AN ANALYSIS OF A DUMP HEAT EXCHANGER FOR THE VERSATILE TEST REACTOR'S SECONDARY LOOP

A Thesis Presented in Partial Fulfillment of the Requirements for the Degree of Master of Science with a Major in Nuclear Engineering in the College of Graduate Studies University of Idaho by Joshua C Young

Approved by: Major Professor: Michael McKellar, Ph.D. Committee Members: David Arcilesi, Ph.D.; Robert Borrelli, Ph.D.; Piyush Sabharwall, Ph.D. Department Administrator: Indrajit Charit, Ph.D.

December 2021

Abstract

The VTR is a new research reactor that uses a Dump Heat Exchanger (DHX) to transfer heat from sodium to the surrounding air. A DHX is used in place of a power cycle for a testing reactor to displace the heat from the secondary loop. An analysis of the existing heat exchanger, a cross-flow design, was completed. Possible heat exchanger options, a shell-and-tube and an annulus heat exchanger, were investigated. Using Aspen HYSYS several iterations of analysis were completed. Sodium data from Argonne National Laboratory (ANL) was inputted into HYSYS to be used with all the models. It was found that having a slower flow rate for air passing through the heat exchanger was instrumental to improving the initial cross-flow design. Upon comparing the other design types with the initial cross-flow design based on footprint, volume of material, and weight, the shell and tube heat exchangers were the best option followed by the annulus heat exchangers and finally the original cross-flow design. Out of two possible shell and tube heat exchanger designs investigated the one that contained 100 tubes was the better option.

Acknowledgements

The completion of this work would not have been possible without Dr. McKellar, my advisor. He has been super helpful and pushed me the entire way.

DEDICATION

This thesis is dedicated to my wife Monica who has supported me through my education.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements	iii
DEDICATION	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ACRONYMS	ix
Chapter 1: Introduction	1
Background	1
What is the Versatile Test Reactor?	2
Chapter 2: Theory	8
Heat Exchangers	8
Types	8
Overall Heat Transfer Coefficient	8
Effectiveness-NTU Method	12
2.1.3.1 Example of Effectiveness-NTU Method	15
Verification of Sodium Properties	19
Chapter 3: Fast Flux Testing Facility's Heat Exchanger Analysis	26
Introduction	26
Methods and Materials	27
Parametric Studies - Humid Air	33
Chapter 4: Potential Heat Exchangers	36
Annulus Heat Exchanger Design	36
Shell-and-tube Heat Exchanger	42
Chapter 5: Results	46
Chapter 6: Summary and Conclusions	49
References	50
Appendix A: Solving Annulus Heat Exchanger from Janna's book [11]	51
Appendix B: HYSYS Models and Reports	55

LIST OF TABLES

1.1	PRISM's specifications.[4]	6
3.1	Initial Conditions of the Dump Heat Exchanger found on the FFTF. $[5]$	28
3.2	Values of UA , NTU , and ΔT for the heat exchanger calculated from HYSYS	
	and correcting the values to accommodate for it being a cross-flow heat ex-	
	changer	29
3.3	Constants for the average Nusselt number for air	31
4.1	Possible inner diameter of sodium, length, pressure drop, and duty found	
	through the design process of the Annulus Heat Exchanger. The highlighted	
	rows are viable choices for the heat exchanger that work	38
4.2	Cross-Flow heat exchanger compared to different Annulus heat exchangers all	
	having a length of 5 meters	39
4.3	Initial Cross-Flow HX vs Annulus HX	41
4.4	Initial Cross-Flow HX vs Annulus HX vs Shell and Tube HX	45
5.1	List of mass flow rate, duty, and sodium outlet temperature for the current	
	design and the corrected valued cases. \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots	46

LIST OF FIGURES

1.1	Render of what the MBIR could look like	1		
1.2	TerraPower's newest design of a sodium cooled reactor that uses depleted ura-			
	nium as its fuel	2		
1.3	Illustration of a coupled reactor (0- outer reflector; 1- thermal annular core; 2-			
	inner reflector; 3- thermal neutron filter; 4- fast core)	4		
1.4	VTR draft core layout. The fast neutron region will be at the center and the			
	thermal neutron region will be towards the outside of the driver fuel area.[3] $\ .$	5		
1.5	Schematic of the Thermal Loop of the PRISM reactor.[4]	6		
1.6	Schematic of Heat Removal Facilities. [5]			
1.7	Plan View of Heat Transport System. [5]	7		
2.1	Parallel-flow concentric tube heat exchanger. Arrows denote the flow path	8		
2.2	Counter-flow concentric tube heat exchanger. Arrows denote the flow path	9		
2.3	A cross section of a cross-flow heat exchanger. Arrows denote the flow path. $\ .$	10		
2.4	Use of the electric resistance method to find UA for a 1-D, steady-state pipe	11		
2.5	Overall energy balances for the hot and cold fluids of a two-fluid heat exchanger.	12		
2.6	Temperature distributions for a counterflow heat exchanger	15		
2.7	Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS			
	for the specific heat capacity of sodium	22		
2.8	Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS			
	for the density of sodium	23		
2.9	Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS			
	for the dynamic viscosity of sodium	24		
2.10	Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS			
	for the thermal conductivity of sodium	25		
3.1	Dump Heat Exchanger for the FastFlux Testing Facitlity.[5]	26		
3.2	Schematic of the Dump Heat Exchanger on Monju. [9]	27		
3.3	Simplified version of a single tube within the tube bank.			
3.4	Primary and Secondary loop of reactor with a single IHX and a single DHX.			
	Model created in HYSYS	29		
3.5	Specification of pipe to solve within HYSYS	30		

3.6	Tube bundle alignment a) Aligned b) Staggered [11]	31
3.7	Calculated values for UA using two different methods to confirm initial look	32
3.8	Changing the humidity of the air on the Dump Heat Exchanger and comparing	
	the NTU and Effectiveness.	34
3.9	Changing the temperature of the air on the Dump Heat Exchanger and com-	
	paring the NTU and Effectiveness.	35
3.10	Changing the flow rate of the air on the Dump Heat Exchanger and comparing	
	the NTU and Effectiveness.	35
4.1	Pressure drop as a function of the inner diameter of the pipe, which contains	
	so dium, and length in meters of a single annulus. \hdots	37
4.2	Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of	
	1.641 MW. The total number of double pipe heat exchanges would be around	
	25	39
4.3	Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of	
	0.4 MW. The total number of double pipe heat exchangers would be around	
	100	40
4.4	Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of	
	0.2 MW. The total number of double pipe heat exchangers would be around	
	200	40
4.5	Geometry of shell-and-tube with 100 tubes	42
4.6	Temperature, pressure, and mass flow rate for the shell-and-tube that contains	
	100 tubes	43
4.7	Geometry of shell-and-tube with 150 tubes	44
4.8	Temperature, pressure, and mass flow rate for the shell-and-tube that contains	
	150 tubes	44
5.1	Total footprint of the potential heat exchangers in m^2	47
5.2	Volume of material needed to create each potential heat exchanger	48
B.1	Final HYSYS model of $1/12$ of the PRISM loop(final project.1)	58
B.2	Annulus Heat Exchanger model designed in HYSYS for 25 tubes	72
B.3	Shell and Tube heat exchanger models in HYSYS	81

LIST OF ACRONYMS

- ATR Advanced Test Reactor
- **ANL** Argonne National Laboratory
- \mathbf{DHX} Dump Heat Exchanger
- EM2 Energy Multiplier Module
- **FFTF** Fast Flux Testing Facility
- **INL** Idaho National Laboratory
- JHR Jules Horowitz Reactor
- **MBIR** Multipurpose fast-neutron research reactor
- **PRISM** Power Reactor Innovative Small Module
- **VTR** Versatile Test Reactor

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The United States has primarily used nuclear reactors, for energy and research that operate in the Thermal Energy range. New instrumentation, fuels, and other advancements need to be tested before they can be implemented into commercial reactors. Currently, they are tested at the Advanced Test Reactor (ATR), at the Idaho National Laboratory (INL). However, there is a lack of ability to test these new advancements in the fast neutron range. Without this ability, companies such as TerraPower, Westinghouse, and General Atomics Energy Multiplier Module (EM2) cannot test their newest ideas for the fast reactor technology. Thus, a versatile testing facility is needed. There are currently two facilities being built outside of the US, the Jules Horowitz Reactor (JHR) in France, and Multipurpose fast-neutron research reactor (MBIR) in Russia, see Figure 1.1.[1]



Figure 1.1: Render of what the MBIR could look like.

The ATR is capable of testing within the thermal range. However, it might not be able to fulfill all of the thermal testing needs in the future [1]. For example, TerraPower is developing molten salt cooled reactors, Figure 1.2, and testing components in the ATR may be difficult.





Designing a test facility to operate for several decades is costly. This test reactor will need to be highly reconfigurable to test in the Fast and Thermal neutron ranges. The INL said, "A domestic versatile neutron irradiation facility will be a critical tool to enable rapid innovation in the US: it will serve to do performance testing of new fuels and materials, and it will provide the data needed for establishing a science based accelerating testing capability that will give our industry a strong competitive advantage." [1]

1.1.1 WHAT IS THE VERSATILE TEST REACTOR?

The DOE-NE established the following requirements for a Versatile Test Reactor (VTR): [1]

1. The reactor will provide a fast flux irradiation environment prototypical of potential

fast reactor designs:

- (a) The fast flux level will be equivalent to that of existing fast test reactors i. At least $4x10^{15}n/cm^2 * s$
- (b) The irradiation environment should be able to change, and accommodate several potential reactor coolants
- (c) The irradiation volume will be able to accommodate a volume equivalent to a fuel assembly
- (d) Several different irradiation vehicles will be allowed:
 - i. Loops
 - ii. Instrumented assemblies
 - iii. Test samples
- (e) Experimental capabilities should enable both integral "traditional" testing, and science-based testing
- 2. The reactor will provide thermal and epithermal flux irradiation environments complementary of those of ATR and HFIR:
 - (a) The thermal flux level will be equivalent to that of ATR
 - i. At least $5x10^{14}n/cm^2 * s$
 - (b) The irradiation volume will be equivalent to that of ATR
 - (c) The irradiation environment should allow for irradiations that are not possible today in ATR and HFIR, inluding loops with various coolants.
- 3. Other possibilities, including beam tubes for scientific experiments, irradiation vehicles for isotope production, support for code validation, and support for reactor technology demonstration will need to be studied during the pre-conceptual design phase.

The VTR is at its basic rendering, a coupled reactor. A coupled reactor works within the thermal neutron energy range as well as in the fast neutron energy range. Figure 1.3 gives a diagram of a coupled reactor operating in both the thermal and fast ranges. The draft core layout of the VTR, Figure 1.4, will use the fast neutron flux in the center test



Figure 1.3: Illustration of a coupled reactor (0- outer reflector; 1- thermal annular core; 2- inner reflector; 3- thermal neutron filter; 4- fast core)

locations and the thermal flux in the outer locations. This is characterized by the neutron multiplicity of each zone and there are four parameters that help define what happens.

- 1. k_F : average number of next generation neutrons in fast zone resulting from a single fission neutron in fast zone
- 2. k_T : average number of next generation neutrons in thermal zone resulting from a single fission neutron in thermal zone
- 3. k_{FT} : average number of next generation fission neutrons in thermal zone resulting from a single fission neutron in fast zone
- 4. k_{TF} : average number of next generation fission neutrons in fast zone resulting from a single fission neutron in thermal zone

If the two zones are far enough apart, then each zone needs to be critical by itself, ie the zones are critical if $k_F = 1$ and $k_T = 1$. However, if they are neutronically coupled, then each zone individually would be subcritical, $k_F < 1$ and $k_T < 1$, and the coupled system is critical only when their coupling coefficients when multiplied together are equal to the product of their local subcriticality's (1 - k).[2]

$$k_{FT}k_{TF} = (1 - k_F)(1 - k_T) \tag{1.1}$$

The power of the coupled system would then be a ratio of how each zone reacts to the changes within it.

$$\frac{P_F}{P_T} = \frac{k_{TF}}{(1-k_F)} = \frac{(1-k_T)}{k_{FT}}$$
(1.2)

Based on this relation it can be said that the further the values of k_F and k_T are from 1 and the closer the values of k_{FT} and k_{TF} are to 1 the system is more stable. This has great importance to the design process about the operation and the safety of the reactor.



Figure 1.4: VTR draft core layout. The fast neutron region will be at the center and the thermal neutron region will be towards the outside of the driver fuel area.[3]

In 2018, the US decided to have General Electric's Power Reactor Innovative Small Module (PRISM) reactor to be used for the VTR. It is a liquid-metal reactor that is cooled by sodium. GE's initial design was developed during the 1980s. In 2006, the reactor was redesigned to recycle spent fuel and could be connect to more than one reactor. [4]

The PRISM is a liquid-metal, pool type of reactor. It is rated at 840 MWth and 311 MWe. Table 1 shows the basic thermal information about the reactor. Each PRISM transfers heat via an intermediate heat exchanger from the primary sodium loop to a secondary loop of sodium [4]. If the reactor was to be used for commercial use, the secondary loop would then transfer heat to a water/steam loop that would go through a generator and a conventional turbine to create electricity, as seen in Figure 1.5. However, the VTR is a test facility, therefore the secondary loop will pass through a set of Sodium to Air Dump Heat Exchangers. Figures 1.6 and 1.7 show the two thermal loops of the testing facility.



Figure 1.5: Schematic of the Thermal Loop of the PRISM reactor.[4]

Table 1.1: PRISM's specifications.[4]

Thermal Power	$840 \mathrm{MW}$
Primary Sodium Inlet/Outlet Temperatures	$360^{\circ}C (680^{\circ}F) / 499^{\circ}C (930^{\circ}F)$
Primary Sodium Flow Rate	$5.4 \ m^3/s \ (86000 \ gal/min)$
Secondary Sodium Inlet/Outlet Temperatures	$326^{\circ}C (619^{\circ}F) / 477^{\circ}C (890^{\circ}F)$
Secondary Sodium Flow Rate	$5.1 \ m^3/s \ (80180 \ gal/min)$



Figure 1.6: Schematic of Heat Removal Facilities. [5]



Figure 1.7: Plan View of Heat Transport System. [5]

CHAPTER 2: THEORY

2.1 Heat Exchangers

2.1.1 Types

There are three types of flow arrangements that heat exchangers utilize: parallel flow, Figure 2.1, counterflow, Figure 2.2, and cross-flow, Figure 2.3. Parallel flow is when the flow of hot and cold fluids flow in the same direction. Counterflow is when the hot and cold fluids flow in opposite directions. Finally, the cross-flow is when the cold fluid flows perpendicular to the hot fluid.

There are different construction designs that are used. The very basic and the one that all other heat exchangers are compared to is a concentric tube, or double-pipe, design. This design allows for either parallel or counterflow. Another type is the shell-and-tube construction. This is where many tubes are surrounded by a single shell and the tubes can pass back and forth several times within the shell. This construction type only allows for counter and parallel flow arrangements. Finally, the cross-flow design. These designs are tubular heat exchangers that either have fins or no fins. The use of fins determines how the flow looks, either mixed or unmixed.



Figure 2.1: Parallel-flow concentric tube heat exchanger. Arrows denote the flow path.

2.1.2 Overall Heat Transfer Coefficient

The overall heat transfer coefficient is related to the total thermal resistance between two fluids. During normal operation, the heat exchanger surfaces experience fouling, such



Figure 2.2: Counter-flow concentric tube heat exchanger. Arrows denote the flow path.

as fluid impurities, rust formation, or other reactions between the fluid and the wall. To account for this, the overall heat transfer coefficient includes the parameter R_f , or the fouling factor. Fouling increases the resistance. In addition, if there is more surface area exposed to the fluid, by adding fins, it will decrease the overall resistance. The overall heat transfer coefficient can be expressed in the following equation

$$\frac{1}{UA} = \frac{1}{U_c A_c} = \frac{1}{U_h A_h} = \frac{1}{(\eta_0 A)_c} + \frac{R''_{f,c}}{(\eta_0 A)_c} + R_w + \frac{R''_{f,h}}{(\eta_0 A)_h} + \frac{1}{(\eta_0 A)_h}$$
(2.1)

where c and h refer to the cold and hot fluids. This generalized equation also includes the overall surface efficiency, η_0 . If fouling can be neglected, the heat transfer rate would look like

$$Q = \eta_0 h A (T_b - T_\infty) \tag{2.2}$$

where T_b is the base surface temperature and A is the total exposed surface area. To calculate η_0 , the following equation can be used.

$$\eta_0 = 1 - \frac{A_f}{A} (1 - \eta_f) \tag{2.3}$$

where the subscript f are fin parameters. If the assumption is made that there are no fins for a tubular heat exchanger, Equation 2.1 simplifies to



Figure 2.3: A cross section of a cross-flow heat exchanger. Arrows denote the flow path.

$$\frac{1}{UA} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{h_i A_i} + \frac{R''_{f,i}}{A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{R''_{f,o}}{A_o} + \frac{1}{(h_o A_o)}$$
(2.4)

This simplification comes from an assumption that it is 1-Dimensional and at steadystate. Figure 2.4, shows the 1-D, Steady-State drawing for a pipe that uses the resistance method to find UA. Each resistance, R_1 , R_2 , and R_3 , depict a different mode of heat transfer. R_1 is the heat transfer mode of convection from the fluid to the surface of the pipe and is defined as Equation 2.5. R_2 is the conduction between the walls of the pipe, see Equation 2.6, and Equation 2.7, or R_3 is the convection from the pipe surface to the outside fluid.



Figure 2.4: Use of the electric resistance method to find UA for a 1-D, steady-state pipe.

$$R_1 = \frac{1}{h_i A_i} \tag{2.5}$$

$$R_2 = \frac{\ln(r_0/r_i)}{2\pi kL} = \frac{\ln(D_0/D_i)}{2\pi kL}$$
(2.6)

$$R_3 = \frac{1}{h_o A_o} \tag{2.7}$$

Using the resistance method, the UA is just the addition of all the resistance terms

$$\frac{1}{UA} = R_{Total} = R_1 + R_2 + T_3 + \frac{R''_{f,i}}{A_i} + \frac{R''_{f,o}}{A_o}$$
(2.8)

Adding in the resistance equations from above, Equation 2.4 comes out. For the rest of the thesis, the assumption that no fouling takes place is made; therefore, the R''_{f} terms drop out of the equation for UA and leaves the equation as

$$\frac{1}{UA} = \frac{1}{U_i A_i} = \frac{1}{U_o A_o} = \frac{1}{h_i A_i} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{(h_o A_o)}$$
(2.9)



Figure 2.5: Overall energy balances for the hot and cold fluids of a two-fluid heat exchanger.

To figure out the effectiveness of a heat exchanger, it is necessary to know the maximum possible heat transfer, \dot{Q}_{max} . To find out what \dot{Q}_{max} is, we must first define what the heat transfer equation is, \dot{Q} . This can be found by using the following equations and Figure 2.5.

$$\dot{Q} = \dot{m}_h (i_i - i_o)_h \tag{2.10}$$

and

$$\dot{Q} = \dot{m}_c (i_o - i_i)_c \tag{2.11}$$

where i is the fluid enthalpy and h and c refer to hot and cold fluids. The subscripts "i" and "o" refer to inlet and outlet conditions. With the assumption that the specific heats are constant, the equations become

$$\dot{Q} = \dot{m}_h c_{p,h} (T_i - T_o)_h$$
 (2.12)

and

$$\dot{Q} = \dot{m}_c c_{p,c} (T_o - T_i)_c$$
 (2.13)

these equations can be further simplified if the mass flow rate and the specific heat are

combined to form heat capacity rates

$$Q = C_h (T_i - T_o)_h \tag{2.14}$$

and

$$Q = C_c (T_o - T_i)_c \tag{2.15}$$

Now that we have defined the equations for Q, we can now look at what Q_{max} is. From the equations above, there is a temperature difference. For Q_{max} the temperature difference is the maximum difference, and it so happens that the max happens between the two inlets, or $T_{h,i} - T_{c,i}$. With the use of two fluids, there could be two different combinations to make the max heat transfer.

$$Q_{max} = C_c (T_{h,i} - T_{c,i})$$
(2.16)

This equation is used when $C_c < C_h$. However, when the hot fluid's heat capacity is less than the cold fluid, $C_c > C_h$, we can use

$$Q_{max} = C_h (T_{h,i} - T_{c,i})$$
(2.17)

So, it can be said that

$$Q_{max} = C_{min}(T_{h,i} - T_{c,i})$$
(2.18)

where C_{min} is equal to which ever heat capacity is smaller. The smallest heat capacity, C_{min} , is used primarily because the fluid that has the smallest C values will have the maximum heat transfer. The maximum heat transfer occurs when the minimum capacity fluid has the maximum temperature difference. If the maximum capacity fluid were used it would calculate a duty that the minimum side could never achieve. Seeing as a fluid will not experience the max heat transfer, it is necessary to define how effective the heat transfer was. This can be done by dividing the heat transfer done by the max that could be done.

$$\epsilon \equiv \frac{Q}{Q_{max}} \tag{2.19}$$

If we then expand the equations for both Q and Q_{max} , we get

$$\epsilon = \frac{C_c (T_o - T_i)_c}{C_{min} (T_{h,i} - T_{c,i})}$$
(2.20)

or

$$\epsilon = \frac{C_h (T_i - T_o)_h}{C_{min} (T_{h,i} - T_{c,i})}$$
(2.21)

Based on the definition of effectiveness above, the effectiveness, ϵ , is between the values of 0 to 1. It can also be said that the heat transfer can be found using effectiveness and the maximum heat transfer.

From Kays and London's <u>Compact Heat Exchanger</u> book [6], they use a definition for effectiveness that follows

$$\epsilon = f\left(NTU, \frac{C_{min}}{C_{max}}\right) \tag{2.22}$$

where C_{min}/C_{max} is either C_h/C_c or C_c/C_h , depending on their respective magnitudes. NTU stands for the number of transfer units and is a dimensionless parameter that is defined as

$$NTU = \frac{UA}{C_{min}} \tag{2.23}$$

NTU signifies how much "number of units" of heat the given heat exchanger is capable of transferring from one fluid to another. The larger the NTU value, the bigger the heat exchanger.

The NTU- ϵ method is primarily used when the outlet temperatures are not known. When those temperatures are known, the method known as the Log Mean Temperature Difference (LMTD) is used. The LMTD is the mean temperature between the hot and cold fluids and is found by using the following equation for a counterflow heat exchanger design.

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{ln(\Delta T_2/\Delta T_1)} \tag{2.24}$$

where

$$\Delta T_2 = T_{h,i} - T_{c,o} \tag{2.25}$$

$$\Delta T_1 = T_{h,o} - T_{c,i} \tag{2.26}$$

To use the LMTD method, the heat transfer equation used is

$$\dot{Q} = UA\Delta T_{lm} * F \tag{2.27}$$

where the F is a correction factor based on the design and is found in figures in most heat transfer books.

2.1.3.1 Example of Effectiveness-NTU Method



Figure 2.6: Temperature distributions for a counterflow heat exchanger

To determine a specific form of the effectiveness-NTU relation, consider a counter-flow heat exchanger for which $C_{min} = C_c$. We start off with the following equations

$$d\dot{Q} = U\Delta T dA \tag{2.28}$$

and

$$\Delta T \equiv T_h - T_c \tag{2.29}$$

change the above equation to look at a small change versus a large change

$$d(\Delta T) = dT_h - dT_c \tag{2.30}$$

To find dT_h and dT_c we use

$$d\dot{Q} = \dot{m}c_p dT \tag{2.31}$$

Apply this equation for the hot fluid

$$d\dot{Q} = \dot{m}_h c_{p,h}(-dT_h) = C_h(-dT_h)$$
 (2.32)

the dT_h is negative, due to the slope found in figure 2.6. Now solving for dT_h we get

$$dT_h = -\frac{d\dot{Q}}{C_h} \tag{2.33}$$

Similarly, we now look at the cold fluid

$$d\dot{Q} = \dot{m}_c c_{p,c}(-dT_c) = C_c(-dT_c)$$
 (2.34)

$$dT_c = -\frac{d\dot{Q}}{C_c} \tag{2.35}$$

Imputing dT_h and dT_c back into the original equation we now get

$$d(\Delta T) = -\frac{d\dot{Q}}{C_h} + \frac{d\dot{Q}}{C_c} = -\frac{d\dot{Q}}{C_c} \left[\frac{C_c}{C_h} - 1\right]$$
(2.36)

We now make four assumptions.

1. $C_c = C_{min}$

- 2. $C_h = C_{max}$
- 3. $C_r = C_{min}/C_{max}$
- 4. $dQ = UdA\Delta T = U\Delta TPdL$
- 5. Assume Steady-State and 1-Dimensional

where P is the perimeter.

