EVALUATION OF ENERGY AND EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT

By

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EVALUATION OF ENERGY AND EMISSIONS

FROM MUNICIPAL WASTEWATER TREATMENT

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Abstract: Wastewater treatment is a core societal commodity responsible for maintaining the health of humans and downstream ecosystems. Because the purpose of wastewater treatment plants (WWTPs) is to remove pathogens and organic matter from the water, other objectives such as energy efficiency and material recycling can easily fall to the way-side. To improve the overall efficiency of these treatment facilities, energy expenditure analysis is needed to better understand how to make electric consumption reduction efforts most effective. The analysis of WWTP energy and emissions for facilities in Oklahoma required the procurement of process data such as flow rates, energy and resource consumption, and unit processes present. The WWTPs chosen for analysis had to fit within two different ranges. First, OK WWTPs were separated by the population size they were serving. Those serving a small population (less than 100,000) were chosen because literature suggests these WWTPs exhibit higher than average electric consumption on a per volume basis. Secondly, facilities need to be treating the wastewater of a large enough population (more than 10,000) for the potential energy use to be significant enough to financially warrant investment in energy saving technology. The population range of the surveyed WWTP's respective municipalities is 10,000 to 100,000 people. Once determining the most energy-intensive unit process of wastewater treatment is activated sludge, analysis in municipal and laboratory applications is necessary to provide insight into possible sustainability improvements. Within a laboratory environment, an activated sludge biological treatment tank is simulated to characterize key water quality parameters throughout the treatment process. Once an effective strategy for accurately simulating a full-scale municipal activated sludge treatment is determined and proven, energy input optimization can occur. This is done as the first step necessary to begin correlating key water parameters to the needed volume of air being pumped into the wastewater.

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CHAPTER I

INTRODUCTION

Biological treatment is a cost-effective method of decreasing the organic matter in water before returning to the environment. Because this process utilizes living organisms, designing and maintaining biological treatment processes requires an understanding of said organisms and the environments in which they work. Common practice in municipal wastewater treatment is over-aerating the water to ensure adequate dissolved oxygen regardless of change in flow. By monitoring the wastewater while it is being treated, this study hopes to create a laboratory environment capable of mimicking a full-scale activated sludge treatment tank so that the system can eventually be used to showcase the direct relationship between water quality measurements, volume of air needed, and electricity saved from a decrease in aeration. Energy and water systems are complex and interconnected since energy production relies on water, and water provision and treatment consumes energy. Because efficiency is not the first objective at wastewater treatment plants (WWTPs), these systems are usually not the focus when communities fund energy improvement projects [1]. Optimizing the energy use of one 75 hp WWTP aeration blower, capable of treating 1.3 MGD, can save a facility 189 MWh/year [1]. These interdependencies, along with an increasing demand for both water and energy, create a need to analyze water and energy systems in an interconnected manner, develop technologies that conserve both resources, and create policies to implement these technologies on a large scale. Because each WWTP contains different treatment processes and consumes different quantities of electrical energy and raw materials, a direct survey of WWTPs is needed to determine potential improvements in energy efficiency.

1.1 WWTP Overview

Municipal wastewater contains a variety of contaminants, including trash, pathogens, nutrients from human waste, inorganic and organic solids, and scum formed from floating fats and greases [2]. WWTPs reduce the levels of these constituents to protect downstream water quality, including the preservation of high dissolved oxygen (DO) levels [3]. Failure to maintain DO levels in receiving waters can cause harmful effects on the downstream ecosystem. The biochemical oxygen demand (BOD) reflects the organic matter concentration of the wastewater, and it is commonly used to assess the potential of the effluent to reduce DO in the water downstream [4]. The higher the BOD, the larger the concentration of organic matter present [5].

The majority of WWTPs in the United States have a similar schematic to the one shown in Figure 1. Screens and grit chambers remove debris and other large solids from the raw influent. The wastewater then passes through a primary clarifier where the majority of suspended solids settle out and flows to an anaerobic digester. The clarifier effluent then flows to the aeration tank for BOD removal.

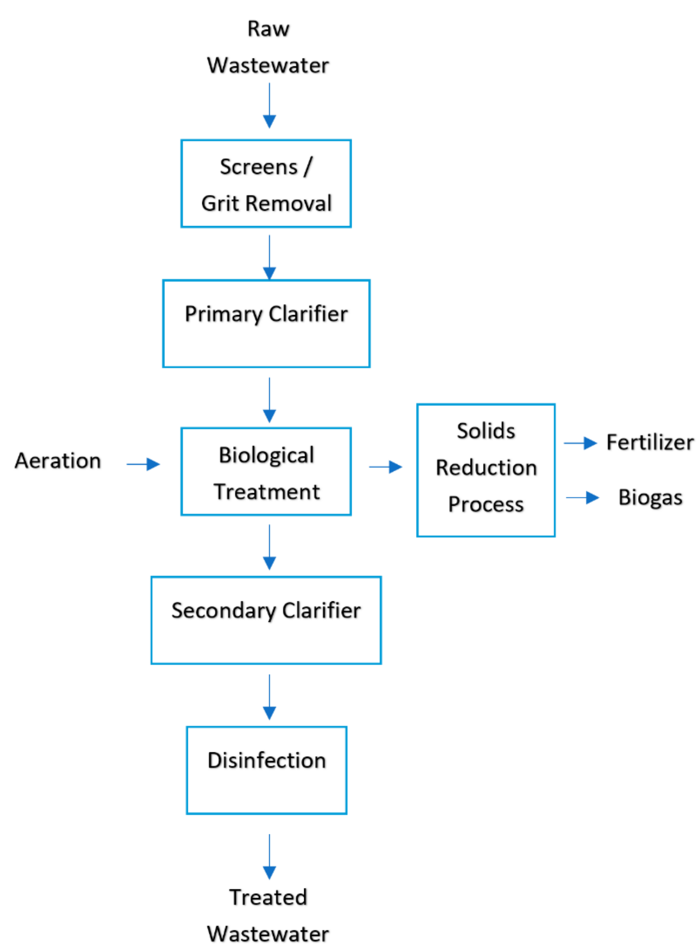

Figure 1: Typical WWTP Layout

The effluent from the aeration tank is then sent to a secondary clarifier that allows remaining solids another chance to settle before being sent to the anaerobic digester. The solids from the clarifiers are often combined and reduced in volume using digesters and other processes. The effluent from the secondary clarifier is disinfected using either ultraviolet (UV) light, ozone, or chlorine before being discharged back into the environment.

Most modern medium and large-scale WWTPs use the activated sludge process (ASP) to reduce BOD and nutrient concentrations. ASPs utilize air blowers to diffuse fine air bubbles, shown in Figure 2, into the wastewater, enabling microorganisms to reduce organic matter by about 95% [6]. However, aeration processes are very energy-intensive, claiming responsibility for about 78% of the total energy consumption at most WWTPs, which implies that this process has the most potential for energy savings and reduced indirect greenhouse gas (GHG) emissions [1]. WWTPs are also major direct emitters of methane (CH_4) and nitrous oxide (N_2O), potent GHGs. CH_4 and N_2O made up 15% and 7% of the world's 100-year global warming potential (GWP100) in 2005, respectively [7]. WWTPs are also large contributors of CO_2, but these emissions are biogenic in origin and are therefore not considered in this analysis, consistent with ISO standards [8]. On average, 10% of a WWTP's total energy footprint is the recovery and use of biogas energy [9]. Methane escapes wastewater in anaerobic conditions as organic matter degrades. The high levels of organic matter within wastewater result in emissions of, on average, 83.3 g CH_4 per million gallons treated (MG) [7], [10], which equates to 3 kg CO_2 eq./MG using a GWP100 factor of 36 [10]–[12]. The microbial processes of nitrification and denitrification within these facilities produce approximately 22.7 g N_2O/MG, equating to the 100 year GWP of 6.8 kg CO_2 eq./MG using a GWP100 factor of 298 [10], [11].


