><td>Valves</td><td></td><td>Fluid Pkg</td><td>2: All</td></th<>	34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 * 80 * 1.000	Valves		Fluid Pkg	2: All
No. No. No. No. No. 47 Feed Pressure (kPa)	34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 ° 80 ° 1.000	Valves		Fluid Pkg	g: All
All Feed Temperature (C) Image: Constraint of the state of th	34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
49 Product Pressure (kPa) 0 50 Product Temperature (C) 0 0 51 Mass Flow (kg/s) 0 0 0 52 Cg 0 0 0 0 0 52 Cg 0	34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 ° 80 ° 1.000	Valves		Fluid Pkg	;: All
50 Product Temperature (C) Image: Second	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Pressure	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	;: All
51 Mass Flow (kg/s) Image: Second	34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Feed Temperature Pressure Drop Feed Temperature Product Pressure	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
S2 Cg	34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Feed Temperature Product Pressure Product Pressure Product Pressure Product Temperature	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
53 Resistance (Cv or K) 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Usensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (c) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Usensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pred Pressure Product Pressure Product Temperature Mass Flow Cg	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
ss 56 57 58 59 60 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pred Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Preduct Pressure Pred Temperature Product Pressure Product Temperature Product Temperature Outor Temperature Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Preduct Pressure Pred Temperature Product Pressure Pred Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	g: All
58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Feed Temperature Product Pressure Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO * Smerified by user	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pred Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
60 61 62 63 Aspen Technology Inc. 64 65 66 67 68 69 69 60 61 62 63 64 65 66 67 68 69 69 60 61 62 63 64 65 66 67 68 69 61 62 63 64 65 65 66 67 68 68 69 69 69 61 62 63 64 65 66 67 68 69 69 69 60 61 62 63 64 65 66 67 68	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Pred Pressure Product Pressure Product Temperature Product Temperature Oduct Temperature Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
61 62 63 Aspen Technology Inc. 64 Aspen HYSYS Version 9 7 Page 2 of 2	34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53 54 55 56 57 58 9 9	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Pred Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
b2 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO * Snewfield by user	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 960	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Pressure Product Pressure Product Pressure Product Pressure Product Pressure Product Serve Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
Licensed to: UNIVERSITY OF IDAHO * Snerified by licen	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 55 55 55 55 57 58 90 61 100	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	3: All
A DECEMBER OF A	34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Air Turbine 0.1051 0.1051 181.0 103.4 506.0 600.0 80 1.000	Valves		Fluid Pkg	p: All





1				Case Name:	recuperated n2 brayton	cycle 600 worst case.hso	c
2	(aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:51:51 20)19	
6			- <i></i>				
7 8	Wor	kbook	Case (Mai	n)			
9				Material Stream	s	Fluid Pkg	g: All
11	Name		Comp Out	Turbine Inlet	Nitrogen	Turbine Outlet	Reactor Inlet
12	Temperature	(C)	102.0	600.0 *	21.11 *	504.9	479.9
13	Pressure	(kPa)	1095	1051 *	588.5 *	600.5	1073
14	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000 *	1.0000000	1.000000
15	Mass Density	(kg/m3)	9.8242102	4.0436817	6.7571552	2.5955575	4.7828441
16	Mass Enthalpy	(kJ/kg)	78.90	628.9	-5.687	520.6	492.6
17	Mass Entropy	(kJ/kg-C)	4.816	5.756	4.746	5.791	5.582
18	Name		Exhaust				
19	Temperature	(C)	127.6				
20	Pressure	(kPa)	588.5 *				
21	Mass Flow	(kg/s)	1.0000000				
22	Mass Density	(kg/m3)	4.9440607				
23	Mass Enthalpy	(kJ/kg)	106.9				
24	Mass Entropy	(kJ/kg-C)	5.072				
25				Compositions		Fluid Pkg	g: All
20	Name		Comp Out	Turbing Inlat	Nitrogon	Turbine Outlet	Pepeter Inlet
27	Comp Mole Erze (Nitrogen)		1 0000	1 0000	1 0000 -	1 0000	1 0000
29	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000 *	0.0000	0.0000
30	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000 *	0.0000	0.0000
31	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000 *	0.0000	0.0000
32	Comp Mole Frac (UC2)		0.0000	0.0000	0.0000 *	0.0000	0.0000
33	Name		Exhaust	0.0000	0.0000	0.0000	0.0000
34	Comp Mole Frac (Nitrogen)		1 0000				
35	Comp Mole Frac (Oxygen)		0.0000				
36	Comp Mole Frac (Argon)		0.0000				
37	Comp Mole Frac (CO2)		0.0000				
38	Comp Mole Frac (H2O)		0.0000				
39				Energy Stream	s	Fluid Pkg	g: All
40	Name		Comp Pwr	Reactor Heat	Turb Pwr		
42	Heat Flow	(MW)	8 459e-002	0 1383	0 1083		
43	The second se	()	0.1000 002	0.1000	0.1000		
44				Heaters		Fluid Pkg	g: All
45	Name		Reactor				
46	DUTY	(MW)	0.1363				
47	Feed Temperature	(C)	479.9				
48	Product Temperature	(C)	600.0 *				
49	Mass Flow	(kg/s)	1.000				
50				Coolere		Eluid Pkr	
51				Coolers		There is no	g. ^ii
52	Name						
53	DUTY	(MW)					
54	Feed Temperature	(C)					
55	Product Temperature	(C)					
56	Mass Flow	(kg/s)					
58 59 60 61 62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
	Licensed to: UNIVERSITY OF IDA	HO					* Specified by user

Image: Second Construction Diversion Construction Data Time: Nuclearies Image: Second Construction Workbook: Case (Main) (continued) Data Time: Tas Nev 28 12:51:51:2019 Image: Second Construction Morkbook: Case (Main) (continued) Second Construction All Image: Second Construction Morkbook: Case (Main) (continued) Second Construction All Image: Second Construction Morkbook: Case (Main) (continued) Second Construction All Image: Second Construction Morkbook: Case (Main) (continued) Second Construction All Image: Second Construction Morkbook: Case (Main) (continued) Second Construction Second Construction Second Construction Image: Second Construction Second Construction Second Construction Second Construction Second Construction Image: Second Construction Second Construction Second Construction Second Construction Second Construction Image: Second Construction Second Construction Second Construction Second Construction Second Construction Image: Second Construction Second Construction Second Construction Second Construct	1				Case Name:	recuperated n2 brayton	cycle 600 worst case.hs	c
displant USA Date/Time: Tace Nov 26 12 21 31 2019 0 Workbook: Case (Main) (continued) 0 Heat Exchangers Poul Pig: All 10 Heat Exchangers Poul Pig: All 11 Name Recogenting Heat Est Image: All 12 Date // Time: Tack Sile Feed Mass Flow (g) 1.000 13 Table Sile Feed Mass Flow (g) 1.000 Image: All 13 Shell Inst Temperature (c) 47.83 Image: All 14 Mare Compressors Fluid Pig: All 21 Mare Compressor Fluid Pig: All 21 Mare Compressor Fluid Pig: All 21 Mare Compressor Fluid Pig: All 22 Product Temperature (c) 21.11 All 23 Product Temperature (c) 21.11 All 24 Name Kapanders <t< td=""><td>3</td><td>(e)aspentech</td><td>Bedford, M</td><td>IY OF IDAHO IA</td><td>Unit Set:</td><td>NuScale3a</td><td></td><td></td></t<>	3	(e)aspentech	Bedford, M	IY OF IDAHO IA	Unit Set:	NuScale3a		
Image: Second	4		USA		Date/Time:	Tue Nov 26 12:51:51 2	019	
9 Heat Exchangers Plud Pig: All 11 Name Requering Heat Eq.	6 7 8	Worl	kbook:	Case (Main	ı) (continue	ed)		
Image Recoperating Heat E Image Image 12 Dufy (MV) 0.4157 Image	9				Heat Exchange	rs	Fluid Pkg	g: All
Dury MVN 0.4137 Image: constraint of the set of	11	Name		Recuperating Heat Ex				
13 Use Side Feed Mass Flow (bg) 1.000 Image: Control of Control	12	Duty	(MW)	0.4137				
14 Del Side Feed Mass Flow (kg)s 1000	13	Tube Side Feed Mass Flow	(kg/s)	1.000				
18 Tube club Ferepretature (C) 102.0	14	Shell Side Feed Mass Flow	(kg/s)	1.000				
Its Dublish Temperature (C) 479.0	15	Tube Inlet Temperature	(C)	102.0				
17 Shel liket Temperature (C) 504.9	16	Tube Outlet Temperature	(C)	479.9				
11 Shel Outlet Temperature (C) 127.6 Immune Approach Immune Approach 20 UA (LUC-A) 5.858+-004 Immune Approach Immune Approach 21 Minimum Approach (C) 25.00 Immune Approach Immune Approach 21 Manie Compressors Fluid Pkg: All 22 Immune Approach Compressor Fluid Pkg: All 23 Power (MW) 8.458-002 Immune Approach Immune Approach 24 Power (Pa) 1006 Immune Approach Immune Approach Immune Approach 25 Power (Pa) 1006 Immune Approach Immune Approach Immune Approach 26 Power (C) 121.11 Immune Approach	17	Shell Inlet Temperature	(C)	504.9				
19 LNTO (C) 23.42	18	Shell Outlet Temperature	(C)	127.6				
20 UA (ULC-h) 5.858-e-004 <td>19</td> <td>LMTD</td> <td>(C)</td> <td>25.42</td> <td></td> <td></td> <td></td> <td></td>	19	LMTD	(C)	25.42				
Immune Approach (c) 25.00 Compressors Fluid Pkg: All 23 Name Compressor Fluid Pkg: All 24 Name Compressor Fluid Pkg: All 25 Porect (MW) 8.459e-002 26 Feed Pressure (Pa) 568.51 27 Product Temperature (C) 1005 27 Product Temperature (C) 102.0 28 Feed Temperature (C) 1000 31 Pressure Ratio 1.860 32 Mass Flow (kgis) 1.000 All	20	UA	(kJ/C-h)	5.858e+004				
22 Compressors Puid Pkg: All 24 Name Compressor All 25 Power (MW) 8.456-002	21	Minimum Approach	(C)	25.00				
23 Compressor Fail Fig. All 24 Name Compressor Image: Compressor Image: Compressor 25 Power (MW) 8.450e-002 Image: Compressor Image: Compressor 26 Product Tenseare (KPa) 1006 Image: Compressor Image: Compressor 27 Product Tenseare (C) 102.0 Image: Compressor Image: Compressor 28 Feed Tenseare (C) 121.11 Image: Compressor Image: Compressor 31 Pressure Ratio 1.660 Image: Compressor Image: Compressor Image: Compressor 31 Pressure Ratio 1.600 Image: Compressor Feed Tenseare Image: Compressor All 33 Poolact Pressure (MW) 0.1063 Image: Compressor Image: Compressor All 34 Name Tubine Image: Compressor Image: Compressor Image: Compressor All 35 Poolact Pressure (Mas) Image: Compressor Image: Compressor Image: Compressor	22				Compressore		Eluid Pkr	
21 Name Compressor Image: Compressor 20 Product Tressure (MV) 8.456-002 Image: Compressor 21 Product Tressure (Passure (Passure (Passure (Passure 21 Product Tressure (C) 102.0 Image: Compressor Image: Compressor 23 Product Tressure (C) 21.11* Image: Compressor Image: Compressor 24 Adabatic Efficiency 70* Image: Compressor Fluid Pkg: All 23 Adabatic Efficiency 1.000* Image: Compressor Fluid Pkg: All 34 Turbine Image: Compressor Fluid Pkg: All 35 Product Tressore (IPA) 000.5 Image: Compressore All 35 Product Tressore (IPA) 000.5 Image: Compressore All 36 Product Tressore (IPA) Image: Compressore All 36 Product Tressore (IPA) Image: Compressore All 37 <td< td=""><td>23</td><td></td><td></td><td></td><td>compressors</td><td></td><td>Fluid P Ng</td><td>. <u>Al</u></td></td<>	23				compressors		Fluid P Ng	. <u>Al</u>
21 Power (MW) 0.8450-002 Image: Constraint of the set of the se	24	Name		Compressor				
28 Feed Pressure (IFA) 588.5 *	25	Power	(MW)	8.459e-002				
27 Product Pressure (kPa) 1006 1006 28 Product Presperature (C) 102.0 1006 29 Feed Temperature (C) 21.11 1 1 30 Adabatic Efficiency 70 1 1 1 31 Pressure Ratio 1.800 1 1 1 32 Mass Flow (kg/s) 1.000 ⁺ 1 1 1 33 Mame Turbine Expanders Fluid Pkg: All 1 34 Turbine 1	26	Feed Pressure	(kPa)	588.5 *				
28 Product Temperature (C) 102.0 29 Feed Temperature (C) 21.11	27	Product Pressure	(kPa)	1095				
20 Feed Temperature (C) 21.11*	28	Product Temperature	(C)	102.0				
30 Adiabatic Efficiency 70 '	29	Feed Temperature	(C)	21.11				
31 Pressure Ratio 1.800 1.800 32 Mass Flow (kg/s) 1.000 ' Image: State	30	Adiabatic Efficiency		70 *				
32 Mass Flow (kg/s) 1.000 ° Fluid Pkg: All 33 Expanders Fluid Pkg: All 34 Turbine 35 Name Turbine 36 Power (MW) 0.1083 37 Feed Pressure (kPa) 1051 ° 38 Product Temperature (C) 600.5 39 Product Temperature (C) 600.0 ° 41 Aliabatic Efficiency 80 ° 42 Mass Flow (kg/s) 1.000 <t< td=""><td>31</td><td>Pressure Ratio</td><td></td><td>1.860</td><td></td><td></td><td></td><td></td></t<>	31	Pressure Ratio		1.860				
33 Expanders Fluid Pkg: All 35 Name Turbine All 36 Name Turbine All 36 Product Pressure (kPa) 1051 +	32	Mass Flow	(kg/s)	1.000 *				
34 Turbing Link and the set of								
33 Name Turbine Image: Constraint of the second	33				Expanders		Fluid Pko	a: All
38 Power (MW) 0.1083	33 34				Expanders		Fluid Pkg	g: All
37 Freed Pressure (KPa) 1001 * 38 Product Temperature (C) 504.9	33 34 35	Name		Turbine	Expanders		Fluid Pkg	g: All
39 Product Pressure (KPa) 000.5 00.5 39 Product Temperature (C) 504.9 00.5 40 Feed Temperature (C) 600.0° 00.5 41 Adiabatic Efficiency 80.° 00.5 42 Mass Flow (kg/s) 1.000 00.5 43 Valves Fluid Pkg: All 44 Valves Fluid Pkg: All 45 Name 00.5 00.5 00.5 46 Pressure Drop (kPa) 00.5 00.5 00.5 47 Feed Temperature (C) 00.5 00.5 00.5 00.5 47 Feed Temperature (C) 00.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5	33 34 35 36	Name Power	(MW)	Turbine 0.1083	Expanders		Fluid Pkg	g: All
30 Product Temperature (C) 004.9	33 34 35 36 37	Name Power Feed Pressure	(MW) (kPa)	Turbine 0.1083 1051 *	Expanders		Fluid Pkg	g: All
40 Pred 1 emperature (C) 00000 00000 00000 00000 00000 00000 000000 000000 000000 000000 000000 000000 0000000 0000000 00000000 00000000 00000000000 0000000000000 000000000000000000000000000000000000	33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)	Turbine 0.1083 1051 * 600.5	Expanders		Fluid Pkg	g: All
Image: state of the s	33 34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)	Turbine 0.1083 1051 * 600.5 504.9 200.0 1	Expanders		Fluid Pkg	g: All
Hass Flow (kg/s) 1.000 Fluid Fluid Pkg: All 43 Valves Fluid Pkg: All 44 Valves Fluid Pkg: All 45 Name 46 Pressure Drop (kPa) 47 Feed Temperature (C) 47 Feed Temperature (C) 47 Feed Temperature (C)	33 34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)	Turbine 0.1083 1051 * 600.5 504.9 600.0 *	Expanders		Fluid Pkg	g: All
Name Valves Fluid Pkg: All 45 Name	33 34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency	(MW) (kPa) (kPa) (C) (C)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 *	Expanders		Fluid Pkg	g: All
*** *** 45 Name	33 34 35 36 37 38 39 40 41 42 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Expanders		Fluid Pkg	g: All
Name Name <th< td=""><td>33 34 35 36 37 38 39 40 41 42 43 44</td><td>Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow</td><td>(MW) (kPa) (kPa) (C) (C) (kg/s)</td><td>Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000</td><td>Valves</td><td></td><td>Fluid Pkg</td><td>g: All</td></th<>	33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
1 1 1 1 1 47 Feed Temperature (KPa) 1 1 1 48 Feed Temperature (C) 1 1 1 1 49 Product Pressure (kPa) 1 1 1 1 1 50 Product Temperature (C) 1 <td< td=""><td>33 34 35 36 37 38 39 40 41 42 43 44</td><td>Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow</td><td>(MW) (kPa) (kPa) (C) (C) (kg/s)</td><td>Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000</td><td>Valves</td><td></td><td>Fluid Pkg</td><td>g: All</td></td<>	33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
In Section (M d) Interview (M d) Interview Inter	33 34 35 36 37 38 39 40 41 42 43 44 45 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
Incomposition (o) Incomposition (o) 49 Product Pressure (kPa) Incomposition Incomposition 50 Product Temperature (C) Incomposition Incomposition Incomposition 51 Mass Flow (kg/s) Incomposition Incomposition Incomposition Incomposition 52 Cg Incomposition	33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
S0 Product Temperature (C) Image: Column Stress Stres Stres Stress	33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 47 48	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
1 Mass Flow (kg/s) i i i 51 Mass Flow (kg/s) i i i 52 Cg i i i i i 53 Resistance (Cv or K) i i i i i i 54 55 i	33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Pressure Drop Feed Temperature Product Pressure	(MW) (kPa) (C) (C) (kg/s) (kg/s) (kPa) (kPa)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
S2 Cg G 53 Resistance (Cv or K) Image: Comparison of the second	33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (C) (C) (kg/s) (kpa) (kPa) (C) (kPa) (C)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
53 Resistance (Cv or K) 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Licensed to: UNIVERSITY OF IDAHO * Specified by user	33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 45 45 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Product Temperature Mass Flow	(MW) (kPa) (C) (C) (kg/s) (kg/s) (kPa) (C) (kPa) (C) (kq/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 2 Usensed to: UNIVERSITY OF IDAHO	33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow	(MW) (kPa) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kPa)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
[53] Aspen Lechnology Inc. Aspen HYSYS Version 9 Page 2 of 2 Licensed to: UNIVERSITY OF IDAHO * Specified by user	33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Pressure Pressure Drop Feed Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kg/s) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	g: All
	33 34 35 36 37 38 39 40 41 42 44 45 50 51 52 53 54 55 57 58 59 60 61 62	Name Product Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Temperature Product Temperature Product Temperature Q Resistance (Cv or K)	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	Turbine 0.1083 1051 * 600.5 504.9 600.0 * 80 * 1.000	Valves		Fluid Pkg	2: All



Aspen HYSYS Process Model of Micro AGile Non-nuclear Experimental Testbed with Helium Operating at 850°C

_							
1				Case Name:	Ini test bed he.hsc		
2	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set	NuScale3a		
4	0	USA		Date/Time:	Fri Jan 31 15:04:56 202	20	
5						-	
7	Worl	kbook:	Case (Mai	n)			
8				,			
9 10				Material Stream	IS	Fluid Pkg	g: All
11	Name		Cold Air In	Cold Air Out	Hot air in	Hot air Out	1
12	Temperature	(C)	71.64	550.0 *	847.8	369.5	369.2
13	Pressure	(kPa)	1300	1076	1050	1001 *	999.7
14	Mass Flow	(kg/s)	0.15985842	0.15985842	0.15985842	0.15985842	0.15985842
15	Mass Density	(kg/m3)	1.8051494	0.62788522	0.45025647	0.74823134	0.74741461
16	Mass Enthalpy	(kJ/kg)	245.7	2730	4276	1792	1790
17	Mass Entropy	(kJ/kg-C)	-4.548	0.3660	2.020	-0.7704	-0.7698
18	Name		3	4	12	13	2
19	Temperature	(C)	850.0 *	548.9	20.00 *	72.25	369.2 *
20	Pressure	(kPa)	1051 *	1073	951.3 *	1301 *	999.7 *
21	Mass Flow	(kg/s)	0.15985842	0.15985842	0.15985842	0.15985842	0.15985842 *
22	Mass Density	(kg/m3)	0.44993347	0.62696132	1.5549339	1.8036323	0.74741461
23	Mass Enthalpy	(kJ/kg)	4288	2724	-23.56	248.8	1790
24	Mass Entropy	(kJ/kg-C)	2.028	0.3647	-4.741	-4.540	-0.7698
25				Compositions		Fluid Pk	g: All
26	Name		Cold Air In	Cold Air Out	Hot air in	Hot air Out	1
28	Comp Mole Frac (Nitrogen)						
29	Comp Mole Frac (CO2)			•••			•••
30	Comp Mole Frac (Argon)						•••
31	Comp Mole Frac (Oxygen)				•••		•••
32	Comp Mole Fran (H2O)						
33	Comp Mole Frac (Hellum-4)		1 0000	1 0000	1 0000	1 0000	1 0000
34	Name		3	4	12	13	2
35	Comp Mole Erac (Nifrogen)						
36	Comp Mole Frac (CO2)						•••
37	Comp Mole Frac (Argon)						•••
38	Comp Mole Frac (Oxygen)				•••		•••
39	Comp Mole Frac (H2O)						•••
40	Comp Mole Frac (Hellum-4)		1.0000	1.0000 *	1.0000	1.0000	1,0000 *
41				Energy Stream		Eluid Dk	
42				Lifergy Stream	5		y. //
43	Name		Heat	Heat Loss Ex Pipe	Heat Loss In Pipe	Heat Loss Into Chamb	Heat Loss Out Chamt
44	Heat Flow	(MW)	0.2500	2.986e-004	5.101e-004	1.836e-003	9.550e-004
45	Name		Chiller Duty	Blower Power			
46	Heat Flow	(MW)	0.2900	4.355e-002			
48				Heaters		Fluid Pkg	g: All
49	Name		Test Article Chamber				
50	DUTY	(MW)	0.2500				
51	Feed Temperature	(C)	548.9				
52	Product Temperature	(C)	850.0 *				
53	Mass Flow	(kg/s)	0.1599				
54				Coolers		Fluid Pkr	a: All
55	Nama		Chiller	000010			
50	DUTY	0.000	0.0000				
50	East Tomporture	(MW)	0.2900				
20	Preduct Temperature	(0)	369.2				
53	More Flow	(6)	20.00 *				
60	MOD FIUN	(Ng/S)	0.1599 *			L	L
62							
F=							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2

1				Case Name:	Ini test bed he.hsc		
3	(e)aspentech	Bedford, M	IA IDAHO	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 15:04:56 20	20	
6	14/	de a alta		. /	0		
7 8	wor	(DOOK:	Case (Main	i) (continue	ea)		
9				Heat Exchange	rs	Fluid Pkg	i: All
11	Name		RHX				
12	Duty	(MW)	0.3971				
13	Tube Side Feed Mass Flow	(kg/s)	0.1599				
14	Shell Side Feed Mass Flow	(kg/s)	0.1599				
15	Tube Inlet Temperature	(C)	71.64				
16	Tube Outlet Temperature	(C)	550.0 *				
17	Shell Inlet Temperature	(C)	847.8				
18	Shell Outlet Temperature	(C)	369.5				
19	LMTD	(C)	297.8				
20	UA	(kJ/C-h)	4800				
21	Minimum Approach	(C)	297.8				
22				Compressors		Fluid Pkg	j: All
23	Name		Biower				
24	Dower	(MM)	4 355e-002				
26	Feed Pressure	(kPa)	951.3 *				
27	Product Pressure	(kPa)	1301 *				
28	Product Temperature	(C)	72.25				
29	Feed Temperature	(C)	20.00 *				
30	Adiabatic Efficiency		75 *				
31	Pressure Ratio		1.368				
32	Mass Flow	(kg/s)	0.1599				
22							
22				Expanders		Fluid Pkr	1° All
34				Expanders		Fluid Pkg	j: All
34 35	Name			Expanders		Fluid Pkg	j: All
34 35 36	Name Power	(MW)		Expanders		Fluid Pkg	j: All
34 35 36 37	Name Power Feed Pressure	(MW) (kPa)		Expanders		Fluid Pkg	;: All
33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)		Expanders		Fluid Pkg	;: Al
34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)		Expanders		Fluid Pkg	;: Al
34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)		Expanders		Fluid Pkg	;: Al
34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kois)		Expanders		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)		Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Molar Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Valves		Fluid Pkg	р: АІІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Molar Flow Pressure Drop	(MW) (kPa) (C) (C) (C) (kg/s) (kgmole/h) (kPa)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure	(MW) (kPa) (C) (C) (C) (kg/s) (kgmole/h) (kPa)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 51 52 2	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 56 57 55 51 52 53 54 55 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 56 57 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 36 37 38 38 39 40 44 44 45 44 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 35 37 34 35 37 39 94 37 38 39 94 14 14 37 38 39 94 14 14 14 38 39 94 15 15 15 15 15 15 15 15 15 15	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	p: All
33 34 34 35 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 55 57 58 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open	(MW) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Valves		Fluid Pkg	
33 34 34 35 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 55 57 58 59 60 61 62 63	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Molar Flow Pressure Drop Feed Pressure Percentage open Aspen Technology Inc.	(MW) (kPa) (C) (C) (kg/s) (kgmole/h) (kPa) (kPa) (%)		Expanders Valves	ion 9	Fluid Pkg	Page 2 of 2

Recuperated Helium Brayton Open Cycle at 850°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% and Compressor 2 Outlet Pressure of 7 MPa