Adding our assumptions to the equation we get

$$d(\Delta T) = -\frac{UdA\Delta T}{C_{min}} \Big[C_r - 1 \Big]$$
(2.37)

Collect similar terms to each side then integrate

$$\int_{\Delta T_1}^{\Delta T_2} \frac{1}{\Delta T} d(\Delta T) = -\frac{U}{C_{min}} \Big[C_r - 1 \Big] * \int dA$$
(2.38)

$$ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = \frac{UA}{C_{min}} \left[1 - C_r\right] = NTU \left[1 - C_r\right]$$
(2.39)

Now using algebra we get rid of the natural log. We also want to multiply both sides by a -1.

$$\frac{\Delta T_1}{\Delta T_2} = EXP(-NTU(1-C_r)) \tag{2.40}$$

From Figure 2.6 we get the values for ΔT_1 and ΔT_2 by looking at the differences at the right and left of the temperature profiles.

$$\frac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}} = EXP(-NTU(1 - C_r))$$
(2.41)

To find the values for the outlet conditions, we go back to the equation

$$\epsilon = \frac{q}{q_{max}} = \frac{C_h(T_{h,i} - T_{h,o})}{C_{min}(T_{h,i} - T_{c,i})} = \frac{C_c(T_{c,o} - T_{c,i})}{C_{min}(T_{h,i} - T_{c,i})}$$
(2.42)

Working with the hot fluid first we can solve for $T_{h,o}$

$$\epsilon = \frac{C_h(T_{h,i} - T_{h,o})}{C_{min}(T_{h,i} - T_{c,i})}$$

$$\epsilon = \frac{C_{max}}{C_{min}} \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$$

$$\epsilon = \frac{1}{C_r} \frac{T_{h,i} - T_{h,o}}{T_{h,i} - T_{c,i}}$$

$$\epsilon C_r(T_{h,i} - T_{c,i}) = T_{h,i} - T_{h,o}$$

$$T_{h,o} = T_{h,i} - \epsilon C_r(T_{h,i} - T_{c,i})$$
(2.43)

Similarly we do this to find $T_{c,o}$

$$\epsilon = \frac{C_{c}(T_{c,o} - T_{c,i})}{C_{min}(T_{h,i} - T_{c,i})}$$

$$\epsilon = \frac{C_{min}}{C_{min}} \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}}$$

$$\epsilon = \frac{T_{c,o} - T_{c,i}}{T_{h,i} - T_{c,i}}$$

$$\epsilon(T_{h,i} - T_{c,i}) = T_{c,o} - T_{c,i}$$

$$T_{c,o} = T_{c,i} + \epsilon(T_{h,i} - T_{c,i})$$
(2.44)

Putting the values for the outlet conditions back into equation 2.32,

$$\frac{T_{h,i} - (T_{c,i} + \epsilon(T_{h,i} - T_{c,i}))}{(T_{h,i} - \epsilon C_r(T_{h,i} - T_{c,i})) - T_{c,i}} = EXP(-NTU(1 - C_r))$$
(2.45)

It simplifies down to

$$\frac{T_{h,i} - T_{c,i} - \epsilon(T_{h,i} - T_{c,i})}{T_{h,i} - T_{c,i} - \epsilon C_r(T_{h,i} - T_{c,i})} = EXP(-NTU(1 - C_r))$$
(2.46)

Pull out like terms

$$\frac{(T_{h,i} - T_{c,i})(1 - \epsilon)}{(T_{h,i} - T_{c,i})(1 - \epsilon C_r)} = EXP(-NTU(1 - C_r))$$
(2.47)

The new equation becomes

$$\frac{1-\epsilon}{1-\epsilon C_r} = EXP(-NTU(1-C_r)) \tag{2.48}$$

Solving for ϵ

$$1 - \epsilon = EXP(-NTU(1 - C_r)) - \epsilon C_r EXP(-NTU(1 - C_r))$$
(2.49)

$$1 - EXP(-NTU(1 - C_r)) = \epsilon - \epsilon C_r EXP(-NTU(1 - C_r))$$
(2.50)

$$1 - EXP(-NTU(1 - C_r)) = \epsilon (1 - C_r EXP(-NTU(1 - C_r)))$$
(2.51)

$$\epsilon = \frac{1 - EXP(-NTU(1 - C_r))}{1 - C_r EXP(-NTU(1 - C_r))}$$
(2.52)

Similarly, we could perform this same process for any orientation of heat exchanger. However, for simplicity, these effectiveness equations can be found in any undergraduate heat transfer book, for example in Incropera and Dewit's <u>Introduction to Heat Transfer</u> book, in Table 11.3 [7]. The equations of note from this table are for the shell-and-tube and cross-flow heat exchangers.

The shell-and-tube equation that has one pass and several tube passes is

$$\epsilon = 2 \left[1 + C_r + (1 + C_r^2)^{1/2} * \frac{1 + EXP[-NTU(1 + C_r^2)^{1/2}]}{1 - EXP[-NTU(1 + C_r^2)^{1/2}]} \right]^{-1}$$
(2.53)

The cross-flow heat exchanger has three different equations based upon how the fluids are behaving. For the work done with this thesis, it was assumed that one side was mixed and the other unmixed. Seeing as there were two equations that could work, a back of the envelope calculation was done to determine which equation was going to be used. It was found that the equation where C_{max} was mixed and C_{min} was unmixed was to be chosen.

$$\epsilon = \left(\frac{1}{C_r}\right) (1 - exp[-C_r(1 - EXP(-NTU))]) \tag{2.54}$$

2.2 VERIFICATION OF SODIUM PROPERTIES

One of the main concerns of using any simulation software, are the properties for the fluid. Within HYSYS there is a property bank; however, sodium is not part of the that bank. So properties were put into HYSYS then verification studies were done to make sure that the properties were usable. ASPEN, the company that owns HYSYS, also owns a program called ASPEN PLUS. This program is more centered on chemical processes and does include a sodium property option. Because both programs were available, HYSYS can use the properties from ASPEN PLUS. The verification studies are a comparison between Argonne National Laboratory (ANL), data, the ASPEN PLUS, and what is called a Hypothetical property in HYSYS. A Hypothetical is a way of creating properties in HYSYS.

To create a Hypothetical, property information must be known for the following: boiling point, molecular weight, and the critical temperature and pressure. These values were found in an ANL document, [8]. Once these values are specified, HYSYS can then estimate the equations to use for property information. After the estimation is complete, a fluid package is chosen. For the hypothetical of sodium, NRTL was chosen. Once chosen, data from ANL was used to correct each property.

The properties that were chosen to enhance the accuracy of the hypothetical, were liquid density, liquid viscosity, heat capacity, thermal conductivity, liquid enthalpy, and surface tension. A temperature range from 400 kelvin to 2400 kelvin was chosen for the properties. This range was chosen because the ANL provided data for all necessary properties at these temperature. Once the data was inputted, HYSYS fit the said data by using pre-programmed equations.. Using a polynomial trendline, each of the equations were found; each of the trendlines had a correlation coefficient or R^2 value of at least 0.999.

$$\rho = -6E - 11 * T^4 + 3E - 07 * T^3 - 0.0005 * T^2 + 0.1479 * T + 922.06$$
(2.55)

Equation 2.55 shows the equation for the density, where T is the temperature in kelvin.

$$C_{p} = 2.3E - 26 * T^{9} - 2.8E - 22 * T^{8} + 1.5E - 18 * T^{7} - 4.3E - 15 * T^{6} + 7.7E - 12 * T^{5} - 8.8E - 9 * T^{4} + 6.4E - 6 * T^{3} - 2.8E - 3 * T^{2} + 0.6967 * T - 70.142$$
(2.56)

$$k = -1.2E - 8 * T^{3} + 5.5E - 5 * T^{2} - 0.114 * T + 124.757$$

$$(2.57)$$

Equation 2.56 is the equation for the specific heat capacity, equation 2.57 is for the thermal conductivity.

$$\mu = -1.9E - 22 * T^{6} - 1.9E - 18 * T^{5} + 7.4E - 15 * T^{4}$$

- 1.5E - 11 * T³ + 1.7E - 8 * T² - 1.006E - 5 * T + 0.0027 (2.58)

$$s = -1.04E - 6 * T^{2} + 0.00555 * T + 1.5096$$
(2.59)

$$h = 1.13E - 9 * T^{4} - 5.42E - 6 * T^{3} + 8.68E - 3 * T^{2} - 3.8997 * T - 2131.2$$
 (2.60)

Similarly, equations 2.58, 2.59, and 2.60 are for the viscosity, mass entropy, and mass enthalpy, respectively. To show how these properties comapred to the original ANL data as well as the properties found in ASPEN PLUS, the specific heat capacity, density, viscosity, and thermal conductivity were compared. Figures 2.7, 2.8, 2.9, and 2.10 show the results of these comparisons. As seen in these figures, the hypothetical was more accurate to the ANL data than that of the ASPEN PLUS. Thus, for the rest of the modeling, the hypothetical will be used for all sodium properties.



Figure 2.7: Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS for the specific heat capacity of sodium



Figure 2.8: Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS for the density of sodium



Figure 2.9: Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS for the dynamic viscosity of sodium



Figure 2.10: Comparison of data from ANL, ASPEN PLUS, and a Hypothetical in HYSYS for the thermal conductivity of sodium

CHAPTER 3: FAST FLUX TESTING FACILITY'S HEAT EXCHANGER ANALYSIS

3.1 INTRODUCTION

The focus of this document will be to analyze the dump heat exchanger found on Figure 1.7. This heat exchanger type is a cross-flow heat exchanger that will have the sodium going through the tubes and air being forced over them with a fan. This dump heat exchanger has been previously designed to look like Figure 3.1. This heat exchanger is very similar to the heat exchanger on Monju in Japan, Figure 3.2.



Figure 3.1: Dump Heat Exchanger for the FastFlux Testing Facitlity.[5]

The heat exchanger is used to cool the hot coolant, sodium, with a forced flow of air. The sodium will enter the heat exchanger via a tube with four-passes that are 30 ft long each and are connected by 180-degree returns and contains fins around the tube [5]. Figure 3.1 shows how this exchanger was designed. There are 66 of these tubes that are in the tube bank. The size of the fins nor the arrangement of the heat exchanger was



Figure 3.2: Schematic of the Dump Heat Exchanger on Monju. [9]

given, the tubes were simplified to have no fins as shown in Figure 3.3. Within the same report that the design of the tubes was found, there were initial conditions of the heat exchanger. These values are found in Table 3.1.

3.2 Methods and Materials

To view the design to its full extent, the primary and secondary loop of this test reactor set-up was modeled in ASPEN HYSYS, as shown in Figure 3.4. HYSYS has parameters that need to be modified to make sure that everything is modeled correctly. First, HYSYS does not contain the thermal and fluid properties of sodium. Thus, one had to be made. ANL published a document of the properties of sodium [8]. Next, using the ANL sodium
Duty	33 MW
Air Inlet Temp	$90^{\circ}\mathrm{F}$
Air Mass Flow	$2.25x10^6$ lb/hr
Air Fan Motor	1250 hp
Δ P Air	11 in of H20
Sodium Inlet Temp	1000°F
Sodium Volume Flow	3625 USGal/min

Table 3.1: Initial Conditions of the Dump Heat Exchanger found on the FFTF.[5]



Figure 3.3: Simplified version of a single tube within the tube bank.

properties within HYSYS, the pressure drop across a single tube was calculated using HYSYS' pipe module, see Figure 3.5. The given the geometric parameters, material of the pipe, and the heat transfer conditions, the module can estimate the pressure drop.

The default heat exchanger within HYSYS is a counter flow heat exchanger and therefore parameters such UA, NTU, and mean temperature difference are evaluated. The DHX is a cross-flow heat exchanger. To obtain the correct values for UA, NTU and ΔT , equation 3.1 found in Incropera and DeWitt's heat transfer book was used [7]. This is equation 2.45 rearranged to solve for NTU.

$$NTU = -ln(1 + \left(\frac{1}{C_r}\right)ln(1 - \epsilon C_r)$$
(3.1)

The comparison of what HYSYS calculated with the heat exchanger module and what the true values should be are in Table 3.2.

To try and match the UA value that HYSYS calculated, a design approach was used in an embedded spreadsheet. An embedded spreadsheet is like an Excel spreadsheet but has the ability to use the thermal and fluid properties in HYSYS. First thing that had to



Figure 3.4: Primary and Secondary loop of reactor with a single IHX and a single DHX. Model created in HYSYS.

Table 3.2: Values of UA, NTU, and ΔT for the heat exchanger calculated from HYSYS and correcting the values to accommodate for it being a cross-flow heat exchanger.

Variable	HYSYS Calculated	Cross-flow Value
UA	86.0 kJ/C-s	92.18 kJ/C-s
NTU	-	0.3626
ΔT	383.6°C	$358^{\circ}\mathrm{C}$

be looked at was the tube arrangement. Figure 3.6 shows the two arrangements of the tube bundle. Upon further research, most tube bundles that have a high number of tubes are staggered, therefore, it will be assumed that the bundle is staggered. Furthermore, due to the large number of tubes, 66, we can use the following equation for finding the average Nusselt number [10]

$$Nu_f = C * Re_{D,max}^m * Pr_f^{0.36} * (Pr_f/Pr_w)^{0.25}$$
(3.2)

where C and m are constants that are found in the Table 3.3. Also note that Pr_w is the Prandtl number found using the properties found with the wall temperature. The Nusselt number is the measure of convection heat transfer at the surface of where the heat transfer is taking place.

	Sodium			
	Inlet	Inside Diameter(1)	1.834	in
Q Pipe	ł.	Outside Diameter(1)	2.000	in
	1	Pipe Length(1)	30.00	ft
		Feed Temperature	1000	F
	Single	Product Temperature	766.2	F
	Tube	Feed Pressure	109.1	psia
		Product Pressure	106.0	psia
		Mass Flow	2.242e+004	lb/hr
S	dium	Overall Pressure Drop	3.133	psi
ŏi	utlet			

Figure 3.5: Specification of pipe to solve within HYSYS.

The Reynolds number here is found at the maximum fluid velocity. However, there are two places where the maximum velocity can happen on a staggered bundle, at the transverse plane, A_1 , or the diagonal plain, A_2 [10]. The equation for the transverse plain is

$$V_{max} = \frac{S_T}{S_T - D} V \tag{3.3}$$

Whereas the diagonal plain maximum velocity can be found by

$$V_{max} = \frac{S_T}{2(S_D - D)}V$$
(3.4)

Using the maximum velocity, it is put into the Reynolds number equation

$$Re_{D,max} = \frac{\rho V_{max} D}{\mu} \tag{3.5}$$

The Reynolds number is the ratio of the inertia and viscous forces. This means that the lower the number, the calmer the flow. The higher the number, the more turbulent.

It is also known that the Prandtl number can be found by

$$Pr_f = \frac{\mu c_p}{k} = \frac{\nu}{\alpha} \tag{3.6}$$



Figure 3.6: Tube bundle alignment a) Aligned b) Staggered [11]

The Prandtl number is the ratio of the momentum and thermal diffusivities. The smaller the number means that the temperature boundary layer will develop first, while the velocity boundary layer will develop slower. Similarly, as the Prandtl number increases in values the boundary layers develop opposite, the velocity boundary layer develops first and is followed by the temperature boundary layer.

Configeration	Reynold's Number	С	m
	1.6 - 40	1.04	0.4
	40 - 1000	0.71	0.5
Staggered	1000 - 200000**	$0.35 * (S_T/S_L)^{0.2}$	0.6
	1000 - 200000	0.4	0.6
	200000 - 2000000	$0.031 * (S_T/S_L)^{0.2}$	0.8
	1.6 - 100	0.9	0.4
In line	100 - 1000	0.52	0.5
III-IIIIe	1000 - 200000	0.27	0.63
	200000 - 2000000	0.033	0.8
$\frac{**S_{T}}{S_{T}} < 2$			

Table 3.3: Constants for the average Nusselt number for air.

 $S_T/S_L < 2$

Once we calculate the Nusselt number, the heat transfer coefficient can be calculated by

$$h_o = \frac{Nu * k}{D_o} \tag{3.7}$$

For the inside of the tubes, to find the average Nusselt number the following equation was used.

$$Nu = 4.82 + 0.185 Pe^{0.827} \tag{3.8}$$

where Pe = RePr. We then use the same relationship found in Equation 11 to find the heat transfer coefficient for the inside of the tubes. From here, the UA can be found by using the following

$$U_o A_o = \left(\frac{1}{h_o A_o} + \frac{\ln(D_o/D_i)}{2\pi kL} + \frac{1}{h_i A_i}\right)^{-1}$$
(3.9)



where the $A = 2\pi D$.

Figure 3.7: Calculated values for UA using two different methods to confirm initial look.

Figure 3.7 shows the values that were obtained using this method. From this calculation, the values for *Uoutside* do not match. Thus, the correction factor method was used to try and confirm the numbers. These numbers seemed to match up; however, further investigation into the Effectiveness-NTU method will be done later on. From here, work will be made to look for improvements of the DHX.

Upon finishing the cross-flow heat exchanger in HYSYS, a discrepancy was found with the heat exchanger itself. Using the simple relationship of duty and the change of temperature, I was able to find the correct values, either for mass flow rate or for the duty. The equation for duty is as follows

$$\dot{Q} = \dot{m}c_p \Delta T \tag{3.10}$$

If the Duty is correct and the inlet and outlet temperatures of the sodium side are achieved, we get a corrected mass flow rate of

$$33MW = \dot{m} * 1.361 \frac{kJ}{kgC} * (1000^{\circ}F - 830^{\circ}F)$$

$$\dot{m} = 253 \frac{kg}{s}$$
(3.11)

If the mass flow rate is correct and the inlet and outlet temperatures of the sodium side are achieved, we get a corrected duty of

$$\dot{Q} = 186.5 \frac{kg}{s} * 1.361 \frac{kJ}{kgC} * (1000^{\circ}F - 830^{\circ}F)$$

= 24.32MW (3.12)

3.3 PARAMETRIC STUDIES - HUMID AIR

Once the heat exchanger was modeled in HYSYS, some parametric studies were done on the air side. There were three different parametric studies: the air mass flow rate, the humidity, and the temperature at which the air enters.

The first study was to see how the humidity of the air would effect the NTU and efficiency of the heat exchanger. To run this study, humidity was taken from 0 to 100% humid at increments of 10%. This would allow for the effects of air from a desert to that of air from a jungle. Figure 3.8, shows the results of this parametric study. As the humidity increased, the NTU increased but the efficiency decreased. Looking at the values of NTU and effectiveness in Figure 3.8, it can be seen that the changes to both the effectiveness and the NTU happen in the fourth decimal place. This means that humidity doesn't affect performance of the heat exchanger; therefore changing the humidity becomes negligible.

The second study looked at the temperature effect on the air. The range of temperature that was looked at was from 10°C to 60°C. This can be seen in Figure 3.9. As seen in the figure, the higher the temperature is, the more advantageous it is to the heat exchanger's operation. It both increases the efficiency and the NTU value. From this



Figure 3.8: Changing the humidity of the air on the Dump Heat Exchanger and comparing the NTU and Effectiveness.

study, changing the temperature has a negligible effect seeing as the change to the NTU and the effectiveness both take place in the fourth decimal place.

Finally, the flow rate of the air was studied. It was determined that the range of the study would be from 200 kg/s to 340 kg/s. This would encompass the original value as well as going below and above to get some idea of what would happen. Figure 3.10, shows the results of the study. The slower the speed the better the values of efficiency and NTU are. This is because it allows for more heat to be transferred to the air as it travels through the heat exchanger. Based on these results slowing down the flow rate would greatly increase how well the heat exchanger performed.



Figure 3.9: Changing the temperature of the air on the Dump Heat Exchanger and comparing the NTU and Effectiveness.



Figure 3.10: Changing the flow rate of the air on the Dump Heat Exchanger and comparing the NTU and Effectiveness.

CHAPTER 4: POTENTIAL HEAT EXCHANGERS

After this analysis was done, work was started from a design point of view for an annulus heat exchanger that was based on the results of the cross-flow heat exchanger. First it was determined to look at a single annulus. In William S. Jenna's book, <u>Design of Fluid</u> <u>Thermal Systems</u>, [11], he gives the steps on how to design an annulus heat exchanger. This process can be found in Appendix A. Following the single annulus heat exchanger, another analysis was performed to include a group of annulus exchangers that had a duty of 40 MW. Finally, a brief look into shell and tube heat exchangers was done to compare to the original cross-flow heat exchanger.

4.1 Annulus Heat Exchanger Design

After going through the design process for a single annulus, tube-in-tube heat exchanger, a case study was done to determine possible inner diameters of the sodium pipe and the length of the heat exchanger that would work with reasonable pressure drops. Originally, it was determined that only pressure drops below 500 kPa would be investigated first. Figure 4.1 shows the results of the case study. In terms of mass flow rate in the annulus, it was varied from 100 kg/s to 300 kg/s and the results only varied the pressure drop in the second to third decimal place. Table 4.1 contains all possible variations of Annulus heat exchangers that have a pressure drop under 500 kPa. The table also values highlighted that match the duty of 33 MW.

After collecting all this data, a further look into allowable pressure was done. It was found that for water in residential piping, [12], a drop of 3 psi over 100 ft is the maximum allowed pressure. When water in residential piping is assumed to be at atmospheric pressure, the 3 psi drop comes out to be about a 20% drop. Taking this approach and applying it to the heat exchangers in this section, the max allowable drop comes out to 21.8 psi (150 kPa). Comparing the annulus heat exchangers with the Fast Flux Testing Facility (FFTF)'s cross-flow design there are four annulus heat exchangers that would work as shown in Table 4.3. Each annulus that came up with a Duty of 33 MW were 5 meters long. When comparing the designs, there was only one option that was below the max allowable pressure of 150 kPa, the annulus that had an inner diameter for the pipe of 30 cm. However, the others still matched the duty of the cross-flow heat exchanger so they were left on the table.



Figure 4.1: Pressure drop as a function of the inner diameter of the pipe, which contains sodium, and length in meters of a single annulus.

After matching the 33MW duty of the cross-flow heat exchanger, it was determined to investigate the addition of multiple annuli. When 25 annuli were looked at, every combination of flowrate, length, and diameter of the sodium pipe gave reasonable pressure drops. When looking at either the single annulus or the 25 annuli, the duty varied greatly. It ranged from 5 to 50 MW, these values can be seen in Table 4.1. The combinations of inner diameter and length that give 33 MW or close to it are highlighted.

Now, it has been decided to investigate a shell-and-tube heat exchanger. This will be done by using the heat exchanger module, which is already built into HYSYS. By using the HYSYS operations manual, a design of the heat exchanger will be made which will work for the project.

Within HYSYS, there is a heat exchanger module that can be used for design. This module can be used to create many types of heat exchangers, mainly shell-and-tube, double pipe, and cross-flow. To verify the calculations that were done with the double pipe heat exchanger above, The heat exchanger module that is built into HYSYS was used. The first heat exchanger that was made, had an inner pipe outer diameter of 0.2 m and an annulus inner diameter of 0.25 m. The length of each double pipe was 10 m and the number of pipes required to match the design parameter of 33 MW, was 22. However,

Table 4.1: Possible inner diameter of sodium, length, pressure drop, and duty found through the design process of the Annulus Heat Exchanger. The highlighted rows are viable choices for the heat exchanger that work.

IDp (cm)	L (m)	Delta P (kPa)	Duty (MW)
18.889	1	245.06	6-7
21.111	1	141.21	6-8
21.111	3	423.64	19-20
23.333	1	86.111	7.5-8.7
23.333	3	258.33	20.9-21.3
23.333	5	430.555	29.7-32.6
25.55	1	54.987	8.2-9.4
25.55	3	164.961	22.7-23.4
25.55	5	274.935	31.4-35
25.55	7	384.9095	37.2-45.2
27.77	1	36.481	4.9-10
27.77	3	109.444	24-25
27.77	5	182.407	32.7-37.4
27.77	7	255.37	38.5-48.3
27.77	9	328.333	42.4-57.7
30	1	24.9969	9.6-10.8
30	3	74.9909	25.2-26.5
30	5	124.9849	34-39.7
30	7	174.9788	39.7-51
30	9	224.9728	43.4-60.7
30	11	274.9668	45.8-69
30	13	324.9607	47.5-76.1
30	15	374.955	48.6-82.5

to come up with this many pipes, each heat exchanger was designed to have a total of 25 pipes. Figure 4.2 shows the portion of the HYSYS module that was used to specify the geometry of one double pipe exchanger. However, to make sure that there would be enough duty, to remove the required heat from the sodium, it was decided to design to a duty of 40 MW.

Heat Exchanger	Number of Tubes	Inner Diameter Pipe (cm)	Inner Diameter Annulus (m)	Mass Flow Rate Air (kg/s)	Total Duty (MW)	Pressure Drop (kPa)
Cross-Flow	66			283.5	33	20.685
Annulus 1	1	23.33	3.6	300	32.6	430.555
Annulus 1	1	25.55	2.3-2.5	120-140	32.8-33.7	274.935
Annulus 1	1	27.77	2.1-2.2	100-110	32.7-33.7	182.407
Annulus 1	1	30	2.105	100	34.07	124.985

Table 4.2: Cross-Flow heat exchanger compared to different Annulus heat exchangers all having a length of 5 meters.

