GHG EMISSIONS AND ENERGY USAGE ASSESSMENT OF PHOSPHORUS RECOVERY FROM MUNICIPAL WASTEWATER SYSTEMS UTILIZING BIOCHAR- CATALYTIC OXIDATION-REACTIVE FILTRATION

A Thesis

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by

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

The Nutrient-Energy-Water Technology (NEW Tech™) system is an emerging wastewater treatment process with the primary objective of addressing the food-energy-water nexus. The system uses biochar- catalytic oxidation- reactive filtration as the means of recovering phosphorus by adsorption onto biochar and producing clean reusable H_20 from wastewater resources. Nutrient enriched biochar used as a soil amendment will sequester carbon from the atmosphere, while offsetting the demand for fertilizers produced through mining and industrial processing.

Emissions and energy analysis includes a detailed analysis and benchmark of the energy required to operate the system, energy efficiency optimization opportunities, and an analysis of greenhouse gas emissions produced as a result of system operations in the treatment of post-secondary treatment municipal wastewater. Currently, the NEW Tech™ system can achieve full operations utilizing approximately 6.3 kW of electricity and is capable of processing 1000 gallons of waste water for 0.68 dollars. Furthermore, the system has state-of-the-art removal of total phosphorus to 0.004 mg/L when treating secondary municipal waste water. Additionally, greenhouse gas analysis determined that the system electrical and material usage produces approximately 3.3 kg of CO_2 per 1000 gallons of water processes.

Energy and greenhouse gas emissions savings can be realized via the implementation of energy efficiency improvements to process equipment. Energy savings identified could lower energy usage costs to approximately \$0.44 per 1000 gallons and reduce the global warming potential of the overall system to 2.69 kg of CO_2 produced.

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CHAPTER I: INTRODUCTION AND SCOPE

INTRODUCTION

As a result of diminishing finite resources and the trajectory of increasing global populations, it is imperative that innovations in resource recovery and recycling be established. Addressing increasing demands on natural resources for food requirements, clean drinking water, and energy, while also ensuring supplies remain adequate are of key importance for the sustainability of life on Earth. One such technology for addressing the nutrient-energy-water nexus is an innovative water treatment process being researched at the University of Idaho known by name as NEW Tech™, or Nutrient-Energy-Water Technology.

The NEW Tech™ system, seen in Figure 1, is built upon several evolutions in treatment processes that has led to 8 issued or pending patents. The NEW Tech™ system utilizes several forms of well-established water treatment methods coupled with new novel approaches to achieve state of the art water treatment, as such, it sterilizes reclaimed water, and also produces a nutrient enhanced biochar fertilizer which can sequester atmospheric carbon, thus ensuring that supplies of finite essential nutrients for agriculture are maintained. The system utilizes reactive filtration and the use of iron modified biochar, along with ozone for oxidation. Currently, this system is capable of sterilizing and binding soluble phosphorus to biochar in reclaimed water post-secondary treatment in municipal water resource recovery facilities.

Figure 1: NEW Tech™ Mobile Research Trailer

Phosphorus is a key component in DNA, and is consequently a fundamentally required element for all living creatures on the planet (Vaccari, 2011).Therefore, nutrient phosphorus is essential for agriculture - maintaining food security and sustaining plant and animal growth. Extensive agricultural activities require that nutrient phosphorus be input and replaced as cultivation and harvesting of crops depletes soil phosphorus. Phosphorus is returned to the soil matrix as various fertilizers and/or soil amendments. Phosphorus is only available in finite reserves that are mined around the globe. Additionally, due to accelerated extraction, and because phosphorus deposits are reformed on the scale of thousands to millions of years, it is possible that readily extractable phosphorus reserves will be scarce or depleted within the next 50 to 100 years (Childers, Corman, Edwards, & Elser, 2011). In 2015, phosphorus mines in the United States produced approximately 27,600 thousand metric tons, and the estimated quantity of phosphorus still contained in domestic reserves is 1,100,000 thousand metric tons (U.S.G.S, 2015). Therefore, at the current rate of extraction, the phosphorus reserves in the United States will be depleted in approximately 40 years.

Furthermore, in addition to depletion of reserves and food security concerns, the adverse environmental effects of nutrient phosphorus production and pollution are of great importance. Nutrient pollution from phosphorus and nitrogen in marine and freshwater aquatic ecosystems is significant. Sources of nutrient pollution include point sources and non-point sources. Contributors to water body nutrient pollution include agricultural runoff, air deposition, storm water runoff, and sewer overflows.

SYSTEM DESCRIPTION

The NEW Tech™ research system, housed atop a 40-foot long trailer and weighing approximately 9 tons, has been deployed and tested in the Pacific Northwest region in and around the Moscow, Idaho area. The main system components of the research vessel, as seen in Figure 2, are comprised of an influent inlet, two influent screens, two influent pumps, two serpentine plug flow reactors, two upward flow moving bed sand filters, and clean water discharge, and a filtered rejects discharge. Additional system components include an onboard air compressor, air dryer, ozone generator, several electromagnetic flow meters, and several chemical dosing pumps. The entire water filtration system is housed onboard a fifth wheel trailer for mobilization.

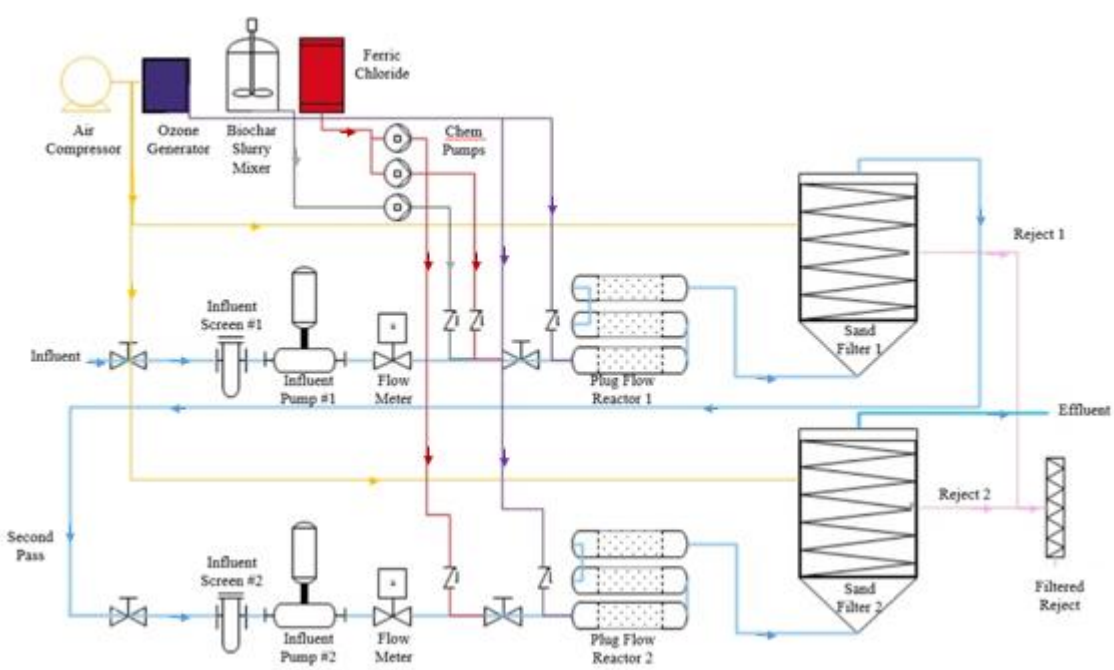

Figure 2: System Diagram of NEW Tech™ Water Treatment System

Influent water is drawn from the source through a suction line via influent pump #1. Influent water drawn into the system begins its treatment process within the trailer container where dosing of biochar slurry, iron salts, and ozone occur. Immediately following the dosing segments with the system, the water flows into the first serpentine plug reactor where adequate mixing and contact times are achieved for oxidation of pathogens and destruction of trace organic contaminants, such as hormones and pharmaceuticals. Following the plug flow reactor, the water flows upward through an upflow moving bed sand filter where phosphorus binding iron-modified biochar is captured and discharged through a reject flow line. Filter sand is continuously turned over using compressed air that carries sand and filtered particles from the lower regions of the reactive filter to the top and is dispensed in a wash box. After the first sand filter, the water has made its way through one-half of the system. The filtered water stream is then fed back through the system where is goes through a nearly identical series of pumping, ozone and FeCl dosing, followed by plug flow reactor #2 and sand filter #2. The final products of the whole process are clean sterilized water and a rejects stream consisting of biochar bound phosphorus that can be separated out for agricultural use and applications. Further details on the mechanisms of sterilization with catalytic oxidation, mechanism of binding phosphorus to biochar, and the advantages of using biochar in the process will be discussed in further detail below.

LITERATURE REVIEW

Ferric Chloride for Phosphorus Adsorption

The importance of removing phosphorus, prior to it being discharged into water bodies due to its contribution to eutrophication, has already been briefly discussed. However, the means by which soluble phosphorus is being removed from the water during this process has yet to be described. Phosphorus, in water treatment, is typically removed via different methods depending on how the system is designed.

Phosphorus removal can be achieved through several different methods, including: physical, biological, or chemical removal. Physical treatment technologies available for phosphorus removal involve filtration to separate particulate phosphorus, or through the use of different membrane technologies. Biological treatment technologies for phosphorus removal include assimilation-the incorporation of phosphorus as an essential element in biomass growth of photosynthetic organisms such as plants and algae. Another method of biological treatment is enhanced biological phosphorus removal (EBPR). EBPR is a biological phosphorus removal method that has the potential to achieve low phosphorus effluent levels at an affordable cost and with minimal additional activated sludge production. Finally, chemical technologies typically consist of chemical additives that create adsorptive precipitates that can be extracted or through other physical-chemical adsorption (Strom, 2006).

Although there are a number of ways to remove phosphorus from wastewater, a common method is through the addition of iron salts such as ferric chloride (California Water Technologies, 2004). Ferric chloride reacts with phosphorus and forms adsorptive hydrous ferric oxide precipitates that are more easily extractable. Additionally, once sufficient ferric chloride has been added to meet the demand for phosphate and hydrogen sulfide, free ferric ions will react with alkalinity to form ferric hydroxide. Ferric hydroxide acts as a coagulant and a flocculent (California Water Technologies, 2004). Therefore, ferric chloride not only works to adsorptively precipitate out soluble phosphorus, but settles out any other unwanted suspended solids in the water. This is an added benefit for easier removal of many unwanted contaminants.

In the reactive filtration process, ferric chloride is pre-reacted with water before the moving bed sand filtration in order to yield adsorptive iron-coated media. Co-precipitation with metal salt solutions is a well-known phosphorus removal technique in wastewater (Sedlak, 1991). Using a reagent, such as ferric chloride, is added to influent and phosphorus is adsorbed onto precipitating hydrous ferric oxide. Ferric ions and hydrous ferric oxide adsorb onto many materials and the formation of iron-coated sand in a moving bed sand bed filter creates a good substrate for reactive filtration (Newcombe, Rule, Hart, & Moller, 2008).

Catalytic Oxidation using Ozone

The NEW Tech™ treatment process uses ozone to achieve sterilization of the treated water. Ozone is an unstable gas comprised of three oxygen atoms. Upon reformation of two oxygen atoms to oxygen gas, there is a free radical oxygen atom remaining that is highly reactive. The free oxygen radical will quickly react to oxidize and destroy bacteria, viruses, and protozoans. The efficiency of the oxidation achieved from the use of ozone in water treatment is thought to be enhanced through the use of what is called catalytic oxidation or catalytic ozonation. There is still more advanced research to be done before the mechanisms and chemistry behind why catalytic oxidation is achieved can be fully understood. However, there is strong evidence that catalytic ozonation using metals compounds and charcoals offers higher efficiency and a homogeneous and heterogeneous reaction mechanism that generates hydroxyl radicals and peroxides as well as other oxidants in water treatment processes (Nawrocki & Kasprzyk-Hordern, 2010). Standard ozonation, under conditions of pH 7, showed a reduction in chemical oxygen demand by 45%, color by 82%, and the turbidity by 55%. Catalytic ozonation, in the same conditions with added metal plates, showed a reduction of chemical oxygen demand of 80%, color by 90%, and turbidity by 90% (Quiroz, et al., 2011). NEW Tech™ trials have been working to utilize catalytic oxidation using ozone combined with the dosing of iron chloride (a metal salt) in its treatment process.

Biochar and Phosphorus Removal

Biochar is a carbon-rich material that is produced when biomass, such as wood, manure, or crop residues, is heated in a closed environment with little or no oxygen. This type of thermochemical conversion process is more commonly known as pyrolysis. During the process, organic biomass is heated in an anaerobic environment where the feedstock is converted to solid char products and volatile constituents are converted to their gas phase and captured. The gaseous products are then quickly quenched in order to condense some gases that can form a tar like liquid known as bio-oil. Bio-oil may further be cracked orsynthesized into usable liquid fuels, whereas the non-condensable gases can be used to power other systems such as heaters or boilers. The solid products are in the form of a carbon rich charcoal material termed "biochar". Biochar, the so-called byproduct from pyrolysis processing, can be used to improve both agriculture and the environment in several ways; also, its stability in soils and superior nutrient-retention properties make it an ideal soil amendment to increase crop yields (Lehmann & Joseph, 2012).

Since biochar is a by-product of organic biomass that is carbon rich, when used as an agricultural soil amendment it will sequester carbon from the atmosphere for up to thousands of years. The use of biomass materials in agriculture is commonly believed to be termed a carbon-negative process: plant growth consumes carbon dioxide from the atmosphere; the plant is then harvested; residues converted into biochar, and applied in agricultural soils. These applications can be considered carbon neutral, granted that GHG emissions from cultivation, harvesting, transportation, and processing of the raw biomass are less than the quantities of carbon captured by the plant during natural growth.

Biochar has the additional benefits of being a natural phosphorus source and serving as a binding agent for aqueous phosphorus compounds. Furthermore, it has been demonstrated that metal enhanced biochar will have enhanced phosphorus removal potential and fertilizing abilities (Cheng, Lehmann, Thies, Burton, & Engelhard, 2006)

OBJECTIVES

Problem Statement

Increasing global population and the related increase in the demand for food and clean water creates a need for technology innovations to ensure sustainability and food security. However, major resources involved in the cultivation of food crops are extracted from finite reserves and processed for agricultural use. Finite reserves of essential nutrients for the cultivation of global food supply are being depleted at an alarming rate. Domestic phosphorus reserves are expected to be depleted within the next century and are a concern for the sustainability of the food supply. Furthermore, demand for clean drinking is an increasing concern as usable water sources become polluted or depleted. Therefore, it is imperative that new innovations in the fields of water treatment, nutrient recovery and recycle, and clean renewable energy sources be investigated.

Purpose of Study

This study is one that aims to assess the greenhouse gas emissions, energy usage, and resource consumption of the NEW Tech™ water treatment process. The main goal of the GHG emissions and energy usage component of the project is to quantify the global warming potential and resource depletion related to the energy use and well-to-use production of raw materials used in reaching desired effluent quality from the process. The specific goal of this paper is to assess the environmental costs or gains associated with electricity usage, the use of dosing chemicals (biochar and ferric chloride), and the capture of nutrient phosphorus from post-secondary treatment in a municipal waste water system. Additionally, opportunities for energy optimization of the system are identified and investigated to determine the potential quantity of energy saved and associated cost reduction via the implementation of the different energy saving recommendations.