1				Case Name:	Case Name: helium brayton cycle 850 water cooled best.hsc				
3	(aspentech	Bedford, M		Unit Set:	NuScale3a				
4 5		USA		Date/Time:	Tue Nov 26 12:55:42 20	019			
6	14/		.	- >					
8	wor	KDOOK:	Case (Mail	n)					
9				Material Stream	s	Fluid Pkg: All			
11	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet		
12	Temperature	(C)	850.0 *	600.7	26.67	88.92	575.6		
13	Pressure	(kPa)	6723	3310 *	4670	7000 *	6860		
14	Mass Flow	(kg/s)	1.0000000 *	1.0000000	1.0000000	1.0000000	1.000000		
15	Mass Density	(kg/m3)	2.8534763	1.8123376	7.3290054	9.0405255	3.8407700		
16	Mass Enthalpy	(kJ/kg)	4306	3000	20.88	351.4	2881		
17	Mass Entropy	(kJ/kg-C)	-1.827	-1.658	-7.935	-7.796	-3.325		
18	Name		Cooler Inlet	Comp 1 Inlet	Comp 1 Outlet	1	3		
19	Temperature	(C)	113.9	26.67	88.84	21.11	32.22 *		
20	Pressure	(kPa)	3244	3179	4765	103.4	101.3 *		
21	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000	6.9661264	6.9661264		
22	Mass Density	(kg/m3)	3.9836978	5.0258408	6.2132033	997.98944	994.95262		
23	Mass Enthalpy	(kJ/kg)	470.8	16.89	344.6	-1.584e+004	-1.579e+004		
24	Mass Entropy	(kJ/kg-C)	-5.848	-7.134	-6.996	0.3120	0.4671		
25	Name		4	5	6	7			
26	Temperature	(C)	21.11	32.22 *	21.11 *	21.11			
27	Pressure	(kPa)	103.4	101.3	101.3 *	101.3			
28	Mass Flow	(kg/s)	9.7658183	9.7658183	6.9661264	9.7658183			
29	Mass Density	(kg/m3)	997.98944	994.95262	997.98854	997.98854			
30	Mass Enthalpy	(kJ/kg)	-1.584e+004	-1.579e+004	-1.584e+004	-1.584e+004			
31	Mass Entropy	(kJ/kg-C)	0.3120	0.4671	0.3120	0.3120			
32 33				Compositions		Fluid Pkg	g: All		
34	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet		
35	Comp Mole Frac (Helium-4)		1.0000 *	1.0000	1.0000	1.0000	1.0000		
35 36	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon)		1.0000 *	1.0000	1.0000	1.0000	1.0000		
35 36 37	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		1.0000 * 0.0000 *	1.0000 0.0000	0.0000	1.0000 0.0000	1.0000 0.0000		
35 36 37 38	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name		1.0000 * 0.0000 *	1.0000 0.0000	1.0000 0.0000 Comp 1 Outlet	1.0000 0.0000	1.0000 0.0000		
35 36 37 38 39	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000	1.0000 0.0000 *** Comp 1 Inlet 1.0000	1.0000 0.0000 *** Comp 1 Outlet 1.0000	1.0000 0.0000 *** 1	1.0000 0.0000 *** 3		
35 36 37 38 39 40	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000	1.0000 0.0000 Comp 1 Inlet 1.0000 0.0000	1.0000 0.0000 *** Comp 1 Outlet 1.0000 0.0000	1.0000 0.0000 1 1	1.0000 0.0000 *** 3 ***		
35 36 37 38 39 40 41	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000	1.0000 0.0000 	1.0000 0.0000 *** Comp 1 Outlet 1.0000 0.0000	1.0000 0.0000 1 1 1.0000	1.0000 0.0000 3 *** *** 1.0000		
35 36 37 38 39 40 41 42	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4	1.0000 0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5	1.0000 0.0000 Comp 1 Outlet 1.0000 0.0000 6	1.0000 0.0000 *** 1 *** 1.0000 7	1.0000 0.0000 3 *** *** 1.0000		
35 36 37 38 39 40 41 42 43	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4	1.000 0.0000 Comp 1 Inlet 1.0000 0.0000 5 5	1.0000 0.0000 Comp 1 Outlet 1.0000 0.0000 	1.0000 0.0000 1 1 1 1 1.0000 7	1.0000 0.0000 3 1.0000		
35 36 37 38 39 40 41 42 43 44	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4	1.0000 0.0000 comp 1 Inlet 1.0000 0.0000 *** 5 5	1.0000 0.0000 Comp 1 Outlet 1.0000 0.0000 6 	1.0000 0.0000 1 1 1.0000 7 7	1.0000 0.0000 3 *** 1.0000		
35 36 37 38 39 40 41 42 43 44 45	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 *	1.000 0.0000 comp 1 Inlet 0.0000 5 5 5 1.0000	1.0000 0.0000 Comp 1 Outlet 1.0000 6 6 1.0000 *	1.0000 0.0000 *** 1 *** 1.0000 7 *** 1.0000 *	1.0000 0.0000 3 1.0000		
35 36 37 38 39 40 41 42 43 44 45 46 47	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 *	1.0000 0.0000 comp 1 Inlet 1.0000 0.0000 comp 1 Inlet 1.0000 5 comp 1 Inlet 1.0000 Energy Stream	1.0000 0.0000 Comp 1 Outlet 1.0000 6 6 1.0000 · S	1.0000 0.0000 *** 1 *** 1.0000 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	1.0000 0.0000 *** 3 *** 1.0000		
35 36 37 38 39 40 41 42 43 44 45 46 47 48	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 *	1.0000 0.0000 comp 1 Inlet 1.0000 0.0000 comp 1 Inlet 1.0000 Energy Stream Comp 2 Power	1.0000 0.0000 "" Comp 1 Outlet 1.0000 0.0000 "" 6 6 5 8 Reactor Heat	1.0000 0.0000 *** 1 1.0000 7 7 7 1.0000 * Fluid Pkg Comp 1 Power	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)	(MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * Turbine Power 1 306	1.000 0.000 Comp 1 Inlet 1.0000 5 5 1.0000 Energy Stream Comp 2 Power 0.3305	1.0000 0.0000 Comp 1 Outlet 1.0000 6 1.0000 · S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 7 1.0000 * Fluid Pkg Comp 1 Power	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name	(MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * Turbine Power 1.306 Water Pmp 2 Pwr	1.000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 7 1.0000 * Fluid Pkg Comp 1 Power 0.3277	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * Turbine Power 1.306 Water Pmp 2 Pwr 2.688e-005	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 5 1.0000 * Fluid Pkg Comp 1 Power 0.3277	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * Turbine Power 1.308 Water Pmp 2 Pwr 2.698e-005	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1.000 0.0000 Comp 1 Outlet 1.0000 6 1.0000 · S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 5 1.0000 * Fluid Pkg Comp 1 Power 0.3277	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * Turbine Power 1.308 Water Pmp 2 Pwr 2.698e-005	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 5 Fluid Pkg Comp 1 Power 0.3277	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name	(MW) (MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 *** 1.0000 * Turbine Power 1.306 Water Pmp 2 Pwr 2.698e-005 Reactor	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 5 1.0000 5 Fluid Pkg Comp 1 Power 0.3277 5 Fluid Pkg	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name DUTY	(MW) (MW)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 *** 1.0000 * Turbine Power 1.306 Water Pmp 2 Pwr 2.698e-005 Reactor 1.425	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 5 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 1.0000 1 Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 3 1.0000 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name DUTY Feed Temperature	(MW) (MW) (C)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 *** 1.0000 * *** 1.0000 * Turbine Power 1.308 Water Pmp 2 Pwr 2.698e-005 Reactor 1.425 575.6	1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Energy Stream 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1.0000 7 7 5 1.0000 5 Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 3 7 1.0000 9: All Water Pmp 1 Pwr 1.925e-005 9: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 57	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 *** 4 4 *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 2.698e-005 * Reactor 1.425 575.6 850.0 *	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 *** 1 *** 1.0000 7 *** 1.0000 * Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C) (C) (kg/s)	1.0000 ° 0.0000 ° *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 ° Turbine Power 1.306 Water Pmp 2 Pwr 2.698e-005 Reactor Reactor 1.425 575.6 850.0 ° 1.000	1.0000 0.0000 10000 0.0000 5 5 5 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C) (C) (kg/s)	1.0000 * 0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * Turbine Power 1.306 Water Pmp 2 Pwr 2.698e-005 Reactor 1.425 575.6 850.0 *	1.0000 0.0000 10000 0.0000 0.0000 0.0000 0.0000 0.0000 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 *** 1 *** 1.0000 7 *** *** 1.0000 * Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C) (C) (kg/s)	1.0000 ° 0.0000 ° *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 ° Turbine Power 1.306 Water Pmp 2 Pwr 2.898e-005 Reactor 1.425 575.6 850.0 ° 1.000	1.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 *** 1 *** 1.0000 7 *** *** 1.0000 * Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Yenon) Comp	(MW) (MW) (MW) (C) (C) (C) (kg/s)	1.0000 ° 0.0000 ° *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 ° Turbine Power 1.306 Water Pmp 2 Pwr 2.698e-005 Reactor 1.425 575.6 850.0 ° 1.000	1.0000 0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 5 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 *** 1 *** 1.0000 7 *** *** 1.0000 7 Fluid Pkg Comp 1 Power 0.3277 Fluid Pkg	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Yenon) Comp Mo	(MW) (MW) (MW) (C) (C) (kg/s)	1.0000 ° 0.0000 ° *** Cooler Inlet 1.0000 *** 4 *** 1.0000 ° Turbine Power 1.306 Water Pmp 2 Pwr 2.898e-005 Reactor 1.425 575.6 850.0 ° 1.000	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 Energy Stream Comp 2 Power 0.3305 Heaters	1.000 0.0000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1 1.0000 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	1.0000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005		
35 36 37 38 39 40 41 42 43 44 45 66 57 55 56 57 58 59 60 61 62 63	Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C) (C) (kg/s)	1.0000 ° 0.0000 ° *** Cooler Inlet 1.0000 *** 4 *** 1.0000 ° Turbine Power 1.306 Water Pmp 2 Pwr 2.608e-005 Reactor 1.425 575.6 850.0 ° 1.000	1.0000 0.0000 Comp 1 Inlet 1.0000 5 5 5 5 Comp 2 Power 0.3305 Heaters Heaters	1.000 0.000 *** Comp 1 Outlet 1.0000 *** 6 *** 1.0000 * S Reactor Heat 1.425	1.0000 0.0000 1 1 1 1.0000 7 7 7 7 8 1.0000 * Fluid Pkg Comp 1 Power 0.3277 5 Fluid Pkg	1.000 0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 1.925e-005 g: All g: All		

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2			TY OF IDALIO	Case Name:	helium brayton cycle 85	0 water cooled best.hsc	
3	(aspentech	Bedford, M	IA III ARU	Unit Set:	NuScale3a		
4	0.1	USA		Date/Time:	Tue Nov 26 12:55:42 20	110	
5				Date Time.	100 100 20 12:00:42 20		
5	Mor	khaaku	Coos (Mai	n) (continuo	d)		
8	vvori	KDOOK:	Case (Mai	n) (continue	ia)		
9							
10				Coolers		Fluid Pkg	g: All
11	Name						
12	DUTY	(MW)					
13	Feed Temperature	(C)					
14	Product Temperature	(C)					
15	Mass Flow	(kg/s)					
16				Heat Exchange	s	Fluid Pkg	g: All
17							
18	Name	(M0A/)	Recuperating HX	Intercooler 0.2220	Cooler 0.4520		
20	Tube Side Feed Mass Flow	(kn/s)	1.000	6.088	0.4358		
21	Shell Side Feed Mass Flow	(kg/s)	1.000	1.000	1.000		
22	Tube Inlet Temperature	(C)	88,92	21.11	21.11		
23	Tube Outlet Temperature	(C)	575.6	32.22 *	32.22 *		
24	Shell Inlet Temperature	(C)	600.7	88.84	113.9		
25	Shell Outlet Temperature	(C)	113.9	26.67	26.67		
26	LMTD	(C)	25.11	21.99	28.33		
27	UA	(kJ/C-h)	3.627e+005	5.299e+004	5.768e+004		
28	Minimum Approach	(C)	25.00	5.556	5.556		
29				Compressors		Fluid Pkg	q: All
30			a				-
31	Name	(1.0.4)	Compressor 2	Compressor 1			
33	Fower Food Processo	(MVV)	4670	0.3277			
34	Product Pressure	(kPa)	7000 *	4785			
35	Product Temperature	(C)	88.92	88.84			
36	Feed Temperature	(C)	26.67	26.67			
37	Adiabatic Efficiency		85	85 *			
38	Pressure Ratio		1.499	1.499			
39	Mass Flow	(kg/s)	1.000	1.000			
40				Expandere		Eluid Pkr	л: АШ
41				Expanders		T did T N	g. All
42	Name		Turbine				
43	Power	(MW)	1.306				
44	Feed Pressure	(kPa)	6723				
40	Product Temperature	(kra) (C)	800.7				
40	Feed Temperature	(0)	850.0 *				
48	Adiabatic Efficiency		90 *				
49	Mass Flow	(ka/s)	1.000 *				
50							
51				Pumps		Fluid Pkg	g: All
52	Name		Water Pump 1	Water Pump 2			
53	Power	(MW)	1.925e-005	2.698e-005			
54	Feed Pressure	(kPa)	101.3 *	101.3 *			
55	Product Pressure	(kPa)	103.4	103.4			
56	Product Temperature	(C)	21.11	21.11			
57	Feed Temperature	(C)	21.11	21.11			
50	Adiabatic Efficiency Pressure Patio	(%)	75.00	75.00			
60	Mass Flow	(ka/s)	8.988	0.788			
61		(* 9 /2)	0.000	0.700	II		I
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 2 of 3
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1				Case Name:	helium brayton cycle 88	0 water cooled best.hsc	
3	(aspentech	Bedford, MA		Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:55:42 2	019	
6							
7	Wo	rkbook:	Case (Main) (continue	ed)		
9				Valves		Fluid Pkg	a: All
10	Name						-
12	Pressure Drop	(kPa)					
13	Feed Pressure	(kPa)					
14	Feed Temperature	(C)					
15	Product Pressure	(kPa)					
16	Product Temperature	(C)					
17	Mass Flow	(kg/s)					
18	Cg						
19	Resistance (Cv or K)						
20							
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63	Aspen Technology Inc.	-	As	spen HYSYS Versi	on 9		Page 3 of 3
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Recuperated Helium Brayton Open Cycle at 850°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 85% and 90% and Turbine Inlet Pressure of 1051 kPa



1		UNIVERSI	TY OF IDAHO	Case Name:	helium brayton cycle 85	0 water cooled best inl.h:	sc
3	(e)aspentech	Bedford, N	IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 11:54:12 20	019	
6							
7	Wor	kbook	Case (Maii	n)			
8			•	'			
9				Material Stream	s	Fluid Pk	g: All
11	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet
12	Temperature	(C)	850.0 *	600.8	26.67	88.64	575.7
13	Pressure	(kPa)	1051	518.0 *	730.5	1095 *	1073
14	Mass Flow	(kg/s)	0.15985842 *	0.15985842	0.15985842	0.15985842	0.15985842
15	Mass Density	(kg/m3)	0.44993347	0.28507069	1.1688736	1.4500299	0.60713706
16	Mass Enthalpy	(kJ/kg)	4288	2992	10.51	333.5	2863
17	Mass Entropy	(kJ/kg-C)	2.028	2.195	-4.076	-3.940	0.5319
18	Name	(Cooler Inlet	Comp 1 Inlet	Comp 1 Outlet	1	3
19	Temperature	(C)	113.6	26.67	88.63	21.11	32.22 ·
20	Pressure	(kPa)	507.6	497.5	745.5	103.4	101.3 *
21	Mass Flow	(ka/s)	0 15985842	0 15985842	0 15985842	1 1073145	1 1073145
22	Mass Density	(kg/m3)	0.63057146	0 79688244	0.98890662	007 08044	994 95282
23	Mass Enthalow	(kg/m3)	481.7	0.78000244	332.4	-1 5840+004	-1 5700+004
24	Mass Entrany	(kJ/kg)	-1.008	-3.277	-3.142	-1.30404004	-1.57804004
25	Name	(10/10)	4	5	8	7	0.1071
26	Tomporatura	(0)	21.11	32.22.	21.11.1	21.11.	
20	Desseure	(6)	21.11	32.22	21.11	21.11	
21	Pressure Mass Elem	(KPa)	103.4	101.3	101.3	101.3	
20	Mass Plow	(kg/s)	1.0040300	1.00405080	1.10/3143	1.0040300	
29	Mass Density	(Kg/m3)	997.98944	994.90202	997.98804	997.98804	
30	Mass Enthalpy	(KJ/Kg)	-1.584e+004	-1.5/9e+004	-1.0840+004	-1.584e+004	
31	Mass Entropy	(kJ/kg-C)	0.3120	0.46/1	0.3120	0.3120	
32				Compositions		Fluid Pk	g: All
34	Name		Turbine Inlet	Turbing Outlat	Comp 2 Inlat	Comp 2 Outlet	Repoter Inlat
35	Comp Mole Erze (Holium 4)		1 0000 *	1 0000	1 0000	1 0000	1 0000
26	Comp Mole Frac (Helium+)		0.0000 *	0.0000	0.0000	0.0000	0.0000
30	Comp Mole Frac (Xenon)		0.0000	0.0000	0.0000	0.0000	0.0000
38	Name		Cooler Islat	Comp 1 lalat	Comp 1 Outlet	4	2
30	Come Mala Free (Halium A)		Cooler Inlet	Comp Timet	Comp Toulet		3
39	Comp Mole Frac (Heilum-4)		1.0000	1.0000	1.0000		
40	Comp Mole Frac (Xenon)		0.0000	0.0000	0.0000	1.0000	1 0000
41	Comp Mole Frac (H2O)		4	5	0	7	1.0000
42	Name		4	5	0	/	
40	Comp Mole Frac (Heilum-4)						
44	Comp Mole Frac (Xenon)		1 0000 1	1 0000	1 0000 1	1 0000 1	
45	Comp Mole Frac (H2O)		1.0000	1.0000	1.0000	1.0000	
40				Energy Stream	s	Fluid Pk	g: All
48	Name		Turbine Power	Comp 2 Power	Reactor Heat	Comp 1 Power	Water Pmp 1 Pwr
49	Heat Flow	(MW)	0.2072	5.163e-002	0.2277	5.156e-002	3.059e-006
50	Name		Water Pmp 2 Pwr				
51	Heat Flow	(MW)	4.293e-006				
52							
53				Heaters		Fluid Pk	g: All
54	Name		Reactor				
55	DUTY	(MW)	0.2277				
56							
~~	Feed Temperature	(C)	575.7				
57	Feed Temperature Product Temperature	(C) (C)	575.7 850.0 *				
57 58	Feed Temperature Product Temperature Mass Flow	(C) (C) (kg/s)	575.7 850.0 * 0.1599				
57 58 59	Feed Temperature Product Temperature Mass Flow	(C) (C) (kg/s)	575.7 850.0 * 0.1599				
57 58 59 60	Feed Temperature Product Temperature Mass Flow	(C) (C) (kg/s)	575.7 850.0 * 0.1599				
57 58 59 60 61	Feed Temperature Product Temperature Mass Flow	(C) (C) (kg/s)	575.7 850.0 ° 0.1599				
57 58 59 60 61 62	Feed Temperature Product Temperature Mass Flow	(C) (C) (kg/s)	575.7 850.0 * 0.1599				
57 58 59 60 61 62 63	Feed Temperature Product Temperature Mass Flow Aspen Technology Inc.	(C) (C) (kg/s)	575.7 850.0 * 0.1599	Aspen HYSYS Versi	on 9		Page 1 of 3

1				Care Name:	holium brauton ouele 95	Questor cooled best in be	~
2	(D)	UNIVERSI	TY OF IDAHO	Gase Marrie.	neium brayion cycle co	o water cooled best miths	
3	(aspentech	Bedford, M	A	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 11:54:12 20	019	
6 7	Worl	kbook:	Case (Mai	n) (continue	ed)		
8				Castan			
10				Coolers		Fiuld PK): All
11	Name						
12	DUTY East Temperature	(MW)					
10	Preduct Temperature	(0)					
15	Mass Flow	(ka/s)					
16	indos rion	(1813)					
17				Heat Exchange	rs	Fluid Pkg	j: Ali
18	Name		Recuperating HX	Intercooler	Cooler		
19	Duty	(MW)	0.4044	5.146e-002	7.223e-002		
20	Tube Side Feed Mass Flow	(kg/s)	0.1599	1.107	1.554		
21	Shell Side Feed Mass Flow	(kg/s)	0.1599	0.1599	0.1599		
22	Tube Inlet Temperature	(C)	88.64	21.11	21.11		
23	Tube Outlet Temperature	(C)	575.7	32.22 *	32.22 *		
24	Shell Inlet Temperature	(C)	600.8	88.63	113.6		
25	Shell Outlet Temperature	(C)	113.6	26.67	26.67		
26	LMTD	(C)	25.02	21.94	28.26		
27	UA	(kJ/C-h)	5.818e+004	8444	9200		
28	Minimum Approach	(C)	25.00	5.556	5.556		
30				Compressors		Fluid Pkg	j: All
31	Name		Compressor 2	Compressor 1			
32	Power	(MW)	5.163e-002	5.156e-002			
33	Feed Pressure	(kPa)	730.5	497.5			
34	Product Pressure	(kPa)	1095 *	745.5			
35	Product Temperature	(C)	88.64	88.63			
36	Feed Temperature	(C)	26.67	26.67			
37	Adiabatic Efficiency		85	85 *			
38	Pressure Ratio		1.498	1.498			
39	Mass Flow	(kg/s)	0.1599	0.1599			
40				Expanders		Fluid Pkg	j: All
42	Name		Turbine				
43	Power	(MW)	0.2072				
44	Feed Pressure	(kPa)	1051				
45	Product Pressure	(kPa)	518.0 *				
46	Product Temperature	(C)	600.8				
47	Feed Temperature	(C)	850.0 *				
48	Adiabatic Efficiency		90 *				
49	Mass Flow	(kg/s)	0.1599 *				
50				Pumps		Fluid Pkg	:: All
51	News		Water Down 1	Water Down 0			
52	Name	(1.040)	Water Pump 1	Water Pump 2			
54	Fower Feed Pressure	(kPa)	3.0388-000	+.283e-000			
55	Product Pressure	(kPa)	101.3	101.3			
56	Product Temperature	(C)	21.11	21.11			
57	Feed Temperature	(C)	21.11	21.11			
58	Adiabatic Efficiency	(%)	75.00	75.00			
59	Pressure Ratio	17	1.020	1.020			
60	Mass Flow	(kg/s)	1.107	1.554			
61							
62					-		
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 2 of 3
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1				Case Name:	helium brayton cycle 8	50 water cooled best inl.h:	sc
3	(aspentech	Bedford, MA		Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 11:54:12 2	019	
6							
7	Work	book:	Case (Mair	n) (continue	ed)		
9				Valves		Fluid Pk	a: All
10	Name						-
12	Pressure Drop	(kPa)					
13	Feed Pressure	(kPa)					
14	Feed Temperature	(C)					
15	Product Pressure	(kPa)					
16	Product Temperature	(C)					
17	Mass Flow	(kg/s)					
18	Cg						
19	Resistance (Cv or K)						
20							
21							
22							
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63	Aspen Technology Inc.	0	1	Aspen HYSYS Versi	ion 9		Page 3 of 3
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Recuperated Helium Brayton Open Cycle at 850°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% and Compressor 2 Outlet Pressure of 7 MPa



265

1				Case Name:	Case Name: helium brayton cycle 850 water cooled Worst.hsc			
2	(aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set:	NuScale3a			
4	<u> </u>	USA		Date/Time:	Tue Nov 26 12:07:53 20)19		
6								
7	Wor	kbook	: Case (Maii	n)				
9				Material Stream	s	Fluid Pkg: All		
11	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet	
12	Temperature	(C)	850.0 *	648.6	26.67	95.20	623.5	
13	Pressure	(kPa)	6723	3560 *	4843	7000 *	6860	
14	Mass Flow	(kg/s)	1.0000000 *	1.0000000	1.0000000	1.0000000	1.0000000	
15	Mass Density	(kg/m3)	2.8534763	1.8476610	7.5942544	8.8902363	3.6378926	
16	Mass Enthalpy	(kJ/kg)	4306	3250	21.34	384.1	3130	
17	Mass Entropy	(kJ/kg-C)	-1.827	-1.532	-8.011	-7.706	-3.039	
18	Name		Cooler Inlet	Comp 1 Inlet	Comp 1 Outlet	1	3	
19	Temperature	(C)	120.2	26.67	95.04	21.11	32.22 *	
20	Pressure	(kPa)	3489	3419	4942	103.4	101.3 *	
21	Mass Flow	(kg/s)	1.0000000	1.0000000	1.0000000	7.6612933	7.6612933	
22	Mass Density	(kg/m3)	4.2128922	5.3990676	6.3322523	997.98944	994.95262	
23	Mass Enthalpy	(kJ/kg)	504.1	17.52	377.4	-1.584e+004	-1.579e+004	
24	Mass Entropy	(kJ/kg-C)	-5.915	-7.285	-6.984	0.3120	0.4671	
25	Name		4	5	6	7		
26	Temperature	(C)	21.11	32.22 *	21.11 *	21.11		
27	Pressure	(kPa)	103.4	101.3 *	101.3 *	101.3 *		
28	Mass Flow	(kg/s)	10.470044	10.470044	7.6612933	10.470044		
29	Mass Density	(kg/m3)	997.98944	994.95262	997.98854	997.98854		
30	Mass Enthalpy	(kJ/kg)	-1.584e+004	-1.579e+004	-1.584e+004	-1.584e+004		
31	Mass Entropy	(kJ/kg-C)	0.3120	0.4671	0.3120	0.3120		
32 33				Compositions		Fluid Pkg	j: All	
34	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet	
35	Comp Mole Frac (Helium-4)		1.0000 *	1.0000	1.0000	1.0000	1.0000	
36	Comp Mole Frac (Xenon)		0.0000 *	0.0000	0.0000	0.0000	0.0000	
37	Comp Mole Frac (H2O)		***	***		***		
38	Name		Cooler Inlet	Comp 1 Inlet	Comp 1 Outlet	1	3	
39	Comp Mole Frac (Helium-4)		1.0000	1.0000	1.0000	***		
40	Comp Mole Frac (Xenon)		0.0000	0.0000	0.0000	***		
41	Comp Mole Frac (H2O)					1.0000	1.0000	
42	Name		4	5	6	7		
43	Comp Mole Frac (Helium-4)							
44	Comp Mole Frac (Xenon)							
45	Comp Mole Frac (H2O)		1.0000 *	1.0000	1.0000 *	1.0000 *		
46 47				Energy Streams	s	Fluid Pkg	j: All	
48	Name		Turbine Power	Comp 2 Power	Reactor Heat	Comp 1 Power	Water Pmp 1 Pwr	
49	Heat Flow	(MW)	1.056	0.3628	1.176	0.3599	2.117e-005	
50	Name		Water Pmp 2 Pwr					
51	Heat Flow	(MW)	2.893e-005					
52				Heatore		Eluid Pla		
53	Name		Reactor	nedler 5			. <u>A</u>	
54	Name	(1.0.4)	1 179					
50	East Temperature	(MW)	1.1/0					
50	Peed remperature	(0)	023.0					
50	Mass Flow	(0)	800.0					
50	Mass Flow	(Kg/S)	1.000					
29								
1.60								
60								
60 61								
60 61 62	Asnen Technolom Joc				on 9		Page 1 of 2	

1				Case Name:	helium brayton cycle 85	0 water cooled Worst.hso	5
2	(e)aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:07:53 20	019	
6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)		
9				Coolers		Fluid Pkg	j: All
11	Name						
12	DUTY	(MW)					
13	Feed Temperature	(C)					
14	Product Temperature	(C)					
15	Mass Flow	(kg/s)					
16				Heat Exchange	rs	Fluid Pkg	: All
17			5				
18	Name	(MMA/)	Recuperating HX	Intercooler 0.2581	Cooler		
20	Tube Side Feed Mass Flow	(ko/s)	2.740	7.881	10.47		
21	Shell Side Feed Mass Flow	(ka/s)	1.000	1.000	1.000		
22	Tube Inlet Temperature	(C)	95.20	21.11	21.11		
23	Tube Outlet Temperature	(C)	623.5	32.22 *	32.22 *		
24	Shell Inlet Temperature	(C)	648.6	95.04	120.2		
25	Shell Outlet Temperature	(C)	120.2	26.67	26.67		
26	LMTD	(C)	25.10	23.61	29.84		
27	UA	(kJ/C-h)	3.938e+005	5.429e+004	5.870e+004		
28	Minimum Approach	(C)	25.00	5.556	5.556		
29 30				Compressors		Fluid Pkg	j: All
31	Name		Compressor 2	Compressor 1			
32	Power	(MW)	0.3628	0.3599			
33	Feed Pressure	(kPa)	4843	3419			
34	Product Pressure	(kPa)	7000 *	4942			
35	Product Temperature	(C)	95.20	95.04			
36	Feed Temperature	(C)	26.67	26.67			
37	Adiabatic Efficiency		/0	/0 -			
30	Mass Flow	(ka/c)	1.440	1.440			
40	massriew	(ng/s)	1.000	1.000			
41				Expanders		Fluid Pkg): All
42	Name		Turbine				
43	Power	(MW)	1.056				
44	Feed Pressure	(kPa)	6723				
45	Product Pressure	(kPa)	3560 *				
46	Product Temperature	(C)	648.6				
47	Feed Temperature	(C)	850.0 *				
48	Adiabatic Efficiency		80 *				
49	Mass Flow	(kg/s)	1.000 -				
51				Pumps		Fluid Pkg	j: All
52	Name		Water Pump 1	Water Pump 2			
53	Power	(MW)	2.117e-005	2.893e-005			
54	Feed Pressure	(kPa)	101.3 *	101.3 *			
55	Product Pressure	(kPa)	103.4	103.4			
56	Product Temperature	(C)	21.11	21.11			
57	Feed Temperature	(C)	21.11 *	21.11			
58	Adiabatic Efficiency	(%)	75.00	75.00			
59	Pressure Ratio		1.020	1.020			
60	Mass Flow	(kg/s)	7.661	10.47			
01 62							
63	Aspen Technology Inc			Aspen HYSYS Versi	on 9		Page 2 of 3
<u> </u>	Licensed to: UNIVERSITY OF IDA	НО			•		" Specified by user.