To compare these results, a case study was done where the outer diameter of the inner pipe was made smaller, 0.1 m and 0.05 m. To do this study, the length of the tubes was kept constant. When the diameter was decreased, the amount of annulus pipes increased. Figure 4.3 shows the annulus dimensions for one pipe for the diameter 0.1 m. When the diameter was changed, the outer pipe diameter was changed until the duty came out to be 0.4 MW. Which led to needing 100 annulus heat exchanger tubes to get to the 40 MW. Likewise, when the diameter was decreased to 0.05 m, it took 200 pipes to reach the 40 MW. Figure 4.4 shows the dimensions of the 0.05 m outer diameter annulus pipe.

Front head ty	/pe:	E	B - bonnet bolted or i	- bonnet bolted or integral with tubesheet 🔹 👻				
Shell type:			Double pipe (D-she	:II)		•		
Rear head typ	oe:		M - bonnet			•		
Exchanger po	osition:	ŀ	Horizontal 🔹 🔻					
Shell(s)			Tubes			Tube Layout		
ID:	0.25 r	m •	Number:			New (optimum)) layout 🔹	
OD:	0.2627	m •	Length:	10	m 🔹	Tubes:	0	
Series:	1		OD:	0.2 m	•	Tube Passes	1	
Parallel:	1		Thickness:	Thickness: 4.57 mm -			0 m •	
						Pattern:	Set default 👻	

Figure 4.2: Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of 1.641 MW. The total number of double pipe heat exchanges would be around 25.

To gain a better understanding of how these designs compared to the original crossflow heat exchanger, Table 4.3 was created. In this table, there are not any pressure drops for the Annulus 25, 100, and 200 heat exchangers due to that data not being pulled from the studies. However, they all reached a convergence of under the allowable pressure drop

Front head type:	B - bonnet bolted or integral with tubesheet			
Shell type:	Double pipe (D-shell)	•		
Rear head type:	M - bonnet	•		
Exchanger position:	Horizontal 👻			
Shell(s)	Tubes	Tube Layout		
ID: 0.215 m	Number: 1	New (optimum) layout		
OD: 0.2277 m	▼ Length: 10 m ▼	Tubes: 0		
Series: 1	OD: 0.1 m •	Tube Passes 1		
Parallel: 1	Thickness: 4.19 mm -	Pitch: 0 m 🔻		
		Pattern: Set default 👻		

Figure 4.3: Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of 0.4 MW. The total number of double pipe heat exchangers would be around 100.

Front head ty	pe:		B - bonnet bolted or integral with tubesheet					
Shell type:	ell type: Double pipe (D-shell)							
Rear head typ	e:		M - E	oonnet			•	
Exchanger po	sition:		Horiz	Horizontal 🔹				
Shell(s)				Tubes			Tube Layout	
ID:	0.146	m •	•	Number:	1		New (optimum)	layout 🔹
OD:	0.1602	m •	·	Length:	10 m •	•	Tubes:	0
Series:	1			OD:	0.05 m •	•	Tube Passes	1
Parallel:	1			Thickness:	2.11 mm •	•	Pitch:	0 m •
							Pattern:	Set default 🔹

Figure 4.4: Double pipe, Annulus, heat exchanger that is 10 m in length and has a duty of 0.2 MW. The total number of double pipe heat exchangers would be around 200.

of 150 kPa. Also on Table 4.3, there are three variations of a single annulus heat exhanger that met the design parameter of 40 MW. These all had a length of 7 meters, with mass flow rates around 100 kg/s of air, and needed to have a Annulus Inner Diameter of over 2 meters to accomplish the 40 MW of duty. None of these annulus heat exchangers gave pressure drops under 150 kPa, but they were included because the pressure drop is what would be expected if the duty of 40 MW was achieved.

Duty Pressure W) (kPa)	3 20.685	0	0	0	40.7 384.909	.1 255.370	.7 174.979
Total (MV		4(4(4(39.7-	40.	39.
Number of Tubes	99	25	100	200	1	1	1
Individual Duty (MW)		1.641	0.4	0.2	39.7-40.7	40.1	39.7
Mass Flow Rate Air (kg/s)	283.5	11.34	2.835	1.142	120 - 130	110	100
Inner Diameter Annulus (m)		0.25	0.215	0.146	2.3 - 2.4	2.2	2.1
Inner Diameter Pipe (cm)		19.54	5.81	2.89	25.55	27.77	30
Heat Exchanger	Cross-Flow	Annulus 25 (L= $10m$)	Annulus $100 (L=10m)$	Annulus $200 (L=10m)$	Annulus 1 (L=7m)	Annulus 1 (L=7m)	Annulus 1 (L=7m)

nnulus HX.
vs A
ΗX
Cross-Flow
Initial
Table 4.3 :

4.2 Shell-and-tube Heat Exchanger

After reaching the design parameters with using annulus heat exchangers, shell-andtube heat exchangers were looked at. This was done using the same HYSYS module from up above. There were two different cases run for the shell-and-tube heat exchangers. First, one with 100 tubes and the second with 150 tubes. The goal was to have each heat exchanger have a duty around 40 MW and have a reasonable temperature of air exiting the shell side. Figure 4.5 shows the geometry of the first module that has 100 tubes. For each tube containing the sodium, the outer diameter was set to 0.038 m (1.5 in). The tubes contained 2 passes and the straight sections were 6 m long. The inner diameter of the shell was then set to 0.65 m (about 25.6 in). With these mechanical properties, the duty of 40 MW was achievable. Figure 4.6 shows the resulting physical states of what surrounds the heat exchanger. The sodium leaves at 446.3°C and the air leaves at 106.5°C. The mass flow rate of the air is what determines the duty of the heat exchanger. For this heat exchanger, the amount of air flow that was needed came out to be 536.8 kg/s. One thing to note, is that the pressure drop across the sodium tubes is quite large. The sodium leaves at 1501 kPa.

Front head ty	/pe:		B - I	onnet bolted o	or integral with tubesheet	t 🔻	
Shell type:			E - 0	one pass shell 🔹			
Rear head ty	pe:		M - 1	- bonnet 🔹			
Exchanger p	osition:		Hori	orizontal 🔹			
Shell(s)				Tubes		Tube Layout	
ID:	0.65	m	•	Number:	100	New (optimum) layout 🔹
OD:	0.66	m	•	Length:	6 m 🔻	Tubes:	106
Series:	1			OD:	0.038 m 🔻	Tube Passes	2
Parallel:	1			Thickness:	1.65 mm 💌	Pitch:	0.0475 m 🔹
						Pattern:	30-Triangular •

Figure 4.5: Geometry of shell-and-tube with 100 tubes.

When looking at the second iteration of the shell-and-tube heat exchanger, more tubes were added to see how much change would happen. The tube size and length all remained the same as the first shell-and-tube module. However, to fit the amount of tubes in it, the shell's inner diameter was changed to 0.8 m (about 31.5 in), see Figure 4.7. When



Figure 4.6: Temperature, pressure, and mass flow rate for the shell-and-tube that contains 100 tubes.

comparing the results of the shell-and-tube heat exchanger that has only 100 tubes, there are some improvements in going with more tubes. The pressure coming out of the heat exchanger is larger, 1564 kPa vs the 1501 kPa. Also the flow rate of the air has decreased on the order of 20 kg/s. This leads to a higher temperature exiting the shell of 109.8°C, but it would require less equipment to achieve this, see Figure 4.8.

To better compare the shell and tube heat exchangers, these two heat exchangers designs were added to Table 4.3. Table 4.4 has the complete comparison. Both two shell and tube designs both had pressure drops under the allowable pressure drop. However, when looking back at the models form HYSYS, it was found that there are some issues with the models, the modules appear yellow, see Figures 4.6 and 4.8, instead of blue like in Figure 3.4.

Front head ty	ype:		B - b	onnet bolted or	integral with	tubesheet	•	
Shell type:			E - 0	ne pass shell			-	
Rear head ty	pe:		M - E	onnet			•	
Exchanger p	osition:		Horiz	zontal •	·			
Shell(s)				Tubes			Tube Layout	
ID:	0.8	m 🔻		Number:	150		New (optimum)	layout 👻
OD:	0.814	<i>m</i> •		Length:	6	m 🔹	Tubes:	165
Series:	1			OD:	38 n	nm 🔹	Tube Passes	2
Parallel:	1			Thickness:	1.65	mm 🔹	Pitch:	47.5 mm •
							Pattern:	30-Triangular 🔹

Figure 4.7: Geometry of shell-and-tube with 150 tubes.



		Materi	al Streams		
		Na Inlet	Na Outlet	AIRINLET	AIROUTLET
Temperature	С	537.8	446.3	32.22	109.8
Pressure	kPa	1620	1564	137.9	63.26
Mass Flow	kg/s	253.0	253.0	514.4	514.4

Figure 4.8: Temperature, pressure, and mass flow rate for the shell-and-tube that contains 150 tubes.

Heat Exchanger	Inner Diameter Pipe (cm)	Inner Diameter Annulus (m)	Mass Flow Rate Air (kg/s)	Individual Duty (MW)	Number of Tubes	Total Duty (MW)	$egin{array}{c} { m Pressure} \\ { m Drop} \\ (kPa) \end{array}$
Cross-Flow			283.5		66	33	20.685
Annulus 25 $(L=10m)$	19.54	0.25	11.34	1.641	25	40	
Annulus $100 (L=10m)$	5.81	0.215	2.835	0.4	100	40	
Annulus $200 (L=10m)$	2.89	0.146	1.142	0.2	200	40	
Annulus 1 (L=7m)	25.55	2.3 - 2.4	120 - 130	39.7 - 40.7	1	39.7 - 40.7	384.909
Annulus 1 (L=7m)	27.77	2.2	110	40.1	1	40.1	255.370
Annulus 1 (L=7m)	30	2.1	100	39.7		39.7	174.979
Shell and Tube 100	36.45	0.65	536.8		100	40	119
Shell and Tube 150	36.45	0.8	514.4		150	40	56

Tube HX.	
and	
Shell	
\mathbf{VS}	
ΗХ	
Annulus	
\mathbf{VS}	
НΧ	
Cross-Flow	
Initial	
Table 4.4:	

CHAPTER 5: RESULTS

One of the crucial portions of this thesis work was creating the hypothetical property package for sodium in HYSYS. ANL data was used to create this hypothetical. The properties that needed to be imported were density, specific heat capacity, thermal conductivity, viscostiy, mass entropy, mass enthalpy. Once equations were created for fitting the data, the resulting hypothetical were compared to the original ANL data, as well as a sodium property found in ASPEN PLUS. These results found that the hypothetical was a better fit to that of the ASPEN PLUS version. Once the sodium property was created and the FFTF heat ecahanger was modeled in HYSYS a parametric study was done on the air side to see how humidity affected it.

There were three studies done on the air side which consisted of changing the humidity, the temperature, and changing the mass flow rate. In each study, only one parameter was changed. The first study consisted of changing the humidity from 0% to 100%. Figure 3.8 shows that as the humidity increased the NTU values increased, but the effectiveness went down. When looking at how much the NTU and effectiveness values were affected, there was not a big difference; thus, humidity did not have a big impact on the heat exchanger. Figure 3.9 shows that as the temperature increased the NTU values and effectiveness values both increased, meaning that it would be beneficial to have higher temperatures for the air going into the heat exchanger. Figure 3.10 shows that has the mass flow rate decreases as the flow rate increases. Thus, having a slower air flow would be beneficial.

Table	5.1:	List	of ma	ass fl	low	rate,	duty,	and	sodium	outlet	temperature	for	the	current
desigr	n and	the	correc	eted y	valu	ed ca	ses.							

	Mass Flow Rate	Duty	Sodium Outlet Temperature
Current Design (FFTF)	186.5 kg/s	$33 \ \mathrm{MW}$	$766.2^{\circ}\mathrm{F}$
Correct \dot{m}	253 kg/s	$33 \ \mathrm{MW}$	830°F
Corrected Duty	$186.5 \mathrm{~kg/s}$	$24.32~\mathrm{MW}$	$830^{\circ}\mathrm{F}$

When investigating the FFTF's heat exchanger there were some differences with the heat exchanged and the outlet temperature on the sodium side. An analysis was done to compare what was modeled to that of (1) changing the mass flow rate and keeping the heat exchanged, and (2) keeping the mass flow rate and changing the duty. Table 5.1, shows the comparison. The original design mass flow rate and duty are on the first row. When the duty is kept, 33 MW, to get the design outlet temperature of 830°F a mass flow rate of 253 kg/s is needed. However, if the mass flow rate is kept the same as the

original, a new lower duty is required to obtain the desired outlet temperature of 24.32 MW.

Potential heat exchangers were looked at. First, a single annulus heat exchanger was used to match the 33 MW duty that the original FFTF's cross-flow heat exchanger. Table 4.2, gives four options all 5 meters in length, but varying in size, that were able to produce 33 MW. Out of the four possible annulus heat exchangers, the last option, with an inner diameter of the pipe of 30 cm and an inner diameter of the annulus of 2.105 meters, is the only design that falls under the allowable pressure drop of 150 kPa. Second, bundles of annuli heat exchangers were investigated. Bundles of 25, 100, and 200 were all designed to have a duty of 40 MW and were compared the existing cross-flow heat exchanger, see Table 4.3. Any of these three heat exchangers would be a viable design. Finally, an initial design on two versions of a shell and tube heat exchangers that were designed with a duty 40 MW. It shows that even though the shell and tube heat exchangers were preliminary results, they were still a viable solution because they gave a pressure drop below the allowable pressure.



Figure 5.1: Total footprint of the potential heat exchangers in m^2



Figure 5.2: Volume of material needed to create each potential heat exchanger.

CHAPTER 6: SUMMARY AND CONCLUSIONS

Conclusions:

- Found discrepancies with mass flow rate of sodium and the duty in the existing FFTF's cross-flow heat excahanger. By using the heat transfer equation $\dot{Q} = \dot{m}c_p\Delta T$, corrected values were found, see Table 5.1.
- It was found that humidity and inlet air temperature for the heat exchanger does not affect the performance of the exchanger. However, changing the mass flow rate does effect the performance. The slower the flow the more efficient the exchanger would be.
- Comparing the possible heat exchangers and the initial cross-flow design the exchangers were ranked based on footprint, volume of material, and weight
 - 1. Shell and Tube with 100 tubes
 - 2. Shell and Tube with 200 tubes
 - 3. Annulus with 25 annuli
 - 4. Annulus with 100 annuli
 - 5. Annulus with 200 annuli
 - 6. Cross-flow design using a staggered tube arrangement
 - 7. Cross-flow design using an inline tube arrangement

Future Work:

- Validate Shell and Tube heat exchanger models
- Add fins to all potential heat exchangers and compare the results to this study.
- Perform an experiment on a smooth tubed cross-flow heat exchanger to confirm assumptions of model.

REFERENCES

- G Youinou, S Sen, P Henslee, M Salvatores, G Palmiotti, R Wigeland, D Hill, C Davis, S Pirmet, S Hayes, J Bumgardner, and P Finck. VCTR: A Versatile Coupled Test Reactor Concept. Technical report, 2016.
- [2] R Avery and R. THEORY OF COUPLED REACTORS. Technical report, Divison of Technical Information Extension, U.S. Atomic Energy Commission, 10 1958.
- [3] Nuclear Research Opportunities Versatile Test Reactor.
- [4] Brian S Triplett, Eric P Loewen, and Brett J Dooies. PRISM: A COMPETITIVE SMALL MODULAR SODIUM-COOLED REACTOR. Technical report, 2010.
- [5] C.P. Cabell. A Summary Description of the Fast Flux Test Facility. Technical report, 1980.
- [6] W M Kays and A L London. Compact heat exchangers. McGraw-Hill, New York, NY, 1 1984.
- [7] Incropera, DeWitt, Bergman, and Lavine. Heat Exchangers. In Introduction To Heat Transfer, chapter 11. 5 edition, 2007.
- [8] J. Fink and L. Leibowitz. Thermodynamic and transport properties of sodium liquid and vapor. Technical report, 1995.
- [9] Hiroyasu Mochizuki and Masahito Takano. Heat transfer in heat exchangers of sodium cooled fast reactor systems. Nuclear Engineering and Design, 239(2):295– 307, 2 2009.
- [10] Incropera, DeWitt, Bergman, and Lavine. External Flow. In Introduction To Heat Transfer, chapter 7. 5 edition, 2007.
- [11] William S. Janna. Design of Fluid Thermal Systems. Cengage Learning, fourth edi edition, 2015.
- [12] Domestic Water Piping Design Guide, How to Size and Select Domestic Water Piping.

APPENDIX A: SOLVING ANNULUS HEAT EXCHANGER FROM JANNA'S BOOK [11]

Assumptions:

1. $V_a = 30m/s$

- (a) Engineering toolbox for max velocity through a pipe
- (b) Setting Velocity, gives IDa
- 2. Initial Conditions
 - (a) $T_1 = 1000^{\circ}F, \dot{m}_p = 253kg/s, P_1 = 752.2kPa$
 - (b) $t_1 = 90^{\circ}F, p_1 = 109.6kPa$
 - (c) Smooth tubes
- 3. Variables to control design
 - (a) Length, L
 - (b) Inner Diameter of pipe, IDp
 - (c) Outer diameter of pipe, *ODp* (Assumed thickness of walls till found solutions that work)
 - (d) Mass flow rate of the annulus, \dot{m}_a

Design Process:

- 1. Get fluid properties a the average temperature (inlet of both sides)
- 2. Set Tubing size (if known)
- 3. Solve for flow area

(a)

$$A_p = \frac{\pi I D p^2}{4} \tag{A.1}$$

(b)
$$A_a = \frac{\pi (IDa^2 - ODp^2)}{4}$$
(A.2)

- 4. Find Fluid Velocities
 - (a)

$$V_p = \dot{m}_p / \rho A_p \tag{A.3}$$

- (b) $V_a = \dot{m}_a / \rho A_a \tag{A.4}$
- 5. Find the Annulus Equivalent Diameters
 - (a) Friction:

$$D_h = IDa - ODp \tag{A.5}$$

(b) Heat Transfer:

$$D_e = (IDa^2 - ODp^2)/ODp \tag{A.6}$$

6. Find Reynold's Number

(a)
$$Re_p = \frac{V_p I D p}{\nu}$$
(A.7)

(b)
$$Re_a = \frac{V_p D_e}{\nu} \tag{A.8}$$

7. Nusselt Numbers

(a)

- $Nu_p = 0.023 (Re_p)^{4/5} Pr^{0.3}$ (A.9)
- (b)

$$Nu_a = 0.023 (Re_a)^{4/5} Pr^{0.4}$$
 (A.10)

- 8. Convection Coefficients
 - $h_i = N u_p k_f / I D p \tag{A.11}$
 - (b)

(a)

$$h_p = h_i IDp/ODp \tag{A.12}$$

(c)

(a)

(b)

$$h_a = N u_a k_f / D_e \tag{A.13}$$

9. Exchaner Coefficient

 $\frac{1}{U_o} = \frac{1}{h_p} + \frac{1}{h_a}$ (A.14)

10. Outlet Temperature Calculation (Length Needed)

- (a) $R = \frac{\dot{m}c_{p,c}}{\dot{m}c_{p,h}}$ (A.15)
 - $A_o = \pi ODpL \tag{A.16}$
- (c) Counter-flow

i.

$$E_{counter} = exp \left[\frac{U_o A_o (R-1)}{\dot{m} c_{p,c}} \right]$$
(A.17)

$$T_{2} = \frac{T_{1}(R-1) - Rt_{1}(1 - E_{counter})}{RE_{counter} - 1}$$
(A.18)

ii.

$$t_2 = t_1 + \frac{T_1 + T_2}{R} \tag{A.19}$$

11. LMTD

(b)

12. Heat Balance

(a) $q_h = \dot{m}c_{p,h}(T_1 - T_2)$ (A.20)

- $q_c = \dot{m}c_{p,c}(t_2 t_1)$ (A.21)
- (c) $q = U_o A_o LMTD \tag{A.22}$

13. Friction Factors

(a)

$$Re_{p} = V_{p}IDp/\nu$$

$$\epsilon/IDp \qquad (A.23)$$

$$f_{p}$$

(b)

$$Re_{a} = V_{a}D_{h}/\nu$$

$$\epsilon/D_{h}$$

$$f_{a}$$
(A.24)

- (c) Turbulent = Chen or Churchill equation
- (d) Laminar = equations found on pg 420
- 14. Pressure Drop Calculations
 - (a)

$$\Delta p_p = \frac{f_p L}{I D p} \frac{\rho_p V_p^2}{2g_c} \tag{A.25}$$

$$\Delta p_p = \left(\frac{f_a L}{D_h} + 1\right) \frac{\rho_a V_a^2}{2g_c} \tag{A.26}$$

- 15. Iterate with new average temperatures for fluid properties
 - (a) Hot Side:

$$T_{avg} = \frac{T_1 + T_2}{2}$$
(A.27)