Figure 2: Aeration Basin Diffusers

1.2 Energy Savings Potential from Decreased Aeration in Activated Sludge Processes

Potential sustainability improvements throughout WWTPs include the recapture of biogas as an energy source for digestion, the production of fertilizers to displace energy used in their production, and reductions in aeration in ASPs. Often WWTP operators lack the operational expertise to understand the relationships between aeration, BOD, and nutrient removal, so they oversupply air to ensure compliance with regulatory limits. For example, a recent study found that using an interactive dynamic model of the activated sludge tank to optimize aeration could decrease overall energy costs by 52% [3]. Reduce the amount of air supplied while maintaining pollution under permitted levels can save substantial amounts of energy while preserving water quality. These savings are the result of three separate phenomena related to decreasing the amount of oxygen supplied and:

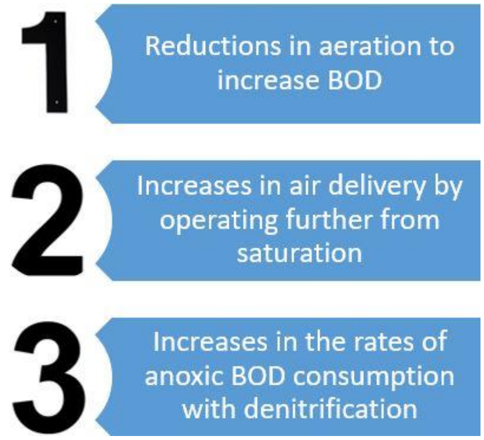

Figure 3: Methods to Decrease Oxygen Input

reductions in aeration to increase effluent BOD, increases in air delivery by operating further from saturation, and increases in the rates of anoxic BOD consumption with denitrification [10], [13], [14].

The importance of DO concentrations on the observed efficiency of delivering oxygen to the wastewater is shown in the following figure, which exhibits DO levels observed within the aeration basin at the Stillwater, OK WWTP, which runs their mechanical aeration blowers continuously. As DO concentrations climb, the delivery efficiency of oxygen from the air (air absorbed by the water relative to air supplied by the blower) drops dramatically, suppressing the rate of denitrification. Increased denitrification improves water quality, decreased sludge volume, and decreased aeration requirements [15], [16].

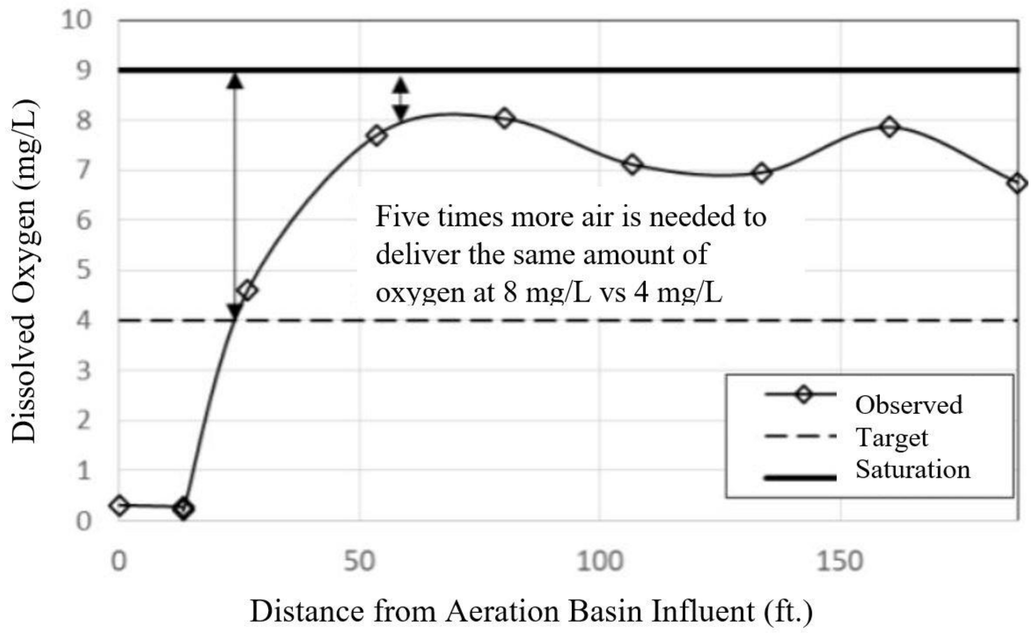

Figure 4: Observed vs. Theoretical Target DO Concentrations

ASPs consume large quantities of electrical energy to supply aeration for the enhancement of microbial degradation rates. Decreasing the air applied to an ASP increases energy efficiency in a nonlinear manner, making potential cost savings estimates somewhat tricky. Such an assessment typically requires a detailed process model informed by data on current operating practices. Several separate mechanisms by which decreasing the amount of aeration improve the energy efficiency of an ASP exist [17]. If the effluent BOD from a WWTP is below the regulatory limit, the difference can be considered wasted aeration. Also, when less air is applied to the wastewater, the DO levels decrease, which improves oxygen delivery efficiency since the oxygen delivery rate is proportional to the difference between the DO concentration in the water and the concentration in equilibrium with air.

Quantitative assessment of the potential WWTP energy savings from decreased aeration via these mechanisms is a somewhat complicated technical issue. Rosso et al. estimated that an ASP with denitrification would use 8% less oxygen for the same effluent BOD concentration [21]. Small decreases in aeration will not ultimately facilitate total denitrification, because denitrification is slower than traditional aerobic sludge processing and would require a larger reactor. For systems in which DO levels reach those close to saturation, the oxygen delivery efficiency can be relatively low, and much larger improvements are possible. This DO and saturation relationship is conveyed in the previous figure.

Excess energy usage for aeration in WWTPs is particularly pervasive in rural areas where operational budgets are limited. The purpose of this investigation was to assess the primary energy consumption and GHG emissions from wastewater treatment processes from a life cycle perspective in mid-sized WWTPs serving between 10,000 and 100,000 people and to identify opportunities for aeration control systems to improve their sustainability. There are 14,748 WWTPs within the United States [18]. Utilizing U.S. census data and assuming each community has 1 WWTP, there are 12,136 WWTPs within this population range.

Large cities serving more than 100,000 people often utilize treatment methods and optimization techniques that are not feasible for moderately sized plants with limited personnel [19]. WWTPs in the target range are assumed to have a greater awareness of energy consumption. Therefore, some degree of energy optimization processes in place (e.g., biogas capture and aeration control). An in-depth analysis of Italy's largest WWTP, serving about 2.7 million, found their yearly energy consumption to be 66.78 GWh/yr, half of which being spent on aeration. Although a substantial number, only 25 – 40% of their expenses are energy-related [20]. This lower than average aeration energy percentage is due to an aeration control automated system that adjusts DO concentrations based on ammonium concentrations. This relationship is conveyed in table to the right.

Table 1: DO Control Based on Ammonia Concentration

NH_4 (mg/L)	O_2 (mg/L)
< 1.5	0.8
$1.5 < x < 3.0$	1.5
$3.0 < x < 5.0$	3.0
$5.0 < x < 7.0$	4.0
$7.0 < x < 9.0$	5.0
> 9.0	7.0

On the other end of the spectrum, WWTPs serving municipalities with fewer than 10,000 people often do not use ASPs and cannot justify large capital and operating expenditures in energy optimization. Because they do not treat enough wastewater to warrant significant capital investment but often have access to land, many of these facilities use aerated lagoons and trickling filters, which have fewer energy savings potential. Trickling filters are inherently less energy efficient than ASPs since they pump water into the air rather than air into water. Lagoons require less aeration than ASPs, but they are a prominent source of CH_4, emitting approximately 91 g CH_4/MG [20].

CHAPTER II

REVIEW OF THE LITERATURE

To understand the complex relationships between wastewater treatment plant (WWTP) energy, direct greenhouse gases produced from treatment, indirect greenhouse gases produced from treatment, and previous endeavors in aeration control, a comprehensive review of published studies relevant to these topics is necessary. Efforts in modeling the relationships between power generation, water use, and water treatment from a watershed perspective have solidified that these WWTPs and factors depend on each other [21]. In 2009, the U.S. Government found that up to 60,000 gallons of fresh water are consumed per MWh of electricity generated [22]. This chapter provides background information on WWTP energy consumption, direct and indirect greenhouse emissions, an analysis of previous aeration control or automation studies, and finished with laboratory simulations of the microbial communities within municipal activated sludge treatment.

2.1 Energy Consumption in Municipal Wastewater Treatment

Because each treatment facility contains different unit processes, pumping configurations, pollutants, and volumes, many WWTP energy studies need to be analyzed. Pratima Singh *et al.* found that small-scale WWTPs consume twelve times the electricity as large-scale facilities [9]. In this study, “small-scale” refers to any decentralized treatment facilities that serve individual communities and were found to consume 4.87 kWh/m^3. “Large-scale” referred to serving large metropolitan areas and centralized conglomerated treatment and exhibited an energy consumption of 0.40 kWh/m^3. The boundary utilized for the estimation of energy and carbon emissions was the entirety of the treatment facilities, including all unit processes, electrical and diesel energy consumption, and the construction of said facility and operations [9]. The energy footprint exhibited in this study is shown in the following figure, with activated sludge processes being the most energy-intensive, followed by oxidation ditch [9].