Functional Unit

Regarding the treatment of municipal waste water treatment, there are several options available for a functional unit for the basis of analysis. Such options include (but are not limited to) volume of sludge produced, quantity of pollutants removed, or volume of water processed. Based on the treatment capacity of the system, an appropriate functional unit to be used in this analysis is the volume of influent water processed by the system. The analysis in this report will be based upon 1000 gallons of water processed by the system. Therefore, quantities of energy, raw material used, greenhouse gas emissions, and global warming potential will be the resulting quantities from processing 1000 gallons through the system.

System Boundary

The system boundary for this study is the NEW Tech™ filtration system. Based on the objectives of the study, the system boundary will include the input raw materials and energy use, as well as the products discharged from the system. These materials and energy use shall be analyzed to determine the environmental impact associated with electricity footprint and the original production of raw chemicals used within the treatment process.

CHAPTER II: MATERIALS AND ENERGY INVENTORY

ELECTRICAL ENERGY USAGE

In order to conduct an environmental assessment of the NEW Tech™ treatment process, electrical energy, raw material inputs, and value added products had to be quantified. For the purposes of this thesis project, it was decided that electrical use would be benchmarked and monitored to effectively quantify the energy that would be consumed from the local utility. Table 1 presents an inventory of all major energy consuming equipment used in the process along with available equipment nameplate information for relevant energy calculations. Entries in Table 1 that are blank are due to the lack of available information on individual pieces of equipment.

Table 1: Nameplate Information of Principle System Components

Treatment Process Component	Voltage	Current	Power	PF	Efficiency
Influent Pump #1	240	9.5	1.5 HP	79	71
Influent Pump #2	240	9.5	1.5 HP	79	71
Biochar Dosing Pump	120	~	~	~	~
FeCl Dosing Pump 1	120	~	40 W	~	~
FeCl Dosing Pump 2	120	~	40 W	~	~
Air Compressor	240	16	3 HP	78	78
Air Dryer	120	~	192 W	~	~
Ozone Generator	240	~	540 W	~	~

After an inventory of the larger equipment onboard had been established, it was necessary to then quantify actual electrical energy consumption of the entire treatment system, as well as of the individual pieces of equipment involved. Instantaneous power readings were measured at each piece of equipment to derive an estimated total power consumption of the major system components.

Knowing that the system has the flow capacity of 15 gallons per minute of water through the system, it was determined that the system was able to pump 1,000 gallons in approximately

1.11 hours. Using the instantaneous power draw measurements and knowing the duration of time it takes to pump 1,000 gallons through the system, the kilowatt-hour electrical consumption for each of the components was determined. To further illustrate the energy and material flows of the system, a Sankey diagram (Figure 3) for the system was created to show the proportions of the energy consumed by each piece of equipment. It can be seen that the production of compressed air to be used in the process is the largest consumer of electrical energy. The second largest use of electricity is the operation of the two influent pumps that move water through the system. Reductions in energy profile would likely be a result of implementing energy efficiency improvements on these components of the system.

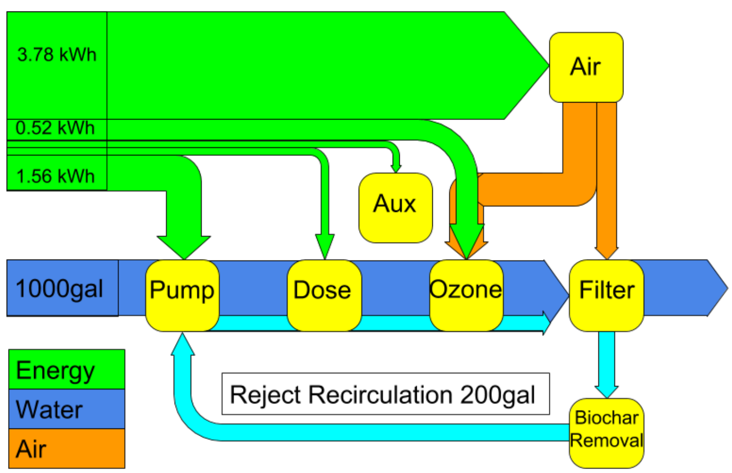

Figure 3: Sankey Diagram of Energy Flows per 1000 Gallons Treated

In order to gain more insight into the energy usage profile of the system, data was collected over an 8-hour duration during a water sampling event during which the system operations were stable and consistent. Data collection on the larger system components was achieved by the installation of data loggers that measured the electrical current draw of the individual pieces of equipment. The pieces of equipment that were logged during this process were the air compressor unit, the ozone generator, and the two influent water pumps. Additionally, the main breaker on the overall system was logged in order to better understand the system response to the operations of other onboard equipment. Collection of electrical current data from system main breaker also served as a method for quantifying the overall system energy use. Figure 4, is a plot of the electrical current data that was logged for the various equipment units during the sampling event on November 3rd, 2015.

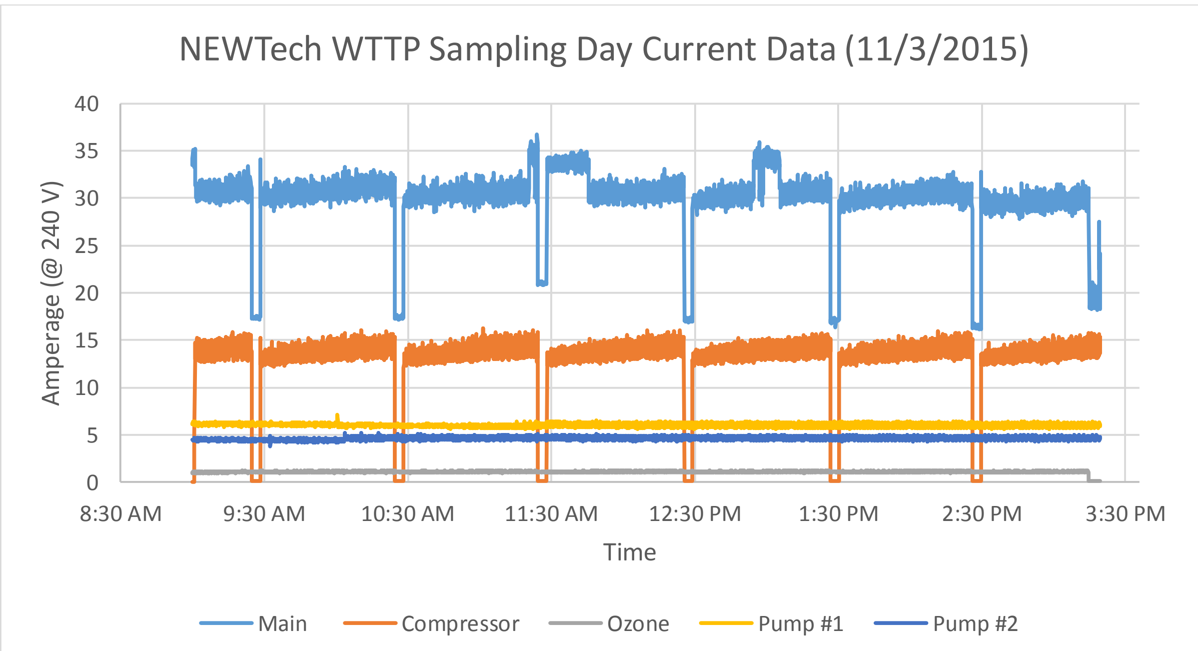

Figure 4: Electrical Current Data for Large Energy Consuming Equipment

The electrical current data collected on the system (Figure 4) was particularly useful in the determination of both the electrical demand and consumption, as well as electrical cost estimates for the system on a monthly, annual, and per 1000-gallon basis. As seen in Appendix A, the amount of electrical demand and consumption have been quantified by utilizing the electrical current data collected on the system. Analysis showed that the system power draw is approximately 6.3 kilowatts 95% of its operating time and 3.2 kilowatts 5% of its operating time. Using the power draw and time to pump 1000 gallons, the system utilizes approximately 7 kilowatt-hours of electricity. Table 2 below shows, using typical costs of electrical demand (kW) and consumption (kWh) provided by the U.S. Energy Information Administration, the estimated cost of electricity to operate the entire system. Table 2 summarizes the calculated electrical demand and consumption costs associated with running the system based on monthly, annual, and per 1,000 gallon of pumping time periods.

Table 2: NEW Tech™ Electrical Cost Summary

	Time Period		
Component	Monthly	Annual	Per 1,000 Gallons
Electrical Demand	$104.00	$1,248.00	$0.16
Electrical Consumption	$328.60	$3,996.60	$0.52
TOTAL	$432.60	$5,244.60	$0.68

RAW MATERIALS AND SYSTEM PRODUCTS

Upon completing a comprehensive inventory and benchmark of the electrical energy consumption of the system during operation, it was then necessary to monitor and inventory the amount of raw material being input to the system to achieve water treatment. Table 3 summarizes the dosing rates for both biochar and ferric chloride. Dosing values were determined simply through observation of operational dosing set points during a day of typical operation of the system. Additionally, the amount of biochar and ferric chloride used in order to treat 1000 gallons of water was calculated.

Table 3: Dosage Summary

Dosing Material	Dosage Rate	Amount Dosed per 1000 Gallons of Water Treated
Biochar	0.068 kg/min	4.520 kg
Ferric Chloride (40% w/v)	2.71 mL/min	0.298 kg

Table 4 presents the influent and effluent water quality with regard to phosphorus concentration. The influent and effluent values allow for the determination of the amount of phosphorus that is removed in the water treatment process. This is an important value to know in order to determine the amount of emissions from industrial processing that will be offset as a result of the recovery of phosphorus from a wastewater resource. Furthermore, in the determination of overall system global warming potential, the quantified emissions from phosphorus will be subtracted from the overall total because the nutrient is being recovered rather than produced in an industrial process. Due to the variability of constituent concentrations in waste water, the values presented in Table 4 are only representative of the specific period of sampling. Data presented in Table 4 was collected at the waste water treatment plant in Moscow, Idaho on November 3, 2015 during an 8-hour sampling event.

Table 4: NEW Tech™ Influent and Effluent Water Quality Measurements (November 3, 2015)

Parameter	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	Mass of Phosphorus Removed per 1000 gallons (mg)
Total Phosphorus	0.117	0.006	421.690

CHAPTER III: IMPACT ANALYSIS

EMISSION FACTORS ASSOCIATED WITH ELECTRICITY PRODUCTION IN THE PACIFIC NORTHWEST REGION

In order to begin to quantify the emissions associated with operation of the NEW Tech™ system, it was necessary to determine the mass of harmful greenhouse gas emissions being produced per unit of energy consumed, with respect to electricity production in the Pacific Northwest region (PNW). Greenhouse gas emission factors were found for carbon dioxide, methane, and nitrous oxide using the EPA's Emissions and Generation Resource Integrated Database (eGRID). The net electricity use of the system can then be multiplied by PNW emission factors (Table 5) for electricity production to determine the mass of each emission produced in the production of electrical energy in the region. The PNW region is located in eGRID sub-region WECC Northwest (EPA, 2015). Typically, emission values are converted to an equivalent weight of carbon dioxide, also known as a global warming potential (GWP), in order to have comparative value to other processes. The equation for calculating GWP was found in the most recent climate change report published by the Intergovernmental Panel on Climate Change. For a detailed description of the calculations performed in order to quantify emissions from electricity production, see Appendix B.

Table 5: GHG Emission Factors from Electricity Production in the PNW (EPA, 2015)

GHG Emissions	Annual Output Emission Rates	Units
CO_2	302.00	kg/MWh
CH_4	5.72	kg/GWh
N_2O	4.71	kg/GWh
*GWP (CO_2 eq)= (CO_2)+(25 x CH_4)+(298 x N_2O)		*Source: (IPCC, 2007)

EMISSION FACTORS ASSOCIATED WITH THE PRODUCTION OF INPUT AND OUTPUT MATERIALS

Emission quantities for phosphate rock and biochar, was acquired using GREET 2015. GREET 2015 is a life-cycle model that is developed and maintained by Argonne National Laboratory's Center for Transportation Research (Argonne National Laboratory, 2015). Biochar quantities are based on the conversion of willow biomass to biochar from fuel processing in an ethanol production facility. The carbon dioxide, methane, and NOX emission factors for ferric chloride are omitted due to the lack of documented specific emission quantities related to the production of ferric chloride. However, a literature search provided a value for the CO_2 equivalent for net emissions for the production of ferric chloride. The CO_2 equivalent factor for ferric chloride is used in order to calculate the global warming potential. The global warming potential emission factor for the production of ferric chloride is approximately 2.71 kg CO_2 equivalent per kg of ferric chloride (Kyung, Kim, Chang, & Lee, 2015). Table 6 shows the quantity of emissions produced (mass/kg used) from the production (well-to-use) of the raw material inputs in the treatment process. The values acquired from these sources are considered to be "well to use" values that include extraction, transport to facility, and production of the product. The values do not include the transport of the materials to the point of use. Ideally, materials should be locally sourced whenever possible to minimize emissions associated with additional transportation.

The emission factor values are to be multiplied by the mass of raw materials used in the dosing of 1000 gallons of treated water to determine the mass of relative GHG emissions associated with the use of each material. Utilizing the calculated emission quantities, the global warming potential (GWP) in units of CO_2 equivalent, can then be determined for each material.

For a detailed description of the calculations performed in order to quantify emissions from material production, see Appendix B.

Table 6: GHG Emission Factors from Production of Chemicals

	Emission Quantities (mass of emissions produced per kg of material used)			
Material	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	GWP (kg)
Biochar	0.06	7.67×10^{-5}	9.12×10^{-5}	-
Ferric Chloride	-	-	-	2.71
Phosphate Rock	0.35	6.60×10^{-4}	7.31×10^{-6}	-
*GWP(in CO_2 eq)= (CO_2)+(25 x CH_4)+(298 x N_2O)			*Source: (IPCC, 2007)	

Analysis of emissions was conducted to estimate the GHG emissions and GWP quantities based upon the data presented for the treatment of 1000 gallons of water. Table 7 summarizes the quantities of GHG emissions associated with the 7 kilowatt-hour electrical consumption utilized during the treatment of 1000 gallons of water. Additionally, the GWP (in kg CO_2 equivalent) for the use of electricity is also noted in Table 7.

Table 7: Calculated GHG Emissions as a Result of Electrical Consumption of System per 1000 Gallons Processed

	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	GWP (in kg CO_2 eq)
Electrical Consumption Emissions	2.11	4.0×10^{-5}	3.0×10^{-5}	2.12

Table 8 shows the calculated values for the emissions generated and GWP via the production of biochar and ferric chloride. All emissions estimates and GWP values are calculated on a kilogram mass basis.

Table 8: Calculated GHG Emissions as a Result of Raw Material Use and Phosphorus Capture per 1000 Gallons Processed

	CO_2 (g)	CH_4 (g)	N_2O (g)	GWP (in g CO_2 eq)
Biochar	271	.347	.412	402
Ferric Chloride	-	-	-	808
Phosphorus Collected	0.15	2.8×10^{-4}	3.0×10^{-6}	0.16

In order to quantify the net GWP for the consumption of electrical energy, as well as the raw materials input and output of the treatment process, the calculated GWP values for each relative constituent was summed to evaluate a value for the cumulative GWP associated with treating 1000 gallons of reclaimed water.

Regarding the amount of carbon being sequestered if the biochar was to be land applied as an agricultural fertilizer, it is necessary to convert the mass of biochar carbon into an equivalent mass of carbon dioxide. The equivalent weight in carbon dioxide, converted from carbon itself, is determined by the multiplication of mass of carbon by ratio of their molecular weights. The ratio of the molecular weights of carbon and carbon dioxide is 3.67 (3.67 CO_2 to each carbon molecule). The amount of carbon dioxide sequestered by the biochar (assuming 70% carbon content) if it were to be land applied can be determined by multiplying the mass of biochar the percent carbon content and by 3.67 (the ratio of molecular weights). Therefore, if the mass of biochar dosed per 1000 gallons of treated water was to be land applied, then the carbon dioxide mass equivalent would be approximately 11.34 kg CO_2 equivalent per 1000 gallons.