(b) Cold Side:
$$T_{avg} = \frac{t_1 + t_2}{2} \tag{A.28}$$

APPENDIX B: HYSYS MODELS AND REPORTS

1		DATTELLE		Case Name:	final project.1.hsc		
3	entech	Bedford, MA	A	Unit Set:	Project Units3s		
4 5		USA		Date/Time:	Sat Aug 7 20:40:45 202	21	
6							
8	vvori	KDOOK:	Case (Mail	n)			
9				Heat Exchange	rs	Fluid Pkg	g: All
11	Name		ІНХ	Dump HX			
12	Duty	(MW)	30.80	33.00			
13	Tube Side Feed Mass Flow	(kg/s)	742.4	186.5			
14	Shell Side Feed Mass Flow	(kg/s)	186.5	283.5 *			
15	Tube Inlet Temperature	(((g/3))	595.8	537.8 *			
16	Tube Outlet Temperature	(0)	565.6 *	407.9			
17	Shell Inlet Temperature	(0)	415.1	32.22 *			
18	Shell Outlet Temperature	(C)	413.1 527.9.*	145.7			
10		(C)	217.5	96.03			
20	04	(10/0-3)	517.5	00.00			
21				Material Stream	IS	Fluid Pkg	g: All
22	Name		1	2	3	Dump HX Inlet	Dump HX Outlet
23	Temperature	(C)	595.8	- 565.6 *	575.0	537.8 *	407.9
24	Mass Flow	(kg/s)	742.4	742.4	742.4	186.5	186.5
25	Pressure	(kPa)	1551 *	1482	2723	752.4	730.8
26	Actual Liquid Flow	(m3/s)	0.9215	0.9148	0.9169	0.2283	0.2216
27	Name	(Air Inlet	Air Fxit	6	Humid Air	Air Surface
28	Temperature	(C)	32 22 *	145.7	415.1	28.97	472.9 *
29	Mass Flow	(kg/s)	283.5 *	283.5	186.5	283.5	283.5
30	Pressure	(kPa)	104.1	101.3 *	1724 *	101.3 *	102.7 *
31	Actual Liquid Flow	(m3/s)	0.0000	0.0000	0 2219	0.0000	0.0000
32		(110/3)	0.0000	0.0000	0.2210	0.0000	0.0000
33				Compositions		Fluid Pkg	g: All
34	Name		1	2	3	Dump HX Inlet	Dump HX Outlet
35	Comp Mole Frac (Sodium*)		***	***	***	***	***
36	Comp Mole Frac (Nitrogen)		***	***	***	***	***
37	Comp Mole Frac (Oxygen)		***	***	***	***	***
38	Comp Mole Frac (H2O)		***	***	***	***	***
39	Comp Mole Frac (Sodium)						
40			1.0000 *	1.0000	1.0000	1.0000 *	1.0000
41	Name		6	1.0000 Air Exit	1.0000 Air Inlet	1.0000 * Sodium Inlet	1.0000 Sodium Outlet
41	Name Comp Mole Frac (Sodium*)		1.0000 * 6 ***	1.0000 Air Exit	1.0000 Air Inlet	1.0000 * Sodium Inlet ***	1.0000 Sodium Outlet ***
42	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen)		1.0000 * 6 *** ***	1.0000 Air Exit 0.7900	1.0000 Air Inlet *** 0.7900	1.0000 * Sodium Inlet *** ***	1.0000 Sodium Outlet *** ***
42 43	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		1.0000 * 6 *** ***	1.0000 Air Exit 0.7900 0.2100	1.0000 Air Inlet *** 0.7900 0.2100	1.0000 * Sodium Inlet *** ***	1.0000 Sodium Outlet *** ***
42 43 44	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O)		1.0000 * 6 **** **** ****	1.0000 Air Exit 0.7900 0.2100 0.0000	1.0000 Air Inlet 0.7900 0.2100 0.0000	1.0000 * Sodium Inlet **** **** ****	1.0000 Sodium Outlet **** **** **** ****
42 43 44 45	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium)		1.0000 * 6 **** *** *** 1.0000	1.0000 Air Exit 0.7900 0.2100 0.0000 ***	1.0000 Air Inlet 0.7900 0.2100 0.0000 ***	1.0000 * Sodium Inlet *** *** *** 1.0000 *	1.0000 Sodium Outlet **** **** **** 1.0000
42 43 44 45 46	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Yagon) Comp Mole Frac (Sodium) Name		1.0000 * 6 *** *** *** 1.0000 Humid Air	1.0000 Air Exit 0.7900 0.2100 0.0000 •••• Air Average	1.0000 Air Inlet 0.7900 0.2100 0.0000 *** HYPO	1.0000 * Sodium Inlet *** *** *** 1.0000 * Aspen	1.0000 Sodium Outlet **** **** 1.0000 4
42 43 44 45 46 47	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*)		1.0000 * 6 *** *** 1.0000 Humid Air	1.0000 Air Exit 0.7900 0.2100 0.0000 	1.0000 Air Inlet 0.7900 0.2100 0.0000 *** HYPO 1.0000 *	1.0000 * Sodium Inlet *** *** 1.0000 * Aspen	1.0000 Sodium Outlet
42 43 44 45 46 47 48	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium*) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen)		1.0000 * 6 *** *** *** 1.0000 Humid Air *** 0.7900	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average *** 0.7744 *	1.0000 Air Inlet 0.7900 0.2100 0.0000 *** HYPO 1.0000 *	1.0000 * Sodium Inlet *** *** 1.0000 * Aspen ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen)		1.0000 * 6 *** *** 1.0000 Humid Air *** 0.7900 0.2100	1.0000 Air Exit 0.7900 0.2100 0.0000 **** Air Average *** 0.7744 * 0.2059 *	1.0000 Air Inlet 0.7900 0.2100 0.0000 *** HYPO 1.0000 * ***	1.0000 * Sodium Inlet *** *** *** 1.0000 * Aspen *** ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen)		1.0000 * 6 *** *** 1.0000 Humid Air *** 0.7900 0.2100 0.0000	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average 0.7744 * 0.2059 * 0.0197 *	1.0000 Air Inlet 	1.000 * Sodium Inlet *** *** *** 1.000 * Aspen *** ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (H2O) Comp Mole Frac (Sodium)		1.0000 * 6 **** **** 1.0000 Humid Air *** 0.7900 0.2100 0.2000 ***	1.0000 Air Exit 	1.0000 Air Inlet 0.7900 0.2100 0.0000 *** HYPO 1.0000 * *** ***	1.0000 * Sodium Inlet *** *** 1.0000 * Aspen *** *** *** *** *** ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (A2O) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Sodium) Name		1.0000 * 6 **** *** 1.0000 Humid Air *** 0.7900 0.2100 0.2100 0.2000 *** Air Surface	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average *** 0.7744 * 0.2059 * 0.0197 * 	1.0000 Air Inlet *** 0.7900 0.2100 0.0000 *** HYPO 1.0000 * *** ***	1.0000 * Sodium Inlet **** *** *** *** *** *** *** *** ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*)		1.0000 * 6 **** *** 1.0000 Humid Air *** 0.7900 0.2100 0.2100 0.2100 *** Air Surface	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average 0.7744 * 0.2059 * 0.0197 * ***	1.0000 Air Inlet 	1.0000 * Sodium Inlet **** *** *** 1.0000 * Aspen *** *** *** 1.0000 *	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Attrongen) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Attrongen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen)		1.0000 * 6 **** *** 1.0000 Humid Air *** 0.7900 0.2100 0.0000 *** Air Surface *** 0.7744 *	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average *** 0.7744 * 0.2059 * 0.0197 * ***	1.0000 Air Inlet 	1.0000 * Sodium Inlet *** *** *** 1.0000 * Aspen *** *** *** *** *** *** ***	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54 55	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Oxygen) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen)		1.0000 * 6 **** **** 1.0000 Humid Air *** 0.7900 0.2100 0.0000 *** Air Surface *** 0.7744 * 0.2059 *	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average 0.7744 * 0.2059 * 0.0197 * ***	1.0000 Air Inlet	1.0000 * Sodium Inlet *** *** *** 1.0000 * Aspen *** *** *** *** *** *** *** *** *** *	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Data (Sodium) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mo		1.0000 * 6 **** 1.0000 Humid Air 0.7900 0.2100 0.2100 0.2100 0.0000 *** Air Surface *** 0.7744 * 0.2059 * 0.0197 *	1.0000 Air Exit	1.0000 Air Inlet	1.0000 * Sodium Inlet *** *** 1.0000 * Aspen *** 4.0000 * *** 1.0000 *	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 52 53 55 56 55	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argon) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Yagon) Comp Mole Frac (Sodium*) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Xitrogen) Comp Mole Frac (Xitr		1.0000 * 6 **** 1.0000 Humid Air *** 0.7900 0.2100 0.2100 0.2000 *** Air Surface *** 0.7744 * 0.2059 * 0.0197 *	1.0000 Air Exit	1.0000 Air Inlet	1.0000 * Sodium Inlet *** *** *** Aspen *** Aspen *** ** ** 1.0000 *	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 53 54 55 56 57 58	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium)		1.0000 * 6 **** 1.0000 Humid Air 0.7900 0.2100 0.2100 0.2100 0.2050 *** Air Surface *** 0.7744 * 0.2059 * 0.2059 *	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average *** 0.7744 * 0.2059 * 0.0197 * *** 0.0197 *	1.0000 Air Inlet	1.0000 * Sodium Inlet **** *** 1.0000 * Aspen *** *** 1.0000 * *** *** *** *** *** *** *** *** *	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54 55 55 56 57 58 59	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Argen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium) Comp Mole Frac (Sodium)		1.0000 * 6 **** 1.0000 Humid Air 0.7900 0.2100 0.2100 0.2000 *** Air Surface 0.7744 * 0.2059 * 0.0197 *	1.0000 Air Exit 0.7900 0.2100 0.0000 *** Air Average 0.7744 * 0.2059 * 0.0197 * *** Energy Stream	1.0000 Air Inlet	1.0000 * Sodium Inlet *** *** 1.0000 * Aspen *** 1.0000 * 1.0000 * *** *** *** *** *** *** **	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 51 52 53 54 55 56 57 58 59 60	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Attorne) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*)		1.0000 * 6 **** 1.0000 Humid Air 0.7900 0.2100 0.2100 0.0000 *** Air Surface *** 0.7744 * 0.2059 * 0.0197 * ***	1.0000 Air Exit 	1.0000 Air Inlet	1.0000 * Sodium Inlet *** 4** 1.0000 * Aspen *** 4** 1.0000 * 1.0000 * 1.0000 * 5** 5** 5** 5** 5** 5** 5** 5** 5** 5	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Nitrogen) Comp Mole Frac (Davgen) Comp Mole Frac (Attorne) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium) Name Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium) Name Name Heat Flow		1.0000 * 6 **** 1.0000 Humid Air *** 0.7900 0.2100 0.2100 0.2100 *** Air Surface *** 0.7744 * 0.2059 * 0.0197 * *** Secondary Pump Pow 2.200	1.0000 Air Exit 	1.0000 Air Inlet *** 0.7900 0.2100 0.0000 *** HYPO 1.0000 * *** *** *** *** S Reactor Heat 19.45	1.0000 * Sodium Inlet **** 	1.0000 Sodium Outlet
42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62	Name Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Oxygen) Comp Mole Frac (Qaygen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Nitrogen) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium*) Comp Mole Frac (Sodium) Name Heat Flow	(MW)	1.0000 * 6 **** 1.0000 Humid Air *** 0.7900 0.2100 0.2000 *** Air Surface *** 0.7744 * 0.2059 * 0.0197 * *** Secondary Pump Pow 2.200	1.0000 Air Exit 	1.0000 Air Inlet *** 0.7900 0.2100 0.0000 *** HYPO 1.0000 * *** *** *** *** S Reactor Heat 19.45	1.0000 * Sodium Inlet **** 3.0000 * Aspen *** 3.0000 * 3.0000 * 3.0000 * 5.000 * 5.000 *	1.0000 Sodium Outlet

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

Case Name: final project.1.hsc 2 3 4 5 BATTELLE ENERGY ALLIANCE (aspentech Bedford, MA Unit Set: Project Units3s USA Date/Time: Sat Aug 7 20:40:45 2021 6 Workbook: Case (Main) (continued) 7 8 9 Unit Ops 10 11 Operation Name Operation Type Products Calc Level Feeds Ignored 12 3 1 Reactor Heater 500.0 No 13 Reactor Heat 14 1 2 IHX 500.0 Heat Exchanger No 15 6 Dump HX Inlet Dump HX Outlet 16 Dump HX Inlet 500.0 Dump HX Heat Exchanger No 17 Air Inlet Air Exit 18 2 3 Primary Pump Pump No 500.0 19 Primary Pump Power 20 Dump HX Outlet 6 Secondary Pump Pump No 500.0 21 Secondary Pump Power 22 SET head Secondary Pump Set No 500.0 * 23 set PipeInlet Pressure 500.0 Set No set PipeInlet Temperature Set No 500.0 * 24 25 SET head Primary Pump No 500.0 Set 26 SET-1 Set No 500.0 * 27 Set Temperature Set No 500.0 * 28 Set PipeMdot Set No 500.0 * 29 500.0 * DumpHX Control Spreadsheet No 30 Humidity Spreadsheet 500.0 * No 31 IHX Effectiveness Spreadsheet No 500.0 * 32 SPRDSHT-1 No 500.0 * Spreadsheet 33 Effectiveness-NTU METHOD Spreadsheet No 500.0 * Correction Factor METHOD No 500.0 * Spreadsheet Sodium Inlet Sodium Outlet Single Tube Pipe Segment 500.0 No Q Pipe Humid Air Air Inlet 37 Air Blower 500.0 * Compressor No Q-104 28 Standard Sub-Flowsheet Humid Air 2500 39 Humidity Calculator No 40 ADJ-1 Adjust No 3500 41 ADJ-2 3500 * Adjust No 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 Aspen HYSYS Version 11 63 Aspen Technology Inc. Page 2 of 2 Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.