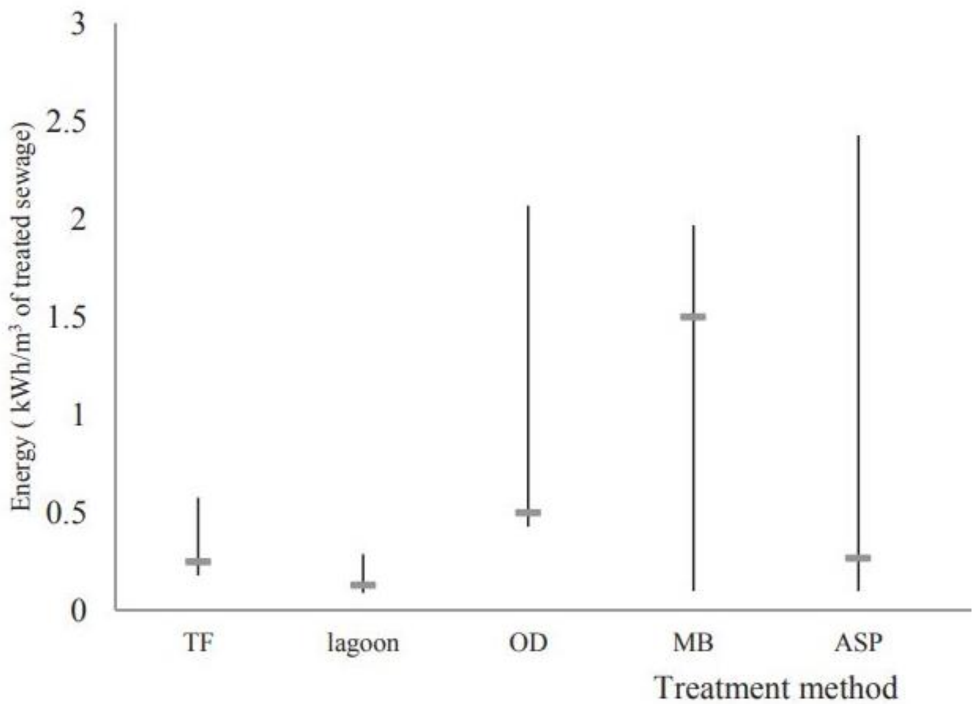

Figure 5: Energy Consumption of Unit Processes

An evaluation of WWTP energy consumption from around the world found that WWTP energy consumption makes up 25% - 40% of a conventional WWTPs operational budget, depending on unit processes and transportation distance [23]. This same study found that 60% of WWTP energy input goes towards aeration within activated sludge treatment [23].

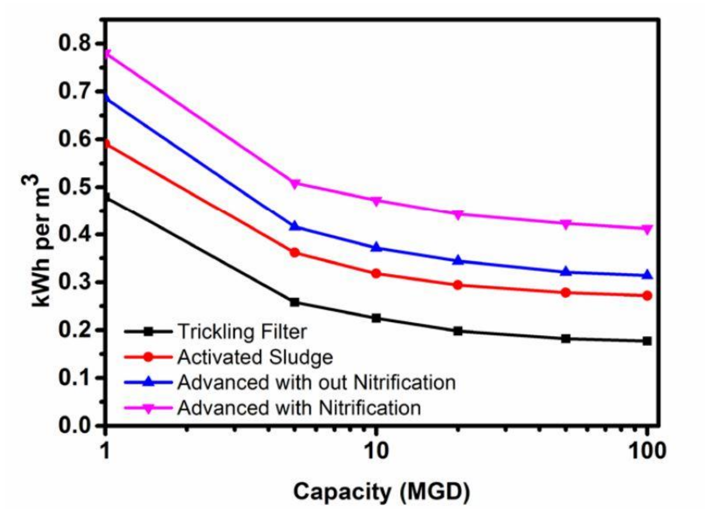

Figure 6: Correlation between WWTP Size and Energy Consumption

Energy input for activated sludge processes in the United States ranges from 0.33-0.60 kWh/m^3, consistent with rates from Australia (0.46), China (0.269), and Japan (0.3-1.89) [23]. A correlation between facility capacity and energy input on a per-volume basis is shown in Figure 5, and smaller facilities exhibit a lower power efficiency [23]. Additionally, decentralized facilities were found to consume a consistently higher amount of energy than centralized WWTPs, the larger of the two options [23].

Yang *et al.* quantified the energy consumption of secondary treatment within 599 Chinese WWTPs in 2006, finding that extended aeration systems consumed 0.340 kWh/m^3, sequencing batch reactors consumed 0.336 kWh/m^3, biomembrane systems consumed 0.330 kWh/m^3, oxidation ditches consume 0.302 kWh/m^3, anaerobic–anoxic–oxic systems (A/A/O) consumed 0.267 kWh/m^3, land treatment or constructed wetlands consumed 0.253 kWh/m^3, trickling filters consumed 0.252 kWh/m^3 and activated sludge consumed 0.349 kWh/m^3 [24]. The same study found small-scale WWTPs consistently consume more than double the energy on a per-volume basis than large-scale WWTPs [24].

Table 2: Secondary Treatment Energy Input

Secondary Treatment	kWh/MG Treated
Activated Sludge	1321
Trickling Filter	954
Extended Aeration	1287
Sequencing Batch	1272
Biomembrane	1249
Oxidation Ditch	1143
Anaerobic–Anoxic–Oxic	1011
Land Treatment	958

An essential aspect of each WWTP energy consumption is the aeration blowers used [25], [26]. K. Bell *et al.* performed an analysis of various aeration blowers used in municipal WWTPs and their relationships of energy savings, airflow rate, and pressure ranges [25]. Single-stage centrifugal blowers were found to exhibit an efficiency range of 65%-80%, multi-stage centrifugal blowers showed an efficiency of 60%-75%, positive displacement blowers demonstrated the efficiency of 45%-60%, and turbo blowers, being the most efficient, exhibited an efficiency of 70%-85% [25].

2.2 Direct Emissions from Wastewater Treatment

In 2015, an estimated 14.8 and 5.0 Tg CO_2 eq. of CH_4 and N_2O, respectively, were from WWTP sludge degradation, approximately 0.3% of the U.S. total emission rate [27]. The majority of greenhouse gases produced at WWTPs are in biogas created and captured within the anaerobic sludge digestion [28], [29]. A long-term study analyzing total greenhouse gases through grab sampling found that 86% of CH_4 emissions came from the aeration basin [30]. Biogas contains 60%-70% CH_4, 30%-40% CO_2, and up to half a percent hydrogen sulfide, inert gases, and water vapor [31]. The other primary source of potent greenhouse gas emissions is direct N_20 emissions from activated sludge processes [11], [11], [32], [33]. Parravicini *et al.* found that WWTPs utilizing anaerobic sludge digestion exhibited approximately 40% of total emissions from direct N_2O emissions within activated sludge tanks. Still, this factor greatly varies based on length, air input rate, and residence time within aeration tanks, as well as temperature, rainfall, and season [34].

Because N_2O has a global warming potential factor 300 times that of CO_2, a deeper understanding of these factors and their effects on direct emission rates is necessary [33], [35]. A New England study monitoring both CH_4 and N_2O on-line utilizing live-feed air pollution sensors found that 1.6 and 3.3 g N_2O and CH_4 were emitted per cubic meter of wastewater treated, respectively [33]. This study found that N_2O and CH_4 emissions made up for 78.4% and 13.5% of total emissions, respectively, and these values varied greatly from previous comparable studies [33]. These comparative studies also used on-line measurement techniques of the two most potent direct emissions (N_2O and CH_4) and found that N_2O made up 2%-88% of total emissions, whereas CH_4 made up 5%-36% [33].

An analysis of direct emissions of small-scale and large-scale WWTP in India found an average emission rate of 0.573 Kg CO_2 eq./m^3 [9]. That same study found that fugitive emissions from large-scale WWTPs accounted for 74% of total greenhouse gas emissions compared to 0.05% of total emissions from small-scale WWTPs [9].

The Intergovernmental Panel on Climate Change (IPCC) in 2006, proposed an N_2O emission factor of 3.2 g N_2O/Population Eq., amounting to 0.35 g N_2O/Kg TKN influent [33]. This factor is based on a single 1995 study done by Czepiel and is approximately eighty times lower than multiple long-term monitoring studies [11], [33]. A single N_2O WWTP emission factor cannot be applied for meaningful results because the effects of temperature and aeration configuration can result in variations of enormous magnitude [32], [33], [36].