Furthermore, in the determination of overall system GWP, the quantified GWP from phosphorus will be subtracted from the overall total because the nutrient is being recovered rather than produced in an industrial process. The nutrient recovery will reduce the need for production and emissions produced as a result of phosphorus rock extraction from finite deposits and being processed in an industrial facility. Table 9 contains the relative GWP values for the system inputs and outputs. The net GWP is shown in the bottom row of Table 9.

Table 9: Net Total Global Warming Potential for System Operations to Process 1000 Gallons

System Input/output	GWP (mass CO_2 equivalent)
Electrical Consumption (kg)	2.120
Production of Biochar (kg)	0.395
Production of Ferric Chloride (kg)	0.808
Captured Phosphorus (kg)	-1.60×10^{-4}
TOTAL (kg)	3.323

Based upon the analysis, the total GWP for the treatment of 1000 gallons of water is approximately 3.323 kg CO_2 equivalent per 1000 gallons. This value is specific to the research scale capacity that the current NEW Tech™ mobile system is capable of processing. However, it is important to note that the nutrient enhanced biochar produced by the NEW Tech™ process has the potential to be a carbon negative product as well as having positive effects on soil properties and plant growth when land applied.

Biochar is believed to have many positive impacts on soils. First, biochar increases a soil's capacity to adsorb plant nutrients and agricultural chemicals that reduces leaching into surface and ground water. Second, biochar used in soils will re-introduce plant nutrients that were removed when the biomass was harvested. Next, the low density of biochar materials can help to lower the bulk density of dense soils and will therefore increase drainage, aeration, and root penetration. Fourth, biochar will help to offset the effects of nitrogen based fertilizers due to its properties as a limiting agent (Glaser, Lehmann, & Zech, 2002). Research has shown that sustainable global implementation of the use of biochar can potentially offset 12% of the current CO_2 emissions (Woolf, Amonette, Street-Perrott, Lehmann, & Joseph, 2010). Furthermore, pyrolysis processes that produce biochar are a source of renewable bioenergy in the forms of bio-oil and syngas. Gaseous bioenergy products are typically used to generate electricity. The bio-oil products can be used directly for low-grade heating and can also be upgraded to be used as a drop in diesel fuel substitute (Bridgwater, Meier, & Radlein, 1999).

The nutrient enhanced biochar material created by the process is a desirable soil amendment for land application. Furthermore, the beneficial properties of nutrient upcycled biochar integrated into soils and ability to sequester atmospheric carbon would likely accelerate the economic and agronomic practicality of biochar use in agriculture. The fertilizer value and environmental benefits of the product will also likely promote the use of this product as a soil amendment rather than for applications where the biochar is used for combustion/heating purposes that would put CO_2 back into the atmosphere. Therefore, even though the biochar being input to the system has the potential to be carbon neutral if combusted or carbon negative if land applied, the NEW Tech™ process does produce a nutrient upcycled biochar product that is good for plant growth, nutrient and moisture retention, and the environment. The agricultural value of the biochar as a fertilizer product would encourage its use for land application and would thus make the biochar a carbon negative product. As mentioned above, the CO_2 equivalent of the biochar dose is 11.8 kilograms per 1000 gallons of water treated. If the carbon negative component associated with the land application of the biochar product is included into the overall process boundary, then the resulting system global warming potential would be a value of -8.02 kilograms of CO_2. In this scenario, the NEW Tech™ system could potentially be considered to be a carbon negative process from a greenhouse gas emissions standpoint, and would essentially be promoting the sequestration of more atmospheric carbon than the process operations are contributing.

CHAPTER IV: ENERGY SAVING OPPORTUNITIES

The following energy optimizing opportunities have been identified as ways the NEW Tech treatment system could reduce the amount of both electrical demand and consumption. For each opportunity, the existing energy profile and proposed energy usage have been analyzed in order to estimate the energy savings potential and energy cost savings associated with implementation of the opportunity. Cost estimates are based on industrial demand and usage electricity costs provided by the Department of Energy's Energy Information Administration. For the purposes of the analysis of energy optimization opportunities, a demand cost rate of 8.32 dollars per kilowatt and an electrical consumption cost rate of 0.075 dollars per kilowatt-hour is used (U.S. Energy Information Administration, 2014). Detailed analysis and calculations of all energy saving opportunities can be found in Appendix C.

MODIFY SAND FILTER AIR LIFT TO RECEIVE AIR FROM AIR PUMP OR BLOWER

Background

Currently, the filtering media (sand) is turned over via air lifts that makes use of compressed air. Air from the compressed air system is injected into the base of the air lifts and as the air percolates upwards, the filter sand is carried with the air bubbles and deposited on the top of the filter column after falling through a torturous path washbox. The compressed air is supplied by an onboard 3 HP rotary screw compressor that provides compressed air to both the ozone generator and to the air lifts that move the sand media in the sand filtration columns. The configuration of the filters requires that the supplied air overcome a backpressure of approximately 5 psi and supply a volumetric flow of 15 cfm and 10 cfm for filters 1 and 2, respectively.

Producing compressed air is a very energy intensive process that, in most cases, consumes more energy than most other equipment in industry. In fact, most compressed air systems have a wire-to-work efficiency which can be as low as 10-15% (U.S. Department of Energy, 2003). Therefore, the majority of the energy supplied to a compressed air system is lost in the production of pressurized air. Due to the low efficiency and high energy consumption of compressed air systems, it is very important that compressed air only be utilized for tasks that truly necessitate its use. Many processes and tasks that commonly use compressed air in an industrial setting can be deemed inappropriate uses of compressed air. Potential inappropriate uses of compressed air include: open blowing, sparging, aspirating, atomizing, padding, dilute-phase transport, dense-phase transport, vacuum generation, personnel cooling, open hand-held blowguns, diaphragm pumps, cabinet cooling, and vacuum venturis (U.S. Department of Energy, 2003). Compressed air is commonly used for many of these potential inappropriate uses due to the fact that compressed air is clean, readily available, and is easy to utilize. However, many of the common inappropriate uses of compressed air can be accomplished much more economically with the use of other methods and/or equipment.

According to the U.S. Department of Energy's compressed air tip sheet, the use of industrial blowers or air pumps are good candidates for use in processes that require large volumes of air at relatively lower pressures. Furthermore, blowers operate at higher efficiencies and can replace the use of compressed air for aspirating purposes at a reduced cost. Typically, centrifugal blowers operate with a full load efficiency of upwards of 80% (Rutgers State University, 2001).

The uses of compressed air in the NEW Tech™ system are for delivering pressurized air necessary for ozone generator operation and for percolating air through the air lifts in the sand filters. The air delivered to the sand filter air lifts has a low pressure and high volume air requirement that could be achieved with the use of an industrial centrifugal blower or an air pump.

Recommended Action

It is recommended that compressed air system be utilized for only the processes that have an adequate pressure requirement to necessitate the use of an air compressor unit. The only equipment in the NEW Tech™ system that requires pressurized air is the ozone generator that requires 30 psi to operate correctly. Therefore, the ozone generator should remain attached to the compressed air system and the air lifts for the sand filters should receive air from a blower or air pump unit.

In order to keep the sand moving in the filters, there is a greater demand for air flow than there is a demand for high pressure. Commercial air pumps are capable of providing adequate flow, as well as necessary pressures to overcome the back pressure caused by the weight of the sand and water column within the filters. Subsequently, energy savings can be realized via the implementation of use of a blower system for filter operations and the reduction in air compressor demand/runtime.

Current Energy Usage

It can be seen in Figure 5 that the compressor runs in an on/off fashion. Additionally, it can be seen that the compressor in in operation for the majority of the time. From the data, it was calculated that the compressor is in operation 95% of the time the NEW Tech™ system is treating water and the compressor is shut off for 5% of the time when it is able to reach the desired pressure set point.

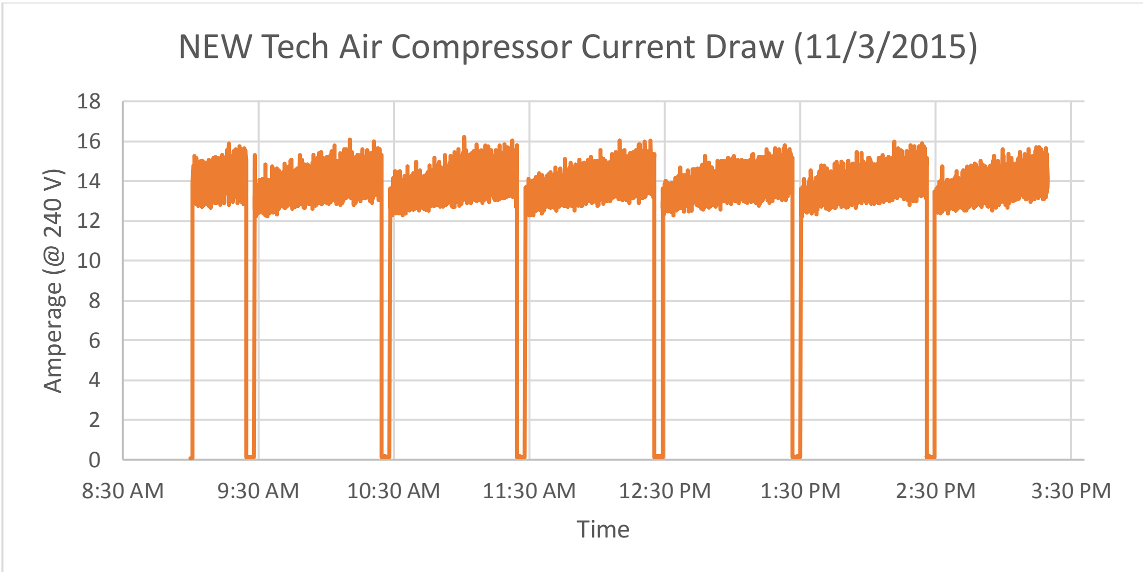

Figure 5: Air Compressor Current Draw

The peaks in current draw are the on state, and the lower in between times are the off state. When the compressor is in operation, the average electrical current draw is 13.8 amps. With the percent of operations that is spend in the on and off state and knowing the average current draw of the compressor motor when in the on state, the annual energy usage of the compressor can be estimated. However, before the annual energy usage can be determined, the power draw of the air compressor when operational has to be determined. Using the current draw and nameplate rated voltage and power factors, the power draw was determined to be 2.37 kW.

Next, the annual, monthly, and per 1000-gallon energy consumption was determined by multiplying the compressor power draw by the number of operating hours in each time period. The calculated electrical consumption for the current air compressor configuration for the various time periods can be seen in Table 10 below.

Table 10: Current Electrical Consumption of Air Compressor

		Operating Hours (Time Spend in On State)			Current Electrical Consumption (kWh)		
Equipment	**Power Draw (kW)**	Annual	Month	Per 1,000 Gallons	Annual	Month	Per 1,000 Gallons
Compressor Motor	2.37	8,322	684	1.05	19,723	1,621	2.50

Proposed Energy Use

In order to estimate the proposed energy usage, the amount of air used for the sand lifts must be known. Table 29 records the results of an air pressure bleed down test performed when only the air lifts were using the compressed air system. Upon observation of the tank pressure when the air compressor motor was in the off state and supplying air only to the air lifts, the pressure bleed rate was determined to be approximately 0.06 psi/second.

Next, the pressure change of the tank during periods of operation must be known. Therefore, upon analyzing the data logger's recorded data (Figure 5), it is estimated that the average complete cycle for the compressor (exactly one off-phase and one on-phase) is approximately 3,600 seconds. Recalling that about 95% of this time is on and 5% of this time is off, the time of pressurization (time to fill the tank) and time of pressure reduction (off state of the compressor) are easily determined by knowing the system oscillated between 125 psi and 75 psi. However, rates include the use of air lifts in the system. If the demand for the air lifts of the system could be eliminated, the bleed-out rate caused by the air lifts could be subtracted from each term. Table 11 shows the results of this calculation performed.

Table 11: Rate of Pressurization/Usage

	Psi/s (before fixing leaks)	**Psi/s (after fixing leaks)**
Rate of Pressurization	0.015	0.075
Rate of Usage	-0.278	-0.218

Table 12 reapplies the new rates to the system to find the percent of time the compressor will have to work after the leaks are fixed.

Table 12: Time to Pressurize/De-pressurize Air Tank

Time to pressurize tank with new rate:	666.7 seconds	74% total time
Time to reduce tank with new rate:	229.4 seconds	26% total time

It is apparent that after fixing the leaks in the system, the compressor will draw current for a reduced period of time. By applying the new proportions of time required to pressurize and de-pressurize the air tank, the annual energy usage of the system after repairing the installing the air pump can be calculated. Similarly, knowing the power draw of the proposed air pump to be installed, the electrical consumption of the air pump was quantified assuming the pump would be in operation 24 hours/day. Appendix D shows the manufacturer specifications for the proposed air pump. Table 13 summarizes the calculated values for the proposed electrical consumption for the air compressor and new air pump.

Table 13: Proposed Air Compressor and Air Pump Electrical Consumption

		Operating Hours			**Proposed Electrical Consumption (kWh)**		
Equipment	**Power Draw (kW)**	Annual	Month	Per 1,000 Gallons	Annual	Month	Per 1,000 Gallons
Compressor Motor	2.37	6,482	533	0.82	15,362	1,263	1.94
Air Pump	0.18	8,760	720	1.11	1,577	130	0.20

Energy Savings and Energy Cost Savings

Once the proposed electrical power draw and consumption were calculated for the proposed system configuration, it was very simple to calculate the energy savings resulting from the proposed upgrade. The energy savings is simply the proposed energy usage subtracted from the existing energy usage. Table 14 below summarizes the calculated kilowatt-hour savings on a monthly, annual, and per 1000 gallons of water treated basis. It can be seen that the electrical usage savings on a monthly, annual, and per 1000 gallon basis is approximately 228, 2784, and 0.36 kilowatt-hours, respectively.

Table 14: Energy Savings from Air Pump Implementation

	Electrical Energy Usage (kWh)		
	Monthly	Annual	Per 1000 gallons
Current	1,621	19,723	2.50
Proposed	1,393	16,939	2.14
Savings	**228**	**2,784**	**0.36**

Knowing the resulting electrical usage savings from the system alterations, the energy cost savings resulting from the upgrade are then easily calculated using the typical electrical demand rates. The calculated energy cost savings from installing an air pump to deliver air to the moving bed sand filter air lifts are summarized in Table 15

Table 15: Energy Cost Savings from Air Pump Implementation

	Electrical Energy Usage ($)		
	Monthly	Annual	Per 1000 gallons
Current	121.60	1,479.23	0.19
Proposed	104.48	1,270.43	0.16
Savings	**17.12**	**208.80**	**0.03**

Implementation Cost and Simple Payback Period

Once the estimated cost savings were determined, it was then necessary to estimate the cost of implementation/installation of the upgrade in order to determine how long the return on investment, or simple payback period, would take. Many companies decide whether or not to implement a project based on how quickly they will make a return on their investment.

Therefore, the estimated implementation cost for the upgrade includes pricing for air pump upgrade, materials, and the cost of labor for installation. The estimated cost of the air pump is approximately $450 and the estimated cost of other materials is $100. Labor costs will include 30 dollars per hour and approximately 3 hours for installation. The total cost of the upgrade including capital costs and labor calculate out to be approximately $640. Knowing that the annual cost savings is $209 and the estimated implementation cost is $640, the simple return on investment is approximated to 3 years.