Image: Separation BarTELLE ENERGY ALLIANCE Case Name: Marrie project. Name	4									
Image: Spectred Beschwit Mathematical Stream Unit Sale Propert Units2a 7 Spreadsheet: DumpHX Control Unit Sale Date Time: Sale Along 7 204251 3021 7 Spreadsheet: DumpHX Control Unit Sale Propert UnitSale Propert UnitSale 8 CONNECTIONS Signal State	2			°E	Case Name:	final project.1.hsc				
d User base Time: base Target Data Time: base Target 0 Spreadsheet: Dump HX Control Use Ser: Project Use 0 CONNECTIONS Imported Variables Value 10 C2 Material Steam: Ar Ent Temperature Value 10 C2 Material Steam: Ar Ent Temperature Value 11 C2 Material Steam: Ar Ent Temperature Value 12 C2 Material Steam: Ar Ent Temperature Value 12 C2 Material Steam: Ar Ent Mass Head Capacity 104 Lings Af 13 B4 Material Steam: Ar Heit Mass Head Capacity 103 Lings Af 14 B4 Material Steam: Ar Heit Mass Head Capacity 103 Lings Af 15 Material Steam: Ar Heit Mass Head Capacity 103 Lings Af 15 Material Steam: Ar Ent Mass Head Capacity 103 Lings Af 16	3	(the as	spentech Bedford, MA	02	Unit Set:	Project Units3s				
A SpreadSheet: DumpHX Control Units Set Project Units 10 CONNECTIONS Imported Variables Set II Set III Set IIII Set IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII	4 5		USA		Date/Time:	Sat Aug 7 20:42:5	2021			
7 Spreadsheet: DumpHX Control Units Set Project Units 9 CONNECTIONS Variable Description	6				•					
n n n 10 Image: Second S	7		Spreadsheet: Durr	ιрНХ	Control			Units Set: Project Units		
n CONNECTIONS No Value No Value No Call Operation Value No Section Value No Section Value No Section Value Value No Value Value Value No Value Value Section Value Value Section <th colspan="2" td="" va<=""><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></th>	<td>8</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>		8							
Imported Variables 13 Cell Object Value 13 Cell Object Value 14 B2 Matherial Stream: Ar Exit Terropecture 145.7 C 15 C2 Matherial Stream: Ar Exit Terropecture 145.7 C 16 D2 Matherial Stream: Ar Exit Terropecture 407.8 C 16 D2 Matherial Stream: Ar Indet Pressure 104.1 kPa 17 E2 Matherial Stream: Ar Indet Mass Density 104.1 kPa 18 B4 Matherial Stream: Ar Indet Mass Entropy 52.74 kJag 18 B8 Matherial Stream: Ar Indet Mass Entropy 52.74 kJag 18 Matherial Stream: Ar Indet Mass Entropy 52.74 kJag 10 S.5 Matherial Stream: Ar Exit Mass Entropy 56.06 kJAg, K 10 S.5 Matherial Stream: Ar Exit Mass Entropy 56.06 kJAg, K 10 Matherial Stream: Ar Exit Mass Entropy 56.06 kJAg, K 10 <t< td=""><td>10</td><td></td><td></td><td></td><td>CONNECTION</td><td>S</td><td></td><td></td></t<>	10				CONNECTION	S				
Name of the second problem of the second pr	11			In	ported Variab	les				
Name Variant Description Data Data 16 B2 Material Steam: Ar Ibit Temperature 427.0 16 C2 Material Steam: Ar Ibit Temperature 447.0 17 E2 Material Steam: Dump HX fult Temperature 407.9 17 E2 Material Steam: Dump HX fult Temperature 407.9 18 B4 Material Steam: Ar Initet Mass Hoat Capacity 1.014.Mgr,HX 18 B5 Material Steam: Ar Initet Mass Flora 7.024.Mgr,KX 21 B7 Material Steam: Ar Initet Mass Flora 7.024.Mgr,KX 23 B9 Material Steam: Ar Initet Mass Flora 7.024.Mgr,KX 23 C5 Material Steam: Ar Ent Mass Flora 1.037.Mgr,KX 24 C4 Material Steam: Ar Ent Mass Flora 1.037.Mgr,KX 25 C5 Material Steam: Ar Ent Mass Flora 1.037.Mgr,KX 26 C8 Material Steam: Dump HX Initet Mass Flora 1.037.Mgr,KX <t< td=""><td>12</td><td>Cell</td><td>Object</td><td></td><td></td><td></td><td></td><td>Value</td></t<>	12	Cell	Object					Value		
1 C2 Meterial Stream: Ar Est Temperature 145.7 C 16 D2 Mederial Stream: Dump HX Outet Temperature 537.8 C 17 E2 Mederial Stream: Ar Indet Pressure 104.1 Mp-4 18 B4 Mederial Stream: Ar Indet Pressure 104.1 Mp-4 28 B6 Mederial Stream: Ar Indet Meas Density 1.03 Mp/4 21 B7 Mederial Stream: Ar Indet Meas Entropy 5.274 M/4/G 21 B7 Mederial Stream: Ar Indet Meas Entropy 5.274 M/4/G 22 C4 Mederial Stream: Ar Indet Meas Entropy 5.274 M/4/G 23 C5 Mederial Stream: Ar Exit Meas Heat Capacity 103.7 M/4/G 24 C4 Mederial Stream: Ar Exit Meas Entropy 0.392 M/4/G 26 G8 Meaterial Stream: Ar Exit Meas Entropy 0.392 M/4/G 27 C7 Meaterial Stream: Ar Exit Meas Entropy 0.392 M/4/G 27 C7 Meaterial Stream: Ar Exit Meas Entropy	14	B2	Material Stream: Air Inlet	Tempe	rature			32 22 C		
ist D2 Material Stream: Dump HX Nield Temperature S7.8 C 18 B4 Material Stream: Air Intel Temperature 10.1 4 J.Mg.X 19 B5 Material Stream: Air Intel Mass Heat Capacity 10.1 4 J.Mg.X 10 B5 Material Stream: Air Intel Mass Density 1.1 6 J.Mg.X 21 B7 Material Stream: Air Intel Mass Density 7.024 J.Mg.X 23 B8 Material Stream: Air Intel Mass Entropy 28.5 S.Jg.A 24 C4 Material Stream: Air Intel Mass Finoroy 28.5 S.Jg.A 25 C5 Material Stream: Air Intel Mass Finoroy 28.5 S.Jg.A 26 Material Stream: Air Exit Mass Finoroy 10.37 J.Mg.K 27 C7 Material Stream: Air Exit Mass Finoroy 23.5 S.Jg.A 27 C7 Material Stream: Air Exit Mass Finoroy 23.5 S.Jg.A 28 C6 Material Stream: Air Exit Mass Finory 23.5 S.Jg.A 29 Material Stream: Air Exit Mass Finory	15	C2	Material Stream: Air Exit	Tempe	rature			145.7 C		
17.1 E2 Material Stream: Air Indet Presoure 407.9 C 18. B4 Maderial Stream: Air Indet Presoure 104.1 kPace 19. B5 Material Stream: Air Indet Mass Entrapy 1.014 kMage/A 21. B7 Material Stream: Air Indet Mass Entrapy 7.024 kMag 22. B8 Material Stream: Air Indet Mass Entrapy 7.024 kMag 23. B9 Material Stream: Air Indet Mass Entrapy 7.024 kMag 24. C4 Material Stream: Air Ent Mass Entrapy 7.024 kMag 25. C5 Material Stream: Air Ent Mass Entrapy 1013 kMag 26. C6 Material Stream: Air Ent Mass Entrapy 0.323 kMag 27. C7 Material Stream: Air Ent Mass Entrapy 0.323 kMag 28. C6 Material Stream: Air Ent Mass Entropy 0.323 kMag 29. C9 Material Stream: Air Ent Mass Entropy 0.324 kMag 29. C9 Material Stream: Air Ent Mass Entropy 2.324 kMag 20. C9 Material Stream: Air Ent Mass Entropy 2.324 kMag 20. C9 Material Stream: Dump HX Indet Mass Entropy 2.324 kMag	16	D2	Material Stream: Dump HX Inlet	Tempe	rature			537.8 C		
18 B4 Material Straam: Air Intel Pressure 10.41 k/sq. 20 B5 Material Straam: Air Intel Mass Dansky 10.41 k/sq. 21 B7 Material Straam: Air Intel Mass Enhalpy 7.024 k/sg. 22 B8 Material Straam: Air Intel Mass Enhalpy 7.024 k/sg. 22 B8 Material Straam: Air Intel Mass Enhalpy 7.024 k/sg. 23 C4 Material Straam: Air Exit Pressure 20.33 k/g. 24 C4 Material Straam: Air Exit Mass Enhalpy 10.13 k/sg. 25 C5 Material Straam: Air Exit Mass Enhalpy 0.033 k/g. 25 C7 Material Straam: Air Exit Mass Enhalpy 10.33 k/sg. 26 C8 Material Straam: Dump HX Intel Mass Enhalpy 13.34 k/sg. 26 C9 Material Straam: Dump HX Intel Mass Enhalpy 13.84 k/sg. 27 C7 Material Straam: Dump HX Intel Mass Enhalpy 13.84 k/sg. 27 D7 Material Straam: Dump HX Intel	17	E2	Material Stream: Dump HX Outlet	Tempe	rature			407.9 C		
19 B5 Material Straam: Air Iniet Mass Heat Capacity 1.014 kuftyck 21 B7 Material Straam: Air Iniet Mass Enthalpy 1.103 kg/m3 23 B8 Material Straam: Air Iniet Mass Enthalpy 7.024 kuftyg 23 B8 Material Straam: Air Iniet Mass Enthalpy 7.024 kuftyg 24 C4 Material Straam: Air Exit Pressure 1.013 kuftyd 25 C5 Material Straam: Air Exit Mass Entropy 1.037 kuftyd 26 C6 Material Straam: Air Exit Mass Entropy 1.037 kuftyd 26 C3 Material Straam: Air Exit Mass Enthalpy 1.037 kuftyd 27 C7 Material Straam: Air Exit Mass Enthalpy 1.038 kuftyd 28 C3 Material Straam: Dump HX Iniet Mass Enthalpy 1.038 kuftyd 29 Material Straam: Dump HX Iniet Mass Enthalpy 1.038 kuftyd 29 Material Straam: Dump HX Iniet Mass Enthalpy 1.048 kuftyd 29 Material Straam: Dump HX Iniet Mass Enthalpy	18	B4	Material Stream: Air Inlet	Pressu	re			104.1 kPa		
20 B6 Material Straam: Air Indet Mass Entropy 1183 kg/m3 22 B8 Material Straam: Air Indet Mass Entropy 7.024 k/k/g. 23 B9 Material Straam: Air Indet Mass Entropy 285 kg/s 24 C4 Material Straam: Air Exit Pressure 101.3 k/a 25 C5 Material Straam: Air Exit Mass Entropy 0.832 kg/m3 27 C7 Material Straam: Air Exit Mass Entropy 0.832 kg/m3 26 C8 Material Straam: Air Exit Mass Entropy 0.832 kg/m3 28 C9 Material Straam: Air Exit Mass Entropy 5.966 k/k/g.K 29 C4 Material Straam: Dump HX Intet Mass Entropy 1.364 k/k/g.K 29 Material Straam: Dump HX Intet Mass Entropy 1.364 k/k/g.K 20 Material Straam: Dump HX Intet Mass Entropy 1.364 k/k/g.K 29 Material Straam: Dump HX Intet Mass Entropy 1.364 k/k/g.K 20 Material Straam: Dump HX Intet Mass Entropy 1.364 k/k/g.K	19	B5	Material Stream: Air Inlet	Mass F	leat Capacity			1.014 kJ/kg-K		
21 B7 Material Straam: Air Initet Mass Enthalpy 7.024 kJ/kg 23 B8 Material Straam: Air Initet Mass Entropy 5.274 kJ/kg~k/C 23 C4 Material Straam: Air Exit Mass arrow 101.3 APa 24 C4 Material Straam: Air Exit Mass Enthalpy 101.3 APa 25 C5 Material Straam: Air Exit Mass Enthalpy 123.4 kJ/kg 26 C8 Material Straam: Air Exit Mass Enthalpy 123.4 kJ/kg 27 C7 Material Straam: Air Exit Mass Enthalpy 123.4 kJ/kg 27 C7 Material Straam: Air Exit Mass Enthalpy 123.4 kJ/kg 28 C6 Material Straam: Dump K Nitet Mass Enthalpy 134.4 kJ/kg 29 Material Straam: Dump K Nitet Mass Enthalpy 134.4 kJ/kg 29 Material Straam: Dump K Nitet Mass Enthalpy 134.4 kJ/kg 29 Material Straam: Dump K Nitet Mass Enthalpy 134.4 kJ/kg 29 Material Straam: Dump K Nitet Mass Enthalpy 134.8 kJ/kg <td>20</td> <td>B6</td> <td>Material Stream: Air Inlet</td> <td>Mass D</td> <td>Density</td> <td></td> <td></td> <td>1.183 kg/m3</td>	20	B6	Material Stream: Air Inlet	Mass D	Density			1.183 kg/m3		
22 B8 Material Stream: Air Intel Mass Entropy 5.274 ALAgA 24 C4 Material Stream: Air Exit Pressure 10.3 KPa 25 C5 Material Stream: Air Exit Pressure 10.3 KPa 26 C5 Material Stream: Air Exit Mass Density 0.8392 kg/m3 27 C7 Material Stream: Air Exit Mass Entropy 5.006 kL/Ag-K 28 C8 Material Stream: Air Exit Mass Entropy 5.006 kL/Ag-K 29 C9 Material Stream: Dump HX Intet Mass Entropy 7024 KPa 29 D6 Material Stream: Dump HX Intet Mass Entropy 7011 KL/Ag 20 D6 Material Stream: Dump HX Intet Mass Entropy 7011 KL/Ag 20 D8 Material Stream: Dump HX Intet Mass Entropy 7011 KL/Ag 21 D8 Material Stream: Dump HX Intet Mass Entropy 7011 KL/Ag 23 D6 Material Stream: Dump HX Intet Mass Entropy 730.8 KPa 26 Material Stream: Dump HX Outet Mass Entr	21	B7	Material Stream: Air Inlet	Mass E	Enthalpy			7.024 kJ/kg		
21 D9 Material Stream: Air Exit Mass riow 243.5 q/g 25 C5 Material Stream: Air Exit Mass Heat Capacity 1.037 kJ/kg/k 26 C6 Material Stream: Air Exit Mass Enthalpy 0.332 eg/m3 27 C7 Material Stream: Air Exit Mass Enthalpy 1.037 kJ/kg/k 28 C8 Material Stream: Air Exit Mass Enthalpy 1.234 kJ/kg 29 C9 Material Stream: Air Exit Mass Enthalpy 2.25 kg/s 20 C9 Material Stream: Air Exit Mass Enthalpy 2.25 kg/s 30 D4 Material Stream: Dump HX Inlet Mess Entrapy 1.36 kJ/kg/k 31 D7 Material Stream: Dump HX Inlet Mass Entrapy 1.46 kJ/kg/k 32 D9 Material Stream: Dump HX Inlet Mass Entrapy 1.46 kJ/kg/k 33 D7 Material Stream: Dump HX Inlet Mass Entrapy 1.46 kJ/kg/k 34 B E4 Material Stream: Dump HX Inlet Mass Entrapy 1.46 kJ/kg/k 34 E6 Material Str	22	88	Material Stream: Air Inlet	Mass E	Intropy			5.274 kJ/kg-K		
of of Material Stream: Ar Exit Pressure 1013 Mag 28 C5 Material Stream: Ar Exit Mass Heat Capacity 10.33 Kulkg-K 28 C5 Material Stream: Ar Exit Mass Enthalpy 12.34 Kulkg 28 C6 Material Stream: Ar Exit Mass Enthalpy 12.34 Kulkg 29 C9 Material Stream: Ar Exit Mass Enthalpy 28.35 kg/s 29 C9 Material Stream: Dump HX Inlet Pressure 73.2 Klkg-K 30 D5 Material Stream: Dump HX Inlet Mass Enthalpy 13.46 kUlkg-K 31 D5 Material Stream: Dump HX Inlet Mass Enthalpy 13.46 kUlkg-K 32 D9 Material Stream: Dump HX Inlet Mass Enthalpy 14.46 kUlkg-K 33 D9 Material Stream: Dump HX Inlet Mass Enthalpy 14.86 kUlkg-K 33 D9 Material Stream: Dump HX Inlet Mass Enthalpy 13.02 KUlkg-K 34 B8 Material Stream: Dump HX Outlet Mass Enthalpy 130.25 KUlkg-K 35 E7 M	23	Б9 С4	Material Stream: Air Frit	Process	ro			283.5 Kg/s		
aCaMaterial Stream: All ExitMass Density0.8392 kg/m327C7Material Stream: All ExitMass Enthalpy12.4 kJ/kg28C8Material Stream:: All ExitMass Enthalpy12.4 kJ/kg29C9Material Stream:: All ExitMass Enthalpy28.3 5 kg/s30D4Material Stream:: Dump HX IntetMass Fictory752.4 kPa31D5Material Stream:: Dump HX IntetMass Enthalpy752.4 kPa32D6Material Stream:: 	25	C5	Material Stream: Air Exit	Mass H	leat Capacity			1 0.37 k.l/kg-K		
21 C7 Material Stream: Air Exit Mass Enthalpy 123.4 kJ/kg 28 C8 Material Stream: Air Exit Mass Findropy 5.606 kJ/kg-K 30 D4 Material Stream: Dump HX Inlet Pressure 752.4 kPa 31 D5 Material Stream: Dump HX Inlet Mass Density 1364 kJ/kg-K 32 D6 Material Stream: Dump HX Inlet Mass Density 1364 kJ/kg-K 33 D7 Material Stream: Dump HX Inlet Mass Enthalpy 701.1 kJ/kg 33 D9 Material Stream: Dump HX Inlet Mass Enthalpy 701.1 kJ/kg 34 D8 Material Stream: Dump HX Inlet Mass Enthalpy 701.1 kJ/kg 35 D9 Material Stream: Dump HX Inlet Mass Enthalpy 703.8 kPa 35 E5 Material Stream: Dump HX Outlet Mass Partopy 186.5 kg/s 36 E6 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg 36 E7 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg 37 E8 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg <t< td=""><td>26</td><td>C6</td><td>Material Stream: Air Exit</td><td>Mass D</td><td>Density</td><td></td><td></td><td>0.8392 kg/m3</td></t<>	26	C6	Material Stream: Air Exit	Mass D	Density			0.8392 kg/m3		
28 C3 Material Stream: Air Exit Mass Entropy 5.606 kJ/kg-K 29 Material Stream: Dump HX Inlet Mass Flow 283 Skg/s 31 D5 Material Stream: Dump HX Inlet Mass Density 136 Ak J/kg-K 32 D6 Material Stream: Dump HX Inlet Mass Density 136 Skg/s 32 D6 Material Stream: Dump HX Inlet Mass Entropy 711 kJ/kg 33 D7 Material Stream: Dump HX Inlet Mass Entropy 701 kJ/kg 34 D8 Material Stream: Dump HX Inlet Mass Entropy 701 kJ/kg 35 D9 Material Stream: Dump HX Inlet Mass Entropy 701 kJ/kg 35 D8 Material Stream: Dump HX Outlet Mass Flow 703 kS/a 36 E6 Material Stream: Dump HX Outlet Mass Entropy 816 kG/m3 36 E7 Material Stream: Dump HX Outlet Mass Flow 7128 kJ/kg-K 41 E9 Material Stream: Dump HX Outlet Mass Flow 733 0.00 MV 42 B16 Heatt Exchanger: Dump HX	27	C7	Material Stream: Air Exit	Mass E	Enthalpy			123.4 kJ/kg		
29 G-9 Material Stream: Arr Exit Mase Tow 28.5 kg/s 30 D5 Material Stream: Dump HX Intet Pressure 752.4 kPa 31 D5 Material Stream: Dump HX Intet Mase Haca Capacity 31.364 k/kg-k 32 D6 Material Stream: Dump HX Intet Mase Enthalpy 81.69 kg/m3 33 D7 Material Stream: Dump HX Intet Mase Enthalpy 1.446 k/kg-k 34 D8 Material Stream: Dump HX Intet Mase Enthalpy 1.446 k/kg-k 35 D9 Material Stream: Dump HX Intet Mase Enthalpy 1.446 k/kg-k 35 E4 Material Stream: Dump HX Outet Mase Stream Stream: Dum PX Outet Mase Stream Stream: Dum PX Outet Mase Stre	28	C8	Material Stream: Air Exit	Mass E	Intropy			5.606 kJ/kg-K		
30 D4 Material Stream: Dump HX Inlet Presure 752 4 kPa 31 D5 Material Stream: Dump HX Inlet Mass Entral Capacity 316 kJkg-K 32 D6 Material Stream: Dump HX Inlet Mass Entralopy 316 kJkg-K 32 D7 Material Stream: Dump HX Inlet Mass Entralopy 116 kJkg-K 33 D7 Material Stream: Dump HX Inlet Mass Entralopy 146 kJkg-K 34 D8 Material Stream: Dump HX Outlet Mass Entralopy 186 kJkg-K 36 E6 Material Stream: Dump HX Outlet Mass Entralopy 816 kJkg-K 36 E7 Material Stream: Dump HX Outlet Mass Entralopy 816 kJkg-K 41 E9 Material Stream: Dump HX Outlet Mass Entralopy 186 kJkg-K 42 B16 Heat Exchanger: Dump HX Outlet Mass Entralopy 186 kJkg-K 43 D7 Material Stream: Dump HX Outlet Mass Entralopy 30.0 MW 44 E6 Material Stream: Dump HX Outlet Mass Entralopy 30.0 MW 45 D7 Material Stream: Dump HX Outlet Mass Entralopy 30.0 MW	29	C9	Material Stream: Air Exit	Mass F	low			283.5 kg/s		
31 D5 Material Stream: Dump HX Inlet Mass Hat Capacity 1.364 kJ/kg-K 32 D6 Material Stream: Dump HX Inlet Mass Entrolapy 701.1 kJ/kg 33 D7 Material Stream: Dump HX Inlet Mass Entrolapy 701.1 kJ/kg 34 D8 Material Stream: Dump HX Inlet Mass Entrolapy 701.1 kJ/kg 36 P4 Material Stream: Dump HX Inlet Mass Entrolapy 701.8 kJ/kg-K 36 E6 Material Stream: Dump HX Outlet Mass Entrolapy 701.8 kJ/kg-K 37 E5 Material Stream: Dump HX Outlet Mass Entrolapy 84.1 kJ/kg-K 38 E6 Material Stream: Dump HX Outlet Mass Entrolapy 524.1 kJ/kg 40 E8 Material Stream: Dump HX Outlet Mass Entrolapy 524.1 kJ/kg 41 E9 Material Stream: Dump HX Outlet Mass Entrolapy 1208 kJ/kg-K 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 43 B17 Heat Exchanger: Dump HX Exchanger Hot Duty 33.00 MW 44 E9 Material Stream: Dump HX Outlet Masse Entrolapy	30	D4	Material Stream: Dump HX Inlet	Pressu	re			752.4 kPa		
32 D6 Material Stream: Dump HX Inlet Mass Density 816.9 kg/m3 33 D7 Material Stream: Dump HX Inlet Mass Enthopy 701.1 kJ/kg 34 D8 Material Stream: Dump HX Inlet Mass Enthopy 186.5 kg/s 35 D9 Material Stream: Dump HX Inlet Mass Flow 186.5 kg/s 36 E4 Material Stream: Dump HX Outlet Pressure 730.8 kPa 37 E5 Material Stream: Dump HX Outlet Mass Enthopy 1.362 kJ/kg-K 38 E6 Material Stream: Dump HX Outlet Mass Enthopy 524.1 kJ/kg 38 E6 Material Stream: Dump HX Outlet Mass Enthopy 524.1 kJ/kg 41 E9 Material Stream: Dump HX Outlet Mass Flow 1065 kg/s 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duly 3.300 MW 43 E9 Material Stream: Dump HX Exchanger Cold Duly 3.300 MW 44 E9 Material Stream: Dump HX Exchanger Cold Duly 3.300 MW 45 Cell Object Variable Stream: Object Variable Description Value	31	D5	Material Stream: Dump HX Inlet	Mass H	leat Capacity			1.364 kJ/kg-K		
33 D7 Material Stream: Dump HX Inlet Mass Entralpy 701.1 kJ/kg 34 D8 Material Stream: Dump HX Inlet Mass Entropy 1446 kJ/kg+K 36 D9 Material Stream: Dump HX Inlet Mass Entropy 1446 kJ/kg+K 36 E4 Material Stream: Dump HX Outlet Pressure 730.8 kPa 37 E5 Material Stream: Dump HX Outlet Mass Heat Capacity 41.6 kJ/m3 38 E6 Material Stream: Dump HX Outlet Mass Entropy 41.6 kJ/m3 38 E7 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 40 E8 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 41 E9 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty -33.00 MW 44 Cell Object Variable Stream: Dump HX Variable Description Value 47 Cell Object Variable Description Value	32	D6	Material Stream: Dump HX Inlet	Mass D	Density			816.9 kg/m3		
34 D8 Material Stream: Dump HX Inlet Mass Entropy 1.446 kJ/kg-K 35 D9 Material Stream: Dump HX Inlet Mass Flow 186.5 kg/s 37 E5 Material Stream: Dump HX Outlet Pressure 730.8 kPa 38 E6 Material Stream: Dump HX Outlet Mass Heat Capacity 1.362 kJ/kg-K 38 E6 Material Stream: Dump HX Outlet Mass Entropy 941.6 kg/m3 39 E7 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 40 E8 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 41 E9 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 42 B16 Heat Exchanger: Dump HX Outlet Mass Flow 188.5 kg/s 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 44 E16 Object Variable Description Value 45 Cell Object Variable Description Value 46 E4 B16 Heat Exchanger Masterial Stream: Dump HX Variable Description Value 47 4 F Variable Description Value Value 48 B17 Heat Exc	33	D7	Material Stream: Dump HX Inlet	Mass E	Inthalpy			701.1 kJ/kg		
35 D9 Material Stream: Material Stream: Dump HX Outlet Mass Few Pressure 1865. kg/s 37 E5 Material Stream: Dump HX Outlet Mass Entropy 1.362 kJ/kg-K 38 E6 Material Stream: Dump HX Outlet Mass Entropy 524.1 kJ/kg 39 E7 Material Stream: Dump HX Outlet Mass Entropy 524.1 kJ/kg 41 E9 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 42 B16 Heat Exchanger: Dump HX Outlet Mass Flow 1865. kg/s 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 44 B16 Heat Exchanger: Dump HX Exchanger Hot Duty 33.00 MW 44 Gell Object Variable Description Value 45 Ferromula Results 53.00 MW 54.1 kJ/kg 46 Cell Object Variable Description Value 47 Ferromula Results 305.4 58 B13 B13: 305.4 58 <td>34</td> <td>D8</td> <td>Material Stream: Dump HX Inlet</td> <td>Mass E</td> <td>Entropy</td> <td></td> <td></td> <td>1.446 kJ/kg-K</td>	34	D8	Material Stream: Dump HX Inlet	Mass E	Entropy			1.446 kJ/kg-K		
30 E+4 Material Stream: Dump HX Outlet Pressure 7.30.8 kPa 31 E5 Material Stream: Dump HX Outlet Mass Belat Capacity 1.332 kJ/kg-K 33 E7 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg-K 33 E7 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg-K 41 E9 Material Stream: Dump HX Outlet Mass Flow 1208 kJ/kg-K 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty -33.00 MW 44 Functed Variables' Formula Results 45 Fige Structed Variable Description Value 46 Cell Value 47 Functeole Variable Description Value 48 Structeole Variable Description Value 49 Structeole Variable Description Value 41 B11 B11: 290.7 51 <td>35</td> <td>D9</td> <td>Material Stream: Dump HX Inlet</td> <td>Mass F</td> <td>low</td> <td></td> <td></td> <td>186.5 kg/s</td>	35	D9	Material Stream: Dump HX Inlet	Mass F	low			186.5 kg/s		
Indefinite outwain Material Stream: Dump HX Outlet Mass Teal Capacity Part All Skight 38 E6 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg 40 E8 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg 41 E9 Material Stream: Dump HX Outlet Mass Enthalpy 524.1 kJ/kg 42 B16 Heat Exchanger: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 44 Heat Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Cell Object Variable Stream: Value 45 PARAMETERS 46 Cell Variable Name Variable Description Value 47 Stream: 48 Stream: Value 49 Stream: 41 Stream: Value 42 B3 B3: Stream: Valu	30	E4 E5	Material Stream: Dump HX Outlet	Mass L	re Joat Capacity			1 362 k l/kg K		
Image Image <t< td=""><td>38</td><td>E6</td><td>Material Stream: Dump HX Outlet</td><td>Mass F</td><td>)ensity</td><td></td><td></td><td>841.6 kg/m3</td></t<>	38	E6	Material Stream: Dump HX Outlet	Mass F)ensity			841.6 kg/m3		
40 E8 Material Stream: Dump HX Outlet Mass Entropy 1.208 kJ/kg-K 41 E9 Material Stream: Dump HX Outlet Mass Flow 186.5 kg/s 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 43 B17 Heat Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exported Variables' Formula Results 46 Cell Object Variable Description Value 47 Exportable Variables 48 Exportable Variable Description Value 49 Cell Visible Name Variable Description Value 49 Exportable Variables 50 Cell Value 51 Cell Value 53 B11 B11: 305.4 53 B12 B12: 290.7 54 B12 B12: 1.025 55 </td <td>39</td> <td>E7</td> <td>Material Stream: Dump HX Outlet</td> <td>Mass E</td> <td>Enthalpy</td> <td></td> <td></td> <td>524.1 kJ/kg</td>	39	E7	Material Stream: Dump HX Outlet	Mass E	Enthalpy			524.1 kJ/kg		
41 E9 Material Stream: Dump HX Outlet Mass Flow 186.5 kg/s 42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty 33.00 MW 43 B17 Heat Exchanger: Dump HX Exchanger Cold Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 45 ExportableS Formula Results Value 47 Exportable Variable Description Value	40	E8	Material Stream: Dump HX Outlet	Mass E	Entropy			1.208 kJ/kg-K		
42 B16 Heat Exchanger: Dump HX Exchanger Cold Duty	41	E9	Material Stream: Dump HX Outlet	Mass F	low			186.5 kg/s		
43 B17 Heat Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 44 Exchanger: Dump HX Exchanger Hot Duty -33.00 MW 44 Cell Object Variables' Formula Results Variable Description Value 46 Cell Object Variable Description Value Value 47 ************************************	42	B16	Heat Exchanger: Dump HX	Exchar	nger Cold Duty			33.00 MW		
Experted Variables' Formula Results Cell Object Variable Description Value PARAMETERS 9 Exportable Variable Description Variable Type Value 9 Exportable Variable Description Variable Type Value 9 Subject Name Variable Description Variable Type Value 1025 B3 B3: Subject Name Variable Description Variable Type Value Subject Name Variable Description Variable Type Value Subject Name Variable Description Variable Type Value B11 B11: Subject Name B12 B12: B13: B13: B13: B13: B14: Subject Nu	43	B17	Heat Exchanger: Dump HX	Exchar	nger Hot Duty			-33.00 MW		
45 Cell Object Variable Description Value 47	44		Exp	orted V	/ariables' Forn	nula Results				
47 48 PARAMETERS 49 50 Exportable Variables 51 Cell Visible Name Variable Description Variable Type Value 52 B3 B3: 305.4 53 B11 B11: 290.7 54 B12 B12: 254.2 55 B13 B13: 1.025 56 B14 B14: 1.025 56 B14 B14: 1.025 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3: C3: 418.9 <t< td=""><td>40 46</td><td>Cell</td><td>Object</td><td></td><td></td><td>Variable Description</td><td></td><td>Value</td></t<>	40 46	Cell	Object			Variable Description		Value		
48 Frequencies 49 50 Exportable Variables 51 Cell Visible Name Variable Description Variable Type Value 52 B3 B3: Solution Solution Solution Solution 53 B11 B11: Solution Solution <thsolution< th=""> Solution <th< td=""><td>47</td><td></td><td></td><td></td><td></td><td>s</td><td></td><td></td></th<></thsolution<>	47					s				
Handbare Exportable Variables 50 Cell Visible Name Variable Description Variable Type Value 51 Cell Visible Name Variable Description Variable Type Value 52 B3 B3: 305.4 305.4 53 B11 B11: 305.4 54 B12 B12: 254.2 55 B13 B13: 1.025 56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.3626 59 B20 B20: NTU NTU 0.3626 50 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3 C3: C3: 418.9	48									
Sub- Variable Description Variable Type Value 51 Cell Visible Name Variable Description Variable Type Value 52 B3 B3: 305.4 305.4 52 B3 B1: 305.4 305.4 53 B11 B11: 290.7 290.7 54 B12 B12: 290.7 55 B13 B13: 1.025 56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 50 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3: C3: C3: 418.9	49			Ex	portable Varia	bles				
Solar France France France Variable Figure Variable Figur	51	Cell	Visible Name		Variable Dee	cription	Variable Type	Value		
B1 B11: 200.7 54 B12 B12: 254.2 55 B13 B13: 1.025 56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 58 B20 B20: NTU NTU 0.3626 60 B21 B21: UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 61 B22 B22: LMTD LMTD 418.9 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 * Specified by user.	52	B3	B3:		Valiable Des			305.4		
54 B12 B12: 254.2 55 B13 B13: 1.025 56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21: DA UA UA 92.18 kJ/C-s 61 B22: LMTD LMTD Temperature 358.0 C 62 C3: C3: 418.9 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE	53	B11	B11:					290.7		
55 B13 B13: 1.025 56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21: DA UA UA 92.18 kJ/C-s 61 B22: LMTD LMTD Temperature 358.0 C 62 C3: C3: 418.9 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE	54	B12	B12:					254.2		
56 B14 B14: 1.363 57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3: C3: 418.9 63 Bspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE	55	B13	B13:					1.025		
57 B18 B18: Max Duty Max Duty Power 128.5 MW 58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3 C3: 418.9 Icensed to: BATTELLE ENERGY ALLIANCE	56	B14	B14:					1.363		
58 B19 B19: Effectiveness Effectiveness 0.2569 59 B20 B20: NTU NTU 0.3626 60 B21 B21: UA UA UA 92.18 kJ/C-s 61 B22 LMTD IMTD Temperature 358.0 C 62 C3 C3: 418.9 Iclensed to: BATTELLE ENERGY ALLIANCE	57	B18	B18: Max Duty	Max Dı	uty		Power	128.5 MW		
59 B20: R20:: NTU NTU 0.3626 60 B21: B21:: UA UA UA 92.18 kJ/Cs 61 B22: LMTD Temperature 358.0 C 62 C3: C3: 418.9 Aspen Technology Inc. Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE *Specified by user.	58	B19	B19: Effectiveness	Effectiv	veness			0.2569		
BZ1 BZ1: UA UA UA 92.18 kJ/C-s 61 B22 B22: LMTD LMTD Temperature 358.0 C 62 C3 C3: 418.9 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user. * Specified by user.	59	B20	B20: NTU	NTU				0.3626		
D12 D22 B22: LM1D LM1D Temperature 358.0 C 62 C3 C3: 418.9 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE	60	B21	B21: UA	UA			UA	92.18 kJ/C-s		
63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 3 Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.	62	Б22 СЗ	BZZ: LMTD	LMTD			Iemperature	358.0 C		
Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.	63	Aspen T	echnology Inc.	Asp	en HYSYS Versi	ion 11		Page 1 of 3		
		Licensed to:	BATTELLE ENERGY ALLIANCE	7.00				* Specified by user.		

_							
1				Case Name:	final project.1.hsc		
2	(aspentech Bedford, MA	NERGY ALLIANCE	Unit Set:	Project Units3s		
4	0	USA		Date/Time:	Sat Aug. 7 20:42:51 2021		
5				Bate/Time.	Outridg 7 20.42.01 2021		
7		Spreadshee	et: DumpHX	Contro	l (continued)	I	Units Set: Project Unit
9				PARAMETE	RS		
11			Ex	portable Var	iables		
12	Се	Visible Name		Variable [Description V	ariable Type	Value
14	D3	D3:		Tunubio E			810.9
15	E3	E3:					681.1
16	E1	1 E11:					1.144
17	E1(6 E16:			Leng	th	36.58 m
18	E1	7 E17: Pipe Length (Pipe Length_1)) Pipe Le	ength (Pipe Leng	th_1) Leng	th	5.080e-002 m
19	E18	B E18: nn tubes	nn tube	es			66.00
20	E2	E21: UOutside	UOutsi	ide	Ht. Ti	an. Coeff	0.2393 kJ/s-m2-C
21 22				User Variab	les		
23 24				FORMULA	S		
25	Ce	1	ł	Formula			Result
26	B3	=b2+273.15					305.4
27	B1	1 =b9*(b5+c5)/2					290.7
28	B1:	2 =d9*(d5+e5)/2					254.2
29	B13	3 =(c7-b7)/(c2-b2)					1.025
30	B14	4 =(e7-d7)/(e2-d2)					1.363
31	B18	3 =B16/B19					128.5 MW
32	B19	e@if(b12 <b11,(d2-e2) (d2-b2),(c2<="" td=""><td>2-b2)/(d2-b2))</td><td></td><td></td><td></td><td>0.2569</td></b11,(d2-e2)>	2-b2)/(d2-b2))				0.2569
33	B2) =@IF(B11 <b12, -(1="" e11)*@ln(e<="" td=""><td>11*@LN(1-B19)+1),-@LN</td><td>I(1+(1/E11)*@LN</td><td>I(1-E11*B19)))</td><td></td><td>0.3626</td></b12,>	11*@LN(1-B19)+1),-@LN	I(1+(1/E11)*@LN	I(1-E11*B19)))		0.3626
34	B2	1 =@IF(B11 <b12,b11*b20,b12*b2< td=""><td>0)</td><td></td><td></td><td></td><td>92.18 kJ/C-s</td></b12,b11*b20,b12*b2<>	0)				92.18 kJ/C-s
35	B2	2 =B16*1000/(B21)					358.0 C
36	C3	=c2+273.15					418.9
37	D3	=d2+273.15					810.9
38	E3	=e2+273.15					681.1
39	E1	1 =b11/b12					1.144
40 41	E2	1 =B21/(PI*E16*E17*e18)					0.2393 kJ/s-m2-C
42		•		SPREADSH			
43 44	1	A	В	Air In *	<u> </u>	ut *	U No. In *
45	2	Temperature (C) *		32 22 C. *	1/5 7	C *	537 8 C *
46	3	Temperature (K) *		305.4 *	418	9 *	810.9 *
47	4	Pressure (kPa) *		104.1 kPa *	101 3 kF	- 'a *	752.4 kPa *
48	5	Cp (kJ/kg*K) *	1	.014 kJ/ka-K *	1.037 k.l/ka-		1,364 kJ/ka-K *
49	6	Density (kg/m3) *		1.183 kg/m3 *	0.8392 ka/m	13 *	816.9 ka/m3 *
50	7	Enthalpy (kJ/kg) *		7.024 kJ/kg *	123.4 kJ/ł	(g *	701.1 kJ/ka *
51	8	Entropy (kJ/kg*K) *	5.	.274 kJ/kg-K *	5.606 kJ/kg	- K *	1.446 kJ/kg-K *
52	9	Mass Flow Rate (kg/s) *		283.5 kg/s *	283.5 kg	/s *	186.5 kg/s *
53	10						
54	11	Ccold *		290.7 *			Cr *
55	12	Chot *		254.2 *			
56	13	Cp Cold *		1.025 *			
57	14	Cp Hot *		1.363 *			
58	15	HX Information *					
59	16	HX Duty Cold Side (MW) *		33.00 MW *			Length of Pipes *
60	17	HX Duty Hot Side (MW) *		-33.00 MW *			Diameter of pipes *
61	18	Maximum Duty (MW) *		128.5 MW *	<empty< td=""><td>r> *</td><td></td></empty<>	r> *	
62	19	Effectiveness *		0.2569 *			
63	Asp	en Technology Inc.	Asp	en HYSYS Ve	rsion 11		Page 2 of 3
	Licens	ed to: BATTELLE ENERGY ALLIANCE					* Specified by user.