1				Case Name:	helium brayton cycle 8	50 water cooled Worst.hs	c
3	(aspentech	Bedford, MA	Y OF IDAHO	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:07:53 2	019	
6			O				
8	vvo	rkbook:	Case (Main) (continue	ea)		
9				Valves		Fluid Pkg	g: All
11	Name						
12	Pressure Drop	(kPa)					
13	Feed Pressure	(kPa)					
14	Feed Temperature	(C)					
15	Product Pressure	(kPa)					
16	Product Temperature	(C)					
17	Mass Flow	(kg/s)					
18	Cg						
19	Resistance (Cv or K)						
20							
21							
22							
23							
24							
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63	Aspen Technology Inc		Δ	spen HYSYS Versi	ion 9		Page 3 of 3
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Recuperated Helium Brayton Open Cycle at 850°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 70% and 80% and Turbine Inlet Pressure of 1051 kPa



_	0	01111211011					
3	(e)aspentech	Bedford, M	A	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:04:22 20)19	
5							
7	Wor	khook	Case (Mai	n)			
8	won	NDOOK.	Case (Mai	'			
9	Material Streams Fluid Pko: All						
10				Material Sucall	3	T Idia T Ng	. <u>nii</u>
11	Name	(0)	Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet
12	Pressure	(U) (kPa)	1051	048.3	20.07	94.75	023.3
14	Mass Flow	(kg/s)	0 15085842 *	0 15085842	0 15085842	0 15085842	0 15085842
15	Mass Density	(kg/m3)	0.44993347	0.29057049	1.2116146	1 4280584	0.57500384
16	Mass Enthalov	(kJ/ka)	4288	3239	10.58	365.2	3110
17	Mass Entropy	(kJ/ka-C)	2.028	2.321	-4.151	-3.853	0.8149
18	Name	(Cooler Inlet	Comp 1 Inlet	Comp 1 Outlet	1	3
19	Temperature	(C)	119.7	26.67	94.72	21.11	32.22 *
20	Pressure	(kPa)	545.6	534.7	772.8	103.4	101.3 *
21	Mass Flow	(kg/s)	0.15985842	0.15985842	0.15985842	1.2162342	1.2162342
22	Mass Density	(kg/m3)	0.66709414	0.85629411	1.0081476	997.98944	994.95262
23	Mass Enthalpy	(kJ/kg)	493.5	10.01	364.2	-1.584e+004	-1.579e+004
24	Mass Entropy	(kJ/kg-C)	-2.065	-3.427	-3.130	0.3120	0.4671
25	Name		4	5	6	7	
26	Temperature	(C)	21.11	32.22 *	21.11 *	21.11	
27	Pressure	(kPa)	103.4	101.3 *	101.3 *	101.3 *	
28	Mass Flow	(kg/s)	1.6631554	1.6631554	1.2162342	1.6631554	
29	Mass Density	(kg/m3)	997.98944	994.95262	997.98854	997.98854	
30	Mass Enthalpy	(kJ/kg)	-1.584e+004	-1.579e+004	-1.584e+004	-1.584e+004	
31	Mass Entropy	(kJ/kg-C)	0.3120	0.4671	0.3120	0.3120	
32				Compositions		Child Die	
33				Compositions		Fluid PK	g: All
34	Name		Turbine Inlet	Turbine Outlet	Comp 2 Inlet	Comp 2 Outlet	Reactor Inlet
35	Comp Mole Frac (Helium-4)		1.0000 *	1.0000	1.0000	1.0000	1.0000
36	Comp Mole Frac (Xenon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
36 37	Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
36 37 38	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name		0.0000 *	0.0000	0.0000	0.0000	0.0000
36 37 38 39	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4)		0.0000 * *** Cooler Inlet 1.0000	0.0000 *** Comp 1 Inlet 1.0000	0.0000 *** Comp 1 Outlet 1.0000	0.0000 *** 1	0.0000 *** 3
36 37 38 39 40	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon)		0.0000 * *** Cooler Inlet 1.0000 0.0000	0.0000 *** Comp 1 Inlet 1.0000 0.0000	0.0000 *** Comp 1 Outlet 1.0000 0.0000	0.0000 *** 1 ***	0.0000 *** 3 ***
36 37 38 39 40 41	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		0.0000 * *** Cooler Inlet 1.0000 0.0000 ***	0.0000 *** Comp 1 Inlet 1.0000 0.0000 ***	0.0000 *** Comp 1 Outlet 1.0000 0.0000 ***	0.0000 *** 1 *** 1.0000	0.0000 3 1.0000
36 37 38 39 40 41 42	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6	0.0000 *** 1 *** 1.0000 7	0.0000 *** 3 *** 1.0000
36 37 38 39 40 41 42 43	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Name Comp Mole Frac (Helium-4)		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 ***	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 ***	0.0000 *** 1 *** 1.0000 7 ***	0.0000 *** 3 *** 1.0000
36 37 38 39 40 41 42 43 44	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon)		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 4 *** ***	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** ***	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** ***	0.0000 *** 1 *** 1.0000 7 *** ***	0.0000 *** 3 *** 1.0000
36 37 38 39 40 41 42 43 44 45	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 4 *** 1.0000 * *** 1.0000 * ***	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** 1.0000	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** *** 1.0000 1.0000 ***	0.0000 *** 1 *** 1.0000 7 *** *** 1.0000 *	0.0000 *** 3 *** 1.0000
36 37 38 39 40 41 42 43 44 45 46 47	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** *** 1.0000 *	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Stream:	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 S	0.0000 *** 1 *** 1.0000 7 *** 1.0000 * Fluid Pkg	0.0000 *** 3 *** 1.0000
36 37 38 39 40 41 42 43 44 45 46 47 48	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O)		0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * 11.0000 * *** 1.0000 *	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Streams Comp 2 Power	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 * S Reactor Heat	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 * Fluid Pkg Comp 1 Bower	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr
36 37 38 39 40 41 42 43 44 45 46 47 48 49	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow	(MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * *** 1.0000 * *** Turbine Power 0.1677	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Streams Comp 2 Power 5 688e-002	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 7 7 1.0000 * Fluid Pkg Comp 1 Power 5 682e-002	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name	(MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * 1.0000 * *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Stream: Comp 2 Power 5.669e-002	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 7 7 7 1.0000 * Fluid Pkg Comp 1 Power 5.662e-002	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * 1.0000 * *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Stream: Comp 2 Power 5.669e-002	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-008	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.689e-002	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 * Fluid Pkg Comp 1 Power 5.662e-002	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 1.0000 Energy Streams Comp 2 Power 5.869e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 7 7 *** 1.0000 * Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006 Reactor	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 5 *** 1.0000 Energy Streams Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.882e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Kenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006 Reactor 0.1882	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.089e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.662e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name DUTY Feed Temperature	(MW) (MW) (MW) (C)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-008 Reactor 0.1882 623.3	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** 1.0000 Energy Stream: Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 *** 1.0000 Fluid Pkg Comp 1 Power 5.662e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (H2O) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-008 Reactor 0.1882 623.3 850.0 *	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Stream: Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.662e-002 Fluid Pkg Fluid Pkg	0.0000 "" 3 "" 1.0000 " g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow Name Heat Flow	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-008 Reactor 0.1882 623.3 850.0 * 0.1599	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.862e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.380e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mo	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006 Reactor 0.1882 623.3 850.0 * 0.1599	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.862e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.360e-006 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006 Reactor 0.1882 623.3 850.0 * 0.1599	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.862e-002 Fluid Pkg Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.380e-008 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Fra	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * Turbine Power 0.1677 Water Pmp 2 Pwr 4.595e-006 Reactor 0.1882 623.3 850.0 * 0.1599	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.669e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 Fluid Pkg Comp 1 Power 5.862e-002 Fluid Pkg	0.0000 *** 3 *** 1.0000 g: All Water Pmp 1 Pwr 3.380e-008 g: All
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 56 57 58 59 60 61 62	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** *** *** *** *** *** *** *** *	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 1.0000 Energy Stream: Comp 2 Power 5.869e-002 Heaters	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 *** 1.0000 * Fluid Pkg Comp 1 Power 5.662e-002 Fluid Pkg	0.0000
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63	Comp Mole Frac (Xenon) Comp Mole Frac (H2O) Name Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Frac (Xenon) Comp Mole Frac (Helium-4) Comp Mole Frac (Xenon) Comp Mole Fra	(MW) (MW) (MW) (C) (C) (C) (kg/s)	0.0000 * *** Cooler Inlet 1.0000 0.0000 *** 4 4 *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** 1.0000 * *** *** *** *** *** *** *** *** *	0.0000 *** Comp 1 Inlet 1.0000 0.0000 *** 5 *** 5 *** 1.0000 Energy Streams Comp 2 Power 5.689e-002 Heaters Heaters Aspen HYSYS Versio	0.0000 *** Comp 1 Outlet 1.0000 0.0000 *** 6 *** 1.0000 * S Reactor Heat 0.1882	0.0000 *** 1 *** 1.0000 7 *** 1.0000 7 *** 1.0000 * Fluid Pkg Comp 1 Power 5.662e-002 Fluid Pkg	0.0000

Case Name:

helium brayton cycle 850 water cooled worst inl.hsc
—							
1				Case Name:	helium brayton cycle 850) water cooled worst inl.h	sc
3	(e)aspentech	Bedford, N	IY OF IDAHO IA	Unit Set:	NuScale3a		
4		USA		Date/Time:	Tue Nov 26 12:04:22 20	19	
5							
7	Worl	khook	Case (Mai	n) (continue	d)		
8			ease (mai		, a,		
9				Coolers		Fluid Pkg	All
10				COORTS			
11	Name						
12	Each Temperature	(MVV) (C)					
14	Product Temperature	(0)					
15	Mass Flow	(kg/s)					
16			I		н — н 		
17				Heat Exchange	rs	Fluid Pkg	: All
18	Name		Recuperating HX	Intercooler	Cooler		
19	Duty	(MW)	0.4388	5.653e-002	7.730e-002		
20	Tube Side Feed Mass Flow	(kg/s)	0.1599	1.216	1.663		
21	Shell Side Feed Mass Flow	(kg/s)	0.1599	0.1599	0.1599		
22	Tube Inlet Temperature	(C)	94.75	21.11	21.11		
23	Tube Outlet Temperature	(C)	623.3	32.22	32.22		
24	Shell Outlet Temperature	(0)	110.7	24.72	28.87		
26	I MTD	(0)	25.02	23.53	20.07		
27	UA	(kJ/C-h)	6.313e+004	8648	9357		
28	Minimum Approach	(C)	25.00	5.556	5.556		
29				Comprosoore		Eluid Dhe	
30				Compressors		Fluid Pkg	: All
31	Name		Compressor 2	Compressor 1			
32	Power	(MW)	5.669e-002	5.662e-002			
33	Feed Pressure	(kPa)	757.4	534.7			
34	Product Pressure	(kPa)	1095 *	772.8			
35	Product Temperature	(C)	94.75	94.72			
30	Adiabatia Efficiency	(C)	20.07	20.07			
38	Pressure Ratio		1 445	1 445			
39	Mass Flow	(ka/s)	0.1599	0.1599			
40		(F	I		
41				Expanders		Fluid Pkg	: All
42	Name		Turbine				
43	Power	(MW)	0.1677				
44	Feed Pressure	(kPa)	1051				
45	Product Pressure	(kPa)	558.7 *				
46	Product Temperature	(C)	648.3				
47	Adiabatia Efficiency	(C)	0.068				
40	Mass Flow	(ko/s)	0 1500 *				
50	massiliow	(Kg/3)	0.1000		I I		
51				Pumps		Fluid Pkg	: All
52	Name		Water Pump 1	Water Pump 2			
53	Power	(MW)	3.360e-006	4.595e-006			
54	Feed Pressure	(kPa)	101.3 *	101.3 *			
55	Product Pressure	(kPa)	103.4	103.4			
56	Product Temperature	(C)	21.11	21.11			
57	Feed Temperature	(C)	21.11	21.11			
58	Adiabatic Efficiency	(%)	75.00	75.00			
60	Mass Flow	(k=/=)	1.020	1.020			
61	WId55 FIUW	(kg/s)	1.210	1.003			
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	ion 9		Page 2 of 3
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Appendix H: Aspen HYSYS Models for Sizing of the PCU Simulator

Modified Simple Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic

Efficiencies of 85% and 90%



1				Case Name:	updated high eff n2 t	prayton sin	nulator.hsc		
3	@aspentech	Bedford, N	IA IDAHO	Unit Set	NuScale3a				
4		USA		Date/Time:	Fri Jan 31 12:23:52	2020			
6	Wor	khook	Case (Mai						
7	wor	KDOOK	. Case (Mail	n)					
9				Material Stream	ns		Fluid Pkg	j:	All
10	Namo		Into DCU Simulator	6	4	1		2	
12	Temperature	(C)	600.0 °	599.2	182 (278.3 *	-	277.9
13	Pressure	(kPa)	1051 *	1050	141.7	,	1029		1029
14	Mass Flow	(ka/s)	0.92378063 *	0.92378063	0.9237806	3	0.92378063		0.92378063
15	Mass Density	(kg/m3)	4.0436817	4.0439842	1.048649	5	6.2687079		6.2695463
16	Mass Enthalpy	(kJ/kg)	628.9	628.0	165.5	5	269.1		268.7
17	Mass Entropy	(kJ/kg-C)	5.756	5.755	5.633	2	5.249		5.249
18	Name		3	Out PCU Simulator	5	7		8	
19	Temperature	(C)	277.7	277.3	21.1	1.1	157.1		21.11
20	Pressure	(kPa)	148.3 *	144.6	135.0	3	389.6		381.8
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.9237806	3	0.92378063		0.92378063
22	Mass Density	(kg/m3)	0.90642639	0.88463860	1.5559534	1	3.0485368		4.3799524
23	Mass Enthalpy	(kJ/kg)	268.7	268.4	-4.420	5	138.7		-5.114
24	Mass Entropy	(kJ/kg-C)	5.825	5.831	5.18	5	5.271		4.876
25	Name		9	10	11	12		13	
26	Temperature	(C)	157.2	252.2	251.0	3	574.0		157.0
27	Pressure	(kPa)	1096 *	1073	1073	3	1051		1095
28	Mass Flow	(kg/s)	0.92378063	0.92378063	0.9237806	3	0.92378063		0.92378063
29	Mass Density	(kg/m3)	8.5567835	6.8598616	6.860984	9	4.1674578		8.5576377
30	Mass Enthalpy	(kJ/kg)	138.0	240.7	240.3	3	599.2		137.8
31	Mass Entropy	(kJ/kg-C)	4.962	5.184	5.183	3	5.722		4.962
32	Name		14						
33	Temperature	(C)	181.8						
34	Pressure	(kPa)	138.6						
35	Mass Flow	(kg/s)	0.92378063						
36	Mass Density	(kg/m3)	1.0259935						
37	Mass Enthalpy	(kJ/kg)	165.2						
38	Mass Entropy	(kJ/kg-C)	5.638						
39				Compositions			Fluid Pkg		All
40				compositions	,				
41	Name		Into PCU Simulator	6	4	1		2	
42	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.000)	1.0000		1.0000
43	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.000)	0.0000		0.0000
44	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.000		0.0000		0.0000
45	Comp Mole Frac (Oxygen)		0.0000 *	0.0000	0.000)	0.0000		0.0000
46	Comp Mole Frac (H2O)		* 0.0000	0.0000	0.0000		0.0000		0.0000
47	Name		3	Out PCU Simulator	5	7		8	
48	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.000		1.0000		1.0000
49	Comp Mole Frac (CO2)		0.000	0.0000	0.0000		0.0000		0.0000
50	Comp Mole Frac (Argon)		0.0000	0.0000	0.000		0.0000		0.0000
51	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.000		0.0000		0.0000
52	Name		0.0000	10	11	40	0.0000	12	0.0000
53	Comp Mole Erze (Niltrogen)		1 0000	10000	1.000/	12	1 0000	10	1 0000
54	Comp Mole Frac (CO2)		0.000	0.000	0.000		0.0000	<u> </u>	0.0000
20	Comp Mole Frac (4mon)		0.000	0.000	0.000		0.0000		0.0000
57	Comp Mole Error (Argori)		0.000	0.0000	0.000		0.0000		0.0000
50	Comp Mole Frac (Uxygell)		0.0000	0.0000	0.000		0.0000		0.0000
50	Comp Mole Frac (H2O)		0.0000	0.0000	0.000		0.0000		0.0000
60									
61									
62									
63	Aspen Technology Inc.			Aspen HYSYS Versi	ion 9				Page 1 of 3

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1				Case Name:	updated high eff n2 bray	yton simulator.hsc	
2	(aspentech	UNIVERSIT Bedford, M	Y OF IDAHO A	Unit Set	NuScale3a	<u>.</u>	
4		USA		Date/Time:	Fri Jan 31 12:23:52 202	o	
6 7 8	Worl	kbook:	Case (Mair	n) (continue	ed)		
9			Cor	mpositions (conti	inued)	Fiuld Pkg	g: All
11	Name		14				
12	Comp Mole Frac (Nitrogen)	1	1.0000				
13	Comp Mole Frac (CO2)		0.0000				
14	Comp Mole Frac (Argon)		0.0000				
15	Comp Mole Frac (Oxygen)		0.0000				
16	Comp Mole Frac (H2O)		0.0000				
17 18				Energy Stream	s	Fluid Pkg	g: All
19	Name		Heat Loss Pipe	Heat Loss Pipe 1	Heat Loss Pipe 2	Heat Loss Pipe 5	Q-102
20	Heat Flow	(MW)	7.990e-004	3.549e-004	3.541e-004	3.189e-004	0.1567
21	Name		Q-103	Comp 1 Power	Comp 2 Power	Heat Loss Pipe 4	Heat Loss Pipe 3
22	Heat Flow	(MW)	0.1328	0.1322	0.1322	1.878e-004	2.220e-004
23				Heaters		Fluid Pkg	g: All
24	Nama						
25	DUTY	(MW)					
20	Feed Temperature	(0)					
70	Product Temperature	(0)					
29	Mass Flow	(kg/s)					
30		(199)					
31				Coolers		Fluid Pkg	g: All
32	Name		HX Chiller 1	HX Chiller 2			
33	DUTY	(MW)	0.1567	0.1328			
34	Feed Temperature	(C)	181.8	157.1			
35	Product Temperature	(C)	21.11	21.11 *			
36	Mass Flow	(kg/s)	0.9238	0.9238			
37 38				Heat Exchanger	s	Fluid Pkg	g: All
39	Name		Recup HX 1	Recup HX 2			
40	Duty	(MW)	0.3315	9.503e-002			
41	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
42	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
43	Tube Inlet Temperature	(C)	251.8	157.0			
44	Tube Outlet Temperature	(C)	574.0	252.2			
45	Shell Inlet Temperature	(C)	599.2	277.3			
46	Shell Outlet Temperature	(C)	278.3 *	182.0 *			
47	LMTD	(C)	25.82	25.10			
48	UA	(KJ/C-h)	4.623e+004	1.363e+004			
49	Minimum Approach	(C)	25.23	25.00			
50				Compressors		Fluid Pkg	g: All
57	Name		Simulator Compressor	Simulator Compressor			
52	Power	(MW)	0 1322	0.1322			
54	Feed Pressure	(kPa)	135.8	381.8			
55	Product Pressure	(kPa)	389.6	1096 -			
56	Product Temperature	(C)	157.1	157.2			
57	Feed Temperature	(C)	21.11	21.11			
58	Adiabatic Efficiency		75	75			
59	Pressure Ratio		2.869 *	2.869			
60	Mass Flow	(kg/s)	0.9238	0.9238			
61			•				
62							
63	Aspen Technology Inc.		A	spen HYSYS Versi	on 9		Page 2 of 3
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1				Case Name:	updated high eff n2 bra	yton simulator.hsc	
2	() aspentech	UNIVERSIT Bedford, MA	Y OF IDAHO	Unit Set	NuScale3a		
4	Gaspanas	USA		Date/Time:	Eri Jon 31 12:23:52 200	20	
5				Daternine.	111 341 31 12.23.32 202		
7	Work	book:	Case (Mai	n) (continue	ed)		
8			-		-		
10				Expanders		Fluid Pkg	g: All
11	Name						
12	Power Food Decourse	(MW)					
13	Pred Pressure Droduct Pressure	(KPa)					
15	Product Temperature	(C)					
16	Feed Temperature	(C)					
17	Adlabatic Efficiency						
18	Mass Flow	(kg/s)					
19				Valves		Fluid Pk	g: All
20	Name		CV-01				_
22	Pressure Drop	(kPa)	880.7				
23	Feed Pressure	(kPa)	1029				
24	Feed Temperature	(C)	277.9			1	
25	Product Pressure	(kPa)	148.3 *				
26	Product Temperature	(C)	277.7				
27	Mass Flow	(kg/s)	0.9238				
28	Cg		1832 *				
29	Resistance (Cv or K/USGPM(60	(F,1psl)	54.73				
30							
31							
33							
34							
35							
36							
37							
38							
39							
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41							
42							
44							
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61							
63	Aspen Technology Inc			Aspen HYSYS Versi	ion 9		Page 3 of 3
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Modified Simple Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



62 63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 3
61							
60							
59							
58	riedt Flow	(WIW)	U.1453	2.0028-004	4.1008-004	1	I
56	Name Heat Flow	(1404)	Comp 1 Power	2 0620-004	Heat Loss Pipe 3		
55	Heat Flow	(MW)	7.990e-004	5.661e-004	9.720e-004	5.297e-004	0.1703
54	Name		Heat Loss Pipe	Heat Loss Pipe 1	Heat Loss Pipe 2	Heat Loss Pipe 5	Q-102
53				Energy Stream	s	Fluid Pkg	g: All
52	carry more r nov (new)	I	0.0000	Energy Office	0.000	0.0000	
50	Comp Mole Frac (Oxygen) Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
49	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
48	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
47	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	
46	Name		11	12	13	14	
45	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	0.0000
44	Comp Mole Frac (Argori)		0.0000	0.0000	0.0000	0.0000	0.0000
42	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000
41	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	1.0000
40	Name		3	Out PCU Simulator	5	7	10
39	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
38	Comp Mole Frac (Oxygen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
37	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
36	Comp Mole Frac (Nu ogen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
35	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	◄ 1.0000	1.0000	1.0000
33	Name		Into DCI I Simulator	6	4	1	2
32				Compositions	1	Fluid Pkg	g: All
31	Mass Entropy	(kJ/kg-C)	5.464	5.720	4.995	5.388	
30	Mass Enthalpy	(kJ/kg)	408.1	598.0	152.1	179.4	
29	Mass Density	(kg/m3)	5.3153879	4.1724381	8.2998897	2.5618872	
28	Mass Flow	(ko/s)	0,92378063	0,92378063	0,92378063	0,92378063	
26	remperature Pressure	(C) (RDa)	404.4	573.0	170.3	195.1	
25	Name		11	12	13	14	
24	Mass Entropy	(kJ/kg-C)	5.828	5.827	4.903	4.995	5.465
23	Mass Enthalpy	(kJ/kg)	437.4	436.4	-5.023	152.3	408.7
22	Mass Density	(kg/m3)	1.7388641	1.7409020	4.0055897	8.2989270	5.3144254
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063
20	Pressure	(kPa)	363.8 *	363.7	349.3	1095 *	1073
18	Name	(0)	3 430.9	Out PCU Simulator	5 21.14.1	170 5	10 404.9
17	Mass Entropy	(kJ/kg-C)	5.756	5.755	5.389	5.520	5.519
16	Mass Enthalpy	(kJ/kg)	628.9	628.0	179.8	438.1	437.4
15	Mass Density	(kg/m3)	4.0436817	4.0439842	2.5598927	4.9069994	4.9076048
14	Mass Flow	(kg/s)	0.92378063 *	0.92378063	0.92378063	0.92378063	0.92378063
13	Pressure	(kPa)	1051 *	1050	356.4	1029	1029
12	Temperature	(C)	600.0 *	599.2	4 195.5 '	431.2 '	430.7
10	Nama		Into DCI I Cimulator	6	4	1	2
9				Material Stream	IS	Fluid Pk	a: All
8		NDOOK.	Case (Mail	"			
6	Wor	khook.	Case (Mai	n)			
5				Date/Time:	mu Jan 30 16:05:53 20	120	
4	Carl	USA		Date/Time:	Thu Ion 30 (6:05:52.00	120	
3	(aspentech	Bedford, M	A	Unit Set	NuScale3a		
1				Case Name:	updated low eff n2 bray	ton simulator.hsc	
_							

1				Case Name:	updated low eff n2 brayt	on simulator.hsc	
3	@aspentech	Bedford, N	IA IDAHO	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 16:05:53 20	20	
6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)		
9 10				Heaters		Fluid Pkg	g: All
11	Name						
12	DUTY	(MW)					
13	Feed Temperature	(C)					
14	Product Temperature	(C)					
15	Mass Flow	(kg/s)					
16				Coolers		Fluid Pkg	g: All
1/	Nama		HV Chiller 1				
19	DUTY	(MW)	0 1703				
20	Feed Temperature	(C)	195.1				
21	Product Temperature	(C)	21.11				
22	Mass Flow	(kg/s)	0.9238				
23				Heat Exchange	rs	Fluid Dia	. AII
24			-	Heat Exchange			g. 761
25	Name		Recup HX 1	Recup HX 2			
26	Duty	(MW)	0.1755	0.2370			
27	Tube Side Feed Mass Flow	(KG/S)	0.9238	0.9238			
28	Shell Side Feed Mass Flow	(Kg/S)	0.9238	0.9238			
29	Tube met remperature	(0)	404.4	170.3			
30	Shell Inlet Temperature	(0)	500.2	404.9			
27	Shell Outlet Temperature	(0)	431.2 *	105.5			
33	I MTD	(C)	26.56	25.17			
34	UA	(kJ/C-h)	2.378e+004	3.390e+004			
35	Minimum Approach	(C)	26.24	25.00			
36				Compressors	· · · · · · · · · · · · · · · · · · ·	Fluid Pk	n: All
37				compressors			
38	Name		Simulator Compressor				
39	Power	(MW)	0.1453				
40	Peed Pressure	(KPa)	349.3				
41	Product Pressure	(kPa)	1096 -				
42	Food Temperature	(0)	1/0.5				
44	Adiabatic Efficiency	(0)	21.11				
45	Pressure Ratio		3.137				
46	Mass Flow	(ka/s)	0.9238				
47		1.2.1		European			
48				Expanders		Fluid Pk	g: All
49	Name						
50	Power	(MW)					
51	Feed Pressure	(kPa)					
52	Product Pressure	(kPa)					
53	Product Temperature	(C)					
54	Feed Temperature	(C)					
55	Adiabatic Efficiency	(herin)					
56	M #65 F10W	(Kg/S)			I		
58 59 60 61 62							
63	Aspen Technology Inc.		1	Aspen HYSYS Versi	on 9		Page 2 of 3
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1				Case Name:	updated low eff n2 bray	ton simulator.hsc	
3	(aspentech	UNIVERSIT Bedford, M	TY OF IDAHO A	Unit Set	NuScale3a		
4	<u> </u>	USA		Date/Time:	Thu Jan 30 16:05:53 2	020	
6							
7	Wo	rkbook:	Case (Mair	n) (continu	ed)		
9				Values		Fluid Dk	т: АП
10	Mama		CV 01	Valves			y. ^ii
12	Pressure Drop	(kPa)	665.0				
13	Feed Pressure	(kPa)	1029				
14	Feed Temperature	(C)	430.7				
15	Product Pressure	(kPa)	363.8 *				
16	Product Temperature	(C)	430.8				
17	Mass Flow	(kg/s)	0.9238				
18	Cg		2086 *				
19	Resistance (Cv or K/USGP	M(60F,1psl))	62.33				
20							
21							
22							
23							
24							
25							
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63	Aspen Technology Inc.			Aspen HYSYS Ver	sion 9		Page 3 of 3
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Modified Nitrogen Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%

1				Case Name:	updated high eff recup	n2 brayton simulator.hsc	
3	@aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 15:56:29 20	020	
6 7 8	Wor	kbook	: Case (Main	n)			
9				Material Stream	IS	Fluid Pk	j: All
11	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
12	Temperature	(C)	600.0 *	599.2	470.3	469.8	470.4
13	Pressure	(kPa)	1051 *	1050	1029	526.9	528.3 *
14	Mass Flow	(kg/s)	0.92378063 *	0.92378063	0.92378063	0.92378063	0.92378063
15	Mass Density	(kg/m3)	4.0436817	4.0439842	4.6464345	2.3852321	2.3896146
16	Mass Enthalpy	(kJ/kg)	628.9	628.0	481.8	481.1	481.8
17	Mass Entropy	(kJ/kg-C)	5.756	5.755	5.580	5.778	5.778
18	Name		2	1	4	8	3
19	Temperature	(C)	117.3	21.11	142.6 *	470.9 *	444.8
20	Pressure	(kPa)	1096 *	505.3	516.4	1029	1073
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063
22	Mass Density	(kg/m3)	9.4409961	5.7989932	4.1803448	4.6459283	5.0192578
23	Mass Enthalpy	(kJ/kg)	95.31	-5.457	123.0	482.4	453.2
24	Mass Entropy	(kJ/kg-C)	4.858	4.792	5.151	5.581	5.528
25	Name		9	10	11	12	
26	Temperature	(C)	444.2	573.1	142.4	117.2	
27	Pressure	(kPa)	1073	1051	515.6	1095	
28	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	
29	Mass Density	(kg/m3)	5.0201229	4.1719382	4.1758000	9.4413571	
30	Mass Enthalpy	(kJ/kg)	452.6	598.2	122.9	95.17	
31	Mass Entropy	(kJ/kg-C)	5.528	5.720	5.151	4.858	
32 33				Compositions		Fluid Pkg	j: All
34	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
35	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.0000	1.0000	1.0000
36	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.0000	0.0000	0.0000
37	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
38	Comp Mole Frac (Oxygen)		• 0000.0	0.0000	0.0000	0.000	0.0000
39	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
40	Name		2	1	4	8	3
41	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	1.0000
42	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000
43	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	0.0000
44	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	0.0000
45	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	0.0000
46	Nama						
47	Name		9	10	11	12	
	Comp Mole Frac (Nitrogen)		9 1.0000	10 1.0000	11 1.0000	12 1.0000	
48	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2)		9 1.0000 0.0000	10 1.0000 0.0000	11 1.0000 0.0000	12 1.0000 0.0000	
48 49	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon)		9 1.0000 0.0000 0.0000	10 1.0000 0.0000 0.0000	11 1.0000 0.0000 0.0000	12 1.0000 0.0000 0.0000	
48 49 50	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen)		9 1.0000 0.0000 0.0000 0.0000	10 1.0000 0.0000 0.0000 0.0000	11 1.0000 0.0000 0.0000 0.0000	12 1.0000 0.0000 0.0000 0.0000	
48 49 50 51	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen)		9 1.0000 0.0000 0.0000 0.0000 0.0000	10 1.0000 0.0000 0.0000 0.0000 0.0000	11 1.0000 0.0000 0.0000 0.0000 0.0000	12 0.0000 0.0000 0.0000 0.0000 0.0000	
48 49 50 51 52 53	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (H2O)		9 1.0000 0.0000 0.0000 0.0000 0.0000	10 1.0000 0.0000 0.0000 0.0000 0.0000 Energy Stream	11 1.0000 0.0000 0.0000 0.0000 0.0000 S	12 0.0000 0.0000 0.0000 0.0000 Fiuld Pkg	j: All
48 49 50 51 52 53 54	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O)		9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr	12 1.0000 0.0000 0.0000 0.0000 Fiuld Pky Chiller 1 Duty	j: All Heat Loss Pipe 2
48 49 50 51 52 53 54 55	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Name Heat Flow	(MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr 9.309e-002	12 1.0000 0.0000 0.0000 0.0000 Fluid Pky Chiller 1 Duty 0.1185	j: All Heat Loss Pipe 2 6.208e-004
48 49 50 51 52 53 54 55 56	Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Name Heat Flow Name	(MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004 Heat Loss Pipe 6	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004 Heat Loss Pipe 4	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr 9.309e-002 Heat Loss Pipe 5	12 1.0000 0.0000 0.0000 0.0000 Fluid Pky Chiller 1 Duty 0.1185	J: All Heat Loss Pipe 2 6.208e-004
48 49 50 51 52 53 54 55 56 57	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004 Heat Loss Pipe 6 5.848e-004	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004 Heat Loss Pipe 4 1.677e-004	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr 9.309e-002 Heat Loss Pipe 5 1.328e-004	12 1.0000 0.0000 0.0000 0.0000 Fluid Pky Chiller 1 Duty 0.1185	J: All Heat Loss Pipe 2 6.208e-004
48 49 50 51 52 53 54 55 56 57 58 59 60 61	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Name Heat Flow Heat Flow	(MW) (MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004 Heat Loss Pipe 6 5.848e-004	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004 Heat Loss Pipe 4 1.677e-004	11 1.0000 0.0000 0.0000 0.0000 0.0000 S S Sim Comp Pwr 9.309e-002 Heat Loss Pipe 5 1.328e-004	12 1.0000 0.0000 0.0000 0.0000 Fluid Pky Chiller 1 Duty 0.1185): All Heat Loss Pipe 2 6.208e-004
48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (H2O) Name Heat Flow Name Heat Flow	(MW) (MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004 Heat Loss Pipe 6 5.848e-004	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004 Heat Loss Pipe 4 1.677e-004	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr 9.309e-002 Heat Loss Pipe 5 1.328e-004	12 1.0000 0.0000 0.0000 0.0000 Fiuld Pky Chiller 1 Duty 0.1185	j: All Heat Loss Pipe 2 6.208e-004
48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 62 63	Asnen Technology Joc	(MW) (MW)	9 1.0000 0.0000 0.0000 0.0000 0.0000 Heat Loss Pipe 1 7.990e-004 Heat Loss Pipe 6 5.848e-004	10 1.0000 0.0000 0.0000 0.0000 Energy Stream Heat Loss Pipe 3 6.201e-004 Heat Loss Pipe 4 1.677e-004	11 1.0000 0.0000 0.0000 0.0000 0.0000 S Sim Comp Pwr 9.309e-002 Heat Loss Pipe 5 1.328e-004	12 1.0000 0.0000 0.0000 0.0000 Fluid Pky Chiller 1 Duty 0.1185	J: All Heat Loss Pipe 2 6.208e-004