The variation in direct CH_4 emissions is far less than N_2O, but still exists. On-line continuous CH_4 emission monitoring of an indoor WWTP found direct CH_4 emissions 25 times higher than the low end of previous peer-reviewed studies [37]. This study found 3.44 g CH_4/m^3 treated, or 1.13% of COD influent, and that dissolved CH_4 was significantly higher during the first half of the plug-flow aeration tank where anoxic conditions occur [37]. Unlike N_2O, where seasonal and temperature variation results in exponential emission changes, no meaningful correlation was found between WWTP CH_4 emission rates, temperature, and season [37].

2.3 Indirect Emissions from Wastewater Treatment

Indirect greenhouse gas emissions come from WWTPs through various processes, but primarily from supplying electric energy for aeration [30], [34]. Parravicini *et al.* compared overall emissions from WWTPs utilizing anaerobic and aerobic digestion and found that aerobic digestion exhibited 2.5 times higher percentages of overall greenhouse gases from electric supply [34]. Approximately 20% of anaerobic digestion WWTP greenhouse gas emissions come from the electricity supply, whereas 60% is from the electricity supply for WWTPs with aerobic digestion [34]. Although this study included procurement of chlorine for disinfection, polymers for sludge thickening and dewatering, and transportation, these factors were negligible compared to indirect emissions from electric supply generation and direct emissions [34].

An analysis of municipal WWTPs in India found that 26% of total emissions from treatment were indirect sources [9]. Small-scale WWTPs experienced a significantly higher rate of indirect emissions because of an increase in electric energy supply, accounting for as high as 99% of total emissions in some facilities [9]. This study used the Indian emission factor of 0.81 kg CO_2/kWh to estimate emissions from electric supply [9]. This factor is 1.8 times larger than the estimated U.S. emission factor of approximately 0.43 kg CO_2/kWh and 2.1 times larger than the estimated European emission factor of 0.38 kg CO2.kWh [9], [34], [38], [39].

A long-term study analyzing life cycle greenhouse gases from municipal WWTPs in Japan found that indirect emissions accounted for 43% of the total emissions produced [30]. These indirect emissions were almost entirely from electricity generation, making the largest source of emissions, followed by direct N_2O, which were found to be 42% of total emissions [30].

2.4 Aeration Automation for Energy Savings

Because aeration is consistently the largest consumer of electricity within WWTPs, one practical way to reduce greenhouse gas emission and electric consumption are by reducing or optimizing aeration rates [25], [26]. Fukushima *et al.* analyzed Japanese municipal WWTP energy as a potential source for the recirculation of materials and energy within the surrounding area. It found that power consumption could be reduced by 70% through reduced aeration and capturing biogases produced during sludge incineration [40].

Daw *et al.* analyzed electric energy input to the WWTP in Crested Butte, Colorado, before and after optimizing energy usage for each unit process [1]. The study's WWTP treats 0.6 MGD via an oxidation ditch with one mechanical aerator of 75 hp. Connecting a DO sensor to the facility's SCADA so that the aerator will not aerate once the DO concentration reaches the previously determined threshold saved 123,000 kWh, equating to a 40% decrease in electric energy input [1].

The Environmental Protection Agency published an overview analysis of optimizations of various municipal WWTPs in 1995 that found aeration reduction, aeration automation, or blower replacement consistently viable sources of profound electric and financial savings [31]. In 1991, Orange County WWTP underwent various energy savings endeavors [31]. Blower refurbishment and control saved 792 kW, equating to $569,100 in annual savings [31]. In Los Angeles, the reduction of running aeration blowers unnecessarily resulted in a 34.3% decrease in overall electricity consumption, equating to $298,000 in annual savings [31].

Franklin, New Hampshire's WWTP, demonstrated these savings potentials by applying DO controls and replacing their 125 hp variable frequency drive blowers [25]. Aeration accounted for 36% of total electric consumption before acquiring high-speed, direct-drive turbo blowers that utilize a permanent magnetic motor, so there is no power surge experienced at their start-up [25]. The facility experienced an overall 32% reduction of electric energy input [25].

Upon consideration of various aeration optimization implementations, this study found the estimated annual power costs of three different aeration blower options [25]. The three blower configurations and their annual power were as follows, centrifugal at 4,000 cfm consumes 1,500,000 kWh/year, turbo at 4,000 cfm consumes 920,000 kWh/year, and turbo at 3,400 cfm consumes 780,000 kWh/year [25]. A 17% reduction in overall electric consumption is estimated to install appropriately sized turbo blowers alone, and a 15%-20% reduction in overall electric consumption is estimated for automatic DO control alone [25].

CHAPTER III

METHODOLOGY

3.1 Goal

The goal of this study was to provide a laboratory-scale analysis of algorithmic automation as a potential solution to increase sustainability in conventional municipal wastewater treatment aeration practices without compromising effluent quality. The laboratory activated sludge analysis utilizes critical water quality parameter sensors and aeration valves dependent on said parameters to quantify the relationships between sensor outputs and required oxygen inputs. In parallel to understanding the application and inner workings of modern wastewater sensing technologies, estimation of the primary energy consumption and GWP100 associated with municipal WWTPs is necessary for a holistic understanding of the interconnectedness of wastewater and energy as well as the identification of opportunities to improve the sustainability of these facilities using aeration control in mid-sized communities. This analysis is expected to provide important insight into current practices and potential improvements in performance for WWTP operations to policy-makers, plant operators, wastewater consulting engineers, city managers, energy analysts, and electricity providers. A better understanding of the life cycle environmental impacts from WWTPs can guide approaches to reduce the environmental impact from their direct and indirect GHG emissions [25].

3.2 Scope

The scope of this study includes the quantification of relevant water quality parameters using both on-line sensor technology as well as traditional calculations. Parameters studied include pH, temperature, conductivity, turbidity, dissolved oxygen, ammonia, nitrates, and UV absorbance.

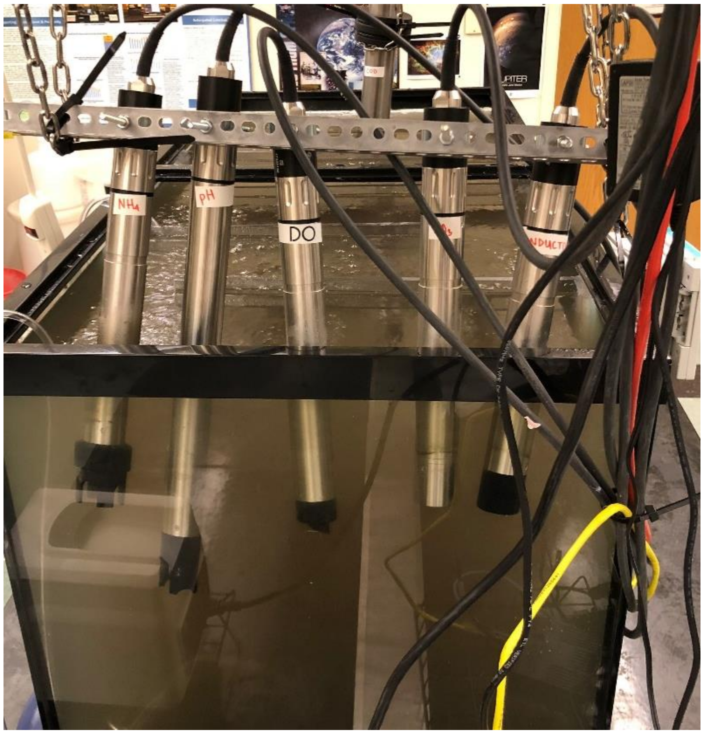

Figure 7: Laboratory Wastewater Sensors

3.3 Commercial Wastewater Sensors Utilized

To monitor the treatment of wastewater within the lab-scale aeration basin, a YSI IQ SensorNet system was installed, as shown in the figure to the right. To utilize said system, a data acquisition system was created to collect sensor output, including pH, temperature, conductivity, turbidity, dissolved oxygen, ammonia, nitrates, and UV absorbance. The logged data are composited into a CSV file and uploaded to a Dropbox folder for retrieval and analysis by the flow-control computer. The flow controller, or mass flow control valve, can utilize the collected data to control the DO delivery. This is performed while the same program that runs the mass flow controller is also monitoring the concentrations of the various sensor parameters to ensure the DO delivered is still effectively treating the wastewater.