INSTALL MOTOR SOFT STARTER ON AIR COMPRESSOR MOTOR

Background

The NEW Tech™ system uses a 3 horsepower air compressor to deliver compressed air to both the onboard ozone generator and to the air lifts that move the filter media in the two onboard sand filters. During steady operation of the water filtration system, the air compressor cycles off when the pressure in the storage tank reaches the desired set point. As the system consumes air for normal operations the compressor motor will start in order to re-pressurize the storage tank.

Presently, the air compressor motor does not utilize a variable frequency drive or a soft start, which causes the motor to experience high inrush current spikes during normal start-up. Typically, a motor will experience a current draw of approximately six to eight times its normal rated current when initially turned on, which it maintains for several seconds prior to reaching its full speed if no controlled starting mechanism is installed (U.S. Department of Energy , 2008). *Figure 6* is logged electrical current data measured at both the main breaker for the system and on the compressor breaker during a period of normal operations. It can be seen that the compressor motor accounts for approximately 50% of the total current draw on the system. The remainder of the current draw is due to operation of remaining equipment integrated in the system. According to the data logger, data, the compressor motor does experience instances of high inrush current loads during motor start-up periods. Electric current draw for the air compressor motor, collected with a data logger, can be seen in

Figure 6. It can be visualized from the electric current data below, that the peak amperage that the compressor motor experienced was approximately 69 amps, which elevated the total system amperage upwards of 90 amps. Additional instances of inrush current likely occurred during other motor startups, but were not logged due to the data sampling interval being every 5 seconds.

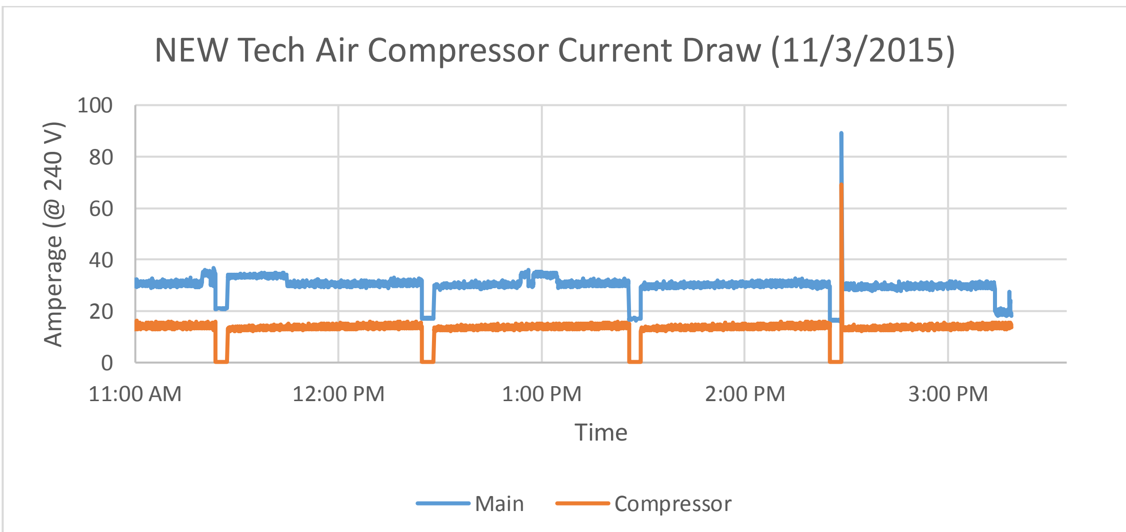

Figure 6: Air Compressor Current Draw Data

Energizing motors with across-the-line starting will typically result in large inrush current. Furthermore, large startup currents can cause voltage drops across other pieces of equipment attached to a common utility. Installation of control systems to manage inrush electrical loadings to motors is one way to reduce the amount of power draw experienced during motor startup. Such control mechanisms include variable frequency drives and motor soft starters. Motor soft starters typically work by controlling start-up voltage in order to keep in-rush current draw minimized. Typically, motor soft starters are able to minimize in-rush starting current to one and one-half to two times the motors nameplate rated current draw (U.S. Department of Energy , 2008).

Recommended Action

It is recommended that a motor soft starter be installed on the air compressor motor. The use of a soft starter will dramatically reduce the inrush current spikes when the compressor motor cycles on. By eliminating the high inrush loads to the motor, there will be reduced shock loading to the motor and belt drive system. Additionally, reduction in inrush loading will result in decreased electrical demand required for the air compressor motor start-up. Reductions in inrush power draw will require less electrical power draw be provided by the electrical utility and electrical demand cost savings will be realized. However, since the soft start neither reduces normal operating power draw, nor reduces the duration in which the compressor motor is operating, there will be no electrical consumption savings related to this implementation.

Current Energy Usage

In order to quantify the energy savings that can be realized by the installation of a motor soft starter on the air compressor motor, it is first necessary to quantify the power draw associated with the start-up demand from the compressor motor. As seen in Figure 6, the current draw associated with the compressor motor start-up and normal operating amperage are 69 amps and 13.8 amps, respectively. The compressor motor nameplate indicates that the motor is a single phase motor that operates on 220 volts and has a power factor of 79%. Therefore, the current power draw associated with the in-rust start-up current of the motor can be calculated using the simple electrical single-phase power equation.

$$Power\ Draw = Voltage \times Amperage \times Power\ Factor$$

Using the above power equation, the calculated power draw for the air compressor motor during start-up loading is 12.14 kilowatts.

Proposed Energy Usage

The proposed electrical demand for the air compressor motor system is calculated in a similar fashion by using the single-phase power equation. However, the proposed demand shall be calculated under the assumption that a motor soft start will be installed. According to the U.S Department of Energy, the motor soft starter should be capable of minimizing the in-rush starting current draw to one and one-half to two times the full load current rating. For the purposes of this calculation, it was assumed that the soft starter would keep the current demand minimized to approximately 22.5 amps (1.5 times full-load current). Using the assumed 22.5 amp starting current maintained by the soft start, the proposed power draw calculates out to approximately 3.96 kilowatts.

Energy Savings and Energy Cost Savings

Energy savings realized from the implementation of a motor soft starter will be a result of reduced electrical demand during motor start-up. In order to quantify the electrical demand savings in kilowatts, the current power draw and the proposed power draw were calculated in order to determine the monthly demand peak reduction resulting from the installation of the motor soft start. The difference between the current and proposed power draw will be the resulting monthly electrical demand savings. Annual demand savings consists of simply the monthly demand values multiplied by 12 months to yield the annual demand values. Additionally, the electrical demand savings per 1000 gallons pumped was calculated. Table 16 shows the calculated values for the electrical demand savings.

Table 16: Electrical Demand Savings from Insallation of Motor Soft Start

	Electrical Demand (kW)		
	Monthly	Annual	Per 1000 gallons
Current	13.25	107.16	0.020
Proposed	4.32	51.84	0.007
Savings	**8.93**	**55.32**	**0.013**

Electrical demand cost savings is calculated by multiplying the power draw (in kilowatts) with the operating hours the motor is in operation. Table 17 shows the calculated demand cost savings for operating hours in a month, year, and the time it takes to pump 1000 gallons (@ 15 gallons per minute). The monthly, annual, and per 1,000 gallons demand savings are $68.05, $816.60, and $0.11, respectively.

Table 17: Electrical Demand Cost Savings from Installation of Motor Soft Start

	Electrical Demand Cost		
	Monthly	Annual	Per 1000 gallons
Current	$101.00	$1,212.00	$0.16
Proposed	$32.95	$395.40	$0.05
Savings	**$68.05**	**$816.60**	**$0.11**

Implementation Cost and Simple Payback Period

Implementation costs for this recommendation include both the capital cost to purchase the motor soft start and the estimated labor cost to install the unit. It is estimated that it would take and experienced electrician approximately 4 hours to install the soft starter with a labor rate of $27 per hour. The material cost for an appropriate motor soft start is estimated at $400. The total implementation cost is estimated to be a total of $508. Knowing that the annual demand cost savings is $816.60 and the cost of implementation is $508, the simple return on investment for this installation is approximately 0.62 years.

REPLACE INFLUENT PUMPS WITH OPTIMALLY SIZED PUMPS

Background

Currently, the NEW Tech™ water filtration system utilizes two 1-horsepower inline influent pumps to pump influent throughout the system. The influent pumps are capable of delivering 45 gallons per minute of flow per pump. However, the two onboard sand filters are only capable of processing a flow of 15 gallons per minute. In order to control the amount of flow delivered by the pumps to an acceptable flow that the sand filters are capable of receiving, the flow from the pumps is reduced by mechanical valves. Currently, the valves are kept mostly closed in order to keep the flows down to 15 gallons per minute. Electrical current data, seen in Figure 11, was collected for each of the pumps in order to determine the average current draw for each of the pumps. The two influent pumps can be seen in Figure 7 below.

Figure 7: Influent Pumps #1 and #2

Recommended Action

In order to reduce the amount of energy that is consumed by the pumps to move water throughout the system, it is recommended that either the pumps be resized to an optimal size for the required flow or that a variable frequency drive be installed on each of the pumps to reduce the flow of water through the pumps. Variable frequency drives work by altering the input frequency to the electric motor in order to alter the rotational speed of the motor. Variable frequency drives are an advantageous method for use in applications where required motor speed is not consistent and needs to be throttle up and/or down. However, the efficiency of variable frequency driven motors declines dramatically when used in applications where the motor loads drop below approximately 40% of their rated loads (U.S. Department of Energy , 2008). Therefore, analysis into the potential motor loading scenarios should be considered when considering the implementation of a variable frequency drive. In scenarios where motor load remains constant, but the equipment that the motor is delivering power to requires the need for speed reduction or throttling (such as pumps or fans), motor resizing should be considered.

Current Energy Usage

In order to estimate the savings, the power draw for each of the influent pump motors must be calculated. According to the electrical current data collected with data loggers, pump #1 and pump #2 had an average current draw of 6.05 amps and 4.68 amps, respectively. Motor nameplate information stated that the motors used 240 volts and had a rated power factor of 81%. The power draw for influent pumps #1 and #2 calculate out to be 1.18 kilowatts and 0.91 kilowatts, respectively. Once the power draw of each pump had been determined, the operating hours that the pumps would be operational in a year, month, and per 1000 gallons pumped was determined in order to calculate the total electrical consumption of the motors over the different time periods. Table 18 shows a summary of the current energy usage information, including: pump power draw, operating hours, and kilowatt-hours of electricity consumed.

Table 18: Current Energy Usage Summary for Influent Pumps

		Operating Hours			Electrical Consumption (kWh)		
Equipment	**Power Draw (kW)**	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1	1.18	8,760	720	1.11	10,336.80	849.60	1.31
Pump #2	0.91				7,971.60	655.20	1.01

Proposed Energy Usage

The proposed power draw was first analyzed to check the feasibility of implementing the use of variable frequency drives on the influent pumps. was implemented can be estimated by the use of the pump affinity laws. The subscripts "1" and "2" can be thought of as before and after, respectively.

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

Currently, both influent pumps are rated at 1 hp and an RPM of 3,450. The pumps are rated for a flow of approximately 45 gpm. Therefore, using the current horsepower, RPM, and rated flow, the required brake horsepower to deliver the operating flow (15 gpm) can be calculated using the affinity laws.

According to the affinity laws, the required horsepower to be delivered to the pump in order to pump 15 gallons per minute would be 0.04 horsepower. Therefore, the use of a variable frequency drive is not advised as there are large drops in efficiency once a motor drops below

40% of its nameplate rated load. Instead, it is recommended that the pumps be replaced with more optimally sized pumps. A suitable replacement would be a multistage in-line pump. Using Grundfos pump performance curves, it was determined that a Grundfos model CR-3 would be capable of delivering adequate flow through the system and utilizing a smaller horsepower motor than the existing pump utilizes.

According to the pump performance curve (Appendix E), the CR-3 can deliver 20 gpm with a requirement of 0.17 horsepower and an efficiency of 55%. Therefore, the input power required to deliver adequate power through the pump can be calculated. In order to determine the power draw, the formula below was used. Once the required motor horsepower was determined, the value was then converted to a kilowatt value

$$\boldsymbol{HP_M = \frac{HP_P}{\eta_P}}$$

Where,

HP_M	=	Required horsepower input, HP
HP_P	=	Pump horsepower requirement, 0.17 HP
η_P	=	Pump efficiency, 55%

Once the required motor horsepower was determined, the value was then converted to a kilowatt value to be the proposed pump motor power draw. This value is then applied to both of the proposed replacement pumps.

Table 19 summarizes the total electrical usage for both pumps. The electrical consumption for both pumps is calculated for three different time periods: annually, monthly and the time required to pump 1000 gallons through the system.

Table 19: Proposed Influent Pump Energy Usage

		Operating Hours			**Electrical Consumption (kWh)**		
Equipment	**Power Draw (kW)**	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1 and #2	0.50	8,760	720	1.11	4,380	360	0.55

Energy Savings and Energy Cost Savings

The amount of electrical consumption savings can easily be calculated as the current electrical consumption in kilowatt-hours minus the proposed electrical consumption in kilowatt-hours. The resulting savings can be seen in Table 20 below.

Table 20: Energy Savings from Pump Replacement

	Electrical Demand (kWh)		
	Monthly	Annual	Per 1000 gallons
Current	1,504	18,308	2.32
Proposed	360	4,380	0.55
Savings	**8.93**	**55.32**	**0.013**

The annual cost savings can be calculated by taking the difference between the current energy costs (existing pumps) and the proposed energy costs (resized pumps). Table 21 shows the estimated cost savings resulting from the influent pump change out.

Table 21: Energy Cost Savings from Pump Replacement

	Electrical Energy Cost ($)		
	Monthly ($/month)	Annual ($/year)	Per 1000 gallons ($/1000gal)
Current	130.25	1,581.79	0.20
Proposed	31.16	378.42	0.09
Savings	**$99.09**	**$1,203.37**	**$0.11**

Implementation Cost and Simple Payback Period

Implementation costs for this recommendation include 8 hours to install both pumps into the existing system. Additionally, included is the capital cost estimate for the purchase of two ¾ horsepower in-line pumps. The cost estimate for the pumps is approximated to be $1,000/pump (See Appendix E for pump specifications). The labor rate is estimated to be approximately $30.00/hour for a qualified commercial electric motor/pump installer to install the pumps. It is estimated that the installation will take approximately 4 hours. Therefore the total estimated implementation cost of this upgrade is estimated to be approximately $2,240. Using the calculated annual energy savings of $1,203 and the estimated implementation cost, the simple return on investment will be approximately 1.86 years.

TOTAL ENERGY SAVINGS AND REDUCTIONS IN GHG ASSOCIATED WITH ENERGY SAVING OPPORTUNITIES

Table 22 contains a summary of the savings associated with the implementation of the energy efficiency recommendations. Included in the table are the annuals resource savings, annual cost savings, estimated capital cost, balance of project cost, and simple payback period. All recommendations result in an energy and energy cost savings, and all projects would have a return on investment in less than 3 years.

Table 22: Summary of Energy Saving Recommendations

Recommendation	Annual Resource Savings	Annual Cost Savings	Estimated Capital Cost	Balance of Project Cost	Simple Payback Period
Modify Sand Filter Air Lifts to Receive Air from Air Pump or Blower	2,784 kWh	$209.00	$550	$90	3 Years
Install Soft Starter on Air Compressor Motor	98.16 kW	$816.60	$400.00	$108.00	< 1 Year
Replace Oversized Influent Pumps with Optimally Sized Pumps	12,351.60 kWh 16.92 kW	$776.58	$2,000	$240	2.8 years

The total electrical demand and usage savings for all of the energy saving opportunities can be seen in Table 23. Savings in Table 23 are on a per 1000 gallons of water treated basis in order to be useful in calculating the proposed emissions savings resulting from the implementation of the various energy saving recommendations. However, the estimated annual cost savings associated with these electrical savings are approximately $1,802 per year (assuming full time operations).