Image: Spention Unit/EGITY OF DAND UDA Unit Set: Nuticals is Image: Spention Unit Set: Nuticals is Date: Time: Time: Time: Time: Time: Spenition Image: Spenition	1				Case Name:	updated high eff recup n2 brayton simula	ator.hsc	
4 USA DateTime: Thu Jan 30 15.86.29 2020 6 7 Workbook: Case (Main) (continued) 8 Pud Pag. Al 10 Mane Pud Pag. Al 11 Name Pud Pag. Al 12 DUTY (MV) Control Pud Pag. Al 13 Name Omuta Chiler 1 Coolers Pud Pag. Al 14 Product Temperature (C) 142.4 Pud Pag. Al 14 Mane Omutar Chiler 11 Omutar Chiler 11 Pud Pag. Al 15 Dutry (MV) 0.1155 Pud Pag. Al 16 Dutry Mane Omutar Chiler 11 Pud Pag. Al 21 Product Temperature (C) 1.211 Pud Pag. Al 22 Mane Recip MC2 Recip MC1 Recip MC1 Pud Pag. Al 23 Mane Recip MC2 Recip MC1 Pud Pag. Al	2	(aspentech	UNIVERSIT Bedford, M	TY OF IDAHO A	Unit Set	NuScale3a		
Image: Second	4	0	USA		Date/Time:	Thu Jan 30 15:56:29 2020		
Image Heaters Fluid Pig: All 11 Xame All 12 State Temperature (C) All All All All	5 6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)		
Image Image Image Image 12 DUTY (MW) Image Image <td>9</td> <td></td> <td></td> <td></td> <td>Heaters</td> <td></td> <td>Fluid Pkg</td> <td>: All</td>	9				Heaters		Fluid Pkg	: All
12 UTY (MV) Image: Section of the sec	11	Name						
19 Feed Temperature (C) Image Temperature (C) 14 Product Temperature (C) Image Temperature (C) 15 Name Dimutator Chiller 1 Image Temperature (C) 15 Name Dimutator Chiller 1 Image Temperature (C) 14 16 Image Temperature (C) 142.4 Image Temperature (C) 17 Product Temperature (C) 142.4 Image Temperature (C) 18 Attain Temperature (C) 142.4 Image Temperature Image Temperature (C) 111 16 Unity (MW) 0.3306 0.1355 Image Temperature Image Temperature <t< td=""><td>12</td><td>DUTY</td><td>(MW)</td><td></td><td></td><td></td><td></td><td></td></t<>	12	DUTY	(MW)					
is Product Temperature (Ng/S) Coolers Fluid Prig: All 19 Name Simulator Chiller 1 Image: Simulator Simul	13	Feed Temperature	(C)					
Id Series Plud Plg: Al 11 Name Dimulator Chlier 1 Coolers Plud Plg: Al 12 Variation Chlier 1 Image: Al Image: Al Image: Al 13 DUTY 0.1185 Image: Al Image: Al 14 DUTY 0.1185 Image: Al Image: Al 15 DUTY Coolers Plud Plg: Al 15 DUTY 0.1185 Image: Al Image: Al 16 Mark Ender (log S) 0.5238 Image: Al Image: Al 21 Mark Exchangers Plud Plg: Al 22 Image: Al Image: Al Image: Al 23 Tube Bide: Feed Mass Flow (log S) 0.5238 0.5238 Image: Al 23 Tube Bide: Feed Mass Flow (log S) 0.5238 0.5238 Image: Al 24 Ded Outer Temperature (C) 1448 573.1 Image: Al 25 Tube Outer Temperature (C) 125.6 470.9 </td <td>14</td> <td>Product Temperature</td> <td>(C)</td> <td></td> <td></td> <td></td> <td></td> <td></td>	14	Product Temperature	(C)					
It Coolers Plus Pig Al Is Name Simulator Chiller 1 Image: Coolers Plus Pig Al 19 DUTY (MW) 0.1185 Image: Coolers Plus Pig Al 20 Feed Temperature (C) 142.4 Image: Coolers Plus Pig Al 21 Product Temperature (C) 142.4 Image: Coolers Flus Pig Al 22 Mass Prov (kgs) 0.5238 Image: Coolers Flus Pig Al 23 Tube Olde Feed Mass Prov (kgs) 0.5238 Image: Coolers Flus Pig Al 23 Tube Olde Feed Mass Prov (kgs) 0.5238 Image: Coolers Flus Pig Al 23 Tube Olde Feed Mass Prov (kgs) 0.5238 0.5238 Image: Coolers Flus Pig Al 24 Tube Olde Feed Mass Prov (kgs) 0.5238 0.5238 Image: Coolers Image: Coolers Image: Coolers Image: Coolers Image: Coolers Image: Coolers I	15	Mass Flow	(kg/s)					
In Name Smulater Chiller 1 Image: Chiller 1 Image: Chiller 1 9 DUTY (MW) 0.1185 Image: Chiller 1 Image: Chiller 1 <td>16 17</td> <td></td> <td></td> <td></td> <td>Coolers</td> <td></td> <td>Fluid Pkg</td> <td>: All</td>	16 17				Coolers		Fluid Pkg	: All
19 DUTY (MV) 0.1185 Image: Constraint of the second	18	Name		Simulator Chiller 1				
Sol Feed Temperature (C) 142.4 Image: Control of the second secon	19	DUTY	(MW)	0.1185				
21 Product Temperature (C) 21.11 ' 22 Mass Flow (bg/s) 0.5236 24 Mass Flow Fluid Pkg: All 24 Name Recup HX 2 Recup HX 1 25 Name Recup HX 1 26 Stoff Feed Mass Flow (kg/s) 0.9238 0.9238 28 Tube Stoff Feed Mass Flow (kg/s) 0.9238 0.9238 29 Tube Outel Temperature (C) 117.2 444.2 20 Tube Outel Temperature (C) 444.8 573.1 21 Shel Outel Temperature (C) 428.3 599.2 23 Shel Outel Temperature (C) 25.00 26.14 24 Marce Compressor 1 25 Name	20	Feed Temperature	(C)	142.4				
21 Mass Flow (tig1s) 0.9235 Heat Exchangers Fluid Pug: All 28 Name Reoup HX 2 Reoup HX 1 Image: Control of Contro of Contro of Control of Contro of Control of Control of Control	21	Product Temperature	(C)	21.11 *				
123 Heat Exchangers Puid Pkg: All 25 Name Recup HX 2 Recup HX 1	22	Mass Flow	(kg/s)	0.9238				
S Name Recup HX 2 Recup HX 1 Image: Constraint of the second sec	23 24				Heat Exchange	rs F	Fluid Pkg	: All
Star Duty (MW) 0.3305 0.1345 1 Tube Side Feed Mass Flow (kg)5 0.5238 0.5238 0.5238 21 Tube Side Feed Mass Flow (kg)5 0.5238 0.5238 0.5238 23 Tube Unit Temperature (C) 117.2 444.2 1 23 Tube Unit Temperature (C) 444.8 573.1 1 21 Shel Side Temperature (C) 142.5 470.9 1 23 Shel Outel Temperature (C) 142.5 470.9 1 23 Shel Outel Temperature (C) 25.31 26.39 1 1 24 UA (kJ/C-h) 4.704e+004 1.835e+004 1 1 25 Mame Compressors Fluid Pkg: Al 26 Compressors Fluid Pkg: Al 27 Mame Compressors Fluid Pkg: Al 28 Poster (MV) 9.309e-002 1 1 </td <td>25</td> <td>Name</td> <td></td> <td>Recup HX 2</td> <td>Recup HX 1</td> <td></td> <td></td> <td></td>	25	Name		Recup HX 2	Recup HX 1			
27 Tube Slide Feed Mass Flow (kgis) 0.9238 0.9238 0.9238 28 Shell Slide Feed Mass Flow (kgis) 0.9238 0.9238 0.9238 28 Tube Initel Temperature (C) 117.2 444.2 0.0000 20 Tube Outlet Temperature (C) 444.8 573.1 0.0000 20 Shell Inite Temperature (C) 444.8 573.1 0.0000 21 Shell Outlet Temperature (C) 444.2 0.0000 0.0000 22 Shell Outlet Temperature (C) 42.3 28.39 0.0000 0.0000 23 LMTO (C) 25.00 25.14 0.0000 0.0000 24 Mame Compressort Fluid Pkg: All 25 Power (MW) 9.0000 0.0000 0.0000 26 Product Temperature (C) 117.3 0.0000 0.0000 24 Product Temperature (C) 1177.3 0.0000 0.0000 <td>26</td> <td>Duty</td> <td>(MW)</td> <td>0.3308</td> <td>0.1345</td> <td></td> <td></td> <td></td>	26	Duty	(MW)	0.3308	0.1345			
28 Shel Side Feed Mass Flow (bgis) 0.9238 0.9238 0.9238 29 Tube Outlet Temperature (C) 117.2 444.2 21 Tube Outlet Temperature (C) 444.8 573.1 21 Shel Inet Temperature (C) 444.8 599.2 23 Shel Outlet Temperature (C) 142.6 470.9 23 Shel Outlet Temperature (C) 142.6 470.9 23 Minimum Approach (C) 25.31 26.39 24 UA (kUC-h) 4.704e+004 1.353e+004 25 Minimum Approach (C) 25.00 26.14 26 Prover (MW) 9.309e+002 0 27 Sheed Pressure (kPa) 505.3 0 28 Power (MW) 9.309e+002 0 40 Feed Pressure (kPa) 1095 0 29 Product Temperature (C) 117.3 0 41 Product Pressure (kPa) 1095 0 42 Product Pressure (kPa) 0.923.8 0 43 Paser Fature (C) 21.66 0 44 Aliabato Efficiency	27	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
23 Tube Inite Temperature (C) 117.2 444.2	28	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
30 Tube Outlet Temperature (C) 444.8 573.1	29	Tube Inlet Temperature	(C)	117.2	444.2	ļ		
31 Shel Initi Temperature (C) 446.8 599.2	30	Tube Outlet Temperature	(C)	444.8	573.1			
32 Shell Outlet Temperature (C) 142.6 ¹ 470.9 ¹ 31 LMTD (C) 25.31 26.39	31	Shell Inlet Temperature	(C)	469.8	599.2			
July To (C) 25.31 26.39	32	Shell Outlet Temperature	(C)	142.6 *	470.9 *			
JOA (kl/c-h) 4.7044-004 1.3394-004 1 36 Minimum Approach (C) 25.00 26.14 Image: Compressors Fluid Pkg: All 38 Name Compressors Fluid Pkg: All 39 Name Compressors Fluid Pkg: All 39 Power (MW) 9.309-002 Image: Compressore Compressore 40 Peed Pressure (kPa) 1096 ° Image: Compressore Compressore 41 Product Pressure (kPa) 1096 ° Image: Compressore Compressore 42 Product Pressure (kPa) 1096 ° Image: Compressore Compressore 43 Product Pressure (kPa) 1096 ° Image: Compressore Compressore 44 Product Pressure (kPa) 0.9238 Image: Compressore All 45 Power (MWy) Image: Compressore Fluid Pkg: All Image: Compressore 46 Name Image: Compressore KPa)	33	LMTD	(C)	25.31	26.39			
Minimum Approach (C) 25.00 26.14 I 36 Compressors Fluid Pkg: All 37 Name Compressors Fluid Pkg: All 38 Name Compressors Fluid Pkg: All 39 Power (MW) 9.309e-002 Image: Compressore Image: Compressore 41 Product Pressure (kPa) 505.3 Image: Compressore Image: Compressore Image: Compressore 42 Product Temperature (C) 117.3 Image: Compressore Image: Compressore Image: Compressore 43 Feed Temperature (C) 21.11 Image: Compressore Image: Compressore Image: Compressore 44 Adabate Efficiency 75 * Image: Compressore Image:	34	UA Malaum Assessab	(KJ/C-N)	4./04e+004	1.8356+004			
Total Compressors Fluid Pkg: All 38 Name Compressor1 Image: Compressor 1	36	Minimum Approach	(0)	23.00	20.14			
38 Name Compressor 1 Image: Compressor 1 Image: Compressor 1 39 Power (MW) 9.309e002 Image: Compressor 2	37				Compressors	· · · · · · · · · · · · · · · · · · ·	Fluid Pkg	: All
38 Power (MV) 9.309e-002	38	Name		Compressor 1				
40 Freed Pressure (kPa) 505.3	39	Power	(MW)	9.309e-002				
41 Product Pressure (KPa) 1096 '	40	Feed Pressure	(kPa)	505.3				
Product remperature (C) 117.3	41	Product Pressure	(KPa)	1096 *				
Precont Periportation CO 21.11 Constraint Constraint <thconstraint< th=""> <thconstraint<< td=""><td>42</td><td>Product Temperature</td><td>(C)</td><td>117.3</td><td></td><td> </td><td></td><td></td></thconstraint<<></thconstraint<>	42	Product Temperature	(C)	117.3				
Indicative Entropy 10 10 45 Pressure Ratio 2.169 1 46 Mass Flow (kg/s) 0.9238 1 47 Expanders Fluid Pkg: All 48 Expanders Fluid Pkg: All 49 Name 1 1 1 50 Power (MW) 1 1 1 51 Feed Pressure (kPa) 1 1 1 52 Product Pressure (kPa) 1 1 1 1 52 Product Temperature (C) 1	43	Adjabatic Efficiency	(0)	21.11		<u> </u>		
Mass Flow (kg/s) 0.9238 Image: Constraint of the second secon	45	Pressure Ratio		2.169				
47 48 Expanders Fluid Pkg: All 49 Name Image: State	46	Mass Flow	(kg/s)	0.9238				
Name Image: Constraint of the source of the so	47				Expanders		Fluid Pkg	: All
Instruction Instruction 50 Power 51 Feed Pressure (kPa) Instruction 52 Product Pressure (kPa) Instruction 53 Product Temperature (C) Instruction 54 Feed Temperature (C) Instruction 55 Adlabatic Efficiency 56 Mass Flow 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 3	49	Name						
S1 Feed Pressure (kPa) Image: Constraint of the second	50	Power	(MW)					
S2 Product Pressure (kPa) Image: Constraint of the second sec	51	Feed Pressure	(kPa)			1		
53 Product Temperature (C) Image: Constraint of the second	52	Product Pressure	(kPa)					
54 Feed Temperature (C) Image: Constraint of the second of	53	Product Temperature	(C)					
SS Adlabatic Efficiency 56 Mass Flow 57 58 59 60 61 62 63 63 64 65 66 67 68 69 60 61 62 Page 2 of 3	54	Feed Temperature	(C)					
56 Mass Flow (kg/s) 57 58 59 60 61 62 63 63 64 65 Page 2 of 3	55	Adiabatic Efficiency						
57 58 59 60 61 62 63 64 63 64 63 64 65 66 67	56	Mass Flow	(kg/s)					
63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 2 of 3	57 58 59 60 61 62							
	63	Aspen Technology Inc.		1	Aspen HYSYS Versi	ion 9		Page 2 of 3

1					Case Name:	updated high eff recup	n2 brayton simulator.hsc	
3	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO A	Ī	Unit Set	NuScale3a		
4		USA		Ī	Date/Time:	Thu Jan 30 15:56:29 20	020	
6								
7	Wor	kbook:	Case (Ma	in)	(continue	ed)		
9					Valves		Fluid Pk	a: All
10	Name		CV-01					
12	Pressure Drop	(kPa)	500.5					
13	Feed Pressure	(kPa)	1029					
14	Feed Temperature	(C)	470.3					
15	Product Pressure	(kPa)	528.3	•				
16	Product Temperature	(C)	470.4					
17	Mass Flow	(kg/s)	0.9238					
18	Cg Resistance /Cu or KNISCON	VEDE (nell)	2220	-				
20	Resistance (CV of RJ03GPN	(our, ipsi))	00.33					
21								
22								
23								
24								
25								
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62	Aspen Technology Inc.			Acres	an HVSVS Vari	ion 9		Page 2 of 2
03	Licensed to: UNIVERSITY OF ID	AHO		Азр	entrioro velsi	1011 0		* Specified by user.



Modified Nitrogen Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%

1				Case Name:	updated low eff recup r	2 brayton simulator.hsc	
3	@aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 16:38:32 20	020	
6 7 8	Wor	kbook:	Case (Main	n)			
9				Material Stream	IS	Fluid Pk	g: All
11	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
12	Temperature	(C)	600.0 *	599.2	505.4	504.9	505.5
13	Pressure	(kPa)	1051 *	1050	1029	600.5	601.8 *
14	Mass Flow	(kg/s)	0.92378063 *	0.92378063	0.92378063	0.92378063	0.92378063
15	Mass Density	(kg/m3)	4.0436817	4.0439842	4.4370918	2.5954368	2.5988451
16	Mass Enthalpy	(kJ/kg)	628.9	628.0	521.3	520.6	521.3
17	Mass Entropy	(kJ/kg-C)	5.756	5.755	5.632	5.791	5.792
18	Name		2	1	4	8	3
19	Temperature	(C)	99.63	21.11 *	125.1 *	506.0 *	479.9
20	Pressure	(kPa)	1096 *	576.1	588.5	1029	1073
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063
22	Mass Density	(kg/m3)	9,8960207	6.6139432	4,9743851	4,4366777	4,7859970
22	Mass Enthainy	(k,1/km)	76.41	-5 653	104.3	522.0	492.6
24	Mass Entrony	(k l/kn-C)	4 809	4 752	5.066	5.633	5 582
26	Name	(noing of	9	10	11	12	0.002
26	Temperature	(C)	479.3	572.9	125.0	99.52	
27	Dressure	(kPa)	1073	1051	587.8	1095	
70	Mass Finw	(knis)	0.92378063	0.92378063	0.92378063	0.92378063	
29	Mass Density	(kg/m3)	4 7867697	4 1731889	4 9707384	9 8960569	
20	Mass Enthainy	(k,1/km)	491.9	597.9	104.1	76.29	
24	Mass Entrony	(k.l/ko-C)	5 581	5 720	5.066	4 808	
32	(1100 Linep)	(10.10) 0/				4.000	
33				Compositions		Fluid Pk	g: All
34	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
35	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.0000	1.0000	1.0000
36	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.0000	0.000	0.0000
37	Comp Mole Frac (Argon)		• 0000.0	0.0000	0.0000	0.0000	0.0000
38	Comp Mole Frac (Oxygen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
39	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
40	Name		2	1	4	8	3
41	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	1.0000
42	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000
43	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	0.0000
44	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	0.0000
45	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	0.0000
46	Name		9	10	11	12	
47	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	
48	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
49	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
50	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	
51	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
52				Energy Stream	s	Fluid Pk	g: All
53	Mama		Hast Loss In Diss 1	Heat Less In Dine 3	Sim Come Dur	Oblige 4 Duby	Heat Loss In Dine 2
54	Name Maat Flam	(1.010)	Teat Loss in Pipe 1	Heat Loss in Pipe 5	Sim Comp Pwi	Chiller Touty	Heat Loss in Pipe 2
25	Nama	(WIVY)	Heat Loss In Dine 6	Heat Loss in Dine 4	Heat Loss in Dine 5	0.1014	0.0938-004
20	Hant Flow	0.000	C DDOS III PIPE 0	treat cost in Pipe 4	rieat coss in Pipe 5		
57	neat Flow	(MW)	6.332e-004	1.4358-004	1.083e-004	I	I
59							
60 61							
60 61 62							
60 61 62 63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 3

1				Case Name:	updated low eff recup n	2 brayton simulator.hsc	
2	(aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set	NuScale3a		
4	<u> </u>	USA		Date/Time:	Thu Jan 30 16:38:32 20	20	
5 6 7 8	Worl	kbook	Case (Mai	n) (continue	ed)		
9				Heaters		Fluid Pk	g: All
11	Name						
12	DUTY	(MW)					
13	Feed Temperature	(C)					
14	Product Temperature	(C)					
15	Mass Flow	(kg/s)					
16 17				Coolers		Fluid Pk	g: All
18	Name		Simulator Chiller 1				
19	DUTY	(MW)	0.1014				
20	Feed Temperature	(C)	125.0				
21	Product Temperature	(C)	21.11				
22	Mass Flow	(kg/s)	0.9238				
23 24				Heat Exchange	rs	Fluid Pk	g: All
25	Name		Recup HX 2	Recup HX 1			
26	Duty	(MW)	0.3846	9.790e-002			
27	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
28	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
29	Tube Inlet Temperature	(C)	99.52	479.3			
30	Tube Outlet Temperature	(C)	479.9	572.9			
31	Shell Inlet Temperature	(C)	504.9	599.2			
32	Shell Outlet Temperature	(C)	125.1	506.0 *			
33	LMTD	(C)	25.42	26.58			
35	Minimum Anoroach	(MJ/G-II) (C)	25.00	26.30			
36		(9)	20.00	0			
37				Compressors		Fiuld PK	g: Al
38	Name	0.000	Compressor 1				
39	Power Food Processo	(MW)	7.5810-002				
40	Droduct Draceura	(kPa)	1006 *				
42	Product Temperature	(Kr-a) (C)	99.63				
43	Feed Temperature	(C)	21.11 *				
44	Adiabatic Efficiency		75 '				
45	Pressure Ratio		1.902				
46	Mass Flow	(kg/s)	0.9238				
47 48				Expanders		Fluid Pk	g: All
49	Name						
50	Power	(MW)					
51	Feed Pressure	(kPa)					
52	Product Pressure	(kPa)					
53	Product Temperature	(C)					
54	Feed Temperature	(C)					
55	Adlabatic Efficiency						
50 57 58 59 60 61 62	Acces Technology Inc.	(kg/s)					Deres 2.4(2)
63	Aspen Technology Inc.	HO		Aspen HYSYS Versi	on 9		Page 2 of 3
	DICENSED ID: UNIVERSITY OF ID/	who:					opeched by user.

Image: Separation of the second sec	1		LININ/EDO/T			Case Name:	updated low eff recup n	2 brayton simulator.hsc	
i USA DateTime: Tru Jan 30 16:36:32 2020 i Workbook: Case (Main) (continued) i Name Pade Page: Al iii Name Ox/00 Page Al iii Pade Page: Al Iiii Pade Page: Al iii Pade Page: Old Iiiiii Pade Page: Al iii Pade Page: Old Sold Iiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiii	3	(aspentech	Bedford, MA			Unit Set	NuScale3a		
Image: Second	4		USA			Date/Time:	Thu Jan 30 16:38:32 20	20	
2 Workbook: Case (Main) (continued) 3 Valves Pus Pig: AI 10 Pressure Drop ((P)) 0/01 0 0 11 Pressure Drop ((P)) 0/01 0 0 0 11 Pressure Drop ((P)) 0/02 0 0 0 0 12 Pressure Drop (P) 0/03 0	5								
1 Name Valves Pud PRg: Al 11 Name 0	7 8	Work	(book:	Case (Main)	(continue	ed)		
Name OV-01 Image: Constraint of the second	9 10					Valves		Fluid Pkg	r All
12 Presure Cirgo (Pa) 426.9	11	Name		CV-01					
13 Feed Temperature (C) 555.4 (C)	12	Pressure Drop	(kPa)		426.9				
If each Temperature (C) 8054 Image: Constraint of the second of the	13	Feed Pressure	(kPa)		1029				
IP Pool Pressure (µPa) 601.8 * IT Muss Flow (µpg) 0.0238	14	Feed Temperature	(C)		505.4				
Import rempetative (C) 00-3 Import (mport for the second seco	15	Product Pressure	(kPa)		601.8 *				
Item Tow (upp) 0.933 * Image: Common temperature 10 Cog Loss * Image: Common temperature Image: Common temperature 10 Resultance (CV or NQUSOPM(60F, tpst)) 70.29 Image: Common temperature Image: Common temperature 21 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 22 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 23 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 23 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 23 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 23 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 24 Image: Common temperature Image: Common temperature Image: Common temperature Image: Common temperature 24 Image: Common temperature	16	Product Temperature	(C)		505.5				
Image: Construction of Resistance (Cv or RQUSGPM(SOF,Tpst)) To.29 Image: Construction of RQUSGPM(SOF,Tpst)) 33 1 1 1 1 33 1 1 1 1 1 33 1 1 1 1 1 1 34 1 <t< td=""><td>1/</td><td>Mass Flow</td><td>(Kg/S)</td><td>U</td><td>9238</td><td></td><td></td><td></td><td></td></t<>	1/	Mass Flow	(Kg/S)	U	9238				
1 Appendix (or dr. ypercent (or dr	19	Resistance (Cy or KILISGRM)	60E (nsl))		70.20				
1 1 <t< td=""><td>20</td><td></td><td>and the still</td><td></td><td></td><td></td><td>1</td><td></td><td></td></t<>	20		and the still				1		
22 23 24 25 27 28 27 28 29 20 20 21 22 23 24 24 24 25 26 27 28 29 29 20 21 22 23 24 25 26 <td>21</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	21								
22 23 24 25 27 28 29 29 21 22 23 24 25 26 27 28 29 20 20 21 22 23 24 24 25 26 26 <td>22</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	22								
24 32 32 32 33 34 35 36 37 38 39 39 39 30 31 32 33 34 35 36 37 38 39 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 42 <td>23</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	23								
12 22 33 34 35 36 37 38 41 42 43 44 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 40 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 56 57 58 59 51 52 53 54 55 56 57 <td>24</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	24								
22 23 24 25 26 27 28 29 20 20 21 22 23 24 24 24 24 24 24 24 24 24 25 26 26 27 28 29 29 29 29 29 29 20 21 21 22 23 24 25 26 <td>25</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	25								
27 38 39 30 31 32 33 34 35 36 37 38 39 39 30 31 32 33 34 35 36 41 42 43 44 45 46 47 48 49 49 40 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 43 44 45 46 47 48 49 49 41 42 43 44 <td>26</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	26								
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22 23 23 24 25 28 29 24 25 25 26 26 27 28 29 29 20 21 22 23 24 25 26 26 <td>29</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	29								
22 33 34 35 36 37 38 39 39 34 44 42 43 44 44 45 46 47 48 49 49 41 42 43 44 45 56 51 52 43 44 45 46 47 48 49 49 41 42 43 44 45 56 51 52 53 54 55 56 57 58 59 50 51 52	30								
3 3 34 35 37 38 40 41 42 43 44 45 46 47 48 58 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53	32								
34 35 36 37 38 39 38 39 39 39 39 39 39 39 39 39 39 39 39 30 31 32 41 42 43 44 44 45 46 47 48 49 49 49 41 42 43 44 45 51 52 53 54 55 56 57 58 59 51 52 43 53 54 54 54	33								
13 13 13 13 13 14 15 15 16 16 17 18 19 10 11 12 13 14 15 14 15 15 16 16	34								
38 39 38 39 38 39 30 40 41 42 43 44 45 46 47 48 49 49 40 41 42 43 44 45 46 47 48 49 49 50 51 52 53 54 55 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 <td>35</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	35								
37 38 39 41 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 55 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 43 44 45 46 47 48 59 51 52 53 54 55 56 57 58 59 50 51 52 <td>36</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	36								
38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 52 53 54 55 56 57 58 59 50 51 <td>37</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	37								
39 40 41 42 43 44 45 46 47 48 49 50 51 52 63 64 65 66 61 62 7 63 64 65 66 61 62 7 63 64 65 66 61 62 7 63 64 65 66 61 62 7 63 64 65 66 67 68 61 62 7 63 64 65 66	38								
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 52 53 54 55 56 57 58 59 51 <td>39</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	39								
1 42 43 44 45 47 48 49 49 49 49 49 49 49 49 49 49 49 49 49 49 49 49 49 40 41 42 51 52 53 54 55 57 58 57 58 57 58 57 58 59 50 51 52 53 54 55 56 57 58 59 51 52 52 53	40								
1 4 4 45 46 47 48 49 50 51 52 53 54 55 56 57 58 69 61 62 53 64 63 64 63 64 63 64 63 64 63 64 63 64 65 66 67 68 69 60 61 62 Page 3 of 3	41								
44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 53 54 55 56 57 58 59 60 61 62 53 64 65 56 57 58 59 60 61 62 53 64 65 56 57 58 59 60 61 62 53 54 55 56 57 58 59 61 62 53 54 55 56 57 58 59 59 <td>42</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	42								
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46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 63 63 64 65 66 61 62 63 64 65 66 67 68 69 60 61 62 63 64 65 62 63 64 65 66 67 68 69 61 62 63 64 65 65 66 67 68 <td>45</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	45								
47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 53 54 55 56 57 58 59 60 61 62 63 43 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	46								
48 49 50 51 52 53 56 57 58 59 60 61 62 63 64 65 65 66 67 68 69 61 62 63 64 65 65 66 67 68 69 60	47								
49 50 51 52 53 56 57 58 59 60 61 62 63 64 65 65 66 67 68 69 61 62 63 64 65 65 66 67 68 69 60	48								
50 51 52 53 54 55 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 63 63 63 63 63 64 65 65 66 67 68 69 60 61 62 63 64 65 65 66 67 68 69 60 61 62 63 64 65 66 67 68 69 69 60 61 62 63 64 65 65 66 67 68 69 <td>49</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	49								
51 52 53 54 55 56 57 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 63 63 Page 3 of 3	50								
52 53 54 55 56 57 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 63 63 63 63 63 64 65 65 66 67 68 69 60 61 62 63 64 65 65 66 67 68 69 60 61 62 63 64 65 65 66 67 68 69 69 60 61 62 63 64 65 66 67 68 69 <td>51</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	51								
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3** 55 56 57 58 59 60 61 62 63 63 63 63 63 63 63 63 63 63 63 63 63 63 63 63 64 65 66 67 68 69 60 61 62 63 64 65 66 67 68 69 69 60 61 62 63 64 65 66 67 68 69	53								
37 56 58 59 60 61 62 63 63 Aspen Technology Inc. 63 Aspen HYSYS Version 9 63 9	54								
57 57 58 59 60 61 62 63 63 Aspen Technology Inc. 63 Aspen HYSYS Version 9 63 9	55								
58 59 60 61 62 63 64 65 63 64 65 63 64 65 66 67 68 69 69 60 61 62 63 64 65 65 66 67 68 69 69 60 61 62 63 64 65 65 66 67 68 69 69 69 61 62 63 64 65 65 66 67 68 69 69 69 60 61 62 63 64 65 65 66 67 68 <td>57</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>	57								
59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	58								
60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	59								
61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	60								
62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	61								
63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 3 of 3	62								
	63	Aspen Technology Inc.			Asp	en HYSYS Versi	on 9		Page 3 of 3