_						
1				Case Name:	final project.1.hsc	
3	(aspentech Bedford, MA	NERGY ALLIANCE	Unit Set:	Project Units3s	
4 5		USA		Date/Time:	Sat Aug 7 20:42:51 2021	
6						
7 8		Spreadshee	et: DumpHX	Contro	ol (continued)	Units Set: Project Unit
9			:	SPREADSH	IEET	
11	20	NTU *		0.3626 *		
12	21	UA actual *	g	2.18 kJ/C-s *		U
13	22	LMTD actual *		358.0 C *		
14	23	_				
15	4	E				
16	1	107.9.C.*				
18	2	681.1 *				
19	4	730.8 kPa *				
20	5	1.362 kJ/kg-K *				
21	6	841.6 kg/m3 *				
22	7	524.1 kJ/kg *				
23	8	1.208 kJ/kg-K *				
24	9	186.5 Kg/S				
26	11	1.144 *				
27	12					
28	13					
29	14					
30	15					
31	16	36.58 m *				
32	1/	5.080e-002 m -				
34	19	00.00				
35	20					
36	21	0.2393 kJ/s-m2-C *				
37	22					
38	23					
39						
40						
42						
43						
44						
45						
46						
47						
48						
50						
51						
52						
53						
54						
55						
56						
57						
59						
60						
61						
62						
63	Asp	en Technology Inc.	Aspe	en HYSYS V	ersion 11	Page 3 of 3
	Licens	ed to: BATTELLE ENERGY ALLIANCE				* Specified by user.

1			25	Case Name:	final project.1.hsc		
3	(the as	spentech Bedford, MA	JE	Unit Set:	Project Units3s		
4		USA		Date/Time:	Sat Aug 7 20:43:04 2	2021	
6					-		
7		Spreadsheet: Effe	ctive	ness-NTU	METHOD		Units Set: Project Units
8							
9				CONNECTIONS	3		
11							
12			In	nported Variabl	es		-
13	Cell	Object		١	/ariable Description		Value
14	B2	Pipe Segment: Single Tube	Inside I	Diameter (Inside Diar	meter_1)		46.58 mm
15	B3	Pipe Segment: Single Tube	Outside	e Diameter (Outside	Diameter_1)		50.80 mm
10	B7	Material Stream: Air Inlet	Actual	Volume Flow)		9.144 m 8.627e+005 m3/b
18	B8	Material Stream: Air Inlet	Mass I	Volume Flow			1 183 kg/m3
19	B9	Material Stream: Air Inlet	Viscosi	ity			1.103 kg/m3
20	B10	Material Stream: Air Inlet	Therma	al Conductivity			2.643e-002 W/m-K
21	B11	Material Stream: Air Inlet	Mass H	leat Capacity			1.014 kJ/kg-K
22	B12	Material Stream: Air Average	Viscos	ity			2.141e-002 cP
23	B13	Material Stream: Air Average	Therma	al Conductivity			3.021e-002 W/m-K
24	B14	Material Stream: Air Average	Mass H	leat Capacity			1.036 kJ/kg-K
25	B21	Material Stream: Sodium Inlet	Mass D	Density			816.9 kg/m3
26	B22	Material Stream: Sodium Inlet	Actual	Volume Flow			12.45 m3/h
27	B23	Material Stream: Sodium Inlet	Mass H	leat Capacity			1.364 kJ/kg-K
28	B24	Material Stream: Sodium Inlet	Viscos	ity			0.2249 cP
29	B25	Material Stream: Sodium Inlet	Therma	al Conductivity			65.54 W/m-K
30	C12	Material Stream: Air Surface	Viscos	ity			3.669e-002 cP
31	C13	Material Stream: Air Surface	Therma	al Conductivity			5.356e-002 W/m-K
32	C14	Material Stream: Air Surface	Mass H	leat Capacity			1.115 kJ/kg-K
33		Exp	orted V	/ariables' Form	ula Results		
35	Cell	Object		\	ariable Description		Value
36		,					
37				PARAMETERS	•		
38			Ex	portable Variab	oles		
39 40	Cell	Visible Name		Variable Desc	ription	Variable Type	Value
41	B1	B1:				Length	0.1016 m
42	B5	B5:				Length	0.1524 m
43	B6	B6: N tubes	N tube:	s			66.00
44	B16	B16:				Area	353.3 m2
45	B17	B17:				Area	385.3 m2
46	B19	B19: Deposition Thermal Conductivity	Deposi	tion Thermal Conduc	tivity	Thermal Cond.	21.50 W/m-K
47	E1	E1:				Area	3.716 m2
48	E2	E2:				Velocity	64.49 m/s
49	E3	E3:				Velocity	129.0 m/s
50	E4	<u>E4:</u>					4.043e+005
51	E5	E5:					0.7352
52	E0 E7	E0.					0.7344
54	E/	E/.				 Ht Tran Cooff	903.0 0.5014 k l/o m2.0
55	E0	E0.	ALI				193.1 k.l/C-e
56	E13	E13: U outside	Unitei	ide		Ht Tran Coeff	0.5011 k.l/s-m2-C
57	E14	E14: U inside	U insid	e		Ht. Tran. Coeff	0.5465 kJ/s-m2-C
58	E17	E17:	2			Length	5.080e-002 m
59	E18	E18:					7.184e-002
60	E21	E21:					1.704e-003
61	E22	E22:				Velocity	2.029 m/s
62	E23	E23:					3.433e+005
63	Aspen T	echnology Inc.	Asp	en HYSYS Versio	on 11		Page 1 of 4

* Specified by user.

1				Case Name:	final project.1.hsc							
3	(the as	spentech Bedford, MA	E	Unit Set:	Project Units3s							
4 5		USA		Date/Time:	Sat Aug 7 20:43:04	2021						
6												
7 8		Spreadsheet: Effect	ctive	ness-NTU	METHOD	(continuec	Units Set:	Project Units				
9				PARAMETERS								
10 11												
12			Ex	portable Variab	les							
13	Cell	Visible Name		Variable Descr	iption	Variable Type	\	Value				
14	E24	E24:					4.681e-0)03				
15	E25	E25:					1607					
10	E20 E27	E28:				 Ht Tran Cooff	19.14	1/c m2 C				
18	E3	E27.				Velocity	64.49 m	/s-11/2-0				
19	F4	F4:					2 021e+	005				
20	F5	F5:					0.7344					
21	F6	F6:					0.7638					
22	F7	F7:					558.0					
23	F8	F8:				Ht. Tran. Coeff	0.2903 k	J/s-m2-C				
24	F12	F12: UA - Staggered	UA - St	taggered		UA	111.8 kJ	J/C-s				
25	F13	F13: U Outside - Staggered	U Outs	ide - Staggered		Ht. Tran. Coeff	0.2903 k	J/s-m2-C				
26	F14	F14: U Inside - Staggered	U Insid	e - Staggered		Ht. Tran. Coeff	0.3165 k	J/s-m2-C				
27	F18	F18:					7.620e-0	002				
28				Lleor Variables								
29				User variables								
30				FORMULAS								
31	1 Chillo Formula Recult											
32	B16		r	Formula			252.2	cesuit				
33	B10	=PI*(b2/1000)*4*b4*b6					353.3 m	2				
35	E1	=P1 (b3/1000) 4 b4 b6					3 716 m	2				
36	E1	=b7/3600/e1					64 49 m	2 /s				
37	E3	=b1//5000/e1 =b1//b1-b3/1000)*e2					129.0 m	/s				
38	E4	=b8*e3*(b3/1000)/(b9/1000)					4.043e+	005				
39	E5	=(b9/1000)*(b11*1000)/b10					0.7352					
40	E6	=(b12/1000)*(b14*1000)/b13					0.7344					
41	E7	=0.021*e4^0.84*e5^0.36*(e5/e6)^0.25					963.5					
42	E8	=e7*b10/(b3/1000)*1/1000					0.5014 k	J/s-m2-C				
43	E12	=(1/(e27*b16)*@ln(b3/b2)/(2*PI*b19/1000*4*b4)+1	/(e8*b17	'))^(-1)			193.1 kJ	J/C-s				
44	E13	=e12/b17					0.5011 k	J/s-m2-C				
45	E14	=e12/b16					0.5465 k	J/s-m2-C				
46	E17	=1/2*b1					5.080e-0)02 m				
47	E18	=(e17^2+(b1/2)^2)^0.5					7.184e-0)02				
48	E21	=PI/4*(b2/1000)^2					1.704e-0)03				
49	E22	=(b22/3600)/e21					2.029 m	/s				
50	E23	=b21*e22*(b2/1000)/(b24/1000)					3.433e+	005				
51	E24	=(b24/1000)*(b23*1000)/b25					4.681e-0	JU3				
52	E25	=e23"e24					1607					
53 54	E20	=4.85+U.U185*625*U.82/					13.14	1/c m2 C				
55	E3	=b1/(2*(2*a17-b3/1000))*o2					10.49 KJ	/ə-1112-0				
56	F4	=b8*f3*(b3/1000)/b9/1000)					2 021c+	005				
57	F5	=(b12/1000)*(b14*1000)/b13					0.7344					
58	 F6	=(c12/1000)*(c14*1000)/c13					0.7638					
59	F7	=0.022*f4^0.84*f5^0.36*(f5/f6)^0.25					558.0					
60	F8	=f7*b10/(b3/1000)*1/1000					0.2903 k	(J/s-m2-C				
61	F12	=(1/(e27*b16)*@ln(b3/b2)/(2*PI*b19/1000*4*b4)+1	/(f8*b17)))^(-1)			111.8 kJ	J/C-s				
62	F13	=f12/b17	. ,	· · ·			0.2903 k	J/s-m2-C				
63	Aspen T	echnology Inc.	Asp	en HYSYS Versio	n 11		F	Page 2 of 4				
_	Licensed to:	BATTELLE ENERGY ALLIANCE					* Speci	fied by user.				
Case Name: final project.1.hsc 2 3 4 5 BATTELLE ENERGY ALLIANCE (aspentech Bedford, MA Unit Set: Project Units3s USA Date/Time: Sat Aug 7 20:43:04 2021 6 7 Spreadsheet: Effectiveness-NTU METHOD (continuec Units Set: Project Units 8 9 FORMULAS 10 11 Cell Formula Result 12 F14 =f12/b16 0.3165 kJ/s-m2-C 13 F18 =(b1+b3/1000)/2 7.620e-002 14 SPREADSHEET 15 16 в С D Α 17 1 S_T * 0.1016 m * <empty> HX Area 18 2 46.58 mm * Velocity Dinside 19 3 Doutside 50.80 mm * Max Velocity 20 4 Pass Length of straight section 9.144 m * Re D Max 21 5 Height of Area Section * 0.1524 m * Pr ' 22 6 N of Tubes 66.00 ' Pr_s 7 23 8.627e+005 m3/h * Air Volume Flow Ave Nu D 24 8 Air Density * 1.183 kg/m3 * h outside 25 9 1.917e-002 cP Air Viscosity 26 10 Air Thermal Conductivity 2.643e-002 W/m-K * 27 11 Air Mass Heat Capacity 1.014 kJ/kg-K * 28 12 Ave Air Viscosity * 2.141e-002 cP * 3.669e-002 cP 3 UA ' 29 13 Ave Air Thermal Cond 3.021e-002 W/m-K 5.356e-002 W/m-K U outside 30 14 Ave Air Mass Heat Cp * 1.036 kJ/kg-K * 1.115 kJ/kg-K * Uinside 31 15 32 16 Inside Area 353.3 m2 * 33 17 Outside Area 385.3 m2 ' S_L <empty> 34 18 S D <empty> <empty> 35 19 Thermal Cond Pipe * 21.50 W/m-K * <empty> 36 20 <empty> <empty> 37 21 Sodium mass density * 816.9 kg/m3 * XArea <empty> 38 22 Sodium Volume Flow * 12.45 m3/h * Velocity ' <empty> ' 39 23 Sodium mass heat Cp 1.364 kJ/kg-K * Reynolds Number 3 <empty> 40 Sodium Viscosity 24 0.2249 cP ' Pr <empty> 41 25 65.54 W/m-K * <empty> Pe Sodium Thermal Cond 26 42 <empty> * <empty> NU_D * 43 27 <empty> * hinside <empty> F 44 F 45 1 3.716 m2 * 46 2 64.49 m/s 47 3 129.0 m/s 64.49 m/s * 48 4 4.043e+005 2.021e+005 * 49 5 0.7352 * 0.7344 * 50 6 0.7344 0.7638 * 51 7 963.5 558.0 * 52 8 0.5014 kJ/s-m2-C * 0.2903 kJ/s-m2-C * 53 9 54 10 <empty> * <empty> * 55 11 56 12 193.1 kJ/C-s * 111.8 kJ/C-s * 57 13 0.5011 kJ/s-m2-C 0.2903 kJ/s-m2-C 58 14 0.5465 kJ/s-m2-C 0.3165 kJ/s-m2-C 59 15 60 16 61 17 5.080e-002 m * 62 18 7.184e-002 * 7.620e-002 * Aspen HYSYS Version 11 63 Aspen Technology Inc. Page 3 of 4

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

1				Case Name:	final project.1.hsc	
2	Call	BATTELLE EN	IERGY ALLIANCE	Linit C-t	Draiget Inite?-	
3	Ce	Bediora, MA		Unit Set:	Project Units3s	
4		00/1		Date/Time:	Sat Aug 7 20:43:04 2021	
6						
7		Sproadshor	t. Effoctivo	noss NT		
8		Spreausnee	a. Enective	11622-IN I		
9						
10				SPREADSHE	ET	
11	19					
12	20					
13	21	1.704e-003 *				
14	22	2.029 m/s *				
15	23	3.433e+005 *				
16	24	4.681e-003 *				
17	25	1607 *				
18	26	13.14 *				
19	27	18.49 kJ/s-m2-C *				
20						
21						
22						
23						
24						
25						
20						
27						
20						
30						
31						
32						
33						
34						
35						
36						
37						
38						
39						
40						
41						
42						
43						
44						
45						
40						
47						
49						
50						
51						
52						
53						
54						
55						
56						
57						
58						
59						
60						
61						
62	Aan		۸		sion 11	Dogo 4 of 4
03	License	ed to: BATTELLE ENERGY ALLIANCE	ASP	entrioro vel		* Specified by user.

_													
1				Case Name:	final project.1.hsc								
3	(aspentech Bedford, MA	NERGY ALLIANCE	Unit Set:	Project Units3s								
4		USA		Date/Time:	Sat Aug. 7 20:43:22 2	021							
5 6				Bato, Hino.	0417 Mg 7 20110.22 2								
7		Spreadshe	et: Correction	on Facto	or METHOD		ι	Jnits Set: Project Unit					
9				CONNECTIO	ONS								
11			Ir	nported Varia	ables								
13	Ce	I Object			Variable Description			Value					
14	B2	Material Stream: Dump HX	Inlet Tempe	erature	· ·			537.8 C					
15	C2	Material Stream: Dump HX	Outlet Tempe	erature				407.9 C					
16	D2	Material Stream: Air Inlet	Tempe	erature				32.22 C					
17	E2		145.7 C										
18	B8	Heat Exchanger: Dump HX	LMTD					383.6 C					
19	B3	Heat Exchanger: Dump HX	Excha	nger Cold Duty				33.00 MW					
20	Exported Variables' Formula Results												
22	Cell Object Variable Description Value												
23				PARAMETE	RS								
24 25													
26	Exportable Variables												
27	Z Cell Visible Name Variable Description Variable Type Value												
28	B5	B5:						0.7431					
29	B6		1.144										
30	C10	0 C10:						<empty></empty>					
31	D3	D3:						385.3					
32	E5	E5:						0.9333					
33	E7	E7: UA	UA			UA		92.18 kJ/C-s					
34	E8	E8: U Outside	U Outs	side		Ht. Tran.	Coeff	0.2392 kJ/s-m2-C					
35 36				User Variab	les								
37 38				FORMULA	S								
39	Ce			Formula				Result					
40	B5	=(c2-d2)/(b2-d2)						0.7431					
41	B6	=(b2-c2)/(e2-d2)						1.144					
42	C10	0 =b9*e5						<empty></empty>					
43	D3	=66*36.58*.0508*PI						385.3					
44	E7	=b3*1000/(e5*b8)						92.18 kJ/C-s					
45	E8	=e7/d3						0.2392 kJ/s-m2-C					
40 47				SPREADSH	EET								
48		Δ	В		c			D					
49	1		<u>ה</u>	ump HX Inlet *	Dumn H	IX Outlet *		Air Inlet *					
50	2	Temperature *		537.8 C *	Campi	407.9 C *		32.22 C *					
51	3	Exchanger Cold Duty *		33.00 MW *		Area *		385.3 *					
52	4												
53	5	Р*		0.7431 *				F (from Graph) *					
54	6	R *		1.144 *				<emptv> *</emptv>					
55	7							UA *					
56	8	T-LogMean-CF *		383.6 C *				U *					
57	9	.		<empty> *</empty>									
58	10					<empty> *</empty>							
59		E											
60	1	Air Exit *											
61	2	145.7 C *											
62	3												
63	Asp	en Technology Inc.	Asp	en HYSYS Ve	rsion 11			Page 1 of 2					
_	License	ed to: BATTELLE ENERGY ALLIANCE						* Specified by user.					



1						-	Cose Name:	final project 1	222				
2	Call	0.00	BAT		NERGY ALLIANC	E -			130				
3	Cill	d	Spentech Bed	lford, MA A		_	Unit Set:	Project Units3	S				
5							Date/Time:	Sat Aug 7 20:	43:40 2021				
6 7			Spread	lsher	et Hum	iditv				ι	Jnits Set: F	ProiectUnits	
8			oprout			iaity							
9 10						С	ONNECTIO	ONS					
11						Imp	orted Var	ables					
12 13	Се		Obi	ject				Variable Descrip	tion		Valu	ie	
14	B6	6	Material Stream:	Water Va	por @TPL1	Mass Flo	w	·			0.0000 kg/s		
15	B5	5	Material Stream:	Dry Air @	TPL1	Mass Flo	w				283.5 kg/s		
16	B2	2	Material Stream:	Saturated	Air @TPL1	Master C	omp Mole Fra	c (H2O)			0.0393		
17	Ы		Material Stream:	Humid Air	@IPL1	Master C	omp Mole Fra	c (H2U)			0.0000		
19	Exported Variables' Formula Results												
20	Ce	II	Obj	ject				Variable Descrip	tion		Valu	ie	
22						P	ARAMETE	RS					
23 24						Expo	ortable Va	riables					
25	Ce		Visible	Name			Variable I	Description	Varia	ble Type	Valu	ie	
26	6 B3 B3: Relative Humidity R						Humidity				0.0000		
27	B4	ŀ	B4: Desired Humidity			Desired H	Humidity				0.0000		
28	B7 B7:								0.0000				
29 30	User Variables												
31 32	FORMULAS												
33	33 Cell Formula									Res	ult		
34	B3	3	=b1/b2								0.0000		
35 36	БЛ		=06/05								0.0000		
37						5	PREADSH			1			
39	1	N	A Iole Fraction of H2O in Hu	umid Air *		в	0.0000 *	<u> </u>			<u> </u>		
40	2	Mole	Fraction of H2O in Satura	ated Air *			0.0393 *						
41	3		Relative H	lumidity *			0.0000 *						
42	4		Desired H	lumidity *			0.0000 *						
43	5		Mass Flow of	Dry Air *		2	283.5 kg/s *						
44	6 7		Mass Flow of Wate	r vapor - lumidity *		0.	0000 kg/s *						
46	8		opeoneri				0.0000						
47	9												
48	10												
49													
50													
52													
53													
54													
55													
56													
57													
58													
60													
61													
62													
63	Asp	en T	echnology Inc.			Asper	HYSYS Ve	ersion 11			Paç	e 1 of 1	
	Licens	ed to:	BATTELLE ENERGY ALLIA	NCE							* Specified	by user.	

Case Name: final project.1.hsc 2 3 4 5 BATTELLE ENERGY ALLIANCE (aspentech Bedford, MA Unit Set: Project Units3s USA Date/Time: Sat Aug 7 20:42:39 2021 6 7 Spreadsheet: IHX Effectiveness Units Set: ProjectUnits 8 9 CONNECTIONS 10 11 Imported Variables 12 13 Cell Object Variable Description Value 14 B2 Material Stream: 1 Temperature 595.8 C 15 В3 Material Stream: 1 Mass Heat Capacity 1.368 kJ/kg-K 16 Β4 Mass Flow 742.4 kg/s Material Stream: 1 17 C2 Material Stream: 2 Temperature 565.6 C 18 C3 Material Stream: 2 Mass Heat Capacity 1.366 kJ/kg-K 19 C4 Material Stream: 2 Mass Flow 742.4 kg/s 20 D2 Material Stream: 6 Temperature 415.1 C 21 D3 Material Stream: 6 1.362 kJ/kg-K Mass Heat Capacity 22 D4 Material Stream: 6 Mass Flow 186.5 kg/s E2 Material Stream: Dump HX Inlet 537.8 C 23 Temperature E3 Material Stream: Dump HX Inlet Mass Heat Capacity 1.364 kJ/kg-K 24 25 E4 Material Stream: Dump HX Inlet Mass Flow 186.5 kg/s 26 Exported Variables' Formula Results 27 Cell 28 Object Variable Description Value 29 PARAMETERS 30 31 **Exportable Variables** 32 33 Cell Visible Name Variable Description Variable Type Value 34 B6 0.6788 B6: IHX Effectiveness IHX Effectiveness ----C5 35 1015 C5: ----36 E5 E5: 254.2 37 User Variables 38 39 FORMULAS 40 41 Cell Formula Result 42 B6 =@if(c5<e5,(b2-c2)/(b2-d2),(e2-d2)/(b2-d2)) 0.6788 43 C5 1015 =b4*(b3+c3)/2 44 E5 =d4*(d3+e3)/2 254.2 45 SPREADSHEET 46 47 С D Α в 48 1 Inlet 1 Outlet 2 Inlet 6 49 2 415.1 C Temperature (C) * 595.8 C * 565.6 C 50 3 1.368 kJ/kg-K ' 1.366 kJ/kg-K 1.362 kJ/kg-K Ср 4 186.5 kg/s 51 742.4 kg/s * Mass Flow 742.4 kg/s 52 5 mdot Cp Hot * 1015 * mdot Cp Cold 53 6 Effectiveness * 0.6788 * 54 7 55 8 56 9 57 10 Е 58 59 1 Outlet 4 * 60 2 537.8 C * 61 3 1.364 kJ/kg-K 62 4 186.5 kg/s * Aspen HYSYS Version 11 63 Page 1 of 2 Aspen Technology Inc. Licensed to: BATTELLE ENERGY ALLIANCE * Specified by user.

1					Case Name	final project.1	.hsc		
2	(1)	aspentech	BATTELLE EI Bedford, MA	NERGY ALLIANCE	Unit Set:	Proiect Units3	ls		
4	C		USA		Date/Time:	Sat Aug 7 20	:42:39 2021		
5 6									
7		Spre	eadshee	et: IHX Effe	ctivene	ss (contin	ued)	Units Set:	ProjectUnits
9						IEET			
10 11	5		254.2 *						
12	6		20112						
13 14	7 8								
15	9								
16 17	10								
18									
20									
21									
22									
24									
25									
27									
28									
30									
32									
33									
35									
36									
38									
39									
41									
42									
44									
45 46									
47									
48 49									
50									
51 52									
53									
54 55									
56									
57 58									
59									
60 61									
62	Δ	on Toobaala		•		anaion 11			
63	License	ed to: BATTELLE ENERGY	ALLIANCE	Asp	UD1515V			* Speci	fied by user.