Table 23: Energy Savings per 1000 Gallons Processed

Recommendation	Electrical Demand Savings (kW/1000 gallons)	Electrical Usage Savings (kWh/1000 gallons)
Modify Sand Filter Air Lift to Receive Air from Air Pump	0	0.36
Install Motor Soft Start on Air Compressor Motor	0.011	0
Replace Influent Pumps with Optimally Sized Pumps	0.001	1.5
Total Savings	0.012	1.86

Using similar methods as discussed in the life cycle inventory and impact analysis sections of the analysis, it is possible to recalculate the emission quantities associated with the proposed energy usage if energy saving recommendations were to be implemented. Using the annual output emission quantities for CO2, CH4, and N2O seen in Table 5, the global warming potential can be re-calculated using the proposed energy consumption per 1000 gallons.

The existing energy consumption for the system was calculated to be approximately 7 kWh per 1000 gallons treated and the proposed savings was calculated to be 2.06 kWh per 1000 gallons treated. Therefore, if energy saving recommendations were to be implemented, it is estimated the system would consume 4.94 kWh per 1000 gallons treated. Using the proposed estimate for electrical energy usage, the associated greenhouse gas emissions discharged in the production of electricity in the Pacific Northwest can then be quantified by multiplying the proposed energy consumption by the relative emission quantities produced per unit of electrical usage. Table 24 shows the calculated GHG emission quantities and the global warming potential (in kg CO_2 equivalent) related to the electrical energy consumption after energy savings are realized.

Table 24: Electrical Consumption Emissions after Energy Savings

	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	GWP (in kg CO_2 eq)
Electrical Consumption Emissions	1.55	2.9×10^{-5}	2.4×10^{-5}	1.55

According to the analysis, it can be seen that the reduction in electrical consumption by the system will result in lower greenhouse gas emission quantities and will thus have a lower global warming potential if efforts to reduce energy usage are pursued. The calculated estimate for the GWP for electrical consumption of the current system was approximately 2.18 kg CO_2 equivalent whereas the estimated GWP for the system after energy reduction efforts are made is 1.55 kg CO_2 equivalent. The overall savings in GWP can be 0.63 kg CO_2 equivalent per 1000 gallons of water processed. This would bring the total system GWP, including electrical consumption and material use, to a value of 2.69 kg CO_2.

CHAPTER V: DISCUSSION AND CONCLUSIONS

The NEW Tech™, with its eight issued or pending patents, utilizes effective reactive filtration with iron modified biochar and ozone to achieve catalytic oxidation in order to sterilize reclaimed water. Furthermore, the system is able to produce a nutrient-upcycled biochar fertilizer product that has the potential to address the need for carbon sequestration while combating aquatic pollution. It uses the principles of catalytic oxidation and reactive filtration employing inexpensive sacrificial catalysts made from iron chloride solutions that are commonly used in water treatment. NEW Tech™ uses ozone as an oxidant that is catalyzed with the iron salts to destroy many unwanted organic compounds and pathogens. Mineralized P and N is captured on the iron-modified biochar and is then recovered as a by-product nutrient enhanced fertilizer with economic value for field application in agriculture and horticulture. The nutrient enhanced biochar carbon produced by the process sequesters carbon when used in agricultural settings and has desirable effects on soil nutrient management and water holding capacity. The NEW Tech™ process has demonstrated that it also has a minimal environmental footprint when compared to other water treatment processes.

The water treatment process for NEW Tech™ has demonstrated that it has a minimal environmental impact from both energy consumption and the use of raw materials consumption perspective. In fact, NEW Tech™ treatment process is capable of producing sterilized water and producing a nutrient enhanced biochar fertilizer that has the potential to sequester carbon from the atmosphere. Currently, the NEW Tech™ system can achieve full operations utilizing approximately 6.3 kW of electricity in order to treat 1,000 gallons of post-secondary treatment municipal waste waters. Analysis, using typical electricity rates (electrical consumption and demand being considered) in the region, has indicated that the treatment process is capable of processing 1000 gallons of waste water for approximately 0.68 dollars. Furthermore, the system has state-of-the-art removal of total phosphorus to 0.004 mg/L when treating post-secondary treatment municipal waste water.

Analysis regarding the global warming potential (GWP) showed that the combined net GWP of the inputs and outputs of the system needed to treat 1000 gallons of water was a positive value. The calculated GWP for the system was estimated to be approximately 3.3 kg of CO_2 equivalent. Therefore, the NEW Tech™ process is a carbon positive process. However, it is important to note that the nutrient enhanced biochar product produced from the system has the potential to be carbon negative as long as it is not combusted to return its carbon constituents back to the atmosphere.

Land application of biochar is believed to have the ability to sequester carbon into the ground for hundreds to a thousand years. Therefore, since the biochar produced from the process will likely have greater value as a fertilizer product, rather than a combustion/heating fuel, this biochar can be considered to most likely be carbon negative. If the biochar from the NEW Tech™ process is land applied for its benefits to the soil and its fertilizer value, the biochar will have the potential to sequester a CO_2 equivalent of 11.8 kilograms per 1000 gallons of water treated. If the carbon sequestration component were to be included in the overall process GWP, then the process could be considered a carbon negative process with a GWP value of -8.02 kg CO_2 and would be sequestering more carbon from the atmosphere than the process contributes. This is a promising result with regard to the mitigation of the effects of global warming and climate change. Using biochar in the treatment process to create an upcycled nutrient enhanced fertilizer is good for the environment while working to maintain increased food security by capturing essential nutrients from waste water systems and other water bodies of concern.

Furthermore, the mass of CO_2 equivalent that is associated with the production of electricity consumed during operation could be reduced by the implementation of various energy saving opportunities. Furthermore, reductions in electrical energy consumption will result in decreased energy costs to operate the system. Based on the analysis of energy and energy cost savings, the system could potential reduce its electrical demand and consumption by 0.012 kilowatts/1000 gallons and 1.86 kilowatt-hours/1000 gallons, respectively. Assuming full time operations for a year, these savings equate to approximately $1,802 annually. If energy efficiency recommendations were to be implemented, the system could lower its electrical energy costs to approximately $0.44 per 1000 gallons processed. Additionally, the CO_2 emissions associated with the production of electricity consumed by the system could be lowered by approximately 0.63 kg CO_2 equivalent just by implementing the energy saving recommendations presented. The reduction in GWP from electrical savings would bring the overall system GWP to 2.69 kg CO_2 (not including biochar carbon sequestration potential) equivalent per 1000 gallons of water treated. Any reduction in energy usage will result in a reduced GWP value for the overall system.

Future research regarding the NEW Tech™ process will be focused upon optimizing the efficiency of the capture of mineralized phosphorus and nitrogen on iron-modified biochar and its subsequent recovery as an Enhanced Efficiency Fertilizer by-product. Increased emphasis will be towards the effective removal of nitrogen from varying reclaimed water opportunities. NEW Tech™ has demonstrated positive results in capturing nutrient phosphorus in post-secondary municipal waste water applications. However, it is of interest to further field test the effectiveness of the system in other complex impaired water systems such as animal waste from livestock, food processing waste, and large scale municipal waste water settings. Furthermore, research into the effectiveness of the introduction of nutrient enhanced biochar products into agricultural soil matrixes is currently being explored to determine its effects on plant growth, nutrient availability, water holding capacity, etc.

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APPENDICES

APPENDIX A: SYSTEM ELECTRICAL ENERGY USAGE AND DEMAND ANALYSIS

Background Information

In order to quantify the electrical energy usage and costs associated with operation of the total system it was very important to collect measurements for both the entire system as well as each piece of equipment. Therefore, measurements for individual pieces of equipment were taken using a handheld power meter that was capable of measuring voltage, amperage, and power draw. The second method of collecting energy usage measurements on the system was to implement the use of data loggers that would collect data over a period of time. For this task, several data loggers that measured electrical current were placed on several pieces of equipment as well as on the main breaker to the system. By collecting data on individual pieces of equipment and also the total usage of the system, it was a good way to benchmark both the overall energy use and the percentage of the total use that each piece of equipment was using.

Below, in Figure 8, is a plot of logged amperage data taken at the main electrical breaker for the entire system.

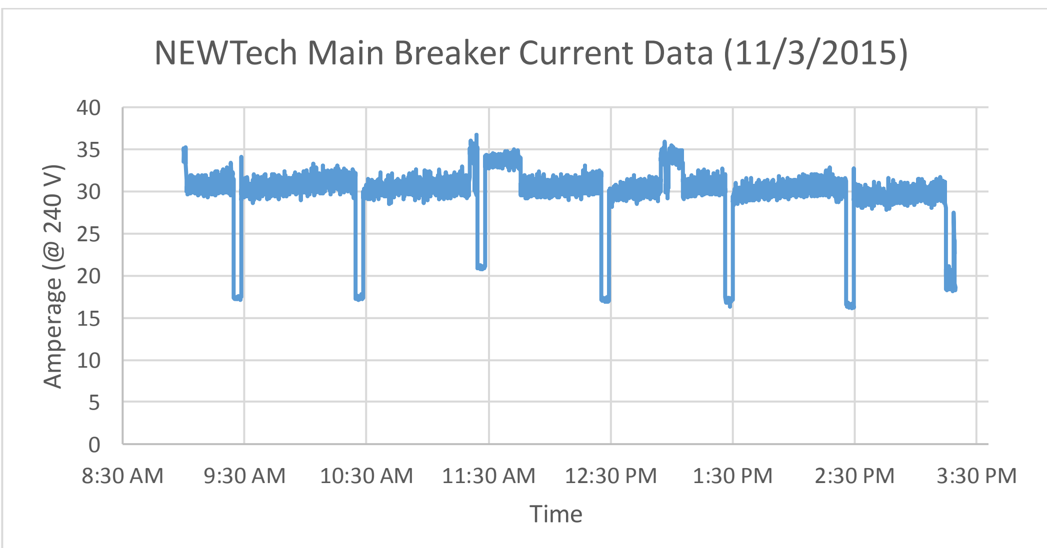


Figure 8: Main Breaker Current Draw

Electrical Usage

Electrical consumption cost estimates are based on a $0.075 per kilowatt-hour basis. This value is a typical value for the state of Idaho according to the U.S. Energy Information Administration.

The volume of water pumped per hour is calculated below.

$$15\,\frac{gallon}{minute} \times 60\,\frac{minutes}{hour} = 900\,\frac{gallons}{hour}$$

From the logged current data from the system, it can be seen that the total system power draw was, on average, approximately 6.3 kW with a 12 kW startup demand spike. Using the average power draw, the cost incurred in order to pump 1000 gallons was determined.

$$\frac{6.3\ kW}{900\,\frac{gallons}{hour}} \times 1000\ gallons = 7\ kWh$$

$$7\ kWh \times 0.075\,\frac{\$}{kWh} = \$\mathbf{0.5243}\ per\ 1000\ gallons$$

For the purposes of calculating the annual consumption of the system, assuming the system is run 24 hours/day all year long, it was necessary to determine the power draw for the high and low loaded states in the electrical current data. The average power draw for the high loaded state was approximately 6.3 kW and the average power draw for the low loaded state was 3.2 kW. Additionally, from the data logger, data, it was determined that the system spent approximately 93% of the time in the high loaded state and 7% in the low loaded state. Therefore, the annual and monthly electrical consumption of the system can be estimated.

If the NEW Tech system was to be used 24 hours per day and all year long, the annual operating hours of the compressor would be,

$$\boldsymbol{OH_a = 24\,\frac{hours}{day} * 365\,\frac{days}{year} = 8,760\,\frac{hours}{year}}$$

Similarly, if the compressor was to be run for 24 hours per day for a month, the monthly (using 30 days) operating hours would be,

$$\boldsymbol{OH_m = 24\,\frac{hours}{day} * 30\,\frac{days}{month} = 720\,\frac{hours}{month}}$$

Finally, in order to determine the operating hours required to pump 1,000 gallons of water through the system at a flow rate of 15 gallons per minute, the operating hours would be,

$$\boldsymbol{OH_{1000} = \frac{1,000\ gallons}{15\,\frac{gallons}{minute} \times 60\,\frac{minutes}{hour}} = 1.11\ hours\ per\ 1,000\ gallons}$$

Table 25: Electrical Consumption of NEW Tech™ System

		Operating Hours		Electrical Consumption (kWh)		Electrical Consumption Cost ($)	
State	**Power Draw (kW)**	Monthly	Annual	Monthly	Annual	Monthly	Annual
High	6.3	670	8,147	4,221	51,326	316.60	3,849.45
Low	3.2	50	613	160	1,962	12.00	147.15
	TOTAL	720	8,760	4,381	53,288	328.60	3,996.60

Electrical Demand

The instantaneous startup load for the system is approximately 12.5 kW. Therefore, this is the amount of power that will be required to be provided by the electrical utility and will be the basis for the calculation of the demand portion of the cost. The basis upon which the utility bases its charges may vary from company-to-company, but the demand is usually calculated using the average of the greatest demand peaks over a 15-minute interval. Therefore, using the 12.5 kW demand spikes as the highest instantaneous demand required, the cost of electrical demand from the system is calculated as follows.

$$12.5\ kW \times 8.32 \frac{\$}{kW} = \$104.00\ per\ month$$

$$900 \frac{gallon}{hour} \times 24 \frac{hours}{day} \times 30 \frac{days}{month} = 648{,}000 \frac{gallons}{month}$$

$$\frac{\$104.00}{\left(\frac{648{,}000\ gallon}{1000}\right)} = \$\mathbf{0.16}\ per\ 1000\ gallons$$

Total Cost of Electricity

$$Total\ Electrical\ Costs = Electrical\ Usage\ Cost + Electrical\ Demand\ Cost$$

$$Total\ Electrical\ Costs\ (per\ 1{,}000\ gallons) = \$0.5243 + \$0.16$$
$$= \$\mathbf{0.68}\ per\ 1000\ gallons$$

$$Total\ Electrical\ Costs\ (Monthly) = \$0.5243 + \$0.16 = \$\mathbf{0.68}\ per\ 1000\ gallons$$

APPENDIX B: GREENHOUSE GAS EMISSION CALCULATIONS

Quantity of Dosing Materials

- Biochar
  - Slurry dosage Rate = 195 mL/min
  - Concentration of biochar slurry = 0.35 kg/L
  - Biochar dosage rate = (.195 L/min) x (0.35 kg/L) = 0.068 kg/min
  - Time to pump 1000 gallons @ 15 gpm = 66.6 minutes
  - Amount of biochar dosed per 1000 gallons = **4.52 kg biochar**

- Ferric Chloride
  - Concentration of solution = 40% $FeCl_3$ solution in water (w/v)
  - Dosage rate of solution = 2.71 mL/min
  - Time to pump 1000 gallons @ 15 gpm = 1.11 hours
  - Solution pumped per 1000 gallons = 3.01 mL
  - $FeCl_3$ dosed per 1000 gallons = 72,000 mg = **72 g**

- Ferric Chloride in Biochar Slurry
  - 0.05 grams of ferric per gram of biochar added
  - Ferric chloride added in biochar slurry = 4.52 kg x 0.05 = 0.226 kg =**226 g**

Quantity of Phosphorus Recovered from Wastewater

- Phosphorus
  - NEW Tech™ influent concentration = 0.117 mg/L
  - NEW Tech™ effluent concentration = 0.006 mg/L
  - Number of liters in 1000 gallons = 3,785.41 liters
  - Mass of phosphorus recovered from 1000 gallons

$$3785.41\ liters \times \left(0.117\frac{mg}{L} - 0.006\frac{mg}{L}\right) = 420.135\ mg$$

Greenhouse Gas Emission Factors

- Electricity Production Emission Factors for the Pacific Northwest
  - Emission factors for electricity production found on the EPA's Emissions and Generation Resource Integrated Database (eGRID)

Table 26: Emission Factors Related to Energy Production for GHG Emission Calculations (EPA, 2015)

GHG Emissions	Annual Output Emission Rates	Units
CO_2	302.00	kg/MWh
CH_4	5.72	kg/GWh
N_2O	4.71	kg/GWh
*GWP (CO_2 eq)= (CO_2)+(25 x CH_4)+(298 x N_2O)		*Source: (IPCC, 2007)

- Material Production Emission Factors
  - The emission factors for the various dosing materials and phosphate rock can be seen in the table below.
  - Phosphate rock will be used to quantify the offset of industrial processing emissions as a result of phosphorus recovered from the wastewater resource.
  - Sources for the values used are listed within the table.