Modified Helium Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%

1				Case Name:	report model updated h	igh eff recup he brayton a	simulator.hsc
2	@aspen tech	UNIVERSI Bedford, N	ITY OF IDAHO /A	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 12:28:37 202	20	
6 7 8	Wor	kbook	: Case (Maii	n)			
9				Material Stream	IS	Fluid Pk	g: All
11	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
12	Temperature	(C)	850.0 *	848.8	601.6	600.8	601.6
13	Pressure	(kPa)	1051 *	1049	1027	518.0	520.0
14	Mass Flow	(kg/s)	0.15990000 *	0.15990000	0.15990000	0.15990000	0.15990000
15	Mass Density	(kg/m3)	0.45049903	0.44986598	0.56487277	0.28530818	0.28614132
16	Mass Enthalpy	(kJ/kg)	4287	4281	2996	2992	2996
17	Mass Entropy	(kJ/kg-C)	23.04	23.04	21.79	23.21	23.21
18	Name		2	1	4	8	3
19	Temperature	(C)	166.9	21.11	191.8 *	602.4 *	575.6
20	Pressure	(kPa)	1096 *	497.1	507.6	1028	1074
21	Mass Flow	(kg/s)	0.15990000	0.15990000	0.15990000	0.15990000	0.15990000
22	Mass Density	(kg/m3)	1.1981812	0.81323676	0.52553363	0.56489570	0.60876098
23	Mass Enthalpy	(KJ/Kg)	737.2	-20.56	866.6	3001	2861
24	Mass Entropy	(KJ/Kg-C)	18.09	17.64	19.97	21.80	21.54
25	Name	(0)	9	10 001.0	11 404.5	12	
26	Droccuro	(6)	3/4.0	021.2	191.0	100.7	
21	Mass Elem	(keic)	0.15000000	0.15000000	0.15000000	0.45000000	
28	Mass Donelly	(kg/s) (kg/m3)	0.13990000	0.15990000	0.13990000	1 1086430	
20	Mass Enthalow	(kj/ma)	2857	4137	0.02042007	735.0	
24	Mass Entrony	(k l/kn_C)	2007	22.91	19.97	18.08	
32	indoo Endopy	(noing o/	21.04		13.51	10.00	
33				Compositions		Fiuld Pkg	g: All
34	Name		Into PCU Simulator	5	6	Out PCU Simulator	7
35	Comp Mole Frac (Nitrogen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
36	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.0000	0.0000	0.0000
37	Comp Mole Frac (Argon)		• 0000.0	0.0000	0.0000	0.0000	0.0000
38	Comp Mole Frac (Oxygen)		• 0000.0	0.0000	0.0000	0.0000	0.0000
39	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
40	Comp Mole Frac (Hellum)		1.0000 *	1.0000	1.0000	1.0000	1.0000
41	Name		2	1	4	8	3
42	Comp Mole Frac (Nitrogen)		0.0000	0.0000	0.0000	0.0000	0.0000
43	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	0.0000
44	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	0.0000
45	Comp Mole Frac (Uxygen)		0.0000	0.0000	0.0000	0.0000	0.0000
47	Comp Mole Frac (Hallum)		1,0000	1 0000	1,0000	1,0000	1,0000
48	Name		9	10	11	12	1.0000
49	Comp Mole Frac (Nifrogen)		0.0000	0.0000	0.0000	0.0000	
50	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
51	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
52	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	
53	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
54	Comp Mole Frac (Hellum)		1.0000	1.0000	1.0000	1.0000	
55				Energy Stream	s	Fluid Pk	a: All
56 57	Name		Heat Loss Pipe 1	Heat Loss Pipe 3	Sim Comp Pwr	Chiller 1 Duty	Heat Loss Pipe 2
58	Heat Flow	(MW)	9.997e-004	6.883e-004	0.1212	0.1416	6.893e-004
59	Name		Heat Loss Pipe 6	Heat Loss Pipe 4	Heat Loss Pipe 5		
60	Heat Flow	(MW)	6.560e-004	2.317e-004	1.984e-004		
61							
62							
63	Aspen Technology Inc.		1	Aspen HYSYS Versi	on 9		Page 1 of 3
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1				Case Name:	report model updated high eff recup he brayton	simulator.hsc
3	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set	NuScale3a	
4		USA		Date/Time:	Fri Jan 31 12:28:37 2020	
5 6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)	
9				Heaters	Fluid Pl	kg: All
11	Nama					
12	DUTY	(MW)				
13	Feed Temperature	(C)				
14	Product Temperature	(C)				1
15	Mass Flow	(kg/s)				
16 17				Coolers	Fluid Pi	tg: All
18	Name		Simulator Chiller 1			
19	DUTY	(MW)	0.1416			
20	Feed Temperature	(C)	191.5			
21	Product Temperature	(C)	21.11 *			
22	Mass Flow	(kg/s)	0.1599			
23 24				Heat Exchange	rs Fluid Pl	kg: All
25	Name		Recup HX 2	Recup HX 1		
26	Duty	(MW)	0.3398	0.2047		
27	Tube Side Feed Mass Flow	(kg/s)	0.1599	0.1599		
28	Shell Side Feed Mass Flow	(kg/s)	0.1599	0.1599		
29	Tube Inlet Temperature	(C)	166.7	574.8		
30	Tube Outlet Temperature	(C)	575.6	821.2		
31	Shell Inlet Temperature	(C)	600.8	848.8		
32	Shell Outlet Temperature	(C)	191.8	602.4 *	<u> </u>	
33	LMTD	(C)	25.17	27.62		
34	UA Misimum Assessab	(KJ/C-N)	4.8600+004	2.6686+004		
36	Minimum Approach	(0)	20.10	21.02		
37				Compressors	; Fiuld Pi	kg: All
38	Name		Compressor 1			
39	Power	(MW)	0.1212			
40	Feed Pressure	(KPa)	497.1			
41	Product Pressure	(KPa)	1096 -			
42	Foduce Temperature	(0)	21.11.1			
44	Adiabatic Efficiency	(0)	75 *			
45	Pressure Ratio		2.204			
46	Mass Flow	(kg/s)	0.1599			1
47				Expanders	Fiuld Pi	ig: All
48	Namo			-		
	Power	(MM)				
51	Feed Pressure	(kPa)			1	1
52	Product Pressure	(kPa)				
53	Product Temperature	(C)				
54	Feed Temperature	(C)				
55	Adiabatic Efficiency					
56	Mass Flow	(kg/s)				
57 58 59 60 61 52						
63	Aspen Technology Inc.			Aspen HYSYS Versi	ion 9	Page 2 of 3
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1				Case Name:	report model updated h	ligh eff recup he brayton s	simulator.hsc
3	@aspentech	Bedford, MA	Y OF IDAHO	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 12:28:37 20	20	
6							
7	Wor	rkbook:	Case (Mai	n) (continue	ed)		
9				Valves		Fluid Pk	I: All
10	Name		CV-01				
12	Pressure Drop	(kPa)	506.7				
13	Feed Pressure	(kPa)	1027				
14	Feed Temperature	(C)	601.6				
15	Product Pressure	(kPa)	520.0 *				
16	Product Temperature	(C)	601.6				
17	Mass Flow	(kg/s)	0.1599				
18	Cg		2220 *				
19	Resistance (Cv or K/USGPI	M(60F,1psl))	66.33				
20							
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62	Annual Test Annual			Annual INCOVERS			D- 0 /0
63	Aspen Technology Inc.			Aspen HTSYS Vers	ion 9		Page 3 of 3
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Modified Helium Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%

1				Case Name:	report model updated lo	w eff recup he brayton si	imulator.hsc
3	@aspentech	Bedford, N	IA IN THE REAL OF IDAHO	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 12:29:21 202	20	
6 7	Worl	kbook	: Case (Mai	n)			
8 9				Material Stream	IS	Fluid Pk	a: Al
10	No			-			-
11	Name	(0)	Into PCU simulator	5	6	Out PCU Simulator	7
12	Proceuro	(6)	1051 *	040.0	1026	640.3	649.2 550.0 ¹
13	Mass Elem	(keic)	0.15000000 *	0.15000000	0.15000000	0.15000000	0.45000000
14	Mass Dooslby	(kg/s) (kg/m2)	0.15990000	0.13990000	0.13990000	0.10990000	0.10990000
15	Mass Density Mass Esthalow	(kg/ms)	0.45049905	0.44900090	0.0002194	0.29001107	0.29172009
10	Mass Entrany	(NJ/NG)	4207	4201	3243	3239	3243
17	Mass Entropy	(Ku/kg-C)	23.04	23.04	22.07	23.33	23.33
10	Name	(0)	2	1	4	0	3
12	Temperature	(0)	101.0	21.11	1/0.4	650.1	023.2
20	Pressure Mass Elem	(KPa)	1096	534.3	545.0	1028	10/4
21	Mass Flow	(KG/S)	0.15990000	0.15990000	0.15990000	0.15990000	0.15990000
22	Mass Density	(Kg/m3)	1.2413828	0.8/411446	0.58414906	0.53575022	0.57642237
23	Mass Enthalpy	(KJ/KG)	657.6	-20.59	786.5	3248	3109
24	Mass Entropy	(KJ/KG-C)	17.90	17.49	19.65	22.07	21.83
25	Name		9	10	11	12	
26	Temperature	(C)	622.4	821.1	176.1	151.4	
27	Pressure	(kPa)	1073	1051	545.2	1096	
28	Mass Flow	(KG/S)	0.15990000	0.15990000	0.15990000	0.15990000	
29	Mass Density	(kg/m3)	0.57640251	0.46230877	0.58409426	1.2418270	
30	Mass Enthalpy	(KJ/Kg)	3104	4137	785.2	656.5	
31	Mass Entropy	(KJ/KG-C)	21.82	22.91	19.65	17.90	
32							
33				Compositions		Fluid Pkg	g: All
33 34	Name		Into PCU Simulator	Compositions 5	6	Fluid Pkg Out PCU Simulator	g: All 7
33 34 35	Name Comp Mole Frac (Nitrogen)		Into PCU Simulator 0.0000 *	5 0.0000	6	Fluid Pkg Out PCU Simulator 0.0000	g: All 7 0.0000
33 34 35 36	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2)		Into PCU Simulator 0.0000 * 0.0000 *	Compositions 5 0.0000 0.0000	6 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000	g: All 7 0.0000 0.0000
33 34 35 36 37	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon)		Into PCU Simulator 0.0000 ° 0.0000 °	Compositions 5 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000
33 34 35 36 37 38	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 °	Compositions 5 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000
33 34 35 36 37 38 39	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 °	Compositions 5 0.0000 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
33 34 35 36 37 38 39 40	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 °	Compositions 5 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000	6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000
33 34 35 36 37 38 39 40 41	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1	6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 4	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000 8	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 3
33 34 35 36 37 38 39 40 41 42	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000	6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000 8 0.0000	g: All 7 0.0000
33 34 35 36 37 38 39 40 41 42 43	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 8 0.0000	g: All 7 0.0000
33 34 35 36 37 38 39 40 41 42 43 44	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 0.0000 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 3 0.0000 0.000 0.000 0.000 0
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 ° 0.0000 0.0000 0.0000 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.0000 0.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum)		Into PCU Simulator 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 2 0.0000 0.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.000 0.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	g: All 7 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name		Into PCU Simulator 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 2 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.00000 1.00000 1.0000 1.00000 1.000000 1.000000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000	g: All 7 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (H1rogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (H2O) Comp Mole Frac (H2O) Comp Mole Frac (H1rogen) Name Comp Mole Frac (Nitrogen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.00000 0.00000 0.0000000 0.000000 0.0000000 0.	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 1.0000 0.00000 0	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.0000 0.0000 0.00
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Hellum) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000000 0.000000 0.000000 0.00000000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 10 0.00000 0.00000 0.00000 0.00000 0.0000 0.00000 0.00000 0.00000 0.0000 0.000000 0.000000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 12 0.0000 12 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.0000 0.0
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Co2) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Hellum) Name Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 9 0.0000 9 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 10 0.00000 0.0000 0.00000 0.0000 0.00000 0.00000 0.	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 11 0.0000 11 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.0000 0.00000 0.00000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 12 0.0000 12 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.0000 0.0
33 34 35 36 37 38 39 40 41 42 43 44 45 45 47 48 49 50 51 52	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 0.0000 0.0000 0.0000 0.0000 9 9 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	Compositions 5 0.0000 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 10 0.0000 10 0.000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 1.0000 0.0000 1.0000 0.0000 11 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000 0.00000000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 12 0.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.0000 0.0
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Hellum) Name Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (HelC)		Into PCU Simulator 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1.0000 * 2 0.0000 0.0000 0.0000 0.0000 1.0000 9 0.00000 0.000000 0.000000 0.000000 0.00000000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000 10 0.00000 0.00000 0	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 1.0000 12 0.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	g: All 7 0.00000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 152 53 54	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum)		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 9 0.00000 0.0000 0.000000 0.00000 0.00000 0.000000 0.00000000	Compositions 5 0.0000 0.0000 0.0000 0.0000 1 0.0000 1 0.0000 0.0000 0.0000 0.0000 10 0.00000 0.00000 0	6 0.0000 0.0000 0.0000 0.0000 0.0000 4 0.0000 0.0000 0.0000 1.0000 11 0.0000 11 0.00000 0.00000 0.00000 0.000000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 1.0000 12 0.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	g: All 7 0.00000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 6	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum)		Into PCU Simulator 0.0000 * 0.0000 * 0.0000 * 0.0000 * 0.0000 * 1.0000 * 2 0.0000 0.00	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 0.0000 0.0000 1.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 12 0.00000 0.00000 0.00000 0.000000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.00000 0.000000 0.00000 0.00000 0.0000 0.0000 0.00000 0.00000
33 34 35 36 37 39 40 41 42 43 44 45 46 47 48 99 51 52 53 54 55 56 57	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Name		Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.00000 0.0000 0.0000 0.0000 0.00000 0.	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 0.0000 0.0000 1.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 12 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.00000 0.000000 0.00000 0.0000 0.0000 0.0000 0.000000 0.00000
33 34 35 36 37 89 40 41 42 43 44 45 46 47 48 90 51 52 53 54 55 56 57 58	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Hellum) Name Name Heat Flow	(MW)	Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.0000 0.00000 0.00000 0.000000 0.000000 0.0000000 0.0	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 1.0000 0.00000 0.00000 0.00000 0.000000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.00000 0.00000 0.00000 0.000000 0.00000 0.0000 0.0000 0.0000 0.000000 0.00000
33 34 35 36 37 38 39 40 41 42 43 44 56 47 48 49 50 51 52 53 54 55 66 57 58 59	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Heat Flow Name	(MWV)	Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.00	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	6 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 0.0000 0.0000 1.0000 0.00000 0.00000 0.00000 0.00000 0.00000 0.00000 0.000000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00000 0.00000 0.00000 0.000000 0.00000 0.00000 0.0000 0.00000 0.00000 0.0000
33 34 35 36 37 38 39 40 41 42 43 44 55 56 57 58 59 60	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Oxygen) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Hellum) Name Heat Flow Name Heat Flow	(MW)	Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.00000 0.0000 0.0000 0.0000 0.00000 0.	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	5 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 1.0000 11 0.0000	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 1.0000 8 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 0.0000 1.0000 0.00000 0.0000 0.0000 0.00000 0.00000 0.000000	g: All 7 0.0000 0.0000 0.0000 0.0000 1.0000 3 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 0.0000 1.0000 0.00000 0.00000 0.00000 0.000000 0.00000 0.00000 0.0000 0.00000 0.00000 0.0000
xx <	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Heat Flow Heat Flow	(MW)	Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.0000 0.00000 0.000000 0.000000 0.000000 0.0000000 0.	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 10 0.00000 0.0000 0.00000 0.0000 0.0000 0.00000 0.0	6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.1084 Heat Loss Pipe 5 1.	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Fluid Pkg Chiller 1 Duty 0.1288	g: All 7 0.00000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.000
R A H A A A 4 <td>Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Heat Flow Heat Flow</td> <td>(MW)</td> <td>Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.0000 0.00000 0.000000 0.000000 0.0000000 0.000000 0.</td> <td>Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 10 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0</td> <td>6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.1084 Heat Loss Pipe 5 1.</td> <td>Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Fluid Pkg Chiller 1 Duty 0.1288</td> <td>g: All 7 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000</td>	Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Comp Mole Frac (Nitrogen) Comp Mole Frac (CO2) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Argon) Comp Mole Frac (Hellum) Name Heat Flow Heat Flow	(MW)	Into PCU Simulator 0.0000 ° 0.0000 ° 0.0000 ° 0.0000 ° 1.0000 ° 2 0.00000 0.0000 0.00000 0.000000 0.000000 0.0000000 0.000000 0.	Compositions 5 0.0000 0.0000 0.0000 0.0000 1.0000 1 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 10 0.00000 0.0000 0.0000 0.0000 0.00000 0.00000 0.0	6 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 4 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.1084 Heat Loss Pipe 5 1.	Fluid Pkg Out PCU Simulator 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.0000 12 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 Fluid Pkg Chiller 1 Duty 0.1288	g: All 7 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

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* Specified by user.

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1				Case Name:	report model updated low	eff recup he brayton si	mulator.hsc
2	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set	NuScale3a		
4	0.	USA		Date/Time:	Fri Jan 31 12:29:21 2020	l.	
5 6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)		
9				Heaters		Fluid Pkg	g: All
11	Name						
12	DUTY	(MW)			i i i		
13	Feed Temperature	(C)					
14	Product Temperature	(C)					
15	Mass Flow	(kg/s)					
16 17				Coolers		Fluid Pkg	g: All
18	Name		Simulator Chiller 1				
19	DUTY	(MW)	0.1288				
20	Feed Temperature	(C)	176.1				
21	Product Temperature	(C)	21.11 '				
22	Mass Flow	(Kg/S)	0.1599				
23				Heat Exchange	rs	Fluid Pkg	g: All
25	Name		Recup HX 2	Recup HX 1			
26	Duty	(MW)	0.3921	0.1651			
27	Tube Side Feed Mass Flow	(kg/s)	0.1599	0.1599			
28	Shell Side Feed Mass Flow	(kg/s)	0.1599	0.1599			
29	Tube Inlet Temperature	(C)	151.4	622.4			
30	Tube Outlet Temperature	(C)	623.2	821.1			
31	Shell Met Temperature	(0)	040.3	040.0			
32	I MTD	(0)	25.04	27.69			
34	UA	(kJ/C-h)	5.637e+004	2.147e+004			
35	Minimum Approach	(C)	25.00	27.69			
36				Compressors		Fluid Pkg	j: All
37	Nama		Comprose of 1				
39	Power	(MW)	0 1084				
40	Feed Pressure	(kPa)	534.3				
41	Product Pressure	(kPa)	1096 *				
42	Product Temperature	(C)	151.6				
43	Feed Temperature	(C)	21.11 *				
44	Adiabatic Efficiency		75 '				
45	Pressure Ratio	(hele)	2.051				
46	Mass Flow	(Kg/S)	0.1599				
48				Expanders		Fluid Pkg	g: All
49	Name						
50	Power	(MW)					
51	Feed Pressure	(kPa)					
52	Product Pressure	(kPa)					
53	Product Temperature	(C)					
54	Feed Temperature	(C)					
35	Mass Flow	(ko/s)			+		
57 58 59 60 61 62					· ·		
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 2 of 3
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1			V OF IDAHO	Case Name:	report model updated lo	ow eff recup he brayton si	mulator.hsc
3	(e)aspentech	Bedford, MA	A CFIDARO	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 12:29:21 20	20	
6							
7	Wor	kbook:	Case (Mai	n) (continue	ed)		
9				Valves		Fluid Pkg	j: All
10	Name		CV-01				
12	Pressure Drop	(kPa)	467.5				
13	Feed Pressure	(kPa)	1026				
14	Feed Temperature	(C)	649.2				
15	Product Pressure	(kPa)	559.0 *				
16	Product Temperature	(C)	649.2				
17	Mass Flow	(kg/s)	0.1599				
18	Cg		2220 *				
19	Resistance (Cv or KJUSGPM	(60F,1psl))	66.33				
20							
21							
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24							
25							
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63	Aspen Technology Inc.			Aspen HYSYS Vers	ion 9		Page 3 of 3
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Appendix I: Aspen HYSYS PCU Simulator Models

PCU Simulator Loop for Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic

Efficiencies of 85% and 90%



1				Case Name:	report model 2 comp	general s	imulator with pipe	s 1-31-20.hsc	
3	@aspentech	Bedford, N	IA ISANG	Unit Set	NuScale3a				
4		USA		Date/Time:	Fri Jan 31 14:11:41	2020			
6	Wor	khook	Case (Mai	n)					
8	WOI	NDOOK.	. Case (Ivial						
9 10				Material Stream	ns		Fluid Pk	g:	All
11	Name		Into PCU Simulator	6	4	1		2	
12	Temperature	(C)	600.0 *	599.2	164.	1.7	342.9 *		342.5
13	Pressure	(kPa)	1051 *	1050	141.3	7	1029		1029
14	Mass Flow	(kg/s)	0.92378063 *	0.92378063	0.9237806	3	0.92378063	0.93	2378063
15	Mass Density	(kg/m3)	4.0436817	4.0439842	1.091622	5	5.6104035	5.	6111887
16	Mass Enthalpy	(kJ/kg)	628.9	628.0	146.	4	340.0		339.6
17	Mass Entropy	(kJ/kg-C)	5.756	5.755	5.58	9	5.371		5.370
18	Name		3	Out PCU Simulator	5	7		8	
19	Temperature	(C)	342.4	277.3 *	21.1	1.	157.1		21.11
20	Pressure	(kPa)	151.6 *	144.6	135.9	9	389.8		382.0
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.9237806	3	0.92378063	0.93	2378063
22	Mass Density	(kg/m3)	0.82921543	0.88466476	1.557426	2	3.0505414	4.	3821784
23	Mass Enthalpy	(kJ/kg)	339.6	268.4	-4.42	5	138.6		-5.114
24	Mass Entropy	(KJ/Kg-C)	5.940	5.831	5.18	4	5.271	12	4.876
25	Name		9	10	11	12		13	
26	Temperature	(C)	15/.1	269.6	269.	5	528.4		156.9
27	Pressure Mass Elem	(KPa)	1096 *	10/3	10/	5	1051		1095
28	Mass Flow	(kg/s) (kg/m2)	0.92370003	0.92370003	0.9237000	, ,	0.92370003	0.9	2370003
29	Mass Density Mass Enthalow	(kg/ms)	0.00042/1	0.0303437	0.039000		4.4044400	0.3	127.7
30	Mass Entropy	(ku/kg)	137.9	5 209.7	209.		5 6 6 6 0		4 052
27	Namo	(Namg-C)	4.502	45	0.21	-	0.005		4.502
33	Temperature	(C)	163.0	342.0					
34	Draccura	(kDa)	138.7	147.6					
35	Mass Flow	(kn/s)	0.92378063	0 92378063					
36	Mass Density	(kg/m3)	1.0689902	0.80778142					
37	Mass Enthaloy	(kJ/ka)	146.1	339.1					
38	Mass Entropy	(kJ/kg-C)	5.595	5.947					
39				C			Eluid Dh		
40				Compositions			Fiuld PK	g.	All
41	Name		Into PCU Simulator	6	4	1		2	
42	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.000		1.0000		1.0000
43	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.000		0.0000		0.0000
44	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.000		0.0000		0.0000
40	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.000	_	0.0000		0.0000
47	Name		3	Out PCU Simulator	5	7	0.0000	8	0.0000
48	Comp Mole Frac (Nifrogen)		1 0000	1 0000	1,000		1.0002		1 0000
49	Comp Mole Frac (CO2)		0.000	0.000	0.000		0.0000		0.0000
50	Comp Mole Frac (Argon)		0.0000	0.0000	0.000		0.0000		0.0000
51	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.000		0.0000		0.0000
52	Comp Mole Frac (H2O)		0.0000	0.0000	0.000	2	0.0000		0.0000
53	Name		9	10	11	12		13	
54	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.000	0	1.0000		1.0000
55	Comp Mole Frac (CO2)		0.0000	0.0000	0.000	0	0.0000		0.0000
56	Comp Mole Frac (Argon)		0.0000	0.0000	0.000	0	0.0000		0.0000
57	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.000	0	0.0000		0.0000
58	Comp Mole Frac (H2O)		0.0000	0.0000	0.000	0	0.0000		0.0000
59 60 61									
62									
63	Aspen Technology Inc.			Aspen HYSYS Versi	ion 9			Page	e 1 of 3
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1				Case Name:	model 0 come co	noral claudator with along	a 4 24 00 bea
2	Demontoch	UNIVERSIT	Y OF IDAHO	Gase Marrie.	report model 2 comp ge	neral sinuator with pipe	8 1-51-20.1180
3	egaspentech	Bedford, M/ USA	•	Unit Set	Nuscale3a		
5				Date/Time:	Fri Jan 31 14:11:41 202	0	
6 7 8	Worl	kbook:	Case (Mai	n) (continue	ed)		
9			Co	mpositions (cont	inued)	Fluid Pkg	g: All
11	Name		14	15			
12	Comp Mole Frac (Nitrogen)		1.0000	1.0000			
13	Comp Mole Frac (CO2)		0.0000	0.0000			
14	Comp Mole Frac (Argon)		0.0000	0.0000			
15	Comp Mole Frac (Oxygen)		0.0000	0.0000			
16	Comp Mole Frac (H2O)		0.0000	0.0000			
17 18		•		Energy Stream	s	Fluid Pkg	g: All
19	Name		Heat Loss Pipe	Heat Loss Pipe 1	Heat Loss Pipe 2	Heat Loss Pipe 5	Q-102
20	Heat Flow	(MW)	7.990e-004	4.441e-004	4.434e-004	3.430e-004	0.1391
21	Name		Q-103	Comp 1 Power	Comp 2 Power	Heat Loss Pipe 4	Heat Loss Pipe 3
22	Heat Flow	(MW)	0.1327	0.1321	0.1321	1.877e-004	1.973e-004
23	Name		Q-100				
24	Heat Flow	(MW)	6.533e-002				
25				Heaters		Eluid Dh	
26	Nama			Heaters		Fluid Pk	g: All
27	Name	(5.04)					
20	Feed Temperature	(0000)					
20	Droduct Temperature	(0)					
24	Mass Flow	(kn/s)					
32	Indoo I form	(kgro/					
33				Coolers		Fluid Pkg	g: All
34	Name		HX Chiller 2	HX Chiller 3	HX Chiller 1		
35	DUTY	(MW)	0.1391	0.1327	6.533e-002		
36	Feed Temperature	(C)	163.9	157.1	342.0		
37	Product Temperature	(C)	21.11	21.11	277.3 *		
38	Mass Flow	(kg/s)	0.9238	0.9238	0.9238		
39 40				Heat Exchange	rs	Fluid Pkg	g: All
41	Name		Recup HX 1	Recup HX 2			
42	Duty	(MW)	0.2660	0.1127			
43	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
44	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
45	Tube Inlet Temperature	(C)	269.3	156.9			
46	Tube Outlet Temperature	(C)	528.4	269.6			
47	Shell Inlet Temperature	(C)	599.2	277.3 *			
48	Shell Outlet Temperature	(C)	342.9 *	164.1 *			
49	LMTD	(C)	72.21	7.446			
50	UA	(kJ/C-h)	1.326e+004	5.449e+004			
51	Minimum Approach	(C)	70.89	7.177			
52 53				Compressors		Fiuld Pkg	g: All
54	Name		Simulator Compressor	Simulator Compressor			
55	Power	(MW)	0.1321	0.1321			
56	Feed Pressure	(kPa)	135.9	382.0			
57	Product Pressure	(kPa)	389.8	1096 *			
58	Product Temperature	(C)	157.1	157.1			
59	Feed Temperature	(C)	21.11 *	21.11			
60	Adiabatic Efficiency		75	75			
61	Pressure Ratio		2.868 *	2.868			
62	Mass Flow	(kg/s)	0.9238	0.9238			
63	Aspen Technology Inc.		1	Aspen HYSYS Versi	on 9		Page 2 of 3
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1				Case Name:	report model 2 comp g	eneral simulator with pipe	s 1-31-20.hsc
2	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO IA	Unit Set	NuScale3a		
4	Cart	USA		Date/Time:	Fri Jan 31 14:11:41 20	20	
5							
7 8	Wor	kbook:	Case (Mair	n) (continue	ed)		
9				Expanders		Fluid Pkg	g: All
11	Name						
12	Power	(MW)					
13	Feed Pressure	(kPa)					
14	Product Pressure	(kPa)					
15	Product Temperature	(C)					
17	Adjabatic Efficiency	(0)					
18	Mass Flow	(ka/s)					
19		(190)	1		1		
20				Valves		Fluid Pkg	g: All
21	Name		CV-01				
22	Pressure Drop	(kPa)	877.3				
23	Feed Pressure	(kPa)	1029				
24	Feed Temperature	(C)	342.5				
25	Product Pressure	(kPa)	151.6 *				
26	Product Temperature	(C)	342.4				
27	Co	(NG/S)	1832 *				
29	Resistance (Cv or K/USGPM	(60F, 1psi))	54.73				
30			•		•	•	
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63	Aspen Technology Inc.	AHO	1	Aspen HYSYS Vers	ion 9		Page 3 of 3

PCU Simulator Loop for Nitrogen Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