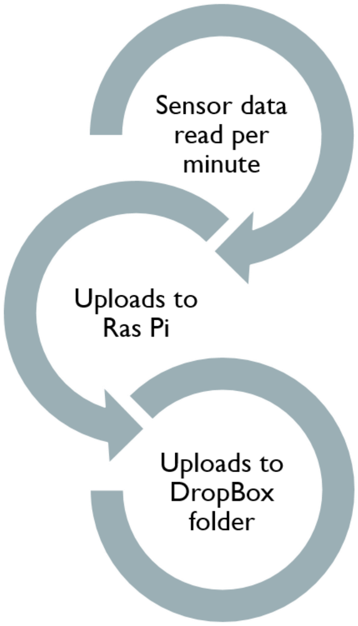

Figure 8: Sensor Data Acquisition

3.31 pH Sensor

The Xylem Analytic's YSI SensoLyt 700 IQ pH sensor was chosen to monitor the tank's acidity, or hydrogen ion (H+) activity. This sensor uses integrated microprocessor electronics, shielded 2-wire connection for power and data transmission [41]. Potentiometric measurement takes place using a combination electrode and a reference electrode of gel polymer solid. Within its watertight plug head, a glass membrane (rather than hydrogen or metal electrode) is used as an ion selective electrode. This ion selective electrode reacts when it comes into contact with either a hydrogen ion or a reference electrode. When it is the hydrogen ion selective electrode coming into contact, a signal, or electrochemical potential, is received by the sensor, the degree of which depends on the ion activity of the solution that is being measured [41]. For the reference electrode, an electrochemical potential is maintained regardless of the solution being measured. It is the difference between these two potentials that allows the sensor to determine the pH value through the Nernst equation [41]. The Nernst equation provides a direct correlation between a solution's ion activity and the measured voltage by portraying a graphical slope for change in one pH unit, characterized by a portion of the Nernst equation referred to as the Nernst slope (S) [41].

$S = -2.303\ RT / nF$ where R and F are constants, T is temperature, n is charge of ion, which in the case of a hydrogen ion (H+) is 1.

1.32 Conductivity Sensor

The Xylem Analytic's YSI 700 IQ conductivity sensor was chosen to monitor the water's ability to conduct electrical currents. This measurement is done through the application of AC voltage to nickel electrodes [41]. When submerged, an electrical sine wave voltage is applied between the two nickel electrode plates, allowing for the current to be measured. The relation of current to conductivity, or the inverse of resistivity, is determined through Ohm's law [41]. Electrical current is dependent on ionic charge present within the solution as well as cell geometry. Measured in Siemens (S), conductivity is standardized to compensate for the variation in cell geometry, expressing conductivity in S/cm to allow for variations in electrode dimensions [41]. A schematic of the conductivity sensor used is shown in the following figure.

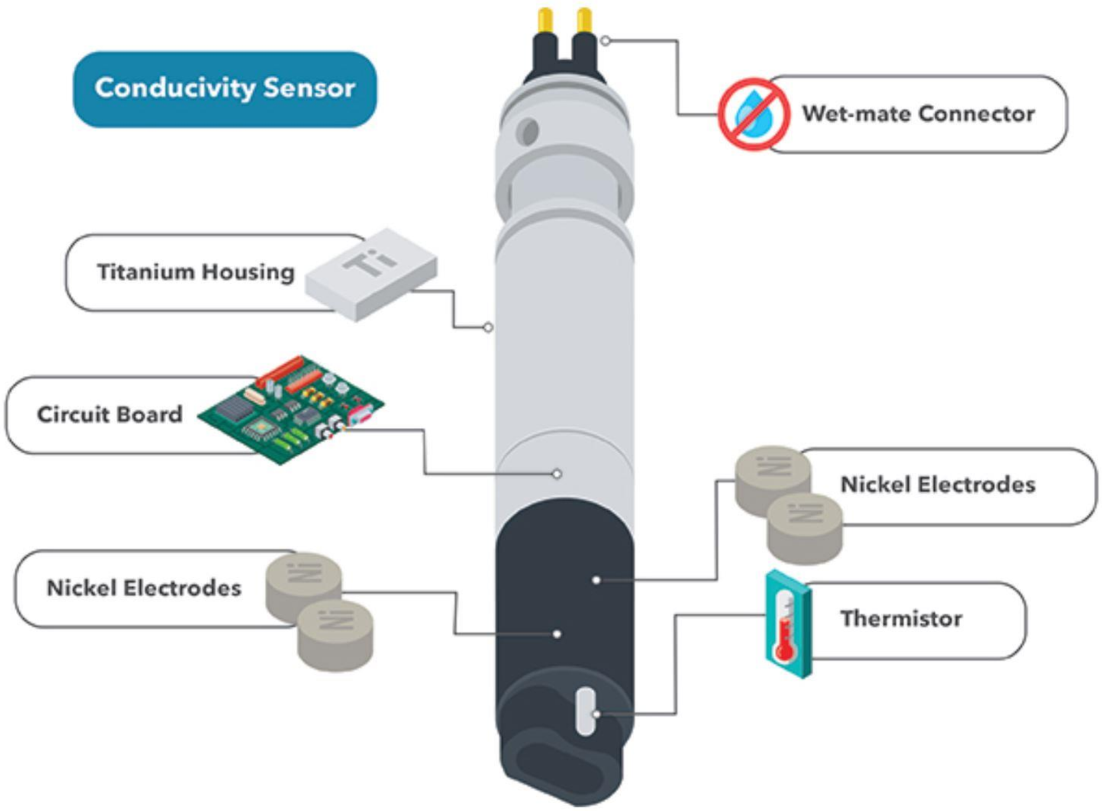

Figure 9: Conductivity Sensor Schematic

3.33 Nitrate and Ammonium Sensor

The Xylem Analytic's YSI NH4 & NO3 VariantPlus sensor was chosen to monitor the water's nitrate and ammonia concentrations. This sensor probe utilizes a silver and silver chloride wire electrode encased within a custom, and proprietary, filling solution [41]. This internally contained solution is separated from the outside environment by a "nonactin" membrane that selectively interacts with NH4 ions. Using ion selective electrode measurement, the desired signal occurs in form of a potential, or potential differences, measured in voltages [41]. This potentiometric procedure provides a data resolution of 0.5 mg/l for NO3 and 0.1 mg/l for NH4 with a response time of under three minutes. Using the Nernst equation shown in the following figure, the sensor contains a fixed U0 ion value to determine the signal's increase and decrease as concentration changes [41].

$$U_{ion} = U^{0}{}_{ion} \pm S \cdot log(a_{ion})$$

Figure 10: Nernst Equation

To relate the Nernst given signal characteristics to nitrate, a synthetic material membrane is used to absorb ion sensitive substances. The following figure shows the correlation of nitrate concentrations to the signal received, with the curve differing from the straight line function only when concentrations are below 1 mg/l [41].

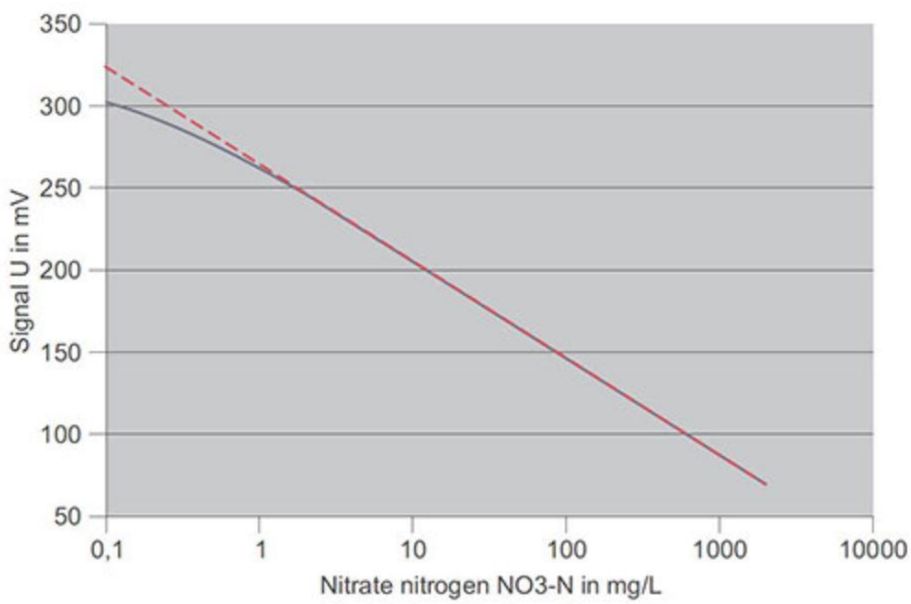

Figure 11: Real characteristic curve of a nitrate Ion Selective Electrode (solid line) and theoretical Nernst function (dashed line)

3.34 Turbidity Sensor

The Xylem Analytic's YSI IQ SensorNet VisoTurb Sensor was chosen for the optical monitoring of turbidity or total suspended solids (TSS). Utilizing nephelometric measurement, or the use of a light beam passing through a sample to measure the scattered light from suspended particles, within wastewater, a highly turbid environment, creates the issue of solid accumulation interfering with measurements. Because of this, the sensor is integrated with an ultrasonic cleaning device to create high frequency oscillations, preventing build-up within the optical window [41]. During a Xylem YSI case study the sensor was placed within a municipal activated sludge tank for 30 days in two conditions: with the ultrasonic cleaning function turned off and turned on [41]. The following figure to the right shows the results, with the cleaning function on conveyed in the top portion and cleaning function off conveyed in the bottom.