1		DATTELL			Case Name:	final project.1.hsc				
3	entech	Bedford, N	IA	, C	Unit Set:	Project Units3s				
4		USA			Date/Time:	Sat Aug 7 20:41:58 202	21			
6				-						
7	Wor	kbook:	Humidit	y C	alculator (FPL1)				
9					Material Stream	s		Fluid Pk	g:	All
11	Name		Water Vapor		Dry Air	Humid Air	Water 2		Air 2	
12	Vapour Fraction				1.0000	1.0000				
13	Temperature	(C)	-		28.97	28.97				
14	Pressure	(kPa)	101	.3	101.3	101.3		101.3		101.3
15	Molar Flow	(kgmole/h)	0.000	00	3.538e+004	3.538e+004	1	.998e+004		1.248e+004
16	Mass Flow	(kg/s)	0.000	00 *	283.5	283.5		100.0 *		100.0 *
17	Liquid Volume Flow	(m3/s)	0.000	00	0.3277	0.3277		0.1002		0.1156
18	Heat Flow	(MW)	-		1.059	1.059				
19	Name		1		Saturated Air	Liquid Water				
20	Vapour Fraction		0.400)1	1.0000	0.0000				
21	Temperature	(C)	28.9	97	28.97	28.97				
22	Pressure	(kPa)	101	.3	101.3	101.3				
23	Molar Flow	(kamole/h)	3.246e+00)4	1.299e+004	1.947e+004				
24	Mass Flow	(ka/s)	200	.0	102.6	97.45				
25	Liquid Volume Flow	(m3/s)	0.215	58	0.1182	9.764e-002				
26	Heat Flow	(MW)	-158	30	-33.92	-1547				
27		. ,								
28					Compositions			Fluid Pk	g:	All
29	Name		Water Vapor		Dry Air	Humid Air	Water 2		Air 2	
30	Comp Mole Frac (Sodium*)		*	**	***	***		***		***
31	Comp Mole Frac (Nitrogen)		0.000	00 *	0.7900 *	0.7900		0.0000 *		0.7900 *
32	Comp Mole Frac (Oxygen)		0.000	00 *	0.2100 *	0.2100		0.0000 *		0.2100 *
33	Comp Mole Frac (H2O)		1.000	00 *	0.0000 *	0.0000		1.0000 *		0.0000 *
34	Comp Mole Frac (Sodium)		*	**	***	***		***		***
35	Name		1		Saturated Air	Liquid Water				
36	Comp Mole Frac (Sodium*)		*	**	***	***				
37	Comp Mole Frac (Nitrogen)		0.303	37	0.7589	0.0000				
38	Comp Mole Frac (Oxvgen)		0.080	07	0.2017	0.0000				
39	Comp Mole Frac (H2O)		0.615	56	0.0393	1.0000				
40	Comp Mole Frac (Sodium)		*	**	***	***				
41					Energy Stream	6		Eluid Pk	a.	
42	N				Energy ou cum				J.	
43	Name Heat Flow	(1.4).4()								
44	Heat Flow	(10100)								
40					Unit Ops					
40	Operation Name	000			Foods	Producto		Ignored		
48		Ope	лацонтуре	Wat	er Vanor	Humid Air		ignored		Jail LEVEI
40	MIX-100	Mixer		Dru	Air			No		500.0 *
50				Wat	er 2	1				-
51	MIX-101	Mixer		Air 2	2			No		500.0 *
52	Set Temp	Set						No		500.0 *
53	Set Pressure	Set						No		500.0 *
54	V-100 Separator		1		Liquid Water		No		500.0 *	
55 56	ADJ-1 Adiust					Saturated Air		No		3500 *
57	7,80 1	710j001					110		0000	
58 59 60 61										
62										
63	Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1									
<u> </u>	Licensed to: BATTELLE ENERGY	ALLIANCE							* Speci	fied by user.



Figure B.2: Annulus Heat Exchanger model designed in HYSYS for 25 tubes

Instruct Barborner Source of the second	1		- -	Case Name:	Ar	nnulus HX.25Tube.hsc	:				
1 USA Data Time: Statup 7 19.59/34 2021 0 Workbook: Case (Main) 1 Material Streams Fuid Pag. A 10 Material Streams Fuid Pag. A 11 Manne Sodium Inter Ar Eet Sodium Inter Ar Eet Sodium Inter 11 Name Comport Fection C) S573* 4442.4 3222* 1440.0 Science 12 Vagour Fection C) S573* 462.4 3222* 1440.0 Science	3	entech	Bedford, M/	A	Ē	Unit Set:	Pr	oject Units3i			
Image: source of the second	4 5		USA			Date/Time:	Sa	at Aug 7 18:59:34 202	:1		
Image: Solution biology of the solution biology of the solution biol o	6	Work	khook:	Caso (M	ain						
1 Material Straam Fuid Pkg: A 11 Name Sodium Niet Sodium Niet Ar Eat Sodium Niet Sodium Niet<	8	WOIR	NUOUK.	Case (IM	am)					
Internation Sodium Net Ar Intel Ar Evet Sodium Intel 1 Vageur Fraction 0.000 0.000 1000 0.000	9 10					Material Stream	s			Fluid Pkg	i: All
12 Outcom 0.000 0.000 1.000 0.000 0.000 1 Tempsarla (C) 537.8 442.4 2.22 14.60 55.15 772.2 15 Maar Flow (kgmoleh) 3.922+004 3.922+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.522+004 3.525+00 3.6370+00 6.0000 0.0000	11	Name		Sodium Inlet		Sodium Exit	A	Air Inlet	Air Exit		Sodium Inlet 1
13 Temperature (C) 537.8 ¹ 442.4 522.2 ¹ 148.0 537.7 14 Pressure (Pa) 3302a+004 3302a+004 3302a+004 3322a+004 537.7 15 Mass Flow (Pa) 3302a+004 3302a+004 3322a+004 3322a+004 537.7 16 Mass Flow (Pa) 0.2692 0.3223 0.3223 0.3223 3.370a-00 16 Heat Flow (Pa) 22.68 Air Ext 1 Air Intel 1 Average Scium Autorge Scium 3.670a-00 21 Vapour Fraction 0.0000 1.0000 1.0000 0.0000 1.0000 21 Temperature (C) 443.54 1.022 44.94 1.022 23 Mater Flow (Re) 3.730 5.670 1.65.70 1.65.5 2.328 24 Mater Flow (Re) 3.370-00 6.446e-003 0.166.5 0.2322 25 Heat Flow (Re) 3.370-00 6.446e-003 0.166.5 0.2324 25 Liqid Volume Flow (Re) 3.026-000	12	Vapour Fraction		0.000	00	0.0000		1.0000		1.0000	0.0000
14 Presure (k ² n) 772.2 079.2 0108.6* S2.15 772.2 15 Mdar Flow (kpd) 3526+004 3525+004 10000 0.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 1.0000 3.0570 10.551 772.2 1.001 3.252e+00	13	Temperature	(C)	537	.8 *	462.4		32.22 *		148.0	537.8 *
Is Mare Flow (tignolefh) 3.9.82±04 3.9.22±04 3.9.22±04 5.2.52±04 9.84 Mase Flow (m3) 0.2830 2.833 2.833 2.835 2.835 3.77 Upped Values Flow (m3) 0.2822 0.3223 0.3223 3.370±00 1 Hast Flow (MW) 228.6 2.056 1.347 4.845 3.51 10 Hast Flow (MW) 228.6 2.000 1.000 0.0000 1.000 11 Ferneration (C) 4.345.4 1.481 3.222* 4.349 1.417.1 12 Fressure (PP4) 751.5 109.6 109.6 752.2 109.7 2 Mater Flow (trags) 3.370±0.03 6.467±0.03 6.445±0.03 0.1985 0.322 2 Hast Flow (MW) 2.858 0.6689 3.895±0.02 142.7 3.48 30 Comp Mole Frac (Sodium) 1.0000 1.0000 142.7 3.48 <t< td=""><th>14</th><td>Pressure</td><td>(kPa)</td><td>752</td><td>.2 *</td><td>679.2</td><td></td><td>109.6 *</td><td></td><td>52.15</td><td>752.2 *</td></t<>	14	Pressure	(kPa)	752	.2 *	679.2		109.6 *		52.15	752.2 *
Is Mass Flow (kg/s) 253.0 263.5 283.5 283.5 37.7 15 Hadd Town (MW) 238.8 205.6 1.947 34.85 3.970-00 16 Heat Flow (MW) 238.8 205.6 1.947 34.95 3.970-00 16 Heat Flow (MW) 23.84 205.6 1.947 34.95 3.970-00 17 Fengerature (C) 43.84 1.48.1 3.222 43.49 1.000 17 Fengerature (CP) 7.51.5 1.006 1.000 7.52.2 1.000 21 Mass Flow (kg/s) 3.370-003 6.448-003 6.448-003 0.1985 0.322 22 Heat Flow (MW) 2.80 0.0689 3.895-002 1.42.7 3.48 23 Heat Flow (MW) 2.80 0.6089 3.895-002 1.42.7 3.48 23 Heat Flow (MW) 2.600 0.1000 1.42.7 3.48 </td <th>15</th> <td>Molar Flow</td> <td>(kgmole/h)</td> <td>3.962e+00</td> <td>)4</td> <td>3.962e+004</td> <td></td> <td>3.525e+004</td> <td>3</td> <td>8.525e+004</td> <td>584.1</td>	15	Molar Flow	(kgmole/h)	3.962e+00)4	3.962e+004		3.525e+004	3	8.525e+004	584.1
12 Liquid Volume Flow (m3ke) 0.2892 0.3223 0.3223 3.870-b0.0 11 Heat Flow (WW) 2386 2056 1.474 444 94 3.51 12 Name Work Fraction 0.000 1.000 1.000 0.000 1.000 12 Temperature (C) 435.4 1.48.1 3.22.2 438.9 1.477 12 Pressure (RPa) 751.5 1.006 1.006.7 752.2 1.09. 21 Mair Flow (Rga) 3.370 6.476-003 6.446-003 0.1985 0.322 23 Liquid Volume Flow (MW) 2.858 0.6889 3.895-002 142.7 3.86 24 Hart Flow (MW) 2.858 0.6889 3.895-002 142.7 3.86 25 Comp Mole Frac (Solum) 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	16	Mass Flow	(kg/s)	253	.0 *	253.0		283.5 *		283.5	3.730 *
11 Heat Flow (MW) 228.6 205.6 1.947 34.95 34.95 10 Name Sodium Ext 2 Ar Exit 1 Art Intel 1 Average Art Temp 20 Yopur Fraction 0.0000 1.0000 1.0000 0.0000 1.0000 21 Temperature (C) 443.4 148.1 32.22 434.9 147. 22 Name Flow (kgm) 3.730 5.670 5.670 16.65 22.22 109. 24 Mase Flow (kgm) 3.970-003 6.446e-003 6.446e-003 0.1985 0.322 24 Heat Flow (MW) 2.88 0.6898 3.895e-002 14.27 3.48 25 Heat Flow (MW) 2.88 0.6989 3.895e-003 1.0000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000	17	Liquid Volume Flow	(m3/s)	0.269	92	0.2692		0.3223		0.3223	3.970e-003
10 Name Sodium Exit Ar Exit 1 Ar Inel 1 Name 1000 Nonce 0000 Nonce 00000 Nonce 00000	18	Heat Flow	(MW)	238	.6	205.6		1.947		34.95	3.518
20 Vapour Fraction 0.0000 1.0000 1.0000 0.0000 1.0000 21 Temperature (C) 435.4 148.1 32.22 449.4 147. 22 Pressure (kPs) 751.5 109.6 109.6 752.2 109. 23 Mass Flow (kgs) 3.730 6.670 6.446e-003 0.1985 0.322. 24 Heat Flow (MW) 2.988 0.6989 3.805-002 142.7 34.8 27 Amme Sodium Intet Sodium Exit Air Intet Air Exit Sodium Intet 30.0989 3.805-002 142.7 34.8 28 Comp Mole Frac (Sodium) 1.0000 <t< td=""><th>19</th><td>Name</td><td></td><td>Sodium Exit 2</td><td></td><td>Air Exit 1</td><td>A</td><td>Air Inlet 1</td><td>Average</td><td>Sodium Temp</td><td>Average Air Temp</td></t<>	19	Name		Sodium Exit 2		Air Exit 1	A	Air Inlet 1	Average	Sodium Temp	Average Air Temp
Image rature (C) 435.4 148.1 3222 443.4 147.7 22 Pressure (kgm oleft) 58.15 109.6 170.51 70.51 22.040.04 3.525e+00 24 Malar Flow (kgm oleft) 58.41 705.1 705.1 2.920e+00.4 3.525e+00 24 Malar Flow (MW) 2.858 0.6989 3.805e+00 0.426 0.01985 0.022 28 Hatt Flow (MW) 2.858 0.6989 3.805e+00 142.7 3.84 28 Comp Mole Frac (Sodium) 1.0000 * 1.0000 1.000	20	Vapour Fraction		0.000	00	1.0000		1.0000		0.0000	1.0000
Image (kg) 751.5 100.6 100.6 772.2* 100.9 Mark Flow (kg/s) 3.730 5.670 5.670* 2.900-004 3.525*00 Mark Flow (kg/s) 3.730 5.670 5.670* 1.965* 2.920 Heat Flow (kg/s) 3.970*003 6.446+003 6.446+003 0.1965 0.322 Heat Flow (kW) 2.858 0.6909 3.895*002 1.42.7 3.84 77 Comp Mole Frac (Sodium) 1.0000* 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 1.000 **** 1.000 **** 1.000 **** 1.000 **** 1.000 **** 1.000	21	Temperature	(C)	435	.4	148.1		32.22 *		434.9 *	147.9 *
1 Main Flow (kg/m) 584.1 705.1 705.1 2.800-004 3.8284-00 24 Mass Flow (kg/s) 3.370 5.670 6.446e-03 0.1865 2.833 25 Liquid Volume Flow (MW) 2.868 0.6969 3.895e-002 14.2.7 3.848 26 Heat Flow (MW) 2.868 0.6969 3.895e-002 14.2.7 3.848 28 Name Sodium Inlet Sodium Exit Air Inlet Air Exit Sodium Inlet 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 *** 1.000 *** 1.000 *** 1.000 *** 1.000 *** 1.000 *** 1.000 *** 1.000 *** 1.00	22	Pressure	(kPa)	751	.5	109.6		109.6 *		752.2 *	109.6 *
24 Mass Flow (ftg) 3.730 5.670 6.670 ⁺ 186.5 ⁺ 283. 26 Liquid Volume Flow (m39) 3.970e-003 6.446e-003 6.446e-003 0.1885 0.322 27 28 Compositions 6.446e-003 6.446e-003 0.1885 0.322 28 Compositions Air Flow 4.42.7 38.48 28 Name Sodium Init Sodium Exit Air Init Air Exit Sodium Init 30 Comp Mole Frac (Sodium) 1.0000 1.0000 1.0000 1.0000 1.0000 3 31 Name Sodium Exit Air Exit Air Init<1	23	Molar Flow	(kgmole/h)	584	.1	705.1		705.1	2	2.920e+004	3.525e+004
1 1	24	Mass Flow	(kg/s)	3.73	30	5.670		5.670 *		186.5 *	283.5 *
20 Heat Flow (MW) 2.858 0.6989 3.895e-002 142.7 34.8 27 Image of the frac Sodium Intel Sodium Exit Air Intel Air Exit Air Exit Sodium Intel Air Intel Air Exit Air Exit Sodium Intel Sodium Intel <th< td=""><th>25</th><td>Liquid Volume Flow</td><td>(m3/s)</td><td>3.970e-00</td><td>)3</td><td>6.446e-003</td><td></td><td>6.446e-003</td><td></td><td>0.1985</td><td>0.3223</td></th<>	25	Liquid Volume Flow	(m3/s)	3.970e-00)3	6.446e-003		6.446e-003		0.1985	0.3223
27 28 29 20 20 20 mm Name Sodium Inlet Sodium Exit Air Inlet Air Exit Sodium Inlet Sodium Inlet Sodium Inlet Air Inlet Air Exit Sodium Inlet Sodium Inlet Sodium Inlet Air Inlet Air Exit Air Exit Sodium Inlet Sodium Inlet Sodium Inlet Air Exit Air Inlet Air Exit Air Inlet Average Sodium Find Average Air Temp 31 Comp Mole Frac (Sodium) 1.0000	26	Heat Flow	(MW)	2.85	58	0.6989		3.895e-002		142.7	34.89
2a Full of Pige Pidlo Pige <th>27</th> <td></td> <td></td> <td></td> <td></td> <td>Compositions</td> <td></td> <td></td> <td></td> <td></td> <td></td>	27					Compositions					
20 Name Sodium Inlet Sodium Exit Air Inlet Air Exit Sodium Inlet 1 20 Comp Mole Frac (Air) 1.0000<	28					Compositions				Fluid Pkg	: All
30 Comp Mole Frac (Air) 1.0000 *** </td <th>29</th> <td>Name</td> <td></td> <td>Sodium Inlet</td> <td></td> <td>Sodium Exit</td> <td>A</td> <td>Air Inlet</td> <td>Air Exit</td> <td></td> <td>Sodium Inlet 1</td>	29	Name		Sodium Inlet		Sodium Exit	A	Air Inlet	Air Exit		Sodium Inlet 1
31 Comp Mole Frac (Air) *** 1.0000 **** 1.0000 **** 32 Name Sodium Exit 2 Air Exit 1 Air Inlet 1 Average Sodium Temp Average Air Temp 33 Comp Mole Frac (Solium) 1.0000 *** 1.0000 *** 1.0000 33 Comp Mole Frac (Air) *** 1.0000 1.0000 *** 1.0000 34 Comp Mole Frac (Air) *** 1.0000 1.0000 *** 1.0000 35 1.0000 1.0000 1.0000 36 1.0000 1.0000 1.0000 37 Name DUTY 1 A 38 Heat Flow (MW) 0.6600 * -0.66000 * A 41 Operation Name Operation Type Feeds Produts Ignored Calc Level 42 Inside Pipe Pipe Segm	30	Comp Mole Frac (Sodium) 1.0				1.0000		***		***	1.0000 *
32 Name Sodium Exit 2 Air Exit 1 Air Inlet 1 Average Sodium Temp Average Air Temp 33 Comp Mole Frac (Air) 1.0000 **** 1.0000 * **** **** 1.000 **** Air Diate Air Diate Air Diate **** **** **** Air Exit * No Sodium Exit * No Sodium Sodium	31	Comp Mole Frac (Air)			**	***		1.0000 *		1.0000	***
33 Comp Mole Frac (Sodium) 1.0000 *** 1.0000 **** 1.0000 ***** 1.0000 ******* 1.0000 ****************	32	Name Sodium Exit 2				Air Exit 1	A	Air Inlet 1	Average	Sodium Tem	Average Air Temp
34 Comp Mole Frac (Air) *** 1.000 1.000 * *** 1.000 35 Energy Streams Fluid Pkg: A 37 Name DUTY 1 Duty1 - - 38 Unit Ops - - - - 38 Operation Name Operation Type Feeds Products Ignored Calc Level 41 Operation Name Operation Type Feeds Products Ignored Calc Level 42 E100 Heat Exchanger Sodium Inlet Sodium Exit No 500. 44 Inside Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 2 No 500. 45 Inside Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 46 POut Set Ves 500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 POut Set Ves <th>33</th> <td colspan="3">Comp Mole Frac (Sodium)</td> <td>00</td> <td>***</td> <td></td> <td>***</td> <td></td> <td>1.0000 *</td> <td>***</td>	33	Comp Mole Frac (Sodium)			00	***		***		1.0000 *	***
Energy Streams Fluid Pkg: A 30 Name DUTY 1 Duty 1 Outy	34	Comp Mole Frac (Air)		*	**	1.0000		1.0000 *		***	1.0000 *
33 Name DUTY 1 Duty1 Outy1 Ou	35					Energy Stream	s			Fluid Pkg	: All
38 Heat Flow (MW) 0.6600* -0.6600* Image: Control Contecont Contecontrol Contro Control Control Control Cont	30	Name		DUTY 1		Duty1					
Unit Ops 1 Operation Name Operation Type Feeds Products Ignored Calc Level 42 E-100 Heat Exchanger Sodium Inlet Sodium Exit No 500. 43 E-100 Heat Exchanger Sodium Inlet Air Exit No 500. 44 Air Pipe Pipe Segment Sodium Inlet Sodium Exit 2 No 500. 46 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set Duty1 No 500. 49 SET-1 Set Yes 500. 50 T Out Set No 500. 51 Spreadsheet No No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No Sodium No 500. 56 Spreadsheet No No 500.	38	Heat Flow	(MW)	0.660	00 *	-0.6600 *					
41 Operation Name Operation Type Feeds Products Ignored Calc Level 42 E-100 Heat Exchanger Sodium Inlet Sodium Exit No \$500. 44 Air Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 2 No \$500. 46 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No \$500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No \$500. 48 P Out Set Duty1 No \$500. 49 SET-1 Set Duty1 No \$500. 50 T Out Set No \$500. \$500. 50 T Out Set No \$500. 50 T Out Set No \$500. 52 Double-Pipe HX Calculations Spreadsheet No \$500. 53 Set No \$500. \$500. 54 Sepen Technology Inc.	39 40					Unit Ops					
42 E-100 Heat Exchanger Sodium Inlet Sodium Exit No 500. 44 Inside Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 2 No 500. 46 Air Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 1 No 500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set DUTY 1 No 500. 49 SET-1 Set Duty 1 No 500. 49 SET-1 Set Ves 500. 50 T Out Set No 500. 50 T Out Set No 500. 50 T Out Set No 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No 500. 500. 56 Spreadsheet No 500. 56 Spreadsheet No 500. 56 Spreadsheet No 500. 56 Spreadsheet No No 500. <tr< td=""><th>41</th><td>Operation Name</td><td>Oper</td><td>ation Type</td><td></td><td>Feeds</td><td></td><td>Products</td><td></td><td>Ignored</td><td>Calc Level</td></tr<>	41	Operation Name	Oper	ation Type		Feeds		Products		Ignored	Calc Level
43 E-100 Heat Exchanger Air Inlet Air Exit No 500. 44 Inside Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 2 No 500. 45 Inside Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 46 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set Duty1 No 500. 49 SET-1 Set Ves 500. 50 T Out Set Ves 500. 51 Spreadsheet No Ves 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No No 500. 54 Set Set No Sodium 56 Set Set No Sodium	42	•			Sod	lium Inlet		Sodium Exit			
44 45 Inside Pipe Pipe Segment Sodium Inlet 1 Sodium Exit 2 No 500. 46 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set Duty1 No 500. 49 SET-1 Set Duty1 No 500. 50 T Out Set Set Yes 500. 50 T Out Set No Yes 500. 50 T Out Set No Yes 500. 51 SPRDSHT-1 Spreadsheet No No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No No 500. 54 Spreadsheet No No 500. 55 Spreadsheet No No 500. 56 Spreadsheet No No 500. 56 Spreadsheet Aspen Technology Inc. Resen HYSYS Version 11 Page 1 of 1 61 Harrow BATT	43	E-100	Heat Excha	anger	Air I	Inlet		Air Exit		No	500.0 *
45 Inside Pipe Pipe Segment DUTY 1 No 500. 46 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set Duty1 No 500. 49 SET-1 Set Uty1 Yes 500. 50 T Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No 500. 500. 54 Spreadsheet No 500. 55 Spreadsheet No 500. 56 Spreadsheet No 500. 57 Spreadsheet No 500. 58 Spreadsheet No 500. 59 Spreadsheet No 500. 60 Spreadsheet Spreadsheet No 59 Spreadsheet Spreadsheet Spreadsheet 59 Spreadsheet Spreadsheet Spreadsheet 60 Spreadshee	44				Sod	lium Inlet 1		Sodium Exit 2			
46 47 Air Pipe Pipe Segment Air Inlet 1 Air Exit 1 No 500. 48 P Out Set Duty1 Yes 500. 49 SET-1 Set Yes 500. 50 T Out Set Yes 500. 50 T Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No S00. 500. 54 Spreadsheet No 500. 500. 55 Spreadsheet No 500. 500. 56 Spreadsheet No S00. 500. 57 Spreadsheet No S00. 500. 56 Spreadsheet No S00. S00. 57 Spreadsheet Spreadsheet No S00. 60 Spreadsheet Spreadsheet Spreadsheet Spreadsheet 58 Spreadsheet Spreadsheet <	45	Inside Pipe	Pipe Segm	ent				DUTY 1		No	500.0 *
41 Pripe Pripe Segment Duty1 No 500. 48 P Out Set Yes 500. 49 SET-1 Set Yes 500. 50 T Out Set Yes 500. 50 T Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 Spreadsheet No 500. 500. 54 Spreadsheet No 500. 500. 55 Spreadsheet No 500. 500. 54 Spreadsheet No 500. 500. 55 Spreadsheet No 500. 500. 56 Spreadsheet No 500. 500. 58 Spreadsheet Spreadsheet No 500. 58 Spreadsheet Spreadsheet Spreadsheet Spreadsheet Sp	46	Air Din -	Dia , O		Air I	Inlet 1		Air Exit 1			500 A *
48 P Out Set Yes 500. 49 SET-1 Set Yes 500. 50 T Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 S Spreadsheet No 500. 54 S Spreadsheet No 500. 55 S Spreadsheet No 500. 56 Spreadsheet No 500. Spreadsheet 57 Spreadsheet No S00. Spreadsheet 58 Spreadsheet Spreadsheet Spreadsheet Spreadsheet 58 Spreadsheet Spreadsheet Spreadsheet Spreadsheet Spreadsheet 60 Spreadsheet Spreadsheet Spreadsheet Spreadsheet Spreadsheet 61 Spreadsheet Spreadsheet Spreadsheet Spreadsheet Spreadsheet	47	Air Pipe	Pipe Segm	ent				Duty1		No	500.0 *
49 SE I-1 Set Yes 500. 50 T Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 54 55 56 56 57 56 56 56 56 56 56 56 56 56 56 56 56 56 56 57 58 59 60 61 62 62 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 10	48	P Out	Set							Yes	500.0 *
SUD 1 Out Set Yes 500. 51 SPRDSHT-1 Spreadsheet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 54 55 56 57 56 56 57 58 59 56 56 50 60 61 62 77 58 59 60 61 62 76 78 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 10	49	SET-1	Set							Yes	500.0 *
SPRUSHI-1 Spreadsneet No 500. 52 Double-Pipe HX Calculations Spreadsheet No 500. 53 54 55 56 57 58 56 57 58 59 60 61 60 61 62 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 10	50		Set	-1						Yes	500.0 *
S2 Double-Pipe HX Calculations Spreadsneet 53 54 55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	51	SPRDSHT-1	Spreadshe	et						No	500.0 *
33 54 55 56 57 58 59 60 60 61 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1000000000000000000000000000000000	52	Double-Pipe HX Calculations	Spreadshe	el						INO	500.0
34 55 57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	53										
55 56 57 58 59 60 61 62 63 Aspen Technology Inc. Page 1 of 1	54										
56 57 58 59 60 61 62 63 63 Aspen Technology Inc.	55										
57 58 59 60 61 62 63 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	50										
38 59 60 61 62 63 Aspen Technology Inc. File 63	57										
Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	58										
Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	59										
62 Aspen Technology Inc. Aspen HYSYS Version 11 Page 1 of 1	61										
63 Aspen Technology Inc. Page 1 of Issues the DATE US ENERGY ALLANCE Page 1 of Page 1 of	62										
Live reperint outputs PATER STREAM AND A SPECIFICATION OF A SPECIFIC ASPECIFICATION OF A SPECIFIC ASPECIFICATION OF A SPECIFICATION OF A SPECIFICA	62	Aspen Technology Inc.			٨	anon HVSVS Vorsia	n í	11			Page 1 of 1
* Specified by year	03	Licensed to: BATTELLE ENERGY	ALLIANCE		AS		11				* Specified by user