1				Case Name:	general simulator v4 lo	v eff n2 brayton.hsc	
3	(aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 16:45:13 20	20	
6 7 8	Wor	kbook	: Case (Mai	n)			
9				Material Stream	18	Fiuld Pkg	j: Ali
11	Name		Into PCU Simulator	Out PCU Simulator	2	1	4
12	Temperature	(C)	600.0 *	429.9 *	170.3	21.11	186.5
13	Pressure	(kPa)	1051 *	363.7 *	1095	349.3	356.4
14	Mass Flow	(kg/s)	0.92378063 *	0.92378063	0.92378063	0.92378063	0.92378063
15	Mass Density	(kg/m3)	4.0436817	1.7408183	8.2941708	4.0060434	2.6103089
16	Mass Enthalpy	(kJ/kg)	628.9	436.4	152.1	-5.023	170.1
17	Mass Entropy	(kJ/kg-C)	5.756	5.827	4.995	4.903	5.368
18	Name		8	3	10	7	
19	Temperature	(C)	455.2	413.7	559.3	455.4	
20	Pressure	(kPa)	1030	1073	1051	371.1	
21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	
22	Mass Density	(kg/m3)	4.7493887	5.2434084	4.2409591	1.7142287	
23	Mass Enthalpy	(kJ/kg)	464.9	418.5	582.4	464.9	
24	Mass Entropy	(kJ/kg-C)	5.557	5.479	5.702	5.860	
25				C			
26				Compositions		Fiuld Pkg	g: All
27	Name		Into PCU Simulator	Out PCU Simulator	2	1	4
28	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.0000	1.0000	1.0000
29	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.0000	0.0000	0.0000
30	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
31	Comp Mole Frac (Oxygen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
32	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
33	Name		8	3	10	7	
34	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	
35	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
36	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
37	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	
38	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
39				Enorgy Stream		Eluid Dk	- All
40				Energy Stream	8	Fluid Phy	j. Al
41	Name		Circ Come Dur	Chiller 1 Duty	0.100		
42			Sim Comp Pwi	onner r ong	04100		
	Heat Flow	(MW)	0.1452	0.1618	2.628e-002		
43	Heat Flow	(MW)	0.1452	0.1618 Heaters	2.628e-002	Fluid Diz	т АШ
43 44	Heat Flow	(MW)	0.1452	0.1618 Heaters	2.628e-002	Fluid Pkg	j: All
43 44 45	Heat Flow Name	(MW)	0.1452	0.1618 Heaters	2.628e-002	Fiuld Pkg	j: All
43 44 45 46	Heat Flow Name DUTY	(MW) (MW)	0.1452	0.1618 Heaters	2.628e-002	Fluid Pkg	j: All
43 44 45 46 47	Heat Flow Name DUTY Feed Temperature	(MW) (MW) (C)	0.1452	0.1618 Heaters	2.628e-002	Fluid Pkg	j: All
43 44 45 46 47 48	Heat Flow Name DUTY Feed Temperature Product Temperature	(MW) (MW) (C) (C)	0.1452	0.1618 Heaters	2.628e-002	Fluid Pkg	j: All
43 44 45 46 47 48 49	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (C) (kg/s)	0.1452	0.1618 Heaters	2.628e-002	Fluid Pk	j: All
43 44 45 46 47 48 49 50	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (C) (kg/s)	0.1452	0.1618 Heaters Coolers	2.628e-002	Fluid Pkg	
43 44 45 46 47 48 49 50 51	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (C) (kg/s)	0.1452	Coolers	2.628e-002	Fluid Pkg): All
43 44 45 46 47 48 49 50 51 51 52	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow Name DUTY	(MW) (MW) (C) (C) (kg/s)	0.1452	Coolers	2.628e-002	Fluid Pkg	j: All
43 44 45 46 47 48 49 50 51 52 53	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow Name DUTY Feed Temperature	(MW) (MW) (C) (C) (kg/s)	U.1452	Coolers HX Chiller 1 2.628=002	2.628e-002	Fluid Pkg	p: All
43 44 45 46 47 48 49 50 51 52 53 54 54	Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow Name DUTY Feed Temperature DUTY Feed Temperature Dutty Feed Temperature Devotes Temperature Devotes Temperature	(MW) (MW) (C) (C) (kg/s) (MW) (C)	HX CHIller 2 0.1618 186.5	Coolers HX Chiller 1 2.628-002 455.4	2.628e-002	Fluid Pkg	2: All
43 44 45 46 47 48 49 50 51 52 53 54 55 55 56	Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Product Temperature Product Temperature Mass Flow	(MW) (C) (C) (kg/s) (MW) (C) (C) (C) (kg/s)	HX CHIller 2 0.1618 186.5 21.11 * 0.9238	Coolers HX Chiller 1 2.628e-002 455.4 429.9 • 0.9238	2.628e-002	Fluid Pkg	j: All
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Product Temperature Product Temperature Mass Flow	(MW) (C) (C) (kg/5) (MW) (C) (C) (kg/5)	U.1452 0.1452 HX CHIIIer 2 0.1618 186.5 21.11 * 0.9238	0.1618 Heaters Coolers HX Chiller 1 2.628e-002 455.4 429.9 ° 0.9238	2.628e-002	Fluid Pk	2 All
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Product Temperature Product Temperature Mass Flow	(MW) (C) (C) (kg/s) (MW) (C) (C) (kg/s)	0.1452 0.1452 HX CHiller 2 0.1618 186.5 21.11 * 0.9238	0.1618 Heaters Coolers HX Chiller 1 2.628e-002 455.4 429.9 · 0.9238	2.628e-002	Fluid Pkg	2: All
43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63	Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Product Temperature Product Temperature Mass Flow Aspen Technology Inc.	(MW) (C) (C) (kg/s) (MW) (C) (C) (C) (kg/s)	0.1452 0.1452 HX CHiller 2 0.1618 186.5 21.11 * 0.9238	0.1618 Heaters Coolers HX Chiller 1 2.628e-002 455.4 429.9 · 0.9238	2.628e-002	Fluid Pkg	j: All

1				Case Name:	general simulator v4 low eff n2 brayton.hsc	
3	(e)aspentech	Bedford, N	IA IDAHO	Unit Set	NuScale3a	
4		USA		Date/Time:	Thu Jan 30 16:45:13 2020	
6 7	Worl	kbook:	Case (Mai	n) (continue	ed)	
9				Heat Exchange	rs Fiuld Pk	g: All
11	Name		Recup HX 2	Recup HX 1		
12	Duty	(MW)	0.2460	0.1515		
13	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238		
14	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238 *		
15	Tube Inlet Temperature	(C)	170.3	413.7		
16	Tube Outlet Temperature	(C)	413.7	559.3		
17	Shell Inlet Temperature	(C)	429.9 *	600.0 *		
18	Shell Outlet Temperature	(C)	186.5	455.2		
19	LMTD	(C)	16.25	41.12		
20	UA Malawar Assesses	(KJ/C-h)	5.449e+004	1.3260+004 *		
21	Minimum Approach	(C)	10.14	40.69		
22				Compressors	Fluid Pk	g: All
23	Name		Compressor 1			
25	Power	(MW)	0.1452			
26	Feed Pressure	(kPa)	349.3			
27	Product Pressure	(kPa)	1095			
28	Product Temperature	(C)	170.3			
29	Feed Temperature	(C)	21.11 *			
30	Adiabatic Efficiency		75 *			
31	Pressure Ratio		3.134			
32	Mass Flow	(kg/s)	0.9238			
22						
22				Expanders	Fluid Pk	a: All
34				Expanders	Fluid Pk	g: All
34 35	Name			Expanders	Fluid Pk	g: All
34 35 36	Name Power	(MW)		Expanders	Fluid Pk	g: All
34 35 36 37	Name Power Feed Pressure	(MW) (kPa)		Expanders	Fluid Pk	g: All
34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)		Expanders	Fluid Pk	g: All
34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Event Temperature	(MW) (kPa) (kPa) (C)		Expanders	Fluid Pk	g: All
34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)		Expanders	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C)		Expanders	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (C) (C) (kg/s)		Expanders	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (C) (kg/s)		Expanders	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)	CV-D1	Expanders	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s)	CV-01 659.2	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	CV-01 659.2 1030	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	CV-01 659.2 1030 455.2	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa)	CV-01 659.2 1030 455.2 371.1	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C)	CV-01 659.2 1030 455.2 371.1 455.4	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Product Temperature Product Temperature Product Temperature Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 659.2 1030 455.2 371.1 455.4 0.9238	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Product Temperature Product Temperature Mass Flow Cg	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 *	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or KJUSGPM)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Pressure Product Temperature Product Temperature Product Temperature Product Temperature Out Temperature Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (c)	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KJUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1p6l))	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 56 57	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F, 1psi))	CV-D1 659.2 1030 455.2 371.1 455.4 0.9238 2352 • 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s) (60F, 1psl))	CV-D1 659.2 1030 455.2 371.1 455.4 0.9238 2352 • 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 42 43 44 45 55 55 55 55 55 55 55 55 55 55 55	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KlUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s) (60F, 1psl))	CV-D1 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fluid Pk	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 47 48 49 50 51 52 53 54 55 55 56 57 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KlUSGPM	(MW) (kPa) (C) (C) (kgis) (kPa) (kPa) (C) (kPa) (C) (kgis) (60F,1psi))	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Valves	Fiuld Pk	g: All
33 34 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or KljUSGPM	(MW) (kPa) (C) (C) (kgis) (kPa) (kPa) (C) (kPa) (C) (kgis) (60F,1p6i))	CV-01 659.2 1030 455.2 371.1 455.4 0.9238 2352 * 70.27	Expanders Valves	Fluid Pk	g: All

PCU Simulator Loop for Nitrogen Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 85% and 90%



1 Case Name general lamitator vi high eff n2 recup his 1 Unit Set: Name match vi high eff n2 recup his 1 Unit Set: Thu an 30 16.42.37 2020 Market in the Set Set Set Set Set Set Set Set Set Se	—							
And Control Unit Date Nutro And Control Unit Date Nutro Date Time: The Anal Streams Fuid Page: Anal And Control Workbook: Case (Main) Material Streams Fuid Page: Anal Anal Mare me In the PCU Binuater 2 1 1 4 139 Anal Mare me In the PCU Binuater 2 1 1 4 139 Anal Mare me In the PCU Binuater 2 1 1 4 139 Anal Mare me In the PCU Binuater 2 1 1 4 139 Anal Mare me In the PCU Binuater 2 3827063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277063 0.63277663 0.63277663 0.63277663 0.63277663 0.63277663 0.63277663 0.63277663 0.63277663<	1				Case Name:	general simulator v4 hig	gh eff n2 recup.hsc	
4 USA DateTmin: Thu Jan 30 16-82.37 2020 6 7	3	@aspentech	Bedford, N	IA IDAHO	Unit Set	NuScale3a		
A Workbook: Case (Main) 10 Material Streams Pus Pig: Al 10 Name Inte POU Brustator Qu POU Brustator 2 1 4 10 Pressure (Pa) 1011 Streams 1012 2 11 4 4 11 Pressure (Pa) 0.0237063 <t< td=""><td>4</td><td></td><td>USA</td><td></td><td>Date/Time:</td><td>Thu Jan 30 16:42:37 20</td><td>020</td><td></td></t<>	4		USA		Date/Time:	Thu Jan 30 16:42:37 20	020	
1 All 10 Material Streams Pud Pkg: All 11 Mane Into PCU Simulator Out PCU Simulator 2 1 4 12 Temperature (C) 600 C 0458.5 117.0 21111 1351 13 Jenseum (May) 0.3237063 0.8237063 0.923	6 7 8	Wor	kbook	: Case (Mai	n)			
Image Into PQU Simulator Out PQU Simulator 2 1 4 12 Temperature (C) 600 0 468.8 117.0 21.111 4 13 Temperature (C) 600 0 468.8 117.0 21.111 4 14 Mase Fow (Bg1) 0.9337063 0.9337065 0.937765 0.93776 0.937 0.93776	9				Material Stream	18	Fluid Pkg	j: All
Image Image <th< td=""><td>10</td><td>Nama</td><td></td><td>Into DOLL Cimulator</td><td>Out DOLL Simulator</td><td></td><td></td><td></td></th<>	10	Nama		Into DOLL Cimulator	Out DOLL Simulator			
Impleature (b) 00000 0000 0000		Tomocrahum	(0)	Into PCU Simulator	Out PCU Simulator	417.0	01.11.1	4 120.4
Image (mail of the standard of the stan	12	Temperature	(C) (bDe)	600.0	469.6	117.0	21.11	139.1
Instruct (1) (1	13	Pressure	(KPa)	1051	526.9	1095	505.0	516.4
Idad Dentify (kgm3) 2.430370 9.440423 5.807796 4.216100 If Mase Entropy (klkg) 628.9 451.1 9.435 5.4369 119.3 If Mase Entropy (klkg) 5.76 5.776 4.885 4.791 5.142 If Name 8 3 10 7 5.11 5.77 4.885 4.791 5.142 If Pressure (kPa) 1030 107.7 1051 5.57.7 4.820 2.339551 2.337063 0.327063 <t< td=""><td>14</td><td>Mass Flow</td><td>(Kg/S)</td><td>0.92378063</td><td>0.92378063</td><td>0.92378063</td><td>0.92378063</td><td>0.92378063</td></t<>	14	Mass Flow	(Kg/S)	0.92378063	0.92378063	0.92378063	0.92378063	0.92378063
14 Mask Entrupy (LMg) 66.8 4.81.1 94.85 6.459 119.3 19 Mask Entrupy (LMg-C) 6.776 4.85 4.791 6.142 19 Impertance (C) 441.9 440.0 566.7 4.420 20 Pressure (K2) 0.0327063 0.9230	15	Mass Density	(kg/m3)	4.0436817	2.3852702	9.4404523	5.8077996	4.2161808
It Mare 6.776 6.776 4.888 4.791 5.142 II Name 8 3 10 7 5.142	16	Mass Enthalpy	(kJ/kg)	628.9	481.1	94.95	-5.459	119.3
Name 8 3 10 7 1 Temperatum (c) 441.5 456.5 420 20 Pressure (kPa) 11030 11073 11551 537.7 21 Mass Drewlly (kJgs) 0.0237063 0.0237063 0.0237063 0.0237063 21 Mass Drewlly (kJgs) 4.5519655 4.203452 2.3945651 23 Mass Enhalpy (kJgs) 4.5519655 4.203452 2.3945631 23 Mass Enhalpy (kJgs) 0.02700505 Fluid Pkg: Al 24 Mass Enhalpy (kJgs) 0.0200 0.0000 1.0000 1.0000 25 Mass Enhalpy (kJgs) 0.0000	17	Mass Entropy	(kJ/kg-C)	5.756	5.778	4.858	4.791	5.142
19 Temperature (C) 441.0 448.0 566.7 482.0 21 Mass Flow (kg)b 0.92376053 0.92360 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000<	18	Name		8	3	10	7	
20 Pressure (PA) 1030 1073 1051 5377 21 Mass Flow (kgh) 0.237063 0.237063 0.237063 0.237063 21 Mass Enthapy (kJkg) 44.8 4.456.8 660.8 444.8 21 Mass Enthapy (kJkg) 44.4 456.8 660.8 444.8 23 Mass Enthapy (kJkg) 44.4 456.8 660.8 444.8 23 Mass Enthapy (kJkg-C) 5.597 5.543 5.712 5.791 23 Comp Mote Frac (Nitrogen) 1.0000 0.0000<	19	Temperature	(C)	481.9	448.0	566.7	482.0	
11 Mase From (tgg) 0.22378063 0.92378063 0.92378063 0.92378063 21 Mase Enthalpy (tLMg) 45819655 4.9204852 2.3945651 23 Mase Enthalpy (tLMg) 494.8 456.8 590.8 494.8 24 Mase Enthalpy (tLMg-C) 5.597 5.534 6.712 5.711 25 Mase Enthalpy (tLMg-C) 5.597 5.534 6.712 5.711 26 Mase Enthalpy (tLMg-C) 5.597 5.534 6.712 5.711 27 Mase Enthalpy (tLMg-C) 5.597 5.534 6.712 5.711 28 Omm Mole Frac (Nitrogen) 1.0000 1.0000 1.0000 0.0000	20	Pressure	(kPa)	1030	1073	1051	537.7	
22 Mass Density (kgm) 44.81 4.9942655 4.2038452 2.344551 23 Mass Enhapy (klkg.c) 5.597 5.534 5.712 5.791 24 Mass Enhapy (klkg.c) 5.597 0.534 5.712 5.791 25 Comp Mole Frac (Nitrogen) 10000 0.0000 0.0000 0.0000 0.0000 0.0000 26 Comp Mole Frac (Argon) 0.0000	21	Mass Flow	(kg/s)	0.92378063	0.92378063	0.92378063	0.92378063	
23 Mass Enhapy (klkg.C) 6.597 5.534 5.712 5.791 34 Mass Entropy (klkg.C) 5.597 5.534 5.712 5.791 35 Compositions Fuld Pkg: All 35 Comp Mole Frac (Ntrogen) 0.0000 1.0000 1.0000 1.0000 0.0000	22	Mass Density	(kg/m3)	4.5819855	4.9942655	4.2038452	2.3945651	
Name (kilkg-C) 5.597 5.334 5.712 5.791 33 34 Compositions Fuid Pkg: All 27 Name into PCU Simulator Out PCU Simulator 2 1 4 27 Name into PCU Simulator Out PCU Simulator 2 1 4 28 Comp Mole Frac (Ntrogen) 0.0000	23	Mass Enthalpy	(kJ/kg)	494.8	456.8	590.8	494.8	
33 Compositions Fluid Pkg: All 24 Name Into PCU Simulator 0ut PCU Simulator 2 1 4 25 Comp Mole Frac (Ntrogen) 1.0000 1.0000 1.0000 1.0000 1.0000 26 Comp Mole Frac (Ntrogen) 0.0000	24	Mass Entropy	(kJ/kg-C)	5.597	5.534	5.712	5.791	
Bit Compositions Fluid Pkg: All 21 Name Into PCU Simulator 2 1 4 22 Name Into PCU Simulator 2 1 4 23 Comp Mole Frac (NItrogen) 1.0000 1.0000 1.0000 0.0000 <	25					•		
Name Into PCU Simulator Out PCU Simulator 2 1 4 28 Comp Mole Frac (Ntrogen) 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.0000	26				Compositions		Fluid Pkg	g: All
Internet Disk of end of the set of th	27	Name		Into PCU Simulator	Out PCU Simulator	2	1	4
all Comp Mole Frac (Co2) 0.0000 1.0000 0.0000	20	Comp Mole Erac (Nitrogen)		1,0000 -	1 0000	1 0000	1 0000	1 0000
Call Comp Mole Frac (Argon) 0.0000	20	Comp Mole Frac (CO2)		0.0000 -	0.0000	0.0000	0.0000	0.0000
al Comp Mole Frac (Ngen) 0.0000	29	Comp Mole Frac (CO2)		0.0000 -	0.0000	0.0000	0.0000	0.0000
31 Comp Mole Frac (H2Q) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 33 Comp Mole Frac (H2Q) 0.0000 1.0000 1.0000 0.0000 0.0000 0.0000 34 Comp Mole Frac (N2Q) 0.0000 1.0000 1.0000 1.0000 0.0000 0.0000 35 Comp Mole Frac (N2Q) 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 36 Comp Mole Frac (N2Q) 0.0000 0	30	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
32 Come Mole Frac (N2O) 0.0000 <	31	Comp Mole Frac (Oxygen)		• 00000	0.0000	0.0000	0.0000	0.0000
33 Name 8 3 10 7 34 Comp Mole Frac (Nitrogen) 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 0.00	32	Comp Mole Frac (H2O)		* 0000.0	0.0000	0.0000	0.0000	0.0000
34 Comp Mole Frac (Ntrogen) 1.0000 1.0000 1.0000 1.0000 35 Comp Mole Frac (CO2) 0.0000	33	Name		8	3	10	7	
38 Comp Mole Frac (CO2) 0.0000 <	34	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	
38 Comp Mole Frac (Argon) 0.0000	35	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
31 Comp Mole Frac (Aygen) 0.0000	36	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
38 Comp Mole Frac (H2O) 0.0000 <	37	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	
Bit Energy Streams Fluid Pkg: All 40 Sim Comp Pwr Chiller 1 Duty Q-100	38	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
40 Energy Streams Fluid Pkg: All 41 Name Sim Comp Pwr Chiller 1 Duty Q-100 42 Heat Flow (MW) 9.2766-002 0.1152 1.2666-002 44 Heat Flow (MW) 9.2766-002 0.1152 1.2666-002 44 Heat Flow (MW) 9.2766-002 0.1152 1.2666-002 44 Mame Image: All Phates Fluid Pkg: All Phates All Phates All Phates All Phates All Phates All Phates Image: All Phates All Phates Image: All Phates <td>39</td> <td></td> <td></td> <td></td> <td>F O</td> <td></td> <td></td> <td></td>	39				F O			
41 Name Sim Comp Pwr Chiler 1 Duty Q-100 Image: Constraint of the	40				Energy Stream	s	Fluid PK	j: Ali
42 Heat Flow (MW) 9.276e-002 0.1152 1.266e-002 43 Heaters Fluid Pkg: All 44 Fluid Pkg: All 45 Name 46 DUTY (MW) 47 Feed Temperature (C) 47 Feed Temperature (C) 48 Product Temperature (C) 49 Mass Flow (kgis) 41 State Fluid Pkg: All 42 Mass Flow (kgis) 51 Tender Temperature (C) 1.266e-002 52 Name HX Chiller 2 HX Chiller 1 52 Name HX Chiller 1 53 Product Temperature (C) 21.11 463.0 54 Feed Temperature (C) 21.11 463.0 55 Mass Flow	41	Name		Sim Comp Pwr	Chiller 1 Duty	Q-100		
44 Heaters Fluid Pkg: All 44 Image: Constraint of the state	42	Heat Flow	(MW)	9.276e-002	0.1152	1,266e-002		
Heaters Fluid Pkg: All 45 Name Image: Constraint of the state of the stat	43							
44 Name Image: Constraint of the second sec	44				Heaters		Fluid Pkg	g: All
Name HX Chiller 2 HX Chiller 1 Image: Constraint of the second of th	45	Name						
Cont (HT) (HT) <th< td=""><td>45</td><td>DUTY</td><td>(MM)</td><td></td><td></td><td></td><td></td><td></td></th<>	45	DUTY	(MM)					
Note temperature Note	47	Feed Temperature	(0)					
Image: State Street Personance (b) Image: State Street State Street State Street Street State Street State Street State Street Street State Street S	40	Droduct Temperature	(0)					
Name (Ng/9) Coolers Fluid Pkg: All 50 51 52 Name HX Chiller 2 HX Chiller 1 All 52 Name HX Chiller 2 HX Chiller 1		Mass Flow	(bain)					
Su 51 Fluid Pkg: All 51 Name HX Chiller 2 HX Chiller 1 Image: Coolers Fluid Pkg: All 52 Name HX Chiller 2 HX Chiller 1 Image: Coolers Image: Coolers Fluid Pkg: All 53 DUTY (MW) 0.1152 1.266e-002 Image: Coolers Imag	42	Middo Flow	(Nyro)					
S1 HX Chiller 2 HX Chiller 1 Image: Constraint of the state o	50				Coolers		Fluid Pkg	j: All
S2 Name HX Chiller 2 HX Chiller 1 Image: Chiller 1<	51	News			LINE OF HERE &			
S3 DOTY (MW) 0.1152 1.2664-002 Image: Constraint of the state of t	52	Name		HX Chiller 2	HX Chiller 1			
54 Feed Temperature (C) 139.1 482.0	53	DUTY	(MW)	0.1152	1.2666-002			
55 Product Temperature (C) 21.11* 469.8* 56 Mass Flow (kg/s) 0.9238 0.9238 0.9238 57 58 59 59 59 59 50 60 61 62 53 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2 Licensed to: UNIVERSITY OF IDAHO * Specified by user. * Specified by user. * Specified by user.	54	Feed Temperature	(C)	139.1	482.0			
ss Mass Flow (kg/s) 0.9238 0.9238 57 58 59 59 59 50 <td>55</td> <td>Product Temperature</td> <td>(C)</td> <td>21.11 *</td> <td>469.8 *</td> <td></td> <td></td> <td></td>	55	Product Temperature	(C)	21.11 *	469.8 *			
57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2 Licensed to: UNIVERSITY OF IDAHO * Specified by user.	56	Mass Flow	(kg/s)	0.9238	0.9238			
63 Aspen Technology Inc. Aspen HYSYS Version 9 Page 1 of 2 Licensed to: UNIVERSITY OF IDAHO * Specified by user.	57 58 59 60 61 62							
Licensed to: UNIVERSITY OF IDAHO 'Specified by user.	63	Aspen Technology Inc.			Aspen HYSYS Versi	ion 9		Page 1 of 2
		Licensed to: UNIVERSITY OF ID/	но		apenini or o versi	0110		* Specified by user.

1				Case Name:	general simulator v4 hig	gh eff n2 recup.hsc	
3	editord, MA		IA IDAHO	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 16:42:37 20	20	
6 7 8	Worl	kbook	: Case (Mai	n) (continue	ed)		
9				Heat Exchange	rs	Fluid Pkg	j: All
11	Name		Recup HX 2	Recup HX 1			
12	Duty	(MW)	0.3342	0.1238			
13	Tube Side Feed Mass Flow	(ka/s)	0.9238	0.9238			
14	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238 *			
15	Tube Inlet Temperature	(C)	117.0	448.0			
16	Tube Outlet Temperature	(C)	448.0	566.7			
17	Shell Inlet Temperature	(C)	469.8 *	600.0 *			
18	Shell Outlet Temperature	(C)	139.1	481.9			
19	LMTD	(C)	22.08	33.62			
20	UA	(kJ/C-h)	5.449e+004 *	1.326e+004 "			
21	Minimum Approach	(C)	21.84	33.33			
22				-			
23				Compressors		Fluid Pkg	g: All
24	Name		Compressor 1				
25	Power	(MW)	9.276e-002				
26	Feed Pressure	(kPa)	506.0				
27	Product Pressure	(kPa)	1095				
28	Product Temperature	(C)	117.0				
29	Feed Temperature	(C)	21.11 *				
30	Adlabatic Efficiency		75 •				
31	Pressure Ratio		2.163				
32	Mass Flow	(ka/s)	0.9238				
22							
34				Expanders		Fluid Pkg	j: Al
34 35	Name			Expanders		Fluid Pkg	j: All
34 35 36	Name Power	(MW)		Expanders		Fluid Pkg	j: Ali
34 35 36 37	Name Power Feed Pressure	(MW) (kPa)		Expanders		Fiuld Pkg	j: All
33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)		Expanders		Fluid Pkg	j: All
34 35 36 37 38 39	Name Power Feed Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C)		Expanders		Fluid Pkg	j: All
34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C) (C)		Expanders		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency	(MW) (kPa) (kPa) (C) (C)		Expanders		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name	(MW) (kPa) (kPa) (C) (C) (kg/s)	CV-D1	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	CV-01 492.5	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	CV-01 492.5 1030	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	CV-01 492.6 1030 481.9	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa)	CV-01 492.6 1030 481.9 537.7	Valves		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C)	CV-01 492.6 1030 481.9 537.7 482.0	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow Cg	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 *	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjusGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Pressure Product Pressure Order Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM)	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Product Pressure Product Temperature Product Temperature Product Temperature Odduct Temperature Product Temperature Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM)	(MW) (kPa) (C) (C) (C) (kgis) (kPa) (c) (kPa) (C) (kPa) (C) (kgis)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pressure Drop Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	2: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	g: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Orduct Temperature Mass Flow Cg Resistance (Cv or Kl/USGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 • 70.27	Valves		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Temperature Mass Flow Cg Resistance (Cv or KljUSGPM)	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-D1 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42 42 44 45 46 47 48 49 50 51 52 53 54 56 57 58 59 60 61 62 53	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Ped Pressure Product Temperature Product Temperature Product Temperature Product Temperature Out Temperature Mass Flow Cg Resistance (Cv or KjUSGPM)	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1p6l))	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Valves		Fluid Pkg	j: All
33 34 35 36 37 38 39 40 41 42 42 44 45 56 57 58 56 57 58 59 60 61 62 63	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Temperature Product Temperature Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjulsGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 492.6 1030 481.9 537.7 482.0 0.9238 2352 * 70.27	Expanders Valves	on 9	Fluid Pkg	p: All
PCU Simulator Loop for Nitrogen Recuperated Brayton Cycle with Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



_							
1				Case Name:	general simulator v4 lo	w eff n2 recup.hsc	
3	(aspentech	UNIVERSI Bedford, N	TY OF IDAHO IA	Unit Set	NuScale3a		
4	<u> </u>	USA		Date/Time:	Thu Jan 30 16:40:16 20	020	
6 7 8	Wor	kbook:	Case (Mai	n)			
9				Material Stream	18	Fiuld Pkg	g: All
11	Name		Into DCI I Simulator	Out PCU Simulator	2	1	4
12	Temperature	(0)	FILL POU SIMUALOI	SDA 0 *	2 00.36	21.11.1	125.0
12	Droccuro	(kDa)	1051 *	504.5 600.5 *	1005	575.7	599.5
14	Mass Flow	(kn/s)	0.92378063 *	000.3	0.92378063	0.92378063	0.92378063
15	Mass Dansity	(kg/o) (kg/m3)	4.0436817	2 5052805	0.92370003	6.523700003	4 0762030
16	Mass Enthainy	(kulka)	628.0	520.6	5.0505400	-5.655	4.5702505
17	Mass Entropy	(ku/kg-C)	5 755	5 701	4 909	4 752	5.065
10	Mass Enu opy	(Narkg-C)	0.700	3	4.000	4./ 52	5.005
10	Tamaanhaa	(0)	0		10	/	
19	Temperature	(0)	500.7	4/9.9	5/3.5	500.0	
20	Pressure Mass Elem	(KPa)	1030	10/3	1051	612.8	
21	Mass Flow	(KG/S)	0.92378063	0.92378063	0.92378063	0.92378063	
22	Mass Density	(kg/m3)	4.4363745	4.7826904	4.1696025	2.6416374	
23	Mass Enthalpy	(kJ/kg)	522.8	492.6	598.7	522.8	
24	Mass Entropy	(kJ/kg-C)	5.634	5.582	5.721	5.788	
25				Compositions		Fluid Pk	0. All
26				compositions			g. 744
27	Name		Into PCU Simulator	Out PCU Simulator	2	1	4
28	Comp Mole Frac (Nitrogen)		1.0000 *	1.0000	1.0000	1.0000	1.0000
29	Comp Mole Frac (CO2)		0.0000 *	0.0000	0.0000	0.0000	0.0000
30	Comp Mole Frac (Argon)		0.0000 *	0.0000	0.0000	0.0000	0.0000
31	Comp Mole Frac (Oxygen)		0.0000 *	0.0000	0.0000	0.0000	0.0000
32	Comp Mole Frac (H2O)		0.0000 *	0.0000	0.0000	0.0000	0.0000
33	Name		8	3	10	7	
34	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000	
35	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000	
36	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000	
37	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000	
38	Comp Mole Frac (H2O)		0.0000	0.0000	0.0000	0.0000	
39				- ~			
40				Energy Stream	s	Fluid Pkg	g: All
41	Name		Sim Comp Pwr	Chiller 1 Duty	Q-100		
42	Heat Flow	(MW)	7.554e-002	0.1014	2.002e-003		
43							
44				Heaters		Fluid Pkg	g: All
45	Name						
46	DUTY	(MW)					
47	Feed Temperature	(C)					
48	Product Temperature	(C)				İ	
49	Mass Flow	(kg/s)					
50		(1944)					
51				Coolers		Fluid Pkg	g: All
52	Name		HX Chiller 2	HX Chiller 1			
53	DUTY	(MW)	0 1014	2 0020-003			
54	Feed Temperature	(0)	125.0	506.8			
50	Product Temperature	(0)	21.11	504.0 -			
22	Mass Flow	(v) (kais)	0.0238	0.0238			
20	Middo I IUW	(Nyro)	0.5230	0.5230			
58 59 60 61							
62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
	Licensed to: UNIVERSITY OF ID/	но					* Specified by user.