Figure 12: Turbidity Sensor Cleaning Function On (Top) and Cleaning Function Off (Bottom)

3.35 Dissolved Oxygen Sensor

The Xylem Analytic's YSI IQ SensorNet TriOxmatic Digital Electrochemical Probe Dissolved Oxygen Sensor was chosen for monitoring the water's dissolved oxygen concentrations. This digital electrochemical method of measuring dissolved oxygen uses an anode and cathode within an electrolytic solution [41]. The electrical current passes through the sensor's semi permeable membrane registering with the TriOxmatic sensor's 3-electrode patented system. This system consists of two silver electrodes and one golden cathode. The silver anode functions as the non-current bearing electrode of reference, while the two silver anodes are used as current bearing, or "live" anodes [41]. The purpose of the reference anode is to increase signal stability, enabling a higher accuracy of measurement. The electrical current's measurement is then correlated to oxygen concentrations of up to 60 mg/l [41].

3.36 UV/ VIS Sensor

The Xylem YSI IQ SensorNet CarboVis 701Sensor was used for monitoring UV spectral data to proxy measurement the oxygen demand present. Scanning between 200 and 720 nm at 256 wavelength scans per measurement, this sensor uses an 8W two-wire shielded cable [41]. This measurement cycle is characterized in the following figure [41].

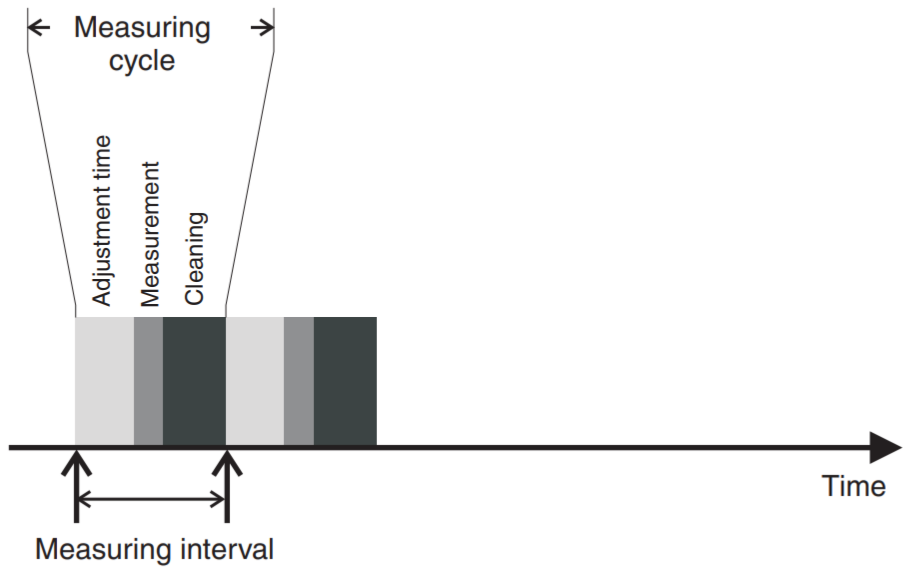

Figure 13: UV/ VIS Sensor Measurement Interval

The sensor's algorithmic relation of absorbance spectrum data to the estimated measured values is shown in the following figure [41].

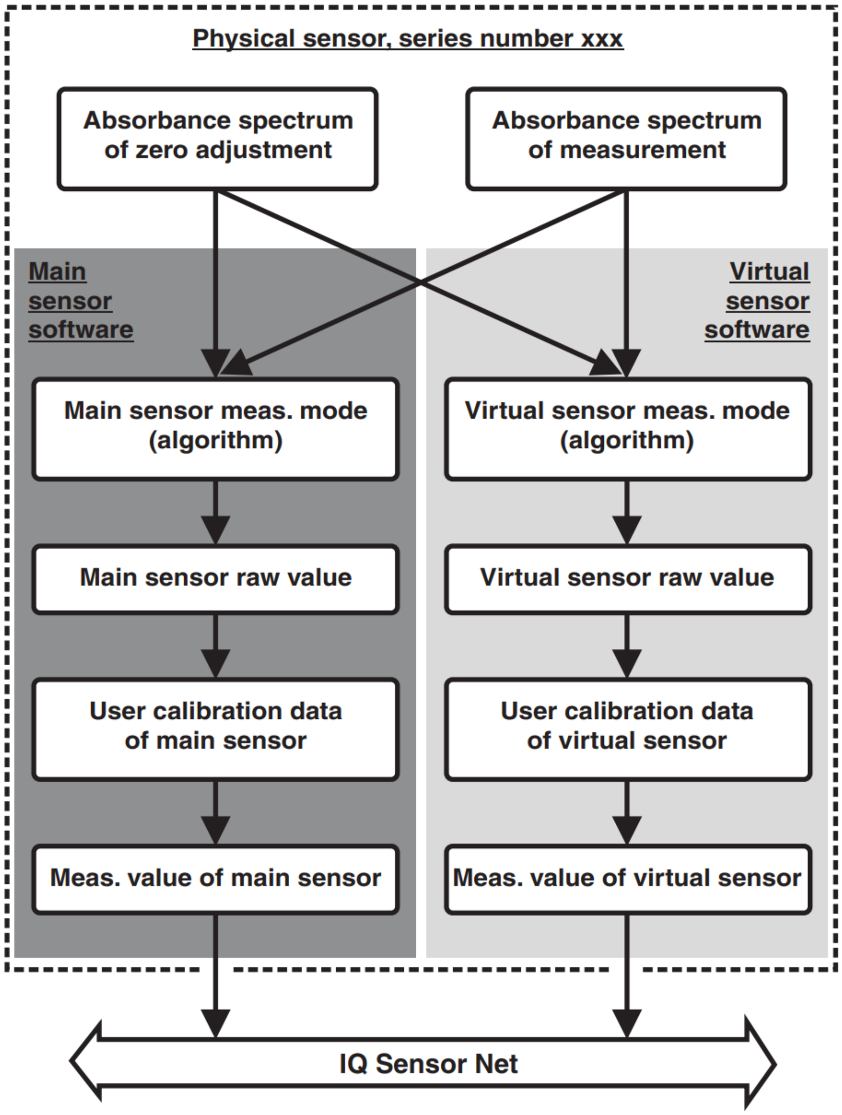

Figure 14: UV/ VIS Sensor Raw Spectral Data Process

Parameters estimated include:

- TSS – total suspended solids
- COD - chemical oxygen demand
- TOC - total organic carbon
- BOD – biochem. oxygen demand
- DOC - dissolved organic carbon
- SAC - spectral absorption coefficient
- UVT-254

Figure 15: UV/ VIS Sensor

The following figure shows the air cleaning system that was installed to combat issues with solids accumulation.