Table 27: Material Emission Factors for GHG Calculations

	Emission Quantities (mass of emissions produced per kg of material used)				
Material	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	GWP (kg)	Source
Biochar	0.06	7.67×10^{-5}	9.12×10^{-5}	-	GREET 2015
Ferric Chloride	-	-	-	2.71	(Kyung, Kim, Chang, & Lee, 2015)
Phosphate Rock	0.35	6.60×10^{-4}	7.31×10^{-6}	-	GREET 2015
*GWP(in CO_2 eq)= (CO_2)+(25 x CH_4)+(298 x N_2O) *Source: (IPCC, 2007)					

Calculated Emissions from System Operations

- Electricity Usage
  - System utilizes 7 kWh to process 1000 gallons of water
  - Emission calculations

$$CO_2\ emissions = 7\ kWh \times 0.302\frac{kg}{kWh} = \ 2.11\ kg\ CO_2$$

$$CH_4\ emissions = 7\ kWh \times 0.00000572\frac{kg}{kWh} = \ 4.0\ x\ 10^{-5}\ kg\ CO_2$$

$$N_2O\ emissions = 7\ kWh \times 0.00000471\frac{kg}{kWh} = \ 3.0\ x\ 10^{-5}\ kg\ CO_2$$

$$\begin{aligned} GWP &= CO_2 + (25 \times CH_4) + (298 \times N_2O) \\ &= 2.11\ kg + (25 \times\ 4.0\ x\ 10^{-5}\ kg) + (298 \times 3.0\ x\ 10^{-5}\ kg) \\ &= \ 2.12\ kg\ CO_2 \end{aligned}$$

- Materials
  - Biochar
    - 4.52 kg of biochar dosed per 1000 gallons of water processed
    - Emission calculations

$$CO_2\ emissions = 4.52\ kg \times 0.06\frac{kg}{kg} = \ 0.271\ kg\ CO_2$$

$$CH_4\ emissions = 4.52\ kg \times .0000767\frac{kg}{kg} = \ 3.47\ x\ 10^{-4} kg\ CO_2$$

$$N_2O\ emissions = 4.52\ kg \times 0.0000912\frac{kg}{kg} = \ 4.12\ x\ 10^{-4}\ kg\ CO_2$$

$$GWP = CO_2 + (25 \times CH_4) + (298 \times N_2O)$$
$$= 0.271\ kg + (25 \times\ \ 3.47\ x\ 10^{-4} kg) + (298 \times 4.12\ x\ 10^{-4}\ kg\ kg)$$
$$=\ 0.402\ kg\ CO_2$$

- Ferric Chloride
  - 0.298 kg of ferric chloride dosed per 1000 gallons of water processed
  - Emission calculations

$$GWP = 0.298\ kg \times 2.71 \frac{kg}{kg} =\ 0.808\ kg\ CO_2$$

- Phosporus
  - 420.135 mg of phosphorus recovered per 1000 gallons of water processed
  - Emission calculations

$$CO_2\ emissions = 4.2\ x\ 10^{-4}\ kg \times 0.35 \frac{kg}{kg} =\ 1.5\ x\ 10^{-4}\ kg\ CO_2$$

$$CH_4\ emissions = 4.2\ x\ 10^{-4}\ kg \times .000660 \frac{kg}{kg} =\ 2.8\ x\ 10^{-7} kg\ CO_2$$

$$N_2O\ emissions = 4.2\ x\ 10^{-4}\ kg \times 0.00000731 \frac{kg}{kg} =\ 3.0\ x\ 10^{-9}\ kg\ CO_2$$

$$GWP = CO_2 + (25 \times CH_4) + (298 \times N_2O)$$
$$= 1.5\ x\ 10^{-4}\ kg\ + (25 \times\ \ 2.8\ x\ 10^{-7} kg) + (298 \times 3.0\ x\ 10^{-9}\ kg)$$
$$= 1.6\ x\ 10^{-3}\ kg\ CO_2$$

APPENDIX C: ENERGY SAVING OPPORTUNITIES ANALYSIS

Opportunity #1: Modify Sand Filter Air Lifts to Receive Air from Air Pump or Blower

Annual Resource Savings	Annual Cost Savings	Estimated Capital Cost	Balance of Project Cost	Simple Payback Period
2,784 kWh	**$209.00**	**$550**	**$90**	**Years**

Background Information
Currently, the NEW Tech™ system utilizes a 3 HP air compressor to supply air to lift sand in its reactive sand filters. The air compressor is also utilized to supply adequate pressure and volume of air to supply the onboard ozone generator. The air requirements for the air lifts are 5 psig at 11 scfm per each of the two sand filter air lifts.

Recommended Action
It is recommended that the air requirement for the air lifts in the sand filters be provided by a low pressure/high volume blower and the compressed air system be utilized for the ozone generator requirements only.

Anticipated Savings
Savings will be a result of reduced compressor runtime realized by only using the compressed air system to provide airflow to the ozone generator. However, there will also be an additional energy use required to operate the new air pump/blower. The anticipated savings will be a result of the reduced runtime of the compressor while accounting for the small additional power use required by the air pump/blower.

Current Energy Use
In order to calculate the energy usage, first an approximate average daily compressor usage and power draw must be established. A current logger was used to collect current draw of the compressor motor. The current draw data can be seen in Figure 9 below.

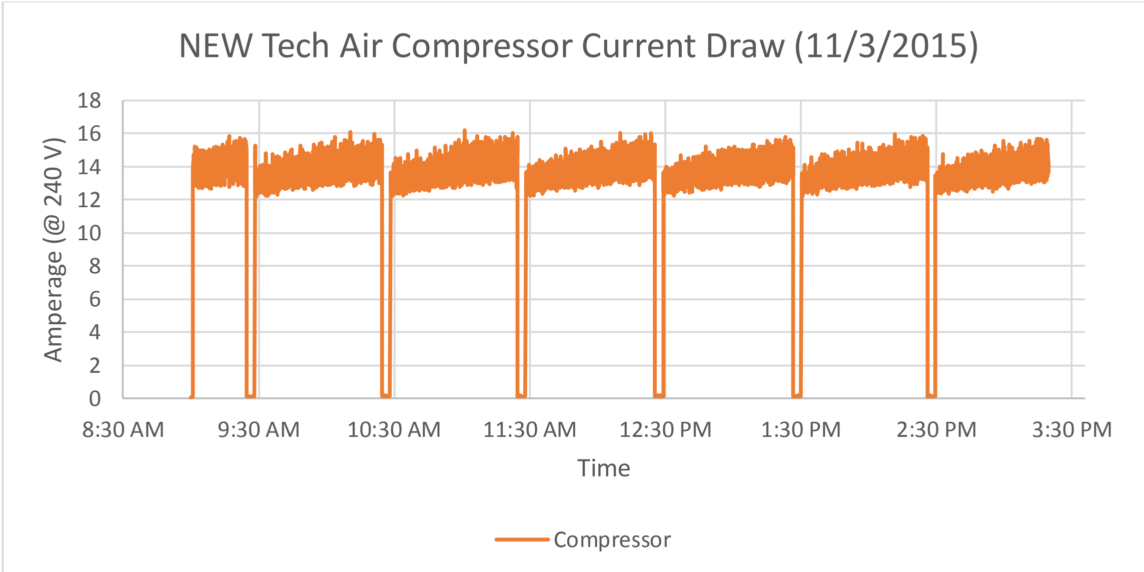


Figure 9: Compressor Current Draw

It can be seen in Figure 9 that the compressor runs in an on/off fashion. Additionally, it can be seen that the compressor in in operation for the majority of the time. From the data, it was calculated that the compressor is in operation 95% of the time the NEW Tech system is treating water and the compressor is shut off for 5% of the time when it is able to reach the desired pressure set point.

The peaks in current draw are the on state, and the lower in between times are the off state. When the compressor is in operation, the average electrical current draw is 13.8 amps. With the percent of operations that is spend in the on and off state, and knowing the average current draw of the compressor motor when in the on state, the annual energy usage of the compressor can be estimated, but first the power draw must be calculated as follows:

Current power draw,

$$PD = V \times I \times PF \times C_1$$

Where,

PD	=	Power draw, kW
V	=	Voltage, 220 Volts
I	=	Current, 13.8 Amps
PF	=	Power factor, 0.79%
C_1	=	Conversion factor (1 kW/1,000 W)

Therefore,

$$PD = 220\ V \times 13.8\ A \times 0.78 \times \frac{1\ kW}{1{,}000\ W} = 2.37\ kW$$

Next, the annual energy usage of the compressor can be estimated as follows:

If the NEW Tech system was to be used 24 hours per day and all year long, the annual operating hours of the compressor would be,

$$OH_a = 24\frac{hours}{day} * 365\frac{days}{year} = 8,760\frac{hours}{year}$$

Similarly, if the compressor was to be run for 24 hours per day for a month, the monthly (using 30 days) operating hours would be,

$$OH_m = 24\frac{hours}{day} * 30\frac{days}{month} = 720\frac{hours}{month}$$

Finally, in order to determine the operating hours required to pump 1,000 gallons of water through the system at a flow rate of 15 gallons per minute, the operating hours would be,

$$OH_{1000} = \frac{1,000\ gallons}{15\frac{gallons}{minute} \times 60\frac{minutes}{hour}} = 1.11\ hours\ per\ 1,000\ gallons$$

Current electrical usage,

$$CEU = CPD \times OH$$

Where,

CEU	=	Current energy usage, kWh
CPD	=	Current power draw, 2.37 kW
OH	=	Annual operating hours of the compressor, 8,760 hours/year

Table 28: Compressor Energy Consumption

		Operating Hours (Time Spend in On State)			Current Electrical Consumption (kWh)		
Equipment	**Power Draw (kW)**	Annual	Month	Per 1,000 Gallons	Annual	Month	Per 1,000 Gallons
Compressor Motor	2.37	8,322	684	1.05	19,723	1,621	2.50

<u>Proposed Energy Use</u>

In order to estimate the proposed energy usage, the amount of air used for the sand lifts must be known. Table 29 records the results of an air pressure bleed down test performed when only the air lifts were using the compressed air system.

Table 29: Compressor Pressure Bleed Out Test

Tank Pressure (psi)	Time (s)
110	0
109.4	10
108.9	20
108.3	30
107.8	40
107.2	50
106.6	60
106.1	70
105.5	80
105.0	90
Bleed out rate:	**-0.06 psi/s**

Next, the pressure change of the tank during periods of operation must be known. After analyzing the data logger's recorded data, it is estimated that the average complete cycle for the compressor (exactly one off phase and one on phase) is 3,600 seconds. Recalling that about 95% of this time is on and 5% of this time is off, the time of pressurization (time to fill the tank) and time of pressure reduction (off state of the compressor) are easily determined.

The system oscillates between 125 psi and 75 psi. With this information the rate of air usage and re-pressurization can be established as follows:

$$\boldsymbol{RoP = \Delta P/\Delta t_{re-pressurization}}$$

$$\boldsymbol{RoU = -\Delta P/\Delta t_{reduction}}$$

Where,

RoP	=	Rate of pressurization (psi/s)
RoU	=	Rate of air usage (psi/s)
ΔP	=	Difference between pressurized state and reduced state (50 psi)
Δt	=	Time required to re-pressurize tank ($3{,}600 \times 0.95 = 3{,}420\ s$) or reduce the tank ($3{,}600 \times 0.572 = 180$)

Therefore,

$$\boldsymbol{RoP = \frac{50\ psi}{3,420\ s} = 0.015\ psi/s}$$

$$\boldsymbol{RoU = \frac{50\ psi}{180\ s} = -0.278\ psi/s}$$

But these rates include the use of air lifts in the system. If the demand for the air lifts of the system could be eliminated, the bleed-out rate caused by the air lifts could be subtracted from each term. Table 30 shows the results of this calculation performed.

Table 30: Rate of Pressurization/Usage

	Psi/s (before fixing leaks)	Psi/s (after fixing leaks)
Rate of Pressurization	0.015	0.075
Rate of Usage	-0.278	-0.218

Table 31 reapplies the new rates to the system to find the percent of time the compressor will have to work after the leaks are fixed.

Table 31: Time to Pressurize/Reduce

Time to pressurize tank with new rate:	666.7 seconds	**74% total time**
Time to reduce tank with new rate:	229.4 seconds	**26% total time**

It is apparent that after fixing the leaks in the system, the compressor will draw current for a reduced period of time. The annual energy usage of the system after repairing the leaks is given by the following equation:

$$\boldsymbol{PEU = PD \times OH}$$

Where,

PEU = Proposed energy usage (kWh)
PD = Power draw (2.37 kW)
OH = Operating hours ($hours \times 0.74$)

Therefore, the proposed energy usage after the air pump has been installed can be seen in Table 32.

Table 32: Air Compressor Proposed Energy Usage w/ Blower Upgrade

		Operating Hours (Time Spend in On State)			Current Electrical Consumption (kWh)		
Equipment	**Power Draw (kW)**	Annual	Month	Per 1,000 Gallons	Annual	Month	Per 1,000 Gallons
Compressor Motor	2.37	6,482	533	0.82	15,362	1,263	1.94

It can be seen that there will indeed be energy savings associated with not using the compressed air system for the sand filter air lifts. However, in order to keep the air lifts functioning, there will need to be a blower installed to provide air to the sand filters. The proposed blower for installation would be a 1/3 horsepower regenerative blower that is capable of providing both the necessary flows and pressures required to operate the sand filters. The proposed blower motor has a rated power draw of 0.18 kW at 240 volts. Therefore, the estimated cost to run the new blower can be seen in Table 33 below.

Table 33: Proposed Blower Energy Usage

		Operating Hours (Time Spend in On State)			Current Electrical Consumption (kWh)		
Equipment	**Power Draw (kW)**	Annual	Month	Per 1,000 Gallons	Annual	Month	Per 1,000 Gallons
Compressor Motor	0.18	8,760	720	1.11	1,577	130	0.20

Energy Savings

Annual energy savings are given by the following equation:

$$AES = CEU - PEU$$

Where,

ES = Energy savings (kWh)
CEU = Current energy usage (kWh)
PEU = Proposed energy usage (kWh)

Therefore, Table 34 shows the calculated energy savings associated with the air pump installation for the airlifts

Table 34: Energy Savings from Blower Implementation

	Electrical Energy Usage (kWh)		
	Monthly	Annual	Per 1000 gallons
Current	1,621	19,723	2.50
Proposed	1,393	16,939	2.14
Savings	**228**	**2,784**	**0.36**

Energy Cost Savings

Energy cost savings are given by the following equation:

$$ECS = ES \times ER$$

Where,

ECS = Energy cost savings ($)
ES = Energy savings (kWh)
ER = Energy rate ($0.075/kWh)

Therefore, Table 35 shows the calculated energy cost savings realized by the upgrade.