1	UNIVERSITY OF IDAHO		Case Name:	general simulator v4 low eff n2 recup.hsc			
3	(aspentech	UNIVERSI Bedford, N	ITY OF IDAHO IA	Unit Set	NuScale3a		
4		USA		Date/Time:	Thu Jan 30 16:40:16 20	20	
6 7	Worl	kbook	: Case (Mai	n) (continue	ed)		
9				Heat Exchange	rs	Fluid Pkg	j: All
10	Name		Recup HX 2	Recup HX 1			
12	Duty	(MW)	0.3847	9.800e-002			
13	Tube Side Feed Mass Flow	(kg/s)	0.9238	0.9238			
14	Shell Side Feed Mass Flow	(kg/s)	0.9238	0.9238 *			
15	Tube Inlet Temperature	(C)	99.36	479.9			
16	Tube Outlet Temperature	(C)	479.9	573.6			
17	Shell Inlet Temperature	(C)	504.9 *	600.0 *			
18	Shell Outlet Temperature	(C)	125.0	506.7			
19	LMTD	(C)	25.42	26.60			
20	UA	(kJ/C-h)	5.449e+004 *	1.326e+004 "			
21	Minimum Approach	(C)	25.00	26.42			
22				Compressors		Fluid Pkg	j: All
23	Name		Compressor 1				
25	Power	(MW)	7.554e-002				
26	Feed Pressure	(kPa)	576.7				
27	Product Pressure	(kPa)	1095				
28	Product Temperature	(C)	99.36				
29	Feed Temperature	(C)	21.11 *				
30	Adlabatic Efficiency		75 •				
31	Pressure Ratio		1.898				
32	Mass Flow	(kg/s)	0.9238				
33				Expanders		Fluid Pkg	a All
33				Expanders	1	Fluid Pkg	j: All
33 34 35	Name			Expanders		Fluid Pkg	j: All
33 34 35 36	Name Power	(MW)		Expanders		Fluid Pkg	j: Ali
33 34 35 36 37	Name Power Feed Pressure	(MW) (kPa)		Expanders		Fiuld Pkg	j: All
33 34 35 36 37 38	Name Power Feed Pressure Product Pressure	(MW) (kPa) (kPa)		Expanders		Fiuld Pkg	j: Al
33 34 35 36 37 38 39 40	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature	(MW) (kPa) (kPa) (C)		Expanders		Fiuld Pkg	ç: Al
33 34 35 36 37 38 39 40 41	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabalic Efficiency	(MW) (kPa) (kPa) (C) (C)		Expanders		Fiuld Pkg	ç: Al
33 34 35 36 37 38 39 40 41 42	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C)		Expanders		Fiuld Pkg	; All
33 34 35 36 37 38 39 40 41 42 43	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s)		Expanders		Fiuld Pkg	; All
33 34 35 36 37 38 39 40 41 42 43 44	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow	(MW) (kPa) (C) (C) (C) (kg/s)		Valves		Fiuld Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name	(MW) (kPa) (C) (C) (C) (kg/s)	CV-01	Valves		Fiuld Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	CV-01 417.5	Valves		Fiuld Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa)	CV-01 417.5 1030	Valves		Fiuld Pkg	E All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C)	CV-01 417.5 1030 506.7	Valves		Fiuld Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa)	CV-01 417.5 1030 506.7 612.8	Valves		Fluid Pkg	p: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C)	CV-01 417.5 1030 506.7 612.8 506.8	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Pred Pressure Product Pressure Product Temperature Mass Flow	(MW) (kPa) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-D1 417.5 1030 506.7 612.8 506.8 0.9238	Valves		Fluid Pkg	: All
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-D1 417.5 1030 506.7 612.8 506.8 0.9238 2352 *	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KJUSGPM)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s)	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Feed Temperature Product Temperature Product Temperature Product Temperature Product Temperature Out Temperature Mass Flow Cg Resistance (Cv or KjUSGPM <td>(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1p6l))</td> <td>CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27</td> <td>Valves</td> <td></td> <td>Fluid Pkg</td> <td>р: АІ</td>	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1p6l))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 54 55 54 55 55 54 55<	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 64 47 48 49 50 51 52 53 54 55 56 7	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Product Pressure Product Pressure Product Pressure Product Pressure Out Pressure Product Remerature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 64 47 48 49 50 51 52 53 54 55 56 57 60	Name Power Feed Pressure Product Pressure Product Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Out Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	р: АІ
33 34 35 36 37 38 39 40 41 42 43 44 45 56 57 58 55 56 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 69 57 58 56 57 58 69 57 58 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 56 57 58 58 56 57 58 56 57 58 56 57 58 56 57 58<	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Pressure Fred Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Out Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-D1 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 59 60 61	Name Power Feed Pressure Product Temperature Feed Temperature Adiabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Pressure Out Cg Resistance (Cv or KjUSGPM)	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 1 12 34 44 45 46 47 48 99 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Power Feed Pressure Product Pressure Product Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Pred Pressure Product Temperature Product Temperature Product Temperature Product Temperature Odd Temperature Product Temperature Mass Flow Cg Resistance (Cv or KljUSGPM)	(MW) (kPa) (C) (C) (C) (kg/s) (kPa) (C) (kPa) (C) (kPa) (C) (kPa) (C) (kg/s)	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Valves		Fluid Pkg	
33 34 35 36 37 38 39 40 1 42 43 44 45 64 7 88 39 40 1 12 33 44 45 46 47 48 99 50 51 52 53 54 55 56 57 58 59 60 61 62 63	Name Power Feed Pressure Product Pressure Product Temperature Feed Temperature Adlabatic Efficiency Mass Flow Name Pressure Drop Feed Temperature Product Pressure Product Pressure Product Temperature Mass Flow Cg Resistance (Cv or KjUSGPM	(MW) (kPa) (C) (C) (kg/s) (kPa) (kPa) (C) (kPa) (C) (kg/s) (60F,1psl))	CV-01 417.5 1030 506.7 612.8 506.8 0.9238 2352 * 70.27	Expanders Valves	on 9	Fluid Pkg	p: All

Appendix J: Control Valve CV-01 Specification Data Sheet and Quote

Flow Serve Quote for CV-01 Control Valve (Flowserve, 2020)

	EL OLAIGE PAR								Sheet 1 of				
		~.			Custo	omer : Univer	sity of Idaho		Project : C	V1		Va	alve Tag # : PCV
(Cont	trol \	/alv	e Specification	PO#	:			Proj Num:			Pa	age # : 101
F	Prep	arec	i By	1	Quote	e#:			Quote ID : wsperry_GTGZ3959PNXT_4357&ID :				SID :
					Rev/E	By:0.0/kpol	berts		Alternate :			Li	ne :
_					Appli	cation : N2						Da	ate / Ver : 09-Dec-2019 / 12.7271
5	۱L	1	+	Pipe Size, Up/Dowr	n	4.000/4	.000				51	Act. Type/Mat	VL Cylinder / Aluminum
1	8 H	2	+	Pipe Sch, Up/Down	- T	40/40					52	Act. Size/Instr. Sup	5. 100 / Air
1	i –	3	┢	Allow Noise/Add At Process Eluid	in/Type	NITROG	EN				33	Stroke/Spring	2.00 / Standard
	;	5	+	Design Press /Tem	n	/ /	si(a)///	۰F		5	55	Vol Tank/Orient/M	open/Close
1		6	+	Driving Cond.	P .	Smallest d	dP1	dP 2	dP 3 {+}	ter l	56	Tubing Size/Mtl	3/8" / 304 SS
1	ιĽ	7		Temperature ("F)	943.900	529.500	821.500	800.900	5	57	Fitting Mfg/Mtl	Bi-Lok / 316 SS
1	íΕ	8		Inlet Press (ps	i (a))	149.300	149.300	149.300	149.300	<u> </u>	58	Handwheel	
18	3	9	1	Outlet Press (ps	il (a))	87.950	21.260	63.650	51.850		50	Actuator O-Rings	Viton A
3	5 -	10	+	Liq Flow Rate (94	nus/min)	7222.000	7222.000	7222.000	7222.000		60	Spud	2.88 / 1.00 - 12 UNF
9		12	┢	Visonsity (rP	n) n	0.000	0.000	0.000	1332.000	\vdash	82	Madal	Lexis 2000 Ceries
2	۶H	13	+	Vapor Press (pa	(a))	0.000	0.000	0.000	0.000		63	Model #	3821-14EA-D43L-0010-00
	έĿ	14	+	SG-MW		28.010	28.010	28.010	28.010	1.1	64	Comm/Sig/Diag	HART / 4 - 20 mA / Standard
ŝ		15		Max Shutoff / Shuto	off Class		149.300 p	si / Class IV		Þ	65	Housing/Shaft	Aluminum - Ex d / D - 316 SS Shaft
å	έC	16		Min Supply Pressur	re / Max	Supply Press	ure 60.000 / 1	150.000 psi (g)	5	66	Connections	M:5/16;P:1/4N;C:1/2N;V:1/4N
	-	17	-	Valve Function			Throttling			8	67	Action	4-way double acting poppet relay
	. –	18	╋	Driving Cond.	4	Smallest d	dP 1	dP 2	dP 3 {+}	•	68	Display/Mounting	None / Standard Mounting
1		19	╋	Flow Coeff. (C) Ect Stroke (%	V)	34.088	20.273	57,000	29.903		70	Act Med/Relay Typ	Air / Double Acting Standard
Ę	; H	21	╈	Pressure Dron (PS	a)	61.350	128.040	85 650	97.450	1 1	71	Eeedback/Tag	4-20 mA Feedback /
		22	+	Choke Drop (ps	a)	111.608	112.868	112.137	112.262	1 1	72	Gauges	SS : Brass psi (bar/kPa)
	3	23		Noise [IEC] (dB	BA)	<70	86	<70	72	Н	73	Model	
2		24		Valve Vel (ma	ach#)	0.137	0.477	0.182	0.221		74		
	-	25	+	Pipe Vel (m	iach#)	0.076	0.265	0.101	0.123	ð	75	_	
	⊢	20	╋	Model / Body Type	/ Irim Iy	ype Ma	ark One / Glo	be / MegaStre	am	믿	/0	_	
	H	28	+	Trim #- Or / Chara	s/body r	-om 3.0	2 Cx:06/Ea	ual Percent		5	78	-	
		29	+	Stages/Hole Size/R	let Guidi	na 1.5	stage / S / / S	tandard		ď	79	\neg	
		30	+	Flow Direction		Flo	w Under				80		
		31		Body Matl / Bonnet	Matl	31	6 SS High-Te	mp / 316 SS I	High-Temp		81		
	F	32		End Conn/Sch/Fac	e to Face	e Int	egral Flange /	/ ISA S75.08	3.01		82	Model/Qty	1
	⊾⊢	33	+	Flange Finish		12	5 - 250 Ra			꽁	83	Cv-Kv/De-en	1
1	í –	39	╋	Bonnet / Unp Plate	Conyo I	ype Ex	tended / /			Ĕ.	89	Volt/Watt	
8		36	+	Plug Mtl/ Facing Tr	eatment	/Stem Cvr31	6 SS High-Te	mp / Full Con	t Allov 6 /	Sol	88	Body/Housing Mt	
1	2 -	37	+	Stem Mtl/ Facing T	reatment	/Pilot Spr31	8 SS High-Te	mp / Allov 6, I	GA/		87	Port Size/Mto	1
Ę	5 -	38	\top	Seat Ring Mtl/ Faci	ng Treat	ment 31	6 SS High-Te	mp / Full Bore	Alloy 6		88	Tao/Reset-Overrid	e / / /
à	6 🗆	39		Soft Seat/Pilot Plug	1	1	/	-	-		89	Air Filter/Mnting	1
2		40	1	Seat Retainer Mtl/ F	Facing T	reatment 31	6 SS High-Te	mp/			90	Filter-Reg/Mnting	Valtek / Nipple Mtd
3	- 1	41	+	Sleeve Mtl/ Facing	Treatme	nt /		the CARANA			91	Flow Booster / Mtg	F /
	H	42	╈	Backing Matt / Shire	er N/Nao/J	31 Fire / Cort Gr	o SS& Graph poblito Dib Dr	nite / Alloy o		2	02	Duick Exhaust	1
		44	+	Packing Mau / Style	ded	File/ GetOi	aprilie Nib-bio	au / Single / I		ĕ	8	SunTube/John Box	
		45		Bonnet Port / Body	Drain	1				0	95	Lockup/Mnting	1
		46		Bellows Type / Mat	erial	1					96	Plate ID	
	⊢	47	+	Body Bolting/Bonne	et Flange	e Mati B8	M-8MA High-	Temp / 316 S	S High-Temp		97	Plate Type	
	⊢	48	╋	Gaskets Cloud Elemen Mater	a al	Sp	iral Graphite,	Inconel			88	Packaging	Standard
	H	50	╋	Gland Flange Mate	nai	St	ainless Steel				00	Wiring Coop. Type	
		Tĩ	+	Charlot hange bord	19		aniess oteer			\vdash	01	Rad Evm	1
		T2									02	Drawings	
		T3									03	Assem Hydro	
	\perp	T4									8	Seat leak/Final tes	tcert. /
	, H	01	+	Certification/Approv	val Type	1	Cort Door				05	PMI/Weld Req	/ ASME BPVC Section IX
8	8 H	102	+	Division or Zone	þ	NO	Cert Reg			ž	00	Clean/Rid/Dec	11
	ťΗ	04	+	Group		No	Cert Reg			ie i	08	CMTR	1
		05	+	Ingress / Temperat	ure	NE	MA 3/			8	09	Special Paint/Test	i
1		06		NACE / Nuclear		NA	/NA			S,	10	Diag Test/FM	1
ć	5	07		SIL VIv-Act / Pos		NA	/NA				11	Cust. Insp/Witn.	No / No
\vdash	+	08	+	Oxygen Service/As	sy. Lubri	cant N/	M.				12		
											13	Cust Furnish	None
											C1	riow resung	
											\$2		

Line # : Remarks :

DB Rev - 567 : 03-Dec-2019 : ID = wsperry_GTGZ3959PNXT_4357

Quantity: 1



Detail Information Prepared By :

Customer : University of Idaho PO # : Quote # : Rev/By : 0.0 / kpoberts Application : N2

Project : CV1 Valve Tag # : PCV Proj Num : Page # : 101 Quote ID : wsperry_GTGZ3959PNXT_4357&ID : Alternate : Line :

Date / Ver : 09-Dec-2019 / 12.7271

	3.00 in (Trim: 2.62 Cv:98) CL 300 Mark One MegaStream Globe										
		Smallest dP	dP 1	dP 2	dP 3	Largest dP					
Process Data											
Temp	(*F)	943.900	529.500	821.500	800.900	529.500					
P1	(psi (a))	149.300	149.300	149.300	149.300	149.300					
P2	(psi (a))	87.950	21.260	63.650	51.850	21.200					
Lig Flow	(galUS/min)										
Gas Flow	(Ibh)	7332.000	7332.000	7332.000	7332.000	7332.000					
Visc	(dP)	0.000	0.000	0.000	0.000	0.000					
VP	(psi (a))	0.000	0.000	0.000	0.000	0.000					
DP	(psi)	61.350	128.040	85.650	97.450	128.100					
DpC	(psi)	111.608	112.868	112.137	112.262	112.868					
Vel	(mach#)	0.137	0.477	0.182	0.221	0.479					
Pipe Vel	(mach#)	0.076	0.265	0.101	0.123	0.266					
Noise	(dBA)	< 70.0	86.000	< 70.0	72.000	86.000					
Flow Cap	(Cv)	34.698	26.273	30.724	29.963	26.273					
Stroke	(% Lift)	61	53	57	56	53					
Info	0										
Detailed Miscel	laneous Info	rmation								,	
FP		0.997	0.998	0.997	0.998	0.998					
FL											
FR		1.000	1.000	1.000	1.000	1.000					
Sg											
K		1.400	1.400	1.400	1.400	1.400					
Xt		0.750	0.757	0.753	0.754	0.757					
Z		1.015	1.015	1.015	1.015	1.015					
FD		0.070	0.070	0.070	0.070	0.070					
MWT		28.010	28.010	28.010	28.010	28.010					
Detailed Cavita	tion (Sigma)	Information									
Sigma											
Sigma MR											
PSE											
SSE											
Sigma V											
Sigma P											
100.00						Fluid: NITR	ROGEN				
						Type: Full	EDVONE	The second second			
90.00			+ $+$ $+$			Owner: EV	ERTONE	Fiuld List: ST	ANDARD		
						vp Equatio	n. Antoine				
80.00				<u></u>		Critical Pre	ssure (psi (a)	/bar (a)) : 492.	275 / 33.950		



Flow Direction : Flow Under Trim Characteristic : Equal Percent Balance Type: Unbalanced Trim Type : MegaStream

2

DB Rev - 567 : 03-Dec-2019

Critical Pressure (psi (a)/bar (a)) : 492.275 / 33.950 Critical Temperature (*F/*C) : -232.570 / -146.983 Reference Specific Gravity. 0.800 Molecular Weight: 28.010 Specific Heat Ratio: 1.400 Reference Temperature (*F/*C) : -319.070 / -195.039 Vp-A: 11.000 Vp-B: 1059.700 Vp-C: -11.800

Minimum Temperature (*F/*C) : -348.270 / -210.150 Maximum Temperature (*F/*C) : -232.870 / -147.150 Bulk Modulas ((lbfin*)/(kg/cm*)) : 340000.000 / 4835820.000

Prepa Clayto Power Univer 875 Pe Mosco United P:(208	red For n Turner Engineering Department sity of Idaho erimeter Drive MS 1023 w ID 83844-1023 States 8) 885-6111 ion: Clayton Turner			Please I Flowser	mak ve U	ke an IS, In⊲	yre c.c/o	sulting orde o CB Pacific,	er out to Inc.
Expire	ation Date	Terms		FOB				RFQ or Reference	ce ID
1/9/20	20	Net 30		Factory					
Addit	ional Notes			Delivery No	otes				
				FREIGHT: N LEAD TIME:	OT IN 20 Wi	CLUDE EEKS A	D RO		
Line	Model Number					Qty	Тах	Unit Price	Ext Price
1	M K 1, 3, 3 00, 2.62, 9 ALLOY6, MEGASTREAU P/N AND DESCRIPTION Model: MK1 Size: 3 Class: 300 Trim #: 2.62 Cv: 96 Trim Characteristic: EQU Body Material: 316SS H End Connection: FL Balance Type: UNBALAU Plug Material: 316SS H Stem Material: 316SS H Seat Material: 316SS H Severe Service (Trims): Guides (Upper / Lower): Packing Material: GRAP Actuator: VL 100 CYLIN Positioner: LOGIX 3821-	AG, 316 S S M, GRAPHITE N ARE FOR INTER! JAL PERCENT T NCED T/ALLOY6 T/ALLOY6 T/ALLOY6 MEGASTREAM 316 SS & Graphite HITE DER -14EA-D43L-0010-0	HT,FL,31 NAL USE ONL / Alloy 6	655 Y	нт/	1	No	\$66,193.00	\$66,193.00
								Subtotal	400,185.UU
								Tax (0%)	\$0.00

CB Pacific 📵

909 - 7th Avenue, Suite 201 Kirkland WA 98033 Phone: 425.822.1702 Fax: 425.822.5442

Prepared by Kevin K Roberts at (801) 717-8297, kevin roberts@cb-pacific.com. Account Manager is Michael J Reeve. Standard Flowserve US, Inc. terms and conditions apply.

Page 1 of 1

\$66,193.00

Total

Quote

Version #1 12/10/2019

#QP121927118

Appendix K: Control Valve BV-01 Specification Data

Sheet and Quote

Manual Control Valve BV-01 Data Sheet and Quote (Flowserve, 2020)

Page 7 of 7

SEVERE WWW.MC		ALVES							(Ph) 281-449	MOGAS industries, inc. 14330 East Hardy Street Houston, Texas 77039 0291, (Fax) 281-590-3412	
				MOG	AS	Valve	e Data She	et			
Custon	ner:	CB PACI	FIC, INC.			MOGAS G	uotation No.:		H007169001		
Refere	nce:					Date:			12/23/2019 11:0	2	
Line Ite	:m:	1 Option	:			Tag:					
Media:		Nitrogen			Service:						
-			DOD: 2		Units Max Norm				Min	Shut-Off	
ŝ	Design Pressu	ire			F	PSI	160				
2	Operating Pre	ssure			1	PSI		160			
8	Differential Pre	essure Pre	eferred	_	-	PSI				160	
8	Differential Pre	essure Re	verse		-	PSI					
2	Design Tempe	erature		_		F	1112		L		
Ø	Operating Ten	nperature			_	-		1112			
8	Hipe Line Size	a sch:		_		Type:			Lever		
5	out:	in la		_		Manuractu Model:	irer:				
	Type:		CA-148			Eall Boolth			l		
	Class:		4 000 lp	_		Min Als Co	unolu Drassure:				
	Pressure Clas	e.	800		8	Power Sur	apply Pressure:				
	Bore Size:		4			Valve One	ning Time (sec)				
	Body Material		A182_E9	_	8	Valve Clor	sing Time (sec)				
	Body Bolting:		A183 B18	—	~	Manual O	verride Required:		l		
ð,	End	in:	RFF	_		Manual O	vertide Type:				
di i	Connection:	Out	ut: RFF			Hand Whe	el Size:				
- E	Sealing Direct	tion:	Uni-Directional			Number of	f Turns to Open:				
>	Packing Type:	:	Graphite			Fire Proof	ing Type:				
	Inner Stem Se	als:	Stellite 3		_	Type:			i i		
	Body Gasket 1	Type:	Spiral Wound		8	Manufactu	irer:				
	Stem:		A638 Gr.660		š I	Model:					
	Load Spring:		Inconel 718		8	Voltage					
	Purge Require	ement				Tag Number					
	Trim Type					Manufacturer:					
	Ball Material:		410 88		5	Model:					
Ē.	Ball Coating		MH 831		8	Type:					
	Seat Material:		410 88	_	Ĕ	Quantity:	-				
	Seat Coating		MH 831		5	Contacts /	Ratings:				
	Nace Require	ment				Tag Numb	ier.				
ě.	NUE Requirer	ilen.			š	Manufactu	irer.				
•	Valve Break T	orque (in-	5957		AL	Model: Eliter			<u> </u>		
	Valve Test		M33-3P-81			Manufactu	rer:		1		
	PMt				¥.	Model:			l		
	Ultrasonic:		i		8	Input:			i		
2	Mag Particle:		i		8	Communic	cation Type:		i		
Ĕ.	LP/DP:					Tag Numb	ier:				
	Radiography:				d	Quick Exh	aust Valve:				
	Oxygen Clean	ed:			š,	Volume Bo	ooster:				
	Other Require	ments:			-	Pliot Valve					
8											
ž											
	L										
	<u> </u>										
	<u> </u>				_						
Course 1											

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CB Pacific 🕝

909 - 7th Avenue, Sulte 201 Kirkland WA 98033 Phone: 425.822.1702 Fax: 425.822.5442

Prepared For

Quote

#QP121927230 Version #1 12/26/2019

Clayto Power Univer 875 Pe Mosco United P:(208	n Turner Engineering Department sity of Idaho erimeter Drive MS 1023 w ID 83844-1023 States I) 885-6111					
Expira	ation Date	Terms	FOB		RFQ or Referen	ce ID
1/25/2	020	Net 30	Factory			
Additi	ional Notes		Delivery Notes			
MAKE	ANY RESULTING PO OU	UT TO CB PACIFIC	FREIGHT: NOT INCL LEAD TIME: 22 WEE	UDED KS ARO		
Line	Model Number		G	ty Ta	Unit Price	Ext Price
1	CA-1AS,4,600,4,A182-F P/N AND DESCRIPTION Model: CA-1AS Size: 4 Class: 600 Bore Size: 4 Body Material: A182-F9 End Connection: RF Direction: UNIDIRECTIO Packing Material: GRAP Trim Type: NA Ball Material: MH 831 Ball Coating: 410 SS Seat Material: MH 831 Seat Coating: MH 831 Operator: LEVER	F9,MH 831,410 SS,LEVER N ARE FOR INTERNAL USE ONL' DNAL PHITE	Y	Yes	\$18,445.00	\$18,445.00
					Subtotal	\$18,445.00
					Tax (0%)	\$0.00
					Total	\$18,445.00

Appendix L: Computer Aided Design Models of Power

Conversion Unit Simulator

CAD Concepts for the PCU Simulator Listing Parts





CAD Front View



CAD Side View



CAD Top View



Appendix M: Aspen HYSYS Models for PCU Start Up

Siemen's SGT-A05 H7KE Natural Gas Open Air Brayton Cycle at 1100°C Turbine Inlet Temperature with Compressor and Turbine Adiabatic Efficiencies of 83.1% and 88.7%



D6: Thermal Efficiency 0.3320

1			Case Name:	Case Name: Report Model combustion brayton sqt-a05 kb7he.hsc					
2	UNIVERS	ITY OF IDAHO	Cabe Hame.	The port include compared	an orașteri egrade korne				
3	edford, M	/A	Unit Set	NuScale3a					
5	our		Date/Time:	Fri Jan 31 14:35:39 202	o				
6									
7	Workbook	: Case (Mair	1)						
9									
10			Material Stream	IS	Fluid Pkg	g: All			
11	Name	Ambient Air In	Compressed Air	Natural Gas	Turbine Iniet	Exhaust			
12	Temperature (C)	15.00	389.3	389.3	1098	522.0			
14	Mass Flow (kr/s)	21 013002 *	21.013002	0 38699769 *	21 399932	21 399932			
15	Liquid Volume Flow (m3/h)	87.89	87.89	4.437	90.70	90.70			
16	Higher Heating Value (kJ/kgmole)	0.0000	0.0000	8.761e+005	2450	2450			
17	Mass Density (kg/m3)	1.2201838	7.3920779	4.3548766	3.5318103	0.43602982			
18	Mass Enthalpy (kJ/kg)	-16.04	375.7	-3506	305.5	-389.7			
19	Mass Entropy (kJ/kg-C)	5.225	5.330	11.73	6.436	6.553			
20	Name	Waste							
21	Temperature (C)	1098							
22	Pressure (kPa)	1419							
23	Mass Flow (kg/s)	0.00000000							
24	Liquid Volume Flow (m3/h)	0.0000							
25	Higher Heating Value (kJ/kgmole)	2450							
26	Mass Density (kg/m3)	3.5318103							
27	Mass Entraipy (KJ/Kg)	305.5							
28	Mass Endopy (Karkg-C)	0.430							
30			Compositions	1	Fluid Pkg	j: All			
31	Name	Amblent Air In	Compressed Air	Natural Gas	Turbine Inlet	Exhaust			
32	Comp Mole Frac (Methane)	0.0000 *	0.0000	0.9433 *	0.0000	0.0000			
33	Comp Mole Frac (Ethane)	0.0000 *	0.0000	0.0237 *	0.0000	0.0000			
34	Comp Mole Frac (Propane)	0.0000 *	0.0000	0.0013 *	0.0000	0.0000			
35	Comp Mole Frac (I-Butane)	0.0000 *	0.0000	0.0002 *	0.0000	0.0000			
36	Comp Mole Frac (n-Butane)	0.0000 *	0.0000	0.0002 *	0.0000	0.0000			
37	Comp Mole Frac (I-Pentane)	0.0000 *	0.0000	0.0001 *	0.0000	0.0000			
38	Comp Mole Frac (n-Pentane)	* 0000.0	0.0000	0.0000 *	0.0000	0.0000			
39	Comp Mole Frac (n-Hexane)	0.0000 *	0.0000	0.0001 *	0.0000	0.0000			
40	Comp Mole Frac (CO2)	0.0004 *	0.0004	0.0080 *	0.0309	0.0309			
41	Comp Mole Frac (H2O)	0.0000 *	0.0000	0.0001	0.0597	0.0597			
43	Comp Mole Frac (Nillogen)	0.0095	0.0095	0.0200 *	0.1055	0.1035			
44	Comp Mole Frac (Argon)	0.0068 *	0.0068	0.0000 *	0.0066	0.0066			
45	Name	Waste							
46	Comp Mole Frac (Methane)	0.0000							
47	Comp Mole Frac (Ethane)	0.0000							
48	Comp Mole Frac (Propane)	0.0000							
49	Comp Mole Frac (I-Butane)	0.0000							
50	Comp Mole Frac (n-Butane)	0.0000							
51	Comp Mole Frac (I-Pentane)	0.0000							
52	Comp Mole Frac (n-Pentañe)	0.0000							
53	Comp Mole Frac (CO2)	0.0000							
55	Comp Mole Frac (H2O)	0.0503							
56	Comp Mole Frac (Nitrogen)	0.7853				L			
57	Comp Mole Frac (Oxygen)	0.1175							
58	Comp Mole Frac (Argon)	0.0066							
59			Energy Stream	e	Fluid Die	T AII			
60			Energy Stream	•	Fluid Phy	, Al			
61	Name Heat Flow	Compressor Power	Turbine Power						
62	Aspen Technology Inc.	8.232	14.88	on 9		Page 1 of 2			
64	Licensed to: UNIVERSITY OF IDAHO		open moro versi	0110		* Specified by user.			

1				Case Name:	Report Model combustion brayton sgt-at	15 kb7he.ha	sc
2	(aspentech	UNIVERSIT Bedford, M/	Y OF IDAHO	Unit Set	NuScale3a		
4	<u> </u>	USA		Date/Time:	Fri Jan 31 14:35:39 2020		
6 7 8	Worl	kbook:	Case (Mair	n) (continue	ed)		
9				Gibbs Reactor	s I	Fluid Pkg:	All
11	Name		Natural Gas Reactor				
12	Heat Flow	(MW)	0.0000				
13	- Teat From		0.0000	Heaters	· · · · ·	Fluid Pkg:	All
15	Name						
16	DUTY	(MW)					
17	Feed Temperature	(C)					
18	Product Temperature	(C)					
19	Mass Flow	(kg/s)					
20 21				Coolers		Fluid Pikg:	All
22	Name						
23	DUTY	(MW)					
24	Feed Temperature	(C)					
25	Product Temperature	(C)					
26	Mass Flow	(kg/s)					
27				Heat Exchange	rs	Fluid Pkg:	All
28	Name						
30	Duty	(MW)					
31	Tube Side Feed Mass Flow	(kg/s)					
32	Shell Side Feed Mass Flow	(kg/c)					
33	Tube Inlet Temperature	(C)					
34	Tube Outlet Temperature	(C)					
35	Shell Inlet Temperature	(C)					
36	Shell Outlet Temperature	(C)					
37	LMTD	(C)					
38	UA	(kJ/C-h)					
39	Minimum Approach	(C)					
40				Compressors		Fluid Pkg:	All
42	Name		Compressor				
43	Power	(MW)	8.232				
44	Feed Pressure	(kPa)	101.3 *				
45	Product Pressure	(kPa)	1419				
46	Product Temperature	(C)	389.3				
47	Feed Temperature	(C)	15.00 *				
48	Adiabatic Efficiency		83 *				
49	Pressure Ratio		14.00 *				
50	Mass Flow	(kg/s)	21.01 *				
51 52				Expanders		Fluid Pkg:	All
53	Name		Turbine				
54	Power	(MW)	14.88				
55	Feed Pressure	(kPa)	1419				
56	Product Pressure	(kPa)	101.3 *				
57	Product Temperature	(C)	522.0				
58	Feed Temperature	(C)	1098				
59	Adlabatic Efficiency		89 *				
60	Mass Flow	(kg/s)	21.40				
61 62							
63	Aspen Technology Inc.		1	Spen HYSYS Versi	ion 9		Page 2 of 3
	Licensed to: UNIVERSITY OF IDA	но		apentitiono versi			' Specified by user.