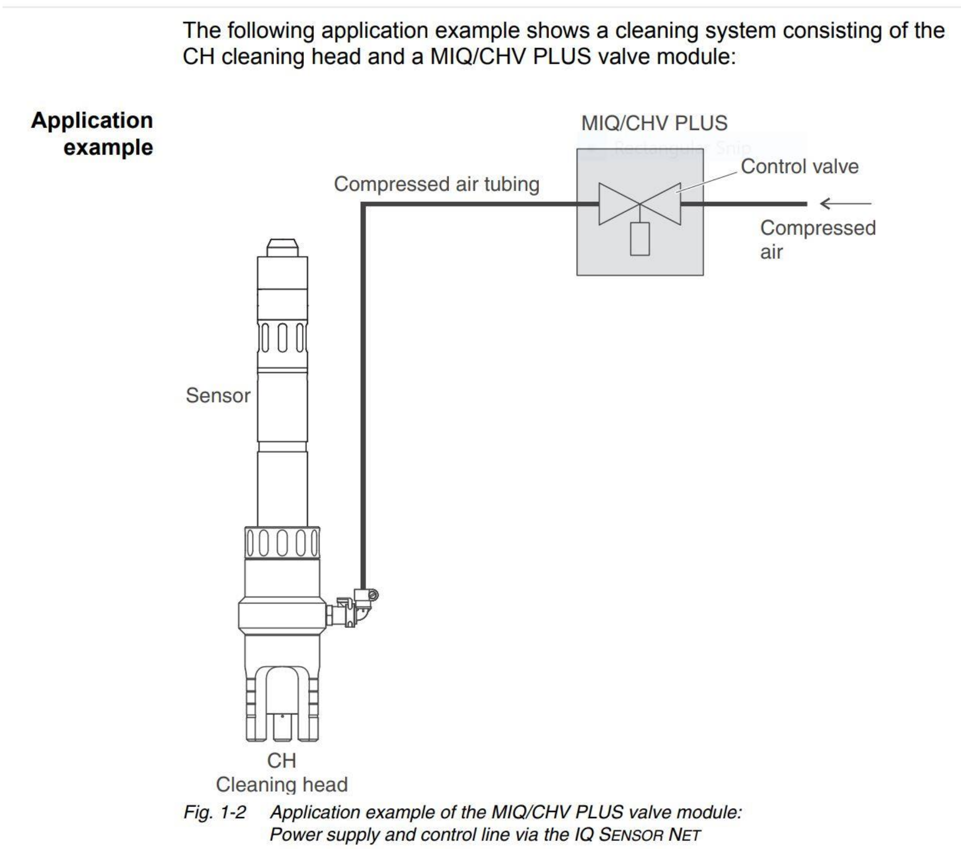

Figure 16: BOD/ COD/ UV VIS Sensor Air Cleaning Installation Schematic

Physical configuration of the BOC/COD sensor is shown in the figures that follow [41].

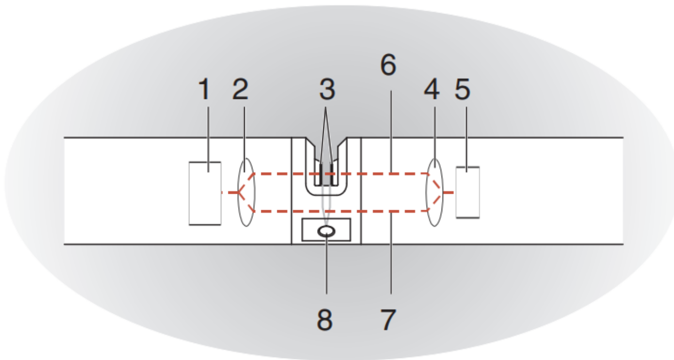

Fig. 1-2 Structure of the sensor

1	Light source
2	Sender of the optical system
3	Measuring gap between the measurement windows
4	Receiver of the optical system
5	Detector
6	Measuring beam
7	Reference beam
8	Connection for the optional compressed air cleaning system

Figure 17: BOD/ COD/ UV VIS Sensor

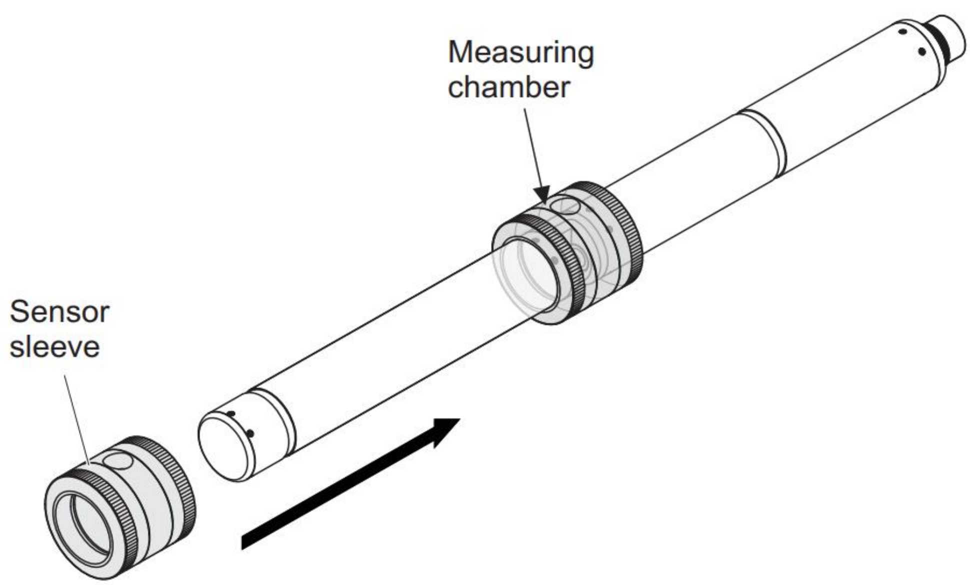

Figure 18: BOD/ COD/ UV VIS Sensor Main Components

This sensor offers three different display options, allowing the user to toggle between functions.

- M button: can switch between “normal“ and PlugIn display
- S button: can switch between quality criteria and spectrum displayed

UVVIS PlugIn is stopped when pressing “ESC” in one of the two PlugIn displays. The toggling between these built-in functions is shown in the following figure.

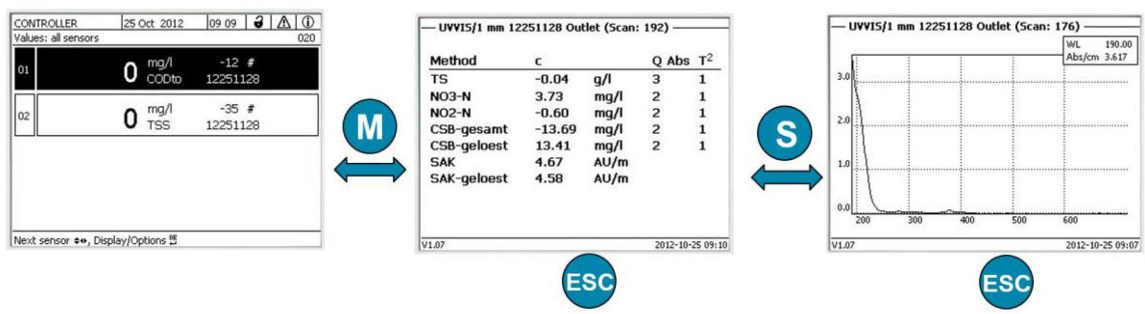

Figure 19: BOD/ COD/ UV VIS Sensor Display Options

For the additional UV/VIS raw spectral data, the manufacturer had to be contacted for the specific code sequences needed to access said data. “UVVIS_PlugIn” can also be used to store spectral data when a USB-Stick is permanently attached to the controller. The data logger function has to be activated by the following code sequence: Press the “C“ button and enter the code 88617.

Table 3: UV/ VIS Sensor Raw Data Reference Values

Default values are marked in bold.

Menu item	Settings	Explanations
Cal - # raw value 1	-10000,00 ... **0,00** ... 20000,00	**Raw value** of the first value pair (lower concentration). For single-point calibration, enter 0.
Cal - ref. value 1	**0,00** ... 20000,00	**Reference value** of the first value pair (lower concentration). For single-point calibration, enter 0.
Cal - # raw value 2	-10000,00 ... **0,00** ... 20000,00	**Raw value** of the second value pair (higher concentration) or **raw value** of the single-point calibration.
Cal - ref. value 2	**0,00** ... 20000,00	**Reference value** of the second value pair (higher concentration) or **reference value** of the single-point calibration.

To avoid data loss, stop the PlugIn before removing the USB-Stick from the controller. A 2 GB-USB-Stick holds approximately two weeks of data collection. Raw data observed through this process is shown in two different formats, tabular and graphical, as shown in the following two figures.