Table 35: Energy Cost Savings from Blower Implementation

	Electrical Energy Usage ($)		
	Monthly	Annual	Per 1000 gallons
Current	121.60	1,479.23	0.19
Proposed	104.48	1,270.43	0.16
Savings	**17.12**	**208.80**	**0.03**

Implementation Cost

The estimated implementation cost for the upgrade includes pricing for air pump upgrade, materials, and the cost of labor for installation. The estimated cost of the air pump is approximately $450 and the estimated cost of other materials is $100. Labor costs will include 30 dollars per hour and approximately 3 hours for installation. The cost of the upgrade would be:

$$\boldsymbol{IC = LC + MC}$$

Where,

IC = Implementation cost, $

LC = Labor cost, $30/hr

MC = Material cost, ($450/pump+$100/materials) = $550

Therefore,

$$\boldsymbol{CR = (30 \frac{\$}{hour} \times 3\ hours) \times \$550 = \$640}$$

Simple Payback Period

The simple payback period for this recommendation is estimated below:

$$\boldsymbol{SPP = \frac{IC}{ECS}}$$

Where,

SPP = Simple payback period, years

IC = Estimated implementation cost, $640

ECS = Energy cost savings, $209

Therefore,

$$\boldsymbol{SPP = \frac{\$640.00}{\$209.00} = 3.06\ years}$$

The simple payback period for implementing an air pump/blower, with the associated cost of installation, is ***approximately 3 years.***

Opportunity #2: Install Soft Start on Air Compressor Motor

Annual Resource Savings	Annual Cost Savings	Capital Cost	Balance of Project Cost	Simple Payback Period
98.16 kW	$816.60	$400.00	$108.00	< 1 Year

Background Information

The NEW Tech™ water filtration system utilizes a 3 horsepower air compressor to deliver compressed air to both the onboard ozone generator and to turn over (lift) the filter media in two fluidized sand filters. During steady operation of the water filtration system, the air compressor cycles off when the pressure in the storage tank reaches the desired set point. As the system consumes air for normal operations the compressor motor will start in order to re-pressurize the storage tank. Currently, the compressor motor does not utilize a variable frequency drive or a soft start which causes the motor to experience high inrush current spikes during normal start-up.

Typically, a motor will experience a current draw of approximately five times its unloaded state when it is turned on, which it maintains for several seconds prior to reaching its full speed if no controlled starting mechanism is installed. Figure 10 is logged electrical current data measured at both the main breaker for the system and on the compressor breaker during a period of normal operations. It can be seen that the compressor motor accounts for approximately 50% of the total current draw on the system. The remainder of the current draw is due to operation of remaining equipment integrated in the system. According to the data logger, data, the compressor motor does experience instances of high inrush current loads during motor start-up periods. The peak amperage that the compressor motor experienced was approximately 69 amps, which elevated the total system amperage upwards of 90 amps. Additional instances of inrush current likely still occurred during other motor startups, but were not logged due to data sampling interval being every 5 seconds.

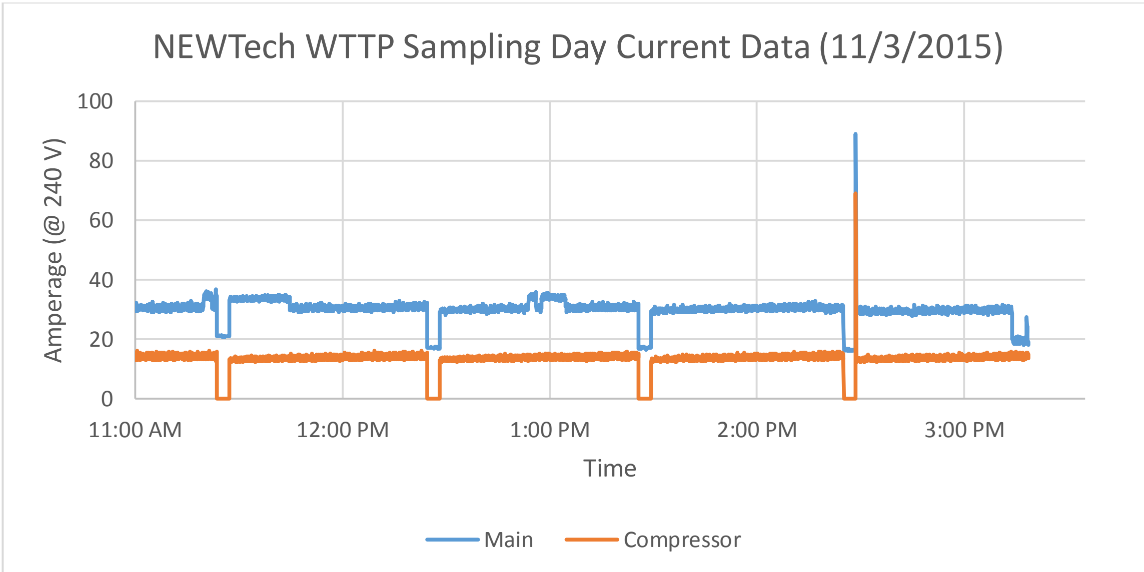


Figure 10: NEW Tech™ Main Breaker Amperage

Energizing motors with across-the-line starting will typically result in large inrush current. Furthermore, large startup currents can cause voltage drops across other pieces of equipment attached to a common utility. Installation of control systems to manage inrush electrical loadings to motors is one way to reduce the amount of power draw experienced during motor startup. Such control mechanisms include variable frequency drives and motor soft starters. Motor soft starters typically work by controlling start-up voltage in order to keep in-rush current draw minimized. Typically, motor soft starters are able to minimize in-rush starting current to one and one-half to two times the motors nameplate rated current draw (U.S. Department of Energy , 2008).

Recommended Action

It is recommended that a soft starter be installed on the air compressor motor. The use of a soft starter will eliminate the inrush current spikes when the compressor motor cycles. By reducing the high inrush loads to the motor, there will be reduced shock loading to the motor and belt drive system. Additionally, reduction in inrush loading will result in decreased electrical demand required for the motor start-up. Reductions in inrush power draw will require less electrical power draw be provided by the electrical utility and cost savings will be realized.

Anticipated Savings
Savings will be a direct result of reduced power draw during air compressor motor startup.

Reduced power draw during start-up will result in electrical demand and cost savings.

Current Electrical Demand
In order to estimate the savings, the power draw for the compressor motor must be calculated.

Power draw for a motor is estimated by the following equation:

$$\boldsymbol{PD = V \times A \times PF}$$

Where,

PD	=	Power Draw (during startup), kW
V	=	Voltage, 220V
A	=	Current, 69 Amps
PF	=	Power Factor, 80%

The power draw for the air compressor motor during startup is calculated below:

$$\boldsymbol{PD = 220V \times 69\ Amps \times 0.80 = 12,144\ Watts = 12.14kW}$$

Current Demand Cost
Using a typical value (in Moscow, Idaho) of $8.32 per kWh for the previous year. The estimated current annual demand cost is:

$$\boldsymbol{CDC = PD \times C}$$

Where,

CDC	=	Current monthly electrical demand cost, $/month
PD	=	Current power draw, 12.14 kW
C	=	Cost of electrical demand, $8.32/kW

Therefore,

$$\boldsymbol{CDC = 12.14\ kW \times 8.32 \frac{\$}{kW} = \$101/month}$$

The estimated annual demand cost of operating the compressed air system is **$1,212**

The following calculations were performed in order to quantify the cost of electrical demand in relation to a functional unit of 1000 gallons of water processed.

The volume of water pumped per hour and per month is calculated below.

$$15\ \frac{gallon}{minute} \times 60\,\frac{minutes}{hour} = 900\,\frac{gallons}{hour}$$

$$900\,\frac{gallon}{hour} \times 24\,\frac{hours}{day} \times 30\,\frac{days}{month} = 648{,}000\,\frac{gallons}{month}$$

$$\frac{\$101}{\left(\frac{648{,}000\ gallon}{1000}\right)} = \$\mathbf{0.16}\ per\ 1000\ gallons$$

Proposed Electrical Demand

From Figure 10 above, it can be seen that the average current draw of the compressor motor (during non-startup periods) has an average value of approximately 14 amps. If a soft starter was utilized, the large in-rush starting current spikes would be reduced to approximately 22.5 amps and the motor would operate consistently around 14 amps during typical operation.

The proposed power draw by the system if a motor soft starter was installed is calculated by the following,

$$\boldsymbol{PPD = V \times A \times PF}$$

Where,

PDC	=	Proposed demand cost, $/month
V	=	Compressor motor voltage, 220 volts
A	=	Compressor motor current draw, 22.5 amps
PF	=	Power factor, 80%

$$\boldsymbol{PPD = 220\,Volts\ \times 22.5\,Amps \times 0.80 = 3{,}960\,Watts = 3.96\,kW}$$

Proposed Demand Cost

Using a typical value (in Moscow, Idaho) of $8.32 per kWh for the previous year. The proposed demand cost is:

$$\boldsymbol{PDC = PPD \times C}$$

Where,

PDC	=	Proposed monthly electrical demand cost, $/month
PPD	=	Proposed power draw, 3.96 kW
C	=	Cost of electrical demand, $8.32/kW

Therefore,

$$\boldsymbol{CDC = 3.96\,kW \times 8.32\,\frac{\$}{kW} = \$32.95/month}$$

The estimated annual demand cost of operating the compressed air system is **$395.40**

$$\frac{\$32.95}{\left(\frac{648{,}000\ gallon}{1000}\right)} = \$\mathbf{0.05}\ per\ 1000\ gallons$$

Demand Savings

The electrical demand savings can be calculated by taking the difference between the current demand costs (without motor soft start) and the proposed demand costs (with motor soft start). Table 36 summarizes the electrical demand cost savings.

Table 36: Electrical Demand Cost and Savings Summary

	Electrical Demand Cost		
	Monthly	Annual	Per 1000 gallons
Current	\$101.00	\$1,212.00	\$0.16
Proposed	\$32.95	\$395.40	\$0.05
Savings	**\$68.05**	**\$816.60**	**\$0.11**

Estimated Implementation Costs

Implementation costs for this recommendation include both the capital cost to purchase the motor soft start and the estimated labor cost to install the unit. It is estimated that it would take and experienced electrician approximately 4 hours to install the soft starter. The total implementation cost is estimated as follows.

$$\boldsymbol{IC = (LC \times LH) + MC}$$

Where,

IC	=	Estimated implementation cost, \$
LC	=	Labor cost, \$27/hour
LH	=	Labor hours, 4 hours
MC	=	Estimated cost of motor soft start, \$400.00

Therefore,

$$\boldsymbol{IC = \left(27\,\frac{\$}{hour} \times 4\ hours\right) + \$400.00 = \$508.00}$$

The estimated cost for implementing this recommendation is **\$508.00**.

Simple Payback Period

The simple payback period for this recommendation is estimated below:

$$\boldsymbol{SPP = \frac{IC}{ECS}}$$

Where,

SPP	=	Simple payback period, years

IC	=	Estimated implementation cost, $508.00
ECS	=	Annual demand cost savings, $816.60

Therefore,

$$\boldsymbol{SPP = \frac{\$508.00}{\$816.60} = .62\ years}$$

The simple payback period for implementing a motor soft starter on the air compressor motor, with the associated cost of installation, is ***less than one year***.

Opportunity #3: Replace Oversized Influent Pumps with Optimally Sized Pumps

Annual Resource Savings	Annual Cost Savings	Capital Cost	Balance of Project Cost	Simple Payback Period
12,351.60 kWh **16.92 kW**	**$776.58**	**$2,000**	**$240**	**2.8 years**

Background Information

Currently, the NEW Tech™ water filtration system utilizes two 1-horsepower inline influent pumps to pump influent throughout the system. The influent pumps are capable of delivering 45 gallons per minute of flow per pump. However, the two onboard sand filters are only capable of processing a flow of 15 gallons per minute. In order to control the amount of flow delivered by the pumps to an acceptable flow that the sand filters are capable of receiving, the flow from the pumps is reduced by mechanical valves. Currently, the valves are kept mostly closed in order to keep the flows down to 15 gallons per minute. Electrical current data, seen in Figure 11, was collected for each of the pumps in order to determine the average current draw for each of the pumps.

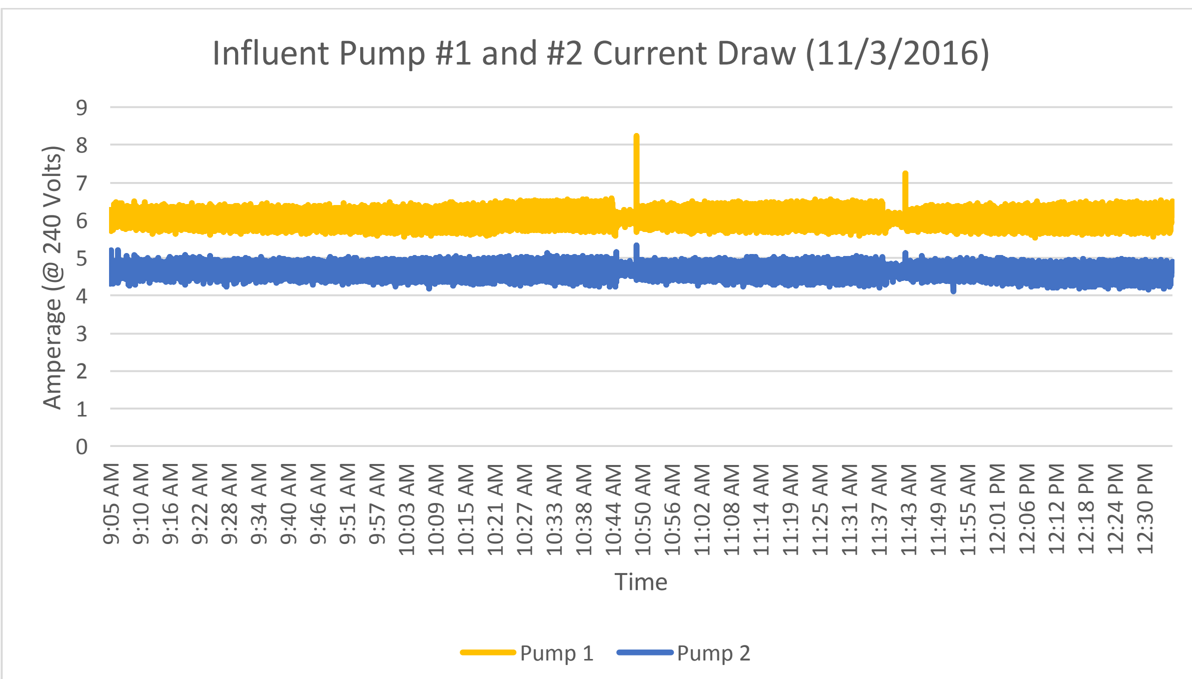


Figure 11: NEW Tech™ Influent Pump Current Draw

Recommended Action

In order to reduce the amount of energy that is consumed by the pumps to move water throughout the system, it is recommended that either the pumps be resized to an optimal size for the required flow or that a variable frequency drive be installed on each of the pumps to reduce the flow of water through the pumps.

Anticipated Savings

Savings will be a direct result of reduced power draw during normal operations due to a reduction in pump motor size and power draw needed in order to deliver the required flow rate through the pumps. Consistent reduction in motor power draw will result in both electrical demand and electrical consumption cost savings.