1	100/27		Case Name:	Report Model combust	on brayton sgt-a05 kb7he	Ehsc
3	(easpentech Bedford	, MA	Unit Set	NuScale3a		
4	USA		Date/Time:	Fri Jan 31 14:35:39 202	20	
6				-0		
7	Workbool	k: Case (Main)	(continue	ed)		
9			Valves		Fluid Pkg	a: Al
10	Name					-
12	Pressure Drop (kPa)					
13	Feed Pressure (kPa)					
14	Feed Temperature (C)					
15	Product Pressure (kPa))				
16	Product Temperature (C)					
17	Mass Flow (kg/s)					
18	Cg					
19	Resistance (CV of K)					
20						
22						
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29						
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62	Aspen Technology Inc.	Ac	pen HVSVS Versi	on 9		Page 3 of 3
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<u> </u>								
1				Case Name:	report model simple bra	iyton 650c high eff QSS.h	ISC	
3	@aspentech	Bedford, M	A NOFIDAHO	Unit Set	NuScale3a			
4		USA		Date/Time:	Fri Jan 31 14:30:22 202	10		
6 7 8	Wor	kbook:	Case (Mai	in)				
9				Material Stream	ıs	Fluid Pkg	j: All	
11	Name		Comp Out	Turbine Inlet	Humid Air	Turbine Outlet		
12	Temperature	(C)	302.8	650.0 *	21.11 *	296.0		
13	Pressure	(kPa)	859.2	842.1	101.3	101.3 *		
14	Mass Flow	(kg/s)	26.075270	26.075270	26.075270 *	26.075270		
15	Mass Density	(kg/m3)	5.1597764	3.1555203	1.1948843	0.61711920		
16	Mass Enthalpy	(kJ/kg)	181.7	565.2	-111.2	174.7		
17	Mass Entropy	(kJ/kg-C)	5.362	5.888	5.283	5.967		
18 19				Compositions	1	Fluid Pkg	j: Ali	
20	Name		Comp Out	Turbine inlet	Humid Air	Turbine Outlet		
21	Comp Mole Frac (Nitrogen)		0.7713	0.7713	0.7713	0.7713		
22	Comp Mole Frac (Oxygen)		0.2069	0.2069	0.2069	0.2069		
23	Comp Mole Frac (Argon)		0.0092	0.0092	0.0092	0.0092		
24	Comp Mole Frac (CO2)		0.0003	0.0003	0.0003	0.0003		
25	Comp Mole Frac (H2O)		0.0123	0.0123	0.0123	0.0123		
26 27	Energy Streams Fluid Pkg: All							
28	Name		Comp Pwr	Reactor Heat	Turb Pwr			
29	Heat Flow	(MW)	7.638	10.00	10.18			
30 31				Heaters		Fluid Pkg	j: Ali	
32	Name		Reactor					
33	DUTY	(MW)	10.00					
34	Feed Temperature	(C)	302.8					
35	Product Temperature	(C)	650.0					
36	Mass Flow	(kg/s)	26.08					
37				Coolers		Fluid Pkg	j: All	
38	Nama							
40	DUTY	(MW)						
41	Feed Temperature	(C)						
42	Product Temperature	(C)						
43	Mass Flow	(kg/s)						
44				Heat Exchange	rs	Fluid Pkg	j: Ali	
46	Name							
47	Duty	(MW)						
48	Tube Side Feed Mass Flow	(kg/s)		1				
49	Shell Side Feed Mass Flow	(kg/s)		1				
50	Tube Inlet Temperature	(C)						
51	Tube Outlet Temperature	(C)						
52	Shell Inlet Temperature	(C)						
53	Shell Outlet Temperature	(C)						
54	LMTD	(C)						
55	UA	(kJ/C-h)		1				
56	Minimum Approach	(C)						
57 58 59 60 61 62 62	Aspen Technology In-			Arnon LIVEVE V	on 0		Page 1 of 2	
63	Aspen Technology Inc.	AHO		Aspen HYSYS Vers	on 9		Page 1 of 2	
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1				Case Name:	report model simple bra	avton 650c high eff QSS.r	ISC
2	(aspentech	UNIVERSI Bedford, M	TY OF IDAHO A	Unit Set	NuScale3a		
4	0.1	USA		Date/Time:	Fri Jan 31 14:30:22 202	20	
5						-	
7	Wor	kbook:	Case (Mair	ı) (continue	ed)		
9				Compressors		Fluid Pk	g: All
11	Name		Air Compressor				
12	Power	(MW)	7.638				
13	Feed Pressure	(kPa)	101.3 *				
14	Product Pressure	(kPa)	859.2				
15	Product Temperature	(C)	302.8				
16	Feed Temperature	(C)	21.11				
17	Adiabatic Efficiency		85 '				
18	Pressure Ratio		8.480 *				
19	Mass Flow	(KQ/S)	26.08 *				
20				Expanders		Fluid Pk	g: All
22	Name		Air Turbine				
23	Power	(MW)	10.18				
24	Feed Pressure	(kPa)	842.1				
25	Product Pressure	(kPa)	101.3 *				
26	Product Temperature	(C)	296.0				
27	Feed Temperature	(C)	650.0 *				
28	Adiabatic Efficiency		90 *				
29	Mass Flow	(kg/s)	26.08				
30 31				Valves		Fluid Pkg	g: All
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(kPa)					
37	Product Temperature	(C)					
38	Mass Flow	(kg/s)					
39	Cg						
40	Resistance (Cv or K)						
41							
42							
44							
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46							
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56 57 58							
56 57 58 59							
56 57 58 59 60 61							
56 57 58 59 60 61 62							
56 57 58 59 60 61 62 63	Aspen Technology Inc			lspen HYSYS Versi	ion 9		Page 2 of 2

Open Air Brayton cycle at 650° Turbine Inlet Temperature with 10 MW Reactor Power and Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



1				Case N	ame: simple brayton cycle	650 low eff.hsc	
2	(aspentech	UNIVERSITY OF IDAHO Bedford, MA		Unit Se	t NuScale3a		
4		USA		Date/Ti	me: Mon Jul 13 14:28:57	2020	
6 7 8		Workbook: Cas	se (Main)				
9				Mate	rial Streams	Fluid	Pka: Al
10	Name		Comp Out		Turbine Inlet	Humid Air	Turbine Outlet
12	Temperature	(C)		192.5	650.0	21.11	453.6
13	Pressure	(kPa)		342.5	335.6	101.3 *	101.3 *
14	Mass Flow	(kg/s)		19.96	19.96	19.96 *	19.96
15	Mass Density	(kgim3)		2.545	1.258	1.193	0.4828
16	Mass Enthalpy	(kJ/kg)		33.75	534.8	-142.8	314.9
1/	Mass Entropy	(KUNG-C)		0.418	0.1/0	5.298	6.249
19				Cor	npositions	Fluid	Pkg: Al
20	Name		Comp Out		Turbine Inlet	Humid Air	Turbine Outlet
21	Comp Mole Frac (Nitrogen)			0.7684	0.7684	0.7884	0.7684
22	Comp Mole Frac (Oxygen)			0.2061	0.2081	0.2061	0.2081
20	Comp Mole Frac (Argon)			0.0092	0.0092	0.0092	0.0082
25	Comp Mole Frac (UC2)			0.0005	0.0003	0.0003	0.0003
26	comp more trac (120)					0.0100	0.0100
27				Ener	gy Streams	Fluid	Pkg: Al
28	Name		Comp Pwr		Reactor Heat	Turb Pwr	
29	Heat Flow	(MW)		3.523	10.00	4.389	
30				-	leaters	Fluid	Pkg: Al
30	Name		Reactor				
33	DUTY	(MW)		10.00			
34	Feed Temperature	(C)		192.5			
35	Product Temperature	(C)		650.0 *			
36	Mass Flow	(kg/s)		19.96			
37				(Coolers	Fluid	Pkg: Al
30	Nama						
40	DUTY	000					
41	Feed Temperature	(C)					
42	Product Temperature	(C)					
43	Mass Flow	(kg/s)					
44				Heat	Exchangers	Fluid	Pkg: Al
46	Name						
47	Duty	(MW)					
48	Tube Side Feed Mass Flow	(kg/s)					
49	Shell Side Feed Mass Flow	(kg/s)					
50	Tube Inlet Temperature	(C)					
51	Tube Outlet Temperature	(C)					
52	Shell Inlet Temperature Shell Outlet Temperature	(C)					
54	LMTD	(C) (C)					
55	UA	(kJ/C-h)					
56	Minimum Approach	(C)					
57 58 59 60							
62							
63	Aspen Technology Inc.			Aspen H	YSYS Version 9		Page 1 of 2
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1		UNDERDOWN OF IDVING		Case N	ame: simple brayton cycle 6	60 low eff.hsc	
3	(aspentech	UNIVERSITY OF IDAHO Bedford, MA		Unit Se	t NuScale3a		
4		USA		Date/Ti	me: Mon Jul 13 14:28:57 2	020	
6							
8		WORKDOOK: Ca	se (main) (contil	nuea			
9				Сог	npressors	Fluid F	Ng: Al
11	Name		Air Compressor				
12	Power	(MW)		3.523			
13	Feed Pressure	(kPa)		101.3			
14	Product Pressure	(kPa)		342.5			
15	Product Temperature	(C)		192.5			
10	Arishatic Efficiency	(*)		21.11			
18	Pressure Ratio			3,380 *			
19	Mass Flow	(kg/s)		19.96 *			
20			•	E	manders	Priot 6	ka: Al
21						nuu r	* ^
22	Name	471	Air Turbine	4 200			
20	Food Pressure	(MW) (kPa)		4.388			
25	Product Pressure	(kPa)		101.3			
26	Product Temperature	(C)		453.6			
27	Feed Temperature	(C)		650.0 *			
28	Adiabatic Efficiency			80 1			
29	Mass Flow	(kg/s)		19.96			
30					Valves	Fluid F	Ng: Al
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(kPa)					
37	Product Temperature	(C)					
38	Mass Flow	(kg/s)					
40	Resistance (Culor K)						
41	Nesistance (ov or hy						
42							
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62	Aspen Technology Inc			Asnen H	YSYS Version 9		Page 2 of 2
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Nitrogen Brayton Cycle at 600°C Turbine Inlet Temperature with 10 MW Reactor Power and Compressor and Turbine Adiabatic Efficiencies of 85% and 90%

B5: Thermal Efficiency 23.39 %



2	-	UNIVERSI	TY OF IDAHO	Case Name:	report model simple bra	yton 600c high eff QSS.h	sc
3	(e)aspentech	Bedford, M	A	Unit Set	NuScale3a		
4		USA		Date/Time:	Fri Jan 31 14:20:33 202	o	
6							
7	Wor	kbook:	Case (Mai	n)			
8							
9				Material Stream	IS	Fluid Pkg	i: All
11	Name		Comp Out	Turbine inlet	Turbine Outlet	Nitrogen in	
12	Temperature	(C)	280.7	600.0 *	278.0	21.11 *	
13	Pressure	(kPa)	747.8	732.8	101.3 *	101.3 *	
14	Mass Flow	(kg/s)	28.019352	28.019352	28.019352	28.019352 *	
15	Mass Density	(kg/m3)	4.5380331	2.8213971	0.61923174	1.1607251	
16	Mass Entropy	(KJ/KG) //k1/km-C)	2/1.8	5.853	209.1	-4.329	
18	Mass Chuopy	(Karkg-C)	0.045	3.003	0.550	3.272	
19				Compositions		Fluid Pkg	j: All
20	Name		Comp Out	Turbine inlet	Turbine Outlet	Nitrogen In	
21	Comp Mole Frac (Nitrogen)		1.0000	1.0000	1.0000	1.0000 *	
22	Comp Mole Frac (Oxygen)		0.0000	0.0000	0.0000	0.0000 *	
23	Comp Mole Frac (Argon)		0.0000	0.0000	0.0000	0.0000 *	
24	Comp Mole Frac (CO2)		0.0000	0.0000	0.0000	0.0000 *	
26							
27				Energy Stream	s	Fluid Pkg	i: All
28	Name		Comp Pwr	Reactor Heat	Turb Pwr		
29	Heat Flow	(MW)	7.737	10.00	10.08		
30				Heaters		Fluid Pkg	i: All
31	Name		Reactor				
33	DUTY	(MW)	10.00				
34	Feed Temperature	(C)	280.7				
35	Product Temperature	(C)	600.0 *				
36	Mass Flow	(kg/s)	28.02				
37				Coolers		Fluid Pkg	i: All
39	Name						
40	DUTY	(MW)					
41	Feed Temperature	(C)					
42	Product Temperature	(C)					
43	Mass Flow	(kg/s)					
44				Heat Exchange	rs	Fluid Pkg	i: All
46	Name						
47	Duty	(MW)					
48	Tube Side Feed Mass Flow	(kg/s)					
49	Shell Side Feed Mass Flow	(kg/s)					
50	Tube Inlet Temperature	(C)					
51	Tube Outlet Temperature	(C)					
53	Shell Outlet Temperature	(C)					
54	LMTD	(C)					
55	UA	(kJ/C-h)					
56	Minimum Approach	(C)					
57							
56 59							
60							
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62							
63	Aspen Technology Inc.			Aspen HYSYS Versi	on 9		Page 1 of 2
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1				Case Name:	report model simple bra	iyton 600c high eff QSS.h	sc
3	(aspentech	NIVERSIT edford, M/	Y OF IDAHO A	Unit Set	NuScale3a		
4	0	SA		Date/Time:	Fri Jan 31 14:20:33 202	20	
6							
7	Workb	ook:	Case (Mair	n) (continue	ed)		
9				Compressors		Fluid Pk	E All
10	Nama		Air Compressor				,
12	Power	(MW)	7 7 37				
13	Feed Pressure	(kPa)	101.3 *				
14	Product Pressure	(kPa)	747.8				
15	Product Temperature	(C)	280.7				
16	Feed Temperature	(C)	21.11 *				
17	Adiabatic Efficiency		85 *				
18	Pressure Ratio		7.380 *				
19	Mass Flow	(kg/s)	28.02 *				
20				Expanders		Fluid Pk	т АШ
21				2.1.1.1.1.1.1			
22	Name		Air Turbine				
23	Power	(MW)	10.08				
24	Feed Pressure	(KPa)	732.8				
25	Product Pressure	(KPa)	101.3 *				
26	Field Temperature	(0)	2/0.0				
27	Adiabatic Efficiency	(0)	000.0 *				
29	Mass Flow	(ko/s)	28.02				
30		(190)					
31				Valves		Fluid Pkg	j: All
32	Name						
33	Pressure Drop	(kPa)					
34	Feed Pressure	(kPa)					
35	Feed Temperature	(C)					
36	Product Pressure	(KPa)					
38	Mass Flow	(ko/s)					
39	Ca	(Ngro)					
40	Resistance (Cv or K)						
41		I	I				
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Nitrogen Brayton Cycle at 600°C Turbine Inlet Temperature with 10 MW Reactor Power and Compressor and Turbine Adiabatic Efficiencies of 70% and 80%



1			Case Name:	simple Low Eff brayton cycle 600).hsc			
3	(aspentech Bedford, MA	l l	Unit Set NuScale3a					
4	USA		Date/Time:	Mon Jul 13 14:34:25 2020				
6	Werkhards. Or							
8	WORKDOOK: Ca	se (Main) (contin	iuea)					
9			Heat Exchange	:(5	Fluid P	kg: Al		
11	Name							
12	Duty (MW)							
13	Tube Side Feed Mass Flow (kg/s)							
14	Shell Side Feed Mass Flow (kg/s)							
15	Tube Inlet Temperature (C)							
16	Tube Outlet Temperature (C)							
17	Shell Inlet Temperature (C)							
18	Shell Outlet Temperature (C)							
19	LMTD (C)							
20	UA (kJIC-h)							
21	Minimum Approach (C)							
22			Compressors	6	Fluid P	kg: Al		
20	Nama	No Companyon						
24	Name (AAA)	All Compressor	1 205					
20	Fower (WW)		3.290					
20	Preduct Processon (kPa)		206.0					
20	Product ressure (kra)		170.0					
29	Food Tomperature (C)		21.11 *					
30	Adiabatic Efficiency		70 '					
31	Pressure Ratio		2.930 *					
32	Mass Flow (kg/s)		21.01 *					
33		•						
33 34			Expanders	I	Fluid P	hg: Al		
33 34 35	Name	Air Turbine	Expanders		Fluid P	Ng: Al		
33 34 35 36	Name Power (MW)	Air Turbine	Expanders 4.016		Fluid P	kg: Al		
33 34 35 36 37	Name Power (MW) Feed Pressure (kPa)	Air Turbine	Expanders 4.016 290.9		Fluid P	kg: Al		
33 34 35 36 37 38	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa)	Air Turbine	Expanders 4.016 290.9 101.3		Fluid P	kg: Al		
33 34 35 36 37 38 39	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C)	Air Turbine	Expanders 4.016 290.9 101.3 4.028		Fluid P	Ng: Al		
33 34 35 36 37 38 39 40	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0		Fluid P	Ng: Al		
33 34 35 36 37 38 39 40 41	Name Power (MM) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Addiatotic Efficiency	Air Turbine	Expanders 4.016 290.9 101.3 4.02 600.0 600.0 600		Fluid P	Ng: Al		
33 34 35 36 37 38 39 40 41 42	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adiatotic Efficiency Mass Flow (kpts)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01		Fluid P	Ng: Al		
33 34 35 36 37 38 39 40 41 41 42 43 44	Name Power (MM) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabasic Efficiency Mass Flow (kg/s)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency Mass Flow (kg/s) Name	Air Turbine	Expanders 4.018 290.9 101.3 430.8 80.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (kgls) Name Pressure Droo (kPa)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 80.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45 45 45	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (Ma) Mass Flow (kgls) Name Pressure Drop (kPa) Feed Pressure (kPa) (kgls)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 80.0 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 41 42 43 44 45 45 46 47 48	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (kgls) Name Pressure Drop (kPa) Feed Pressure (kPa) (kgls)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 80.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (Ma) Mass Flow (kgls) Name (kPa) Pressure Dop (kPa) Feed Pressure (kPa) Feed Pressure (kPa) Feed Temperature (C) Product Pressure (kPa)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (kgls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kgls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 41 42 43 44 45 45 45 45 45 45 50 51	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabasic Efficiency (kgls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabasic Efficiency (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Fred Temperature (C) Product Pressure (kPa) Product Pressure (kPa)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 41 42 43 44 45 45 46 47 48 49 50 51 52	Name Power (MA) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Feed Temperature (C) Adabatic Efficiency (kgls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kPa) Pressure Drop (kPa) Feed Pressure (kPa) Freed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Product Pressure (kPa) Product Pressure (kPa) Product Pressure (C) Mass Flow (kgls)	Air Turbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Pressure (C) Feed Temperature (C) Adatabic Efficiency (kpis) Name (kpis) Pressure Drop (kPa) Feed Temperature (C) Adatabic Efficiency (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Fred Temperature (C) Name (C) Resistance (C) or K) (kpis)	Air Tutbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53 54	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (Mass Flow) Mass Flow (kpts) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Mass Flow (kpts) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4.016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 54	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (Mass Flow Mass Flow (kpts) Name (kPa) Pressure Drop (kPa) Feed Pressure (C) Adabatic Efficiency (kPa) Pressure Drop (kPa) Feed Pressure (C) Product Pressure (C) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgts) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 55	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (kpis) Mass Flow (kpis) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kPa) Pressure Drop (kPa) Feed Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgis) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4016 290.9 101.3 430.8 600.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53 54 55 56 57	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabasic Efficiency (kpls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabasic Efficiency (kpls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgls) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4.016 200.9 101.3 4.03.8 600.0 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (kpts) Mass Flow (kpts) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kpts) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgts) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4.016 200.9 101.3 4.30.8 600.0 21.01 Valves Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 55 55 55 55 55 55 55 55 55 55 55 55	Name Power (MW) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (kpts) Mass Flow (kpts) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabatic Efficiency (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgts) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4.016 200.9 101.3 4.026 200.9 101.3 430.8 000.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 55 55 55 55 55 55 55 55 55 55 55 55	Name Power (MM) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabasic Efficiency (Mass Flow Mass Flow (kpls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabasic Efficiency (kPa) Pressure Drop (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Product Temperature (C) Mass Flow (kgls) Cg	Air Tutbine	Expanders 4.016 200.9 101.3 4.30.8 000.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 55 56 57 58 59 60 61 52	Name Power (MM) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabasic Efficiency (Mass Flow Mass Flow (kpls) Name (kPa) Pressure Drop (kPa) Feed Temperature (C) Adabasic Efficiency (kPa) Product Pressure (kPa) Feed Pressure (kPa) Feed Temperature (C) Product Temperature (C) Product Temperature (C) Mass Flow (kgls) Cg Resistance (Cv or K)	Air Tutbine	Expanders 4.018 200.9 101.3 430.8 000.0 80 21.01 Valves		Fluid P	kg: Al		
33 34 35 36 37 38 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 57 58 59 60 61 62 63 60	Name Power (MM) Feed Pressure (kPa) Product Pressure (kPa) Product Temperature (C) Adabatic Efficiency (Mass Flow Mass Flow (kpls) Name (KPa) Pressure Drop (kPa) Feed Pressure (KPa) Feed Pressure (kPa) Feed Temperature (C) Product Pressure (kPa) Feed Temperature (C) Product Temperature (C) Product Temperature (C) Mass Flow (kgls) Cg Cg Resistance (Cv or K) Ensement (Cv or K)		Expanders 4.018 4.018 200.9 101.3 430.8 000.0 80 21.01 Valves		Fluid P	lg: Al		

2			Cas	e Name:	simple Low Eff brayton	cycle 600.hsc		
3	(aspentech	UNIVERSITY OF IDAHO Bedford, MA	Unit	Set	NuScale3a			
4		USA	Date	/Time:	Mon Jul 13 14:34:25 2	020		
6			(11-1-)					
7		Workbook: Ca	se (Main)					
9			Ма	terial Streams			Fluid F	Pia: A
10	Name		Comp Out	Turbine Inlet		Humid Air		Turbine Outlet
12	Temperature	(C)	170.0		600.0 *		21.11	430.
13	Pressure	(kPa)	296.9		290.9		101.3	101.3
14	Mass Flow	(kg/s)	21.01		21.01		26.08 *	21.0
15	Mass Density	(kgim3)	2.256		1.122		1.195	0.484
16	Mass Enthalpy	(kJ/kg)	152.5		628.5		-111.2	437.
17	Mass Entropy	(kJ/kg-C)	5.384		6.138		5.283	6.20
10	Name	101	Nittogen in					
13	Proceino	(C) (AD=)	21.11					
21	Mass Flow	(Ard)	101.3					
22	Mass Density	(ng/s) (kn/m3)	1 181					
23	Mass Enthalov	(kJ/ka)	4.329					
24	Mass Entropy	(kJ/kg-C)	5.272					
25		(
26			C	ompositions			Fluid F	Pkg: A
27	Name		Comp Out	Turbine Inlet		Humid Air		Turbine Outlet
28	Comp Mole Frac (Nitrogen)		1.0000		1.0000		0.7713	1.000
29	Comp Mole Frac (Oxygen)		0.0000		0.0000		0.2069	0.000
30	Comp Mole Frac (Argon)		0.0000		0.0000		0.0092	0.000
31	Comp Mole Frac (CO2)		0.0000		0.0000		0.0003	0.000
32	Comp Mole Frac (H2O)		0.0000		0.0000		0.0123	0.000
33	Name		Nitrogen In					
34	Comp Mole Frac (Nitrogen)		1.0000	•				
35	Comp Mole Frac (Oxygen)		0.0000	•				
36	Comp Mole Frac (Argon)		0.0000					
3/ 20	Comp Mole Frac (CO2)		0.0000					
30	Comp Note Frac (F2O)		0.000					
							Fluid F	Pkg: A
40			Er	ergy Streams				
40 41	Name		Er Comp Pwr	Reactor Heat		Turb Pwr		
40 41 42	Name Heat Row	(MW)	Er Comp Pwr 3.295	Reactor Heat	10.00	Turb Pwr	4.016	
40 41 42 43	Name Heat Row	(MAI)	Er Comp Par 3.295	Reactor Heat	10.00	Turb Pwr	4.016	
40 41 42 43 44	Name Heat Row	(MW)	Er Comp Per 3.296	Reactor Heat	10.00	Turb Pwr	4.016 Fluid F	Ping A
40 41 42 43 44 45	Name Heat Row Name	(MN)	Er Comp Pwr 3 206 Reactor	ergy Streams Reactor Heat Heaters	10.00	Turb Pwr	4.016 Fluid F	Pig: A
40 41 42 43 44 45 46	Name Heat Row Name DUTY	(MN) (MN)	Er Comp Per 3.295 Reactor 10.00	ergy Streams Reactor Heat Heaters	10.00	Turb Pwr	4.016 Fluid F	Ng: A
40 41 42 43 44 45 46	Name Heat Row Name DUTY Feed Temperature	(MN) (MN) (C)	Er Comp Per 3.299 Reactor 10.00 170.0	Reactor Heat	10.00	Turb Pwr	4.016 Fluid F	Ng: A
40 41 42 43 44 45 46 47 48	Name Heat Row Name DUTY Feed Temperature Product Temperature	(MN) (MN) (C) (C)	Er Comp Per 3.299 Reactor 10.00 170.0 000.0	Reactor Heat Heaters	10.00	Turb Pwr	4.018 Fluid F	Pig: A
40 41 42 43 44 45 45 46 47 48 49	Name Heat Row Name DUTY Feed Temperature Product Temperature Mass Flow	(MN) (MN) (C) (C) (kgis)	Er Comp Per 3.299 Reactor 10.00 170.0 000.0 21.01	Reactor Heat Heaters	10.00	Turb Pwr	4.018 Fluid F	Pilg: A
40 41 42 43 44 45 45 46 47 48 49 50 50	Name Heat Row Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (C) (kgis)	Er Comp Per 3.299 Reactor 10.00 170.0 000.0 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid F Fluid F	Pig: A
40 41 42 43 43 44 45 46 47 48 49 50 51	Name Heat Row Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (C) (kgis)	Er Comp Per 3.296 Reactor 10.00 170.0 000.0 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.016 Fluid F Fluid F	Pho: A
0 11 12 13 14 15 16 17 18 19 10 11 12 13	Name Heat Flow Name DUTY Feed Temperature Product Temperature Mass Flow Name Name DUTY	(MW) (MW) (C) (C) (kgis)	Er Comp Per 3.296 Reactor 10.00 170.0 600.0 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Ruid F Ruid F	Pilg: A
40 40 41 42 43 44 45 46 45 46 49 50 51 51 52 53 54	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Name DUTY Feed Temperature Feed Temperature Fiel Temperature Fi	(MN) (MN) (C) (C) (kgis) (MN) (C)	Er Comp Per 3.296 Reactor 10.00 170.0 000.0 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid f	Pilg: A
0 11 12 3 4 5 5 6 7 8 9 0 11 2 3 4 5 5 6 7 8 9 0 11 2 3 4 5 5 5 7 8 9 0 11	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Name DUTY Feed Temperature Froduct Temperature	(MW) (MW) (C) (C) (kgis) (MW) (C) (C)	Er Comp Per 3.296 Reactor 10.00 170.0 000.0 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid f	Pilg: A
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 4 5 6 6	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MA) (C) (C) (kps) (MW) (C) (C) (C) (kps)	Er Comp Per 3.299 Reactor 10.00 170.0 000.0 21.01 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid F	Pig: A
33 40 41 42 43 44 45 45 45 50 51 52 53 54 55 55 55 55 55 55 55 55 55 55 55 55	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Name DUTY Feed Temperature Mass Flow	(MN) (MN) (C) (C) (kgs) (MS) (MA) (C) (C) (C) (kgs)	Er Comp Per 3.295 Reactor 10.00 170.0 000.0 21.01 21.01	Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid F Fluid F	Pig: A
33 40 40 41 42 43 44 45 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name DUTY Feed Temperature Product Temperature Mass Flow	(MW) (MW) (C) (kgis) (MW) (C) (C) (kgis)	Er Comp Par 3 296 Reactor 10.00 170.0 600.0 21.01 21.01	regy Streams Reactor Heat Heaters Coolers	10.00	Turb Pwr	4.018 Fluid F	Phg A
10 11 12 3 4 5 5 5 5 7 8 9 0 1 2 3 4 5 5 5 7 8 9 0 1 2 3 4 5 5 5 7 8 9 0 1 1 2 3 4 5 5 5 5 7 8 9 0 1 1 2 3 4 5 5 5 5 7 8 9 9 0 1 1 2 3 1 2 3 1 4 5 5 5 5 7 8 9 9 1 1 2 3 3 3 2 3 3 3 1 3 3 1 1 2 3 3 3 1 2 3 1 2 3 1 2 3 1 2 3 3 3 3	Name Heat Flow Name DUTY Feed Temperature Mass Flow Name Name Name Name Name Name Name Name	(MN) (MN) (C) (kgs) (kgs) (MN) (C) (C) (kgs)	Er Comp Par 3 206 Reactor 10.00 170.0 000.0 21.01 21.01 Aspen	regy Streams Reactor Heat Heaters Coolers HYSYS Version S		Turb Pwr	4.018 Fluid F	Page 1 of 2