				-			
1				Case Name:	Annulus HX.25Tube.	nsc	
3	(the as	spentech Bedford, MA	CE	Unit Set:	Project Units3i		
4		USA		Date/Time:	Sat Aug 7 19:00:54 2	2021	
6							
7 8		Spreadsheet: Dou	ble-F	Pipe HX C	alculations		Units Set: Project Units
9 10				CONNECTION	IS		
11			In	nported Varial	oles		
12	Cell	Object			Variable Description		Value
14	B3	Material Stream: Average Sodium Temp	Mass [Density	· ·		836.5 kg/m3
15	B4	Material Stream: Average Sodium Temp	Therm	al Conductivity			69.62 W/m-K
16	B5	Material Stream: Sodium Inlet	Tempe	rature			537.8 C
17	B6	Material Stream: Average Sodium Temp	Mass H	leat Capacity			1.720 kJ/kg-K
18	C3	Material Stream: Average Air Temp	Mass D	Density			0.9065 kg/m3
19	C4	Material Stream: Average Air Temp	Therm	al Conductivity			3.232e-002 W/m-K
20	C5	Material Stream: Air Inlet	Tempe	erature			32.22 C
21	C6	Material Stream: Average Air Temp	Mass H	Heat Capacity			1.016 kJ/kg-K
22	B9	Material Stream: Average Sodium Temp	Kinema	atic Viscosity			0.3144 cSt
23	C9	Material Stream: Average Air Temp	Kinema	atic Viscosity			27.03 cSt
24	B11	Material Stream: Sodium Inlet	Pressu	ire			752.2 kPa
25	C11	Material Stream: Air Inlet	Pressu	ire			109.6 kPa
26	E2	Material Stream: Sodium Inlet	Mass F	low			253.0 kg/s
27	F2	Material Stream: Air Inlet	Mass F	low			283.5 kg/s
28 29		Exp	orted \	/ariables' Forr	nula Results		
30	Cell	Object			Variable Description		Value
31 32				PARAMETER	s		
33 34			Ex	portable Varia	Ibles		
35	Cell	Visible Name		Variable Des	scription	Variable Type	Value
36	B2	B2: Mass Flow	Mass F	Flow		Mass Flow	10.12 kg/s
37	B7	B7:					6.497e-003
38	B8	B8:					2.630e-004
39	B10	B10:					1.195e-003
40	B12	B12:					<empty></empty>
41	B13	B13:				Length	0.1282 m
42	B14	B14:				Length	0.1413 m
43	B15	B15:				Length	0.7500 m
44	B17	B17:					1.291e-002
45	B18	B18:					0.4261
46	B20	B20:					3.821e+005
47	B21	B21:					4.170e+006
48	B22	B22:					<empty></empty>
49	B23	B23:					148.4
50	D24	D24.					4090
51	B27	D20.					00.57 KJ/S-M2-C
52	B28	D27.				nt. man. Coell	23.43 KJ/S-III2-C
54	B20	B20.					1 3070-005
55	B30	B30 [.]				Temperature	203.3.0
56	B31	B31 [.]				Temperature	370.5 C
57	B32	B32: Qsodium	Qsodii	ım		Energy	5.822 MW
58	B33	B33:	Goodic	••••			1.520e-006
59	B35	B35:					1.391e-002
60	B36	B36:					1.252e-002
61	B38	B38:				Pressure	148.7 kPa
62	B39	B39:				Pressure	69.77 kPa
63	Aspen 7	echnology Inc.	Asp	en HYSYS Vers	ion 11		Page 1 of 5
		57	· ·- P				

Licensed to: BATTELLE ENERGY ALLIANCE

* Specified by user.

1					Case Name: Annulus HX.25Tube.hsc						
2	(the as	spentech	BATTELLE ENERG Bedford, MA	Y ALLIANCE	Unit Set:	Project Units3i					
4	0	e.	USA		Date/Time:	Sat Aug 7 19:00:54 2	021				
6											
7 8		Spr	eadsheet:	Double-	Pipe HX	Calculations	(continue	Units Set: Project Units			
9 10					PARAMETE	RS					
11				Ex	portable Var	iables					
12	Cell	Ň	/isible Name		Variable D	escription	Variable Type	Value			
14	C2	C2: Mass Flow		Mass	Flow		Mass Flow	11.34 kg/s			
15	C7	C7:						0.7698			
16	C8	C8:						2.450e-005			
17	C10	C10:						1.103			
18	C31	C31:					Temperature	285.0 C			
19	C32	C32: Q		Q			Energy	5.822 MW			
20	D17	D17:					Velocity	0.9373 m/s			
21	D18	D18:					Velocity	29.36 m/s			
22	D26	D26:					Ht. Tran. Coeff	73.10 kJ/s-m2-C			
23	D29	D29:						<empty></empty>			
24	D30	D30:					Temperature	537.8 C			
25	E3	E3:						25.00			
26	E27	E27:					Length	36.58 m			
27	E28	E28:						16.24			
28	E34	E34:						1.196e+022			
29	E35	E35:						7.488e-017			
30	E36	E36:						3.821e+005			
31	F12	F12:						<empty></empty>			
32	F13	F13:					Length	0.6087 m			
33	F14	F14:					Length	3.840 m			
34	F17	F17:						784.0			
35	F18	F18:						26.61			
36	F26	F26:					Thermal Cond.	34.49 W/m-K			
37	F32	F32:					Power	145.5 MW			
38	F34	F34:						2.787e+022			
39	F35	F35:						1.164e-020			
40	F36	F36:						6.611e+005			
41 42					User Variab	les					
43 44					FORMULA	S					
45	Cell				Formula			Result			
46	B2	=e2/e3						10.12 ka/s			
47	B7	=B8*B6*1000/B4						6.497e-003			
48	B8	=B9/1000000*B3						2.630e-004			
49	B10	=1/b3						1.195e-003			
50	B17	=PI*B13^2/4						1.291e-002			
51	B18	=PI*(B15^2-B14^2	2)/4					0.4261			
52	B20	=D17*B13/(B9/10	00000)					3.821e+005			
53	B21	=D18*F14/(C9/10	00000)					4.170e+006			
54	B23	=0.023*B20^(4/5)	*B7^0.3					148.4			
55	B24	=0.023*B21^(4/5)	*C7^0.4					4096			
56	B26	=B23*B4/1000/B1	3					80.57 kJ/s-m2-C			
57	B27	=1/(1/D26+1/F26)						23.43 kJ/s-m2-C			
58	B28	=c2*c6/(b2*b6)						0.6616			
59	B29	=@EXP(B27*E28	*(B28-1)/(C2*C6))					1.397e-005			
60	B30	=(B5*(B28-1)-B28	8*C5*(1-B29))/(B28*B2	9-1)				203.3 C			
61	B31	=(B5+B30)/2						370.5 C			
62	B32	=B2*B6*(B5-B30)	/1000					5.822 MW			
63	Aspen T	echnology Inc.		Asp	en HYSYS Ve	rsion 11		Page 2 of 5			

Licensed to: BATTELLE ENERGY ALLIANCE

1 Core Name: Apply LV 25Tube has																		
2	(1	BATTELLE E	NERGY ALLIANCE	Unit Set	Project Inits 3i													
4	C	USA		Unit Set.														
5				Date/Time:	Sat Aug 7 19:00:54 2021													
6		a																
7		Spreadshe	et: Double-P	пре нх	Calculations (con	tinue Units Set: Project U	nit											
9					-													
10				FORMULA	AS													
11	Ce	11	F	ormula		Result												
12	B3	5 =8*((8/e36)^12+1/(E34+E35)^1.5	i)^(1/12)			1.391e-002												
13	B3	6 =8*((8/f36)^12+1/((F34+F35)^1.5	i))^(1/12)			1.252e-002												
14	B3	8 =B35*E27/B13*b3*(d17^2)/(2*9.8	31)			148.7 kPa												
15	<u>в</u> з	$9 = (D36^{\circ}e27/T13+1)^{\circ}c3^{\circ}d18^{\circ}2/(2^{\circ}9)$.81)			09.77 KPa												
17	C7	z =12/e3 7 =C8*C6*1000/C4	=C8*C6*1000/C4															
18	CE	3 =C9/1000000*C3				2.450e-005												
19	C1	0 =1/c3				1.103												
20	C3	1 =(C5+D30)/2				285.0 C												
21	C3	2 =C2*C6*(D30-C5)/1000				5.822 MW												
22	D1	7 =B2/B3/B17				0.9373 m/s												
23	D1	8 =C2/C3/B18				29.36 m/s												
24	D2	6 =B26*B13/B14				73.10 kJ/s-m2-C												
25	D3	0 =C5+(B5-B30)/B28				537.8 C												
26	E2	8 =PI*B14*E27				16.24												
27	E3	$4 = (2.457^* @LN(1/((7/e36)^{0.9}+(0.2500))) = (0.2500) = (0.250$	27*B33/B13))))^16			1.196e+022												
20	E3	6 =d17*b13//b0/100000)	2 8210+005															
30	 F1	3 =B15-B14	0.6087 m															
31	F1	4 =(B15^2-B14^2)/B14	3.840 m															
32	F1	7 =B2/B17	784.0															
33	F1	8 =C2/B18	26.61															
34	F2	6 =B24*C4/F14				34.49 W/m-K												
35	F3	2 =b32*e3				145.5 MW												
36	F3	4 =(2.457*@LN(1/((7/f36)^0.9+(0.2	?*B33/F13))))^16			2.787e+022												
37	F3	5 =(37530/f36)^16				1.164e-020												
38	F3	6 =d18*f13/(c9/1000000)				6.611e+005												
39			:	SPREADSH	EET													
41		Α	В		С	D												
42	1			Hot Fluid *	Cold Fluid *	-	_											
43	2	mass flow *		10.12 kg/s *	11.34 kg/s *	Mass Flov	N *											
44	3	density *	8	336.5 kg/m3 *	0.9065 kg/m3 *	number of tube	s *											
45	4	thermal conductivity *	6	9.62 W/m-K *	3.232e-002 W/m-K *													
46	5	Inlet Temperature *		537.8 C *	32.22 C *													
47	6	Cp *	1.	720 kJ/kg-K *	1.016 kJ/kg-K *													
48	1	Pr*		6.497e-003 *	0.7698 *													
49	<u>ठ</u>	Dynamic Viscosity *		2.030e-004 *	2.450e-005 *													
51	9 10	specific volume *		1 1950-003 *	27.03 CST - 1 102 *													
52	11	Pressure *		752.2 kPa *	109.6 kPa *													
53	12			<empty> *</empty>	100.0 M U													
54	13	ID of pipe *		0.1282 m *	<empty> *</empty>		_											
55	14	OD of pipe *		0.1413 m *	<empty> *</empty>													
56	15	ID of Annulus *		0.7500 m *														
57	16																	
58	17	Area Pipe *		1.291e-002 *	Velocity Pipe *	0.9373 m/	s *											
59	18	Area Annulus *		0.4261 *	Velocity Annulus *	29.36 m/	s *											
60	19			0.004-1005 *														
62	20 21			1 170e+006 *														
63	Asn	en Technology Inc	Asn	en HYSYS Ve	ersion 11	Page 3 of 4	5											
	Licens	ed to: BATTELLE ENERGY ALLIANCE	7.500			* Specified by user.	3 Aspen Technology Inc. Aspen HYSYS Version 11 Page 3 of 5											

1				Case Name: Annulus HX.25Tube.hsc					
3		aspentech Bedford, MA	NERGY ALLIANCE	Unit Set:	Project Units3i				
4		USA		Date/Time:	Sat Aug 7 19:00:54 2021				
6									
7 8		Spreadshee	et: Double-	Pipe HX	Calculations (con	tinue Units Set: Project Units			
9 10				SPREADSH	IEET				
11	22			<empty> *</empty>					
12	23	Nu pipe *		148.4 *					
13	24	Nu annulus *		4096 *					
14	25		90	E7 k 1/a m2 C *		72.10 k l/a m2 C *			
16	20	Uo *	23.	43 kJ/s-m2-C *	пр	/ 3.10 kJ/s-112-C			
17	28	R*		0.6616 *		A0 *			
18	29	Ecounter *		1.397e-005 *		<empty> *</empty>			
19	30	T2 *		203.3 C *	t2 *	537.8 C *			
20	31	Avg Temp *		370.5 C *	285.0 C *				
21	32	q *		5.822 MW *	5.822 MW *	<pre> <empty> *</empty></pre>			
22	34	Epsilon		1.5208-006		b *			
24	35	friction factor pipe *		1.391e-002 *		c *			
25	36	friction factor annulus *		1.252e-002 *		Re *			
26	37								
27	38	Pressure Drop pipe *		148.7 kPa *					
28	39	Pressure Drop Annulus		69.77 KPa *					
30		E	F						
31	1	Sodium *		Air *					
32	2	253.0 kg/s *		283.5 kg/s *					
33	3	25.00 *							
34	4								
36	6								
37	7								
38	8	<empty> *</empty>							
39	9								
40	10								
41	12			<empty> *</empty>					
43	13	Dh *		0.6087 m *					
44	14	De *		3.840 m *					
45	15								
46	16			70.1.0.1					
47 48	18	G pipe -		784.0 " 26.61 *					
49	19	O Annulus		20.01					
50	20								
51	21								
52	22								
53 54	23								
55	25								
56	26	ha *		34.49 W/m-K *					
57	27	36.58 m *							
58	28	16.24 *							
59 60	29								
61	31								
62	32	True Q *		145.5 MW *					
63	Asp	en Technology Inc.	As	oen HYSYS V	ersion 11	Page 4 of 5			
	License	ed to: BATTELLE ENERGY ALLIANCE				* Specified by user.			

1					Case Name:	Appulus HX 25Tube bsc	
2	Call	acmentach	BATTELLE EN	ERGY ALLIANCE		Annuas HX.20 rube.hsc	
3	C	aspentech	Bedford, MA USA		Unit Set:	Project Units3i	
5					Date/Time:	Sat Aug 7 19:00:54 2021	
6		Sor	aadabaa	t: Double	Dina HV (Calculations (con	
8		Shi	eausnee	t. Double-	гіре пл (
9					SPREADSHE	ET	
10	33		pipe *		anulus *		
12	34		1.196e+022 *		2.787e+022 *		
13	35		7.488e-017 *		1.164e-020 *		
14 15	36 37		3.821e+005 *		6.611e+005 *		
16	38						
17	39						
10	40						
20							
21							
22							
24							
25							
26							
28							
29							
30 31							
32							
33							
34							
36							
37							
38							
40							
41							
42							
43							
45							
46							
48							
49							
50							
52							
53							
54							
56							
57							
58							
60							
61							
62	Aar			A		sion 11	Daga E of E
03	Licens	en rechnology InC. ed to: BATTELLE ENERGY	ALLIANCE	As			* Specified by user.

1	1						Caso Namo						
2	alle	Jacor	ntoch	BATTELLE EN	NERGY ALLIANCI	e -							
3	U	aspe	entech	Bedford, MA USA			Unit Set:	Project Units	3i				
5							Date/Time:	Sat Aug 7 1	9:00:37 2021				
6			Sor	adaba		רעפר	Г 4				Lipita Cati	Droiget Inite	
8			Spre	eausnee	I. JPRL	JSHI					Units Set.	Projectornits	
9						с	ONNECT	ONS					
10 11													
12						Imp	ported Va	riables					
13 14	Cel B2		Pine Segme	Object		Inside Di	ameter (Insid	Variable Descr	iption		3 068 in	/alue	
14	02	·	Fipe Segine		5.000 11								
16	0.1				Expo	rtea va	ITIADIES F	ormula Result	S				
17 18	Cel C4	II Air	Pipe	Object		Inside Di	ameter (Insid	e Diameter 1)	iption		41.93 in	/alue	
19	-					F	PARAMET	ERS					
20 21						-							
22	Exportable Variables												
23	Cel		V	isible Name		0.1.1.1	Variable	Description	Varia	ble Type	1 000 :	/alue	
24	 В7	B3	. Outside Diame	eter (Outside Di	ameter_1)	Outside	Diameter (Ou	tside Diameter_1)	Small Le	ngtn	4.068 IN		
26	B8	В8	:								0.6440		
27	C2	2 C2	2:								46.00		
28	C4	C4	: Inside Diamete	er (Inside Diame	eter_1)	Inside Di	ameter (Insid	e Diameter_1)	Small Le	ngth	41.93 in		
29	C7	' C7	' :								8.625		
30	User Variables												
32	FORMULAS												
33 34	Cel					Fc	ormula				F	Result	
35	B3	=b	2+1								4.068 in		
36	B8	=c	7-b7								0.6440		
37	C4	=c	2-b3								41.93 in		
38 39						S	PREADSH	IEET					
40			Α			В		(;		D		
41	1					So	dium Pipe *		Air Pipe *				
42	2		Inr	ner Diameter *			3.068 in *		46.00 *				
43	3		Ou	ter Diameter *			4.068 in *						
44	4		Diam	neter Friction *					41.93 in *				
45	5												
47	7			<empty></empty>			7 981 *		8 625 *				
48	8			t*			0.6440 *		0.020				
49	9												
50	10												
51			E										
52	1												
53	2												
54	3												
55	4												
57	c a												
58	7												
59	8									1			
60	9												
61	10												
62													
63	Aspe	en Tech	nology Inc.			Asper	n HYSYS V	ersion 11			F	Page 1 of 1	
	License	ed to: BAT	TELLE ENERGY	ALLIANCE							* Speci	fied by user.	

1		BATTELLE ENERGY ALLIANCE Bedford, MA		Case Name:	ShellAndTubeCaseStud	lies.hsc			
2	(aspentech			Unit Set:	Piyush Eng				
4	USA		Date/Time:	Sat Aug 7 23:29:11 2021					
5 6									
7	Work	kbook:	Case (Ma	ain)					
9									
10	Nama		No Inlat	No Outlet				Sadium Inlat	
12	Temperature	(F)	100) * 835.4	90.00 *	AIROUTLE	229.6	1000 *	
13	Pressure	(psia)	235.	226.8	20.00 *		9.175	235.0 *	
14	Mass Flow	(lb/hr)	2.008e+00	6 * 2.008e+006	4.083e+006 *	4.0	083e+006	2.008e+006 *	
15	Name		Sodium Outlet	Air Inlet	Air Outlet				
16	Temperature	(F)	835.4	4 90.00 *	223.8				
17	Pressure	(psia)	217.	7 20.00 *	9.175				
18	Mass Flow	(lb/hr)	2.008e+00	6 4.261e+006 *	4.261e+006				
19 20	Compositions Fluid Pkg: All								
21	Name		Sodium Inlet	Air Inlet	Sodium Outlet	Air Outlet		Na Inlet	
22	Comp Mole Frac (Air)		**	* 1.0000 *	***		1.0000	***	
23	Comp Mole Frac (Sodium)		1.000)* ***	1.0000		***	1.0000 *	
24	Name		AIRINLEI	Na Outlet	AIROUTLET				
25	Comp Mole Frac (Air)		**	* 1,000	***				
27				1.0000					
28				Energy Stream	S		Fluid Pkg	I: All	
29	Name								
30	Heat Flow	(Btu/hr)							
31	Unit Ops								
32									
32 33	Operation Name	Ope	eration Type	Feeds	Products		Ignored	Calc Level	
32 33 34	Operation Name	Ope	eration Type	Feeds Sodium Inlet	Products Sodium Outlet		Ignored	Calc Level	
32 33 34 35	Operation Name Shell And Tube - 100	Ope Heat Exch	eration Type	Feeds Sodium Inlet Air Inlet	Products Sodium Outlet Air Outlet		lgnored No	Calc Level 500.0 *	
32 33 34 35 36	Operation Name Shell And Tube - 100 S&T 150	Ope Heat Exch Heat Exch	nanger	Feeds Sodium Inlet Air Inlet Na Inlet	Products Sodium Outlet Air Outlet Na Outlet		Ignored No No	Calc Level 500.0 * 500.0 *	
32 33 34 35 36 37	Operation Name Shell And Tube - 100 S&T 150	Ope Heat Exch Heat Exch	nanger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No	Calc Level 500.0 * 500.0 *	
32 33 34 35 36 37 38 39	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty AD1-Duty150	Ope Heat Exch Heat Exch Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 *	
32 33 34 35 36 37 38 39 40	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	anger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	anger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	nanger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	ration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		lgnored No No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	anger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		lgnored No No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Heat Exch Adjust Adjust	ration Type	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger -	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger -	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger -	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger -	Feeds Sodium Inlet Air Inlet Aanlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger -	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 3500.0 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 3500.0 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 3500.0 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Na Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 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	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	aration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 34 35 36 37 38 39 40 41 42 43 44 45 45 56 57 58 56 57 58 56	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	ration Type	Feeds Sodium Inlet Air Inlet AarinLET	Products Sodium Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 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 9 40	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	ration Type	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 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 60	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	ration Type	Feeds Sodium Inlet Air Inlet Ai Inlet AIRINLET	Products Sodium Outlet Air Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 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	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	anger	Feeds Sodium Inlet Air Inlet Na Inlet AIRINLET	Products Sodium Outlet Air Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 500.0 * 3500 * 3500 *	
32 33 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 63	Operation Name Shell And Tube - 100 S&T 150 ADJ-Duty ADJ-Duty150	Ope Heat Exch Adjust Adjust	eration Type	Feeds Sodium Inlet Air Inlet Air Inlet AIRINLET ARRINLET ARRINLET	Products Sodium Outlet Air Outlet AIROUTLET		Ignored No No No	Calc Level 500.0 * 3500 * 3500 *	



oر م
5
$\dot{\mathbf{v}}$
\geq
iΨi
in
\mathbf{ls}
de
ŏ
Ε
Gr
õ
JU
ĥ
X
Ð
at
Je
ą
2
L '
no.
5
I
he
\mathbf{v}
÷
m
H
ц€
5
Ē

lb/hr 2.008e+006 2.008e+006 4.083e+006 4.083e+006 2.008e+006

psia

Mass Flow Pressure

223.8 9.175

Air Outlet

2.008e+006 4.261e+006 4.261e+006