Current Electrical Demand

In order to estimate the savings, the power draw for each of the influent pump motors must be calculated. Power draw for each motor is estimated by the following equation:

$$PD = V \times A \times PF$$

Where,

PD	=	Power Draw (during startup), kW
V	=	Voltage, 240V
A	=	Current, Amps
PF	=	Power Factor, 79%

According to the electrical current data collected with data loggers, pump #1 and pump #2 had an average current draw of 6.05 amps and 4.68 amps, respectively. Motor nameplate information stated that the motors used 240 volts and had a rated power factor of 81%. The power draw for both influent pumps during normal operation are calculated in Table 37.

Table 37: Operating Parameters and Calculated Power Draw of Influent Pumps

Equipment	Voltage	Average Amperage	Power Factor	Power Draw (Watts)
Pump #1	220	6.05	81%	1,078
Pump #2	220	4.68	81%	834
			TOTAL	1,912

Current Electrical Usage

If the NEW Tech system was to be used 24 hours per day and all year long, the annual operating hours of the compressor would be,

$$\boldsymbol{OH_a = 24\frac{hours}{day} * 365\frac{days}{year} = 8,760\frac{hours}{year}}$$

Similarly, if the compressor was to be run for 24 hours per day for a month, the monthly (using 30 days) operating hours would be,

$$\boldsymbol{OH_m = 24\frac{hours}{day} * 30\frac{days}{month} = 720\frac{hours}{month}}$$

Finally, in order to determine the operating hours required to pump 1,000 gallons of water through the system at a flow rate of 15 gallons per minute, the operating hours would be,

$$\boldsymbol{OH_{1000} = \frac{1,000\ gallons}{15\frac{gallons}{minute} \times 60\frac{minutes}{hour}} = 1.11\ hours\ per\ 1,000\ gallons}$$

Knowing the power draw and relevant operating hours, the current electrical usage can be determined in kilowatt-hours as follows.

$$\boldsymbol{CEU = CPD \times OH}$$

Where,

CEU	=	Current electrical usage, kWh
CPD	=	Current power draw, kW/year
OH	=	Annual operating hours, hours/year

Table 38 summarizes the electrical usage per pump. The electrical consumption for each pump is calculated for three different time periods: annually, monthly and the time required to pump 1000 gallons through the system.

Table 38: Current Influent Pump Electrical Usage Summary

Equipment	Power Draw (kW)	Operating Hours			Electrical Consumption (kWh)		
		Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1	1.08	8,760	720	1.11	9,460.80	777.60	1.20
Pump #2	0.83				7,270.80	597.60	0.92

<u>Current Energy Cost</u>

Using typical values for the cost of electrical demand ($/kW) and consumption ($/kWh) in Moscow, Idaho. The estimated current energy costs can be calculated as the following:

$$\boldsymbol{CEC = (PD \times CD) + (CEU \times CC)}$$

Where,

CEC	=	Current energy cost, $
PD	=	Current power draw, Pump #1: 1.08 kW and Pump #2: 0.83 kW
CD	=	Cost of electrical demand, $8.32/kW
CEU	=	Current electrical usage, kWh
CC	=	Cost of electrical consumption, $0.075/kWh

Therefore,

Table 39: Current Electrical Energy Cost Summary

		Electrical Consumption (kWh)			Electricity Costs ($)		
Equipment	**Power Draw (kW)**	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1	1.08	9,460.80	777.60	1.20	709.56	58.32	0.09
Pump #2	0.83	7,270.80	597.60	0.92	545.31	44.82	0.07

The estimated annual electrical costs of operating the two influent pumps, including electrical demand and consumption, is **$1,155**

Proposed Electrical Demand

The proposed power draw that could be realized for the influent pumps if the use of variable frequency drives was implemented can be estimated by the use of the pump affinity laws. The subscripts "1" and "2" can be thought of as before and after, respectively.

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

Where,

Q	=	Flow rate, gallons per minute
H	=	Hydraulic head, feet
N	=	Motor RPM
BHP	=	Brake horsepower, horsepower

Currently, both influent pumps are rated at 1 hp and an RPM of 3,450. The pumps are rated for a flow of approximately 45 gpm. Therefore, using the current horsepower, RPM, and rated flow, the required brake horsepower to deliver the operating flow (15 gpm) can be calculated using the affinity laws.

$$\boldsymbol{N_2 = N_1 \times \left(\frac{Q_2}{Q_1}\right) = 3,450\ RPM \times \left(\frac{15\ gpm}{45\ gpm}\right) = 1,150\ RPM}$$

$$\boldsymbol{BHP_2 = BHP_1 \times \left(\frac{N_2}{N_1}\right)^3 = 1\ HP \times \left(\frac{1,150\ RPM}{3,450\ RPM}\right)^3 = 0.04\ HP}$$

According to the affinity laws, the required horsepower to be delivered to the pump in order to pump 15 gallons per minute would be 0.04 horsepower. Therefore, the use of a variable frequency drive is not advised as there are large drops in efficiency once a motor drops below 40% of its nameplate rated load.

Instead, it is recommended that the pumps be replaced with more optimally sized pumps. A suitable replacement would be a multistage in-line pump. Using Grundfos pump performance curves, it was determined that a Grundfos model CR-3 would be capable of delivering adequate flow through the system and utilizing a smaller horsepower motor than the existing pump utilizes.

According to the pump performance curve, the CR-3 can deliver 20 gpm with a requirement of 0.17 horsepower and an efficiency of 55%. Therefore, the input power required to deliver adequate power through the pump can be calculated.

$$HP_M = \frac{HP_P}{\eta_P}$$

Where,

HP_M	=	Required horsepower input, HP
HP_P	=	Pump horsepower requirement, 0.17 HP
η_P	=	Pump efficiency, 55%

$$HP_M = \frac{0.17\ HP}{0.55} = 0.31\ HP \times 746\frac{Watts}{HP} = 231.26\ Watts = 0.25\ kW \text{ per pump}$$

<u>Proposed Electrical Usage</u>

$$PEU = PPD \times OH$$

Where,

PEU	=	Proposed electrical usage, kWh
PPD	=	Proposed power draw, kW/year
OH	=	Operating hours, hours

Table 40 summarizes the total electrical usage of both pumps. The electrical consumption for the pumps is calculated for three different time periods: annually, monthly and the time required to pump 1000 gallons through the system.

Table 40: Proposed Electrical Usage Summary

		Operating Hours			**Electrical Consumption (kWh)**		
Equipment	**Power Draw (kW)**	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1 and #2	0.50	8,760	720	1.11	4,380	360	0.55

Proposed Energy Cost

Using typical values for the cost of electrical demand ($/kW) and consumption ($/kWh) in Moscow, Idaho. The estimated current energy costs can be calculated as the following:

$$CDC = (PD \times CD) + (CEU \times CC)$$

Where,

CDC	=	Current energy cost, $
PD	=	Proposed current power draw, 0.50 kW (both pumps combined)
CD	=	Cost of electrical demand, $8.32/kW
PEU	=	Proposed electrical usage, kWh
CC	=	Cost of electrical consumption, $0.075/kWh

Therefore, the proposed electrical costs for the existing influent pumps can be seen in Table 41

Table 41: Proposed Influent Pump Electrical Cost Summary

		Electrical Consumption (kWh)			Electricity Costs ($)		
Equipment	**Power Draw (kW)**	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)	Annual	Monthly	Per 1000 Gallons (@ 15 gpm)
Pump #1 and #2	0.50	4,380	360	0.55	378.42	31.16	0.09

The proposed estimated annual cost of operating the new pumps is approximately $**378**

Annual Cost Savings

The annual cost savings can be calculated by taking the difference between the current energy costs (existing pumps) and the proposed energy costs (resized pumps). Table 42 shows the estimated cost savings resulting from the influent pump change out.

Table 42: Electrical Demand Cost Savings Summary

	Electrical Energy Cost ($)		
	Monthly ($/month)	Annual ($/year)	Per 1000 gallons ($/1000gal)
Current	103.14	1,155.00	0.16
Proposed	31.16	378.42	0.09
Savings	**$71.98**	**$776.58**	**$0.07**

Estimated Implementation Costs

Implementation costs for this recommendation include 8 hours to install both pumps into the existing system. Additionally, included is the capital cost estimate for the purchase of two ¾ horsepower in-line pumps. The cost estimate for the pumps is approximated to be $1,000/pump2. The labor rate is estimated to be approximately $30.00/hour1 for a qualified commercial electric motor/pump installer.

$$IC = LC + MC$$

Where,

IC	=	Estimated implementation cost, $
LC	=	Labor cost, $30.00/hour[1]
MC	=	Capital cost of new pumps, $1,000.00/pump[2]

Therefore,

$$IC = \left(30.00\frac{\$}{hour} \times 4\frac{hours}{pump} \times 2\ pumps\right) + \left(2\ pumps \times 1{,}000\frac{\$}{pump}\right) = \$2{,}240$$

The estimated cost for implementing this recommendation is **$2,240**.

Simple Payback Period

The simple payback period for this recommendation is estimated below:

$$SPP = \frac{IC}{ECS}$$

Where,

SPP	=	Simple payback period, years
IC	=	Estimated implementation cost, $2,240
ECS	=	Energy cost savings, $1,203.37

Therefore,

$$SPP = \frac{\$2{,}240.00}{\$776.58} = 2.8\ years$$

The simple payback period for replacing the existing influent pumps with more optimally sized pumps is approximately **2.8 years.**

[1] Hourly wage estimated from United States Department of Labor's Bureau of Labor Statistics. http://www.bls.gov/oes/current/oes_id.htm#49-0000

[2] Pump cost estimate taken from ePumps online. http://www.epumps.com/cr3-5-34-hp-96083061.html?utm_source=google&utm_medium=cpc&utm_campaign=shopping&m=simple&gclid=CNfaz_6B1s0CFYhffgodIcQGXw

APPENDIX C: WATER QUALITY LAB RESULTS

University of Idaho Analytical Sciences Laboratory
Electronic Data Delivery

Client: **Greg Moller & Martin Baker**
Case ID: **WNOV15-001**

Lab ID	Customer ID	Collection Date	Reporting Limit (mg/L)	Estimated Detection Limit (mg/L)	Total Phosphorus
W1500360	A1WTP - 1	03-Nov-15	0.003	0.0015	0.1174
W1500361	A2WTP - 1	03-Nov-15	0.003	0.0015	0.1222
W1500362	A3WTP - 1	03-Nov-15	0.003	0.0015	0.1204
W1500363	A4WTP - 1	03-Nov-15	0.003	0.0015	0.1222
W1500364	A5WTP - 1	03-Nov-15	0.003	0.0015	0.1178
W1500365	A6WTP - 1	03-Nov-15	0.003	0.0015	0.1178
W1500366	B1WTP - 1	03-Nov-15	0.003	0.0015	0.0508
W1500367	B2WTP - 1	03-Nov-15	0.003	0.0015	0.0491
W1500368	B3WTP - 1	03-Nov-15	0.003	0.0015	0.0587
W1500369	B4WTP - 1	03-Nov-15	0.003	0.0015	0.0491
W1500370	B5WTP - 1	03-Nov-15	0.003	0.0015	0.0439
W1500371	B6WTP - 1	03-Nov-15	0.003	0.0015	0.0430
W1500372	C1WTP - 1	03-Nov-15	0.003	0.0015	0.0178
W1500373	C2WTP - 1	03-Nov-15	0.003	0.0015	0.0187
W1500374	C3WTP - 1	03-Nov-15	0.003	0.0015	0.0187
W1500375	C4WTP - 1	03-Nov-15	0.003	0.0015	0.0187
W1500376	C5WTP - 1	03-Nov-15	0.003	0.0015	0.0221
W1500377	C6WTP - 1	03-Nov-15	0.003	0.0015	0.0195
W1500378	FBWTP - 1	03-Nov-15	0.003	0.0015	0.004
W1500379	FBWTP - 2	03-Nov-15	0.003	0.0015	0.004
W1500380	FBWTP - 3	03-Nov-15	0.003	0.0015	0.004

APPENDIX D: GAST 0523 SEPTIC AIR PUMP SPECIFICATIONS

GAST
Post Office Box 97
Benton Harbor, Michigan
Ph: 269/926-6171
Fax: 269/925-8288

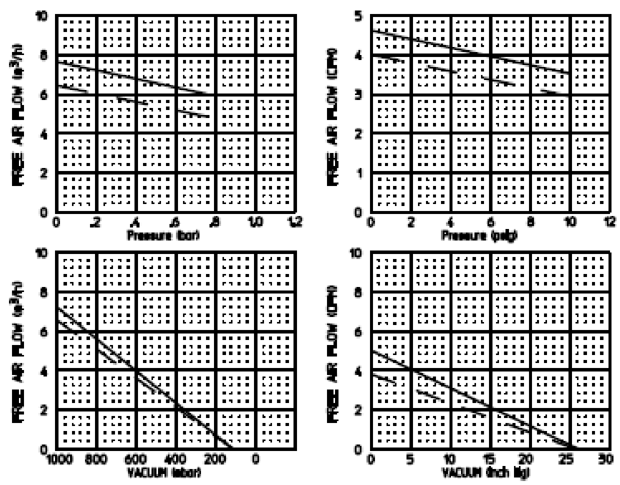
Product Specifications

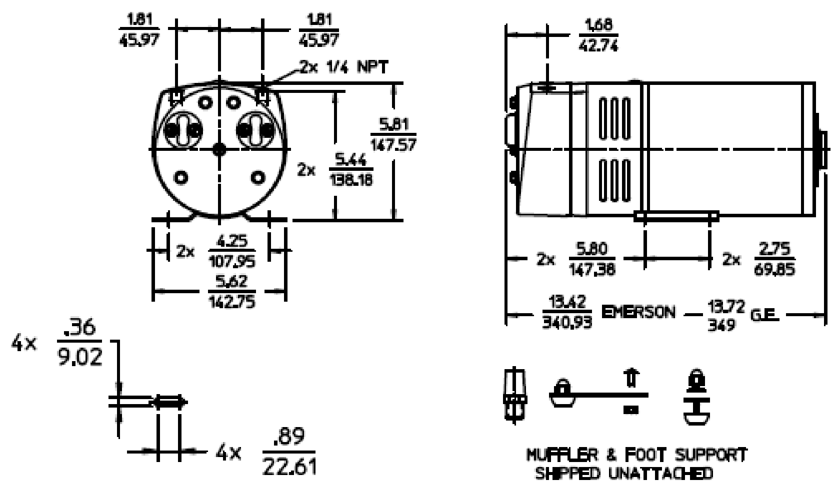
PART NUMBER: STD387
REVISION: D

Model Number	Motor Voltage	RPM 60 cycle	RPM 50 cycle	HP	kW	Net Wt. lbs.	Net Wt. kg	"A" DIM.	"B" DIM.
0523-1010-SG588DX 0523-1030-SG588DX 0523-101BQ-G588EDX 0523-M1010-SG588DX	115/230 115/230 100-110/220-240	1725	1425	.25	0.18	30	13.6	319 12.57	N/A

SOUND LEVEL LESS THAN 70 dB(A)
NORMAL AMBIENT 1°C. - 40°C.
RELATIVE HUMIDITY 8% - 100% NON CONDENSING
ENVIRONMENT CLEAN DUST FREE

TECHNICAL DATA SUBJECT TO CHANGE WITHOUT NOTICE.
DIMENSIONS ARE FOR REFERENCE ONLY.
DASHED LINE INDICATES 50 Hz. PERFORMANCE.
SOLID LINE INDICATES 60 Hz. PERFORMANCE.





APPENDIX E: GRUNDFOS CR-3 PUMP PERFORMANCE CURVE

CR, CRI, CRN 3