UVVIS/1 mm 12251128 Outlet (Scan: 192)

Method	c		Q Abs	T^2
TS	-0.04	g/l	3	1
NO3-N	3.73	mg/l	2	1
NO2-N	-0.60	mg/l	2	1
CSB-gesamt	-13.69	mg/l	2	1
CSB-geloest	13.41	mg/l	2	1
SAK	4.67	AU/m		
SAK-geloest	4.58	AU/m		

Figure 20: BOD/ COD/ UV VIS Sensor Spectral Data

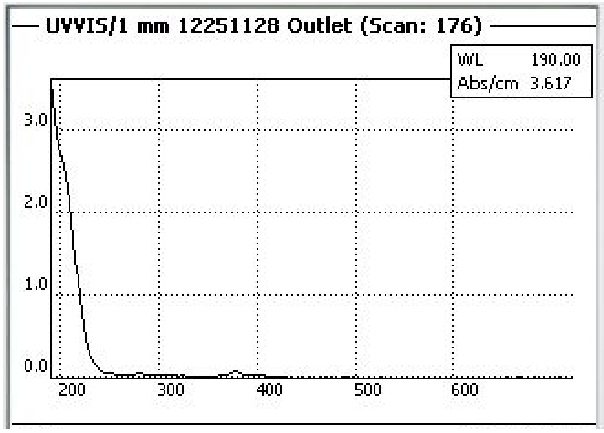

Figure 21: BOD/ COD/ UV VIS Sensor Graphical Display of Spectral Data

3.4 Laboratory-Scale Activated Sludge Treatment

A laboratory-scale prototype has been developed, and data have been collected from the bench-scale WWTP system. Version 1 was less than 5 gallons and was incapable of housing a sufficient microbial habitat.

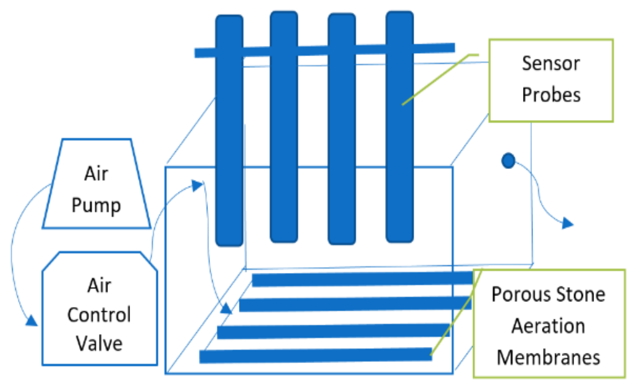

Figure 22: WWTP Microcosm Schematic V1.

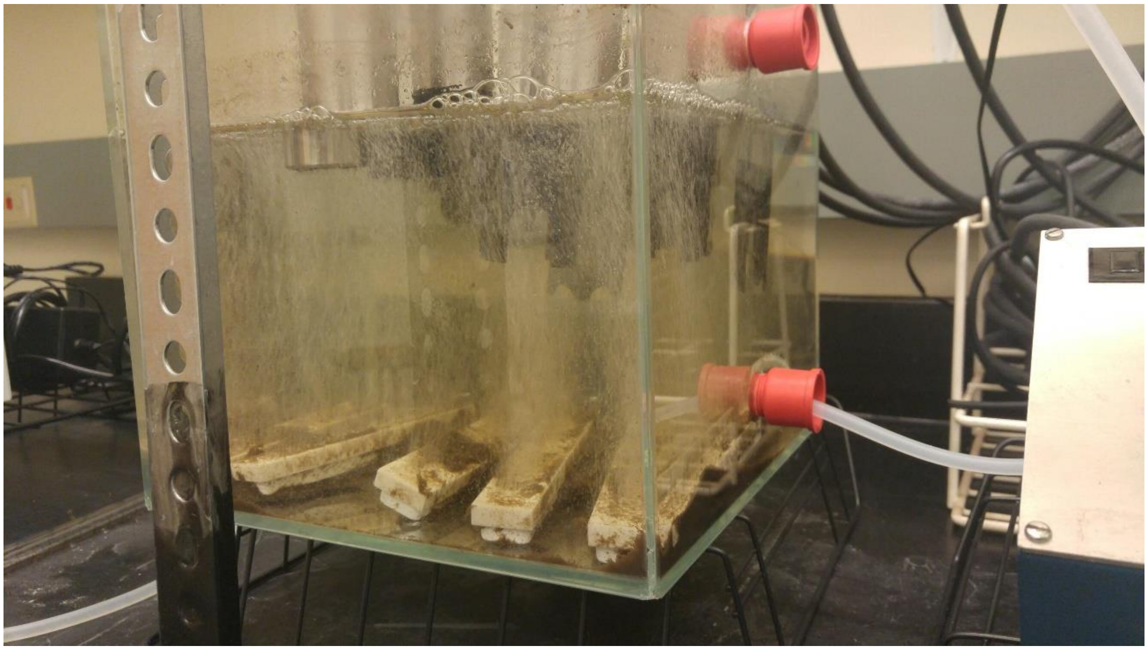

Figure 23: WWTP Microcosm V1

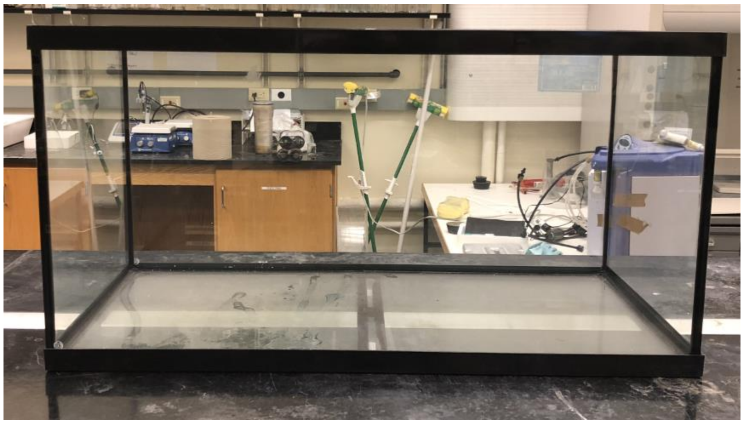

Figure 24: WWTP Microcosm Before

Version two is a 120-gallon reactor fit with the same sensor probes seen in version 1, but with the addition of a BOD/ UV absorbance sensor. The system has been used to mimic that of a full-scale aeration basin by aerating wastewater while monitoring the water's characteristics through the use of real-time wastewater sensors, as previously described in the preceding section. The reactor was constructed by taking a 120-gallon fish tank, as shown in the following picture, then adding clear acrylic baffles to increase the length of treatment train to width ratio, making it more similar to that of a full-scale facility.

Once baffles were successfully installed through high-grade silicon caulk, aeration stones connected to three main air valves were placed to line the entire bottom of the tank. To further explore the potential of aeration decreases, automation of air delivery based on a set parameter threshold was attempted, as shown in Version three and Figure 15, that follows.

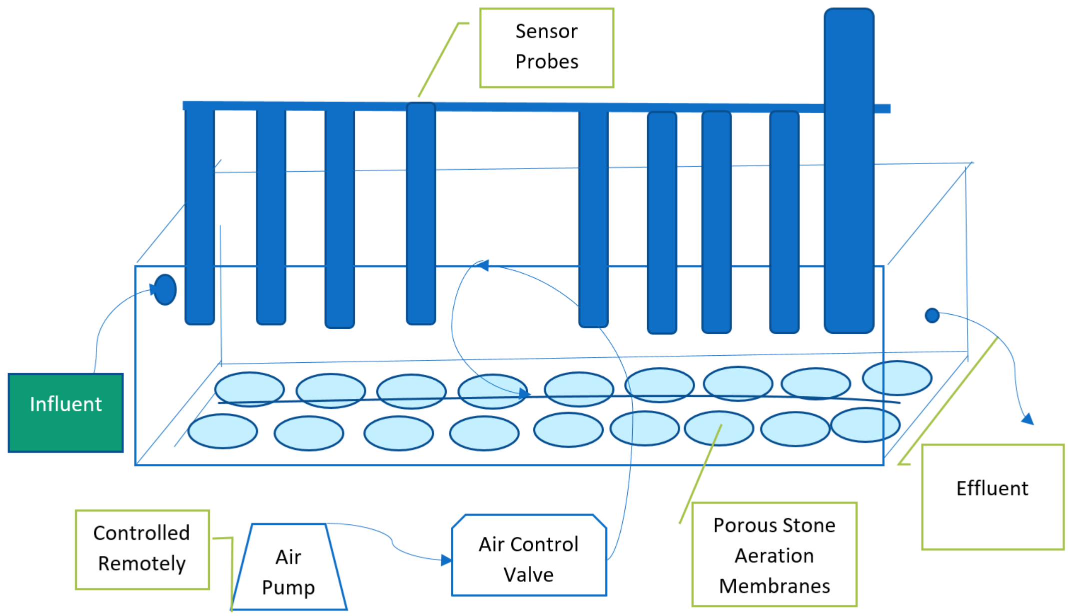

Figure 25: WWTP Microcosm Schematic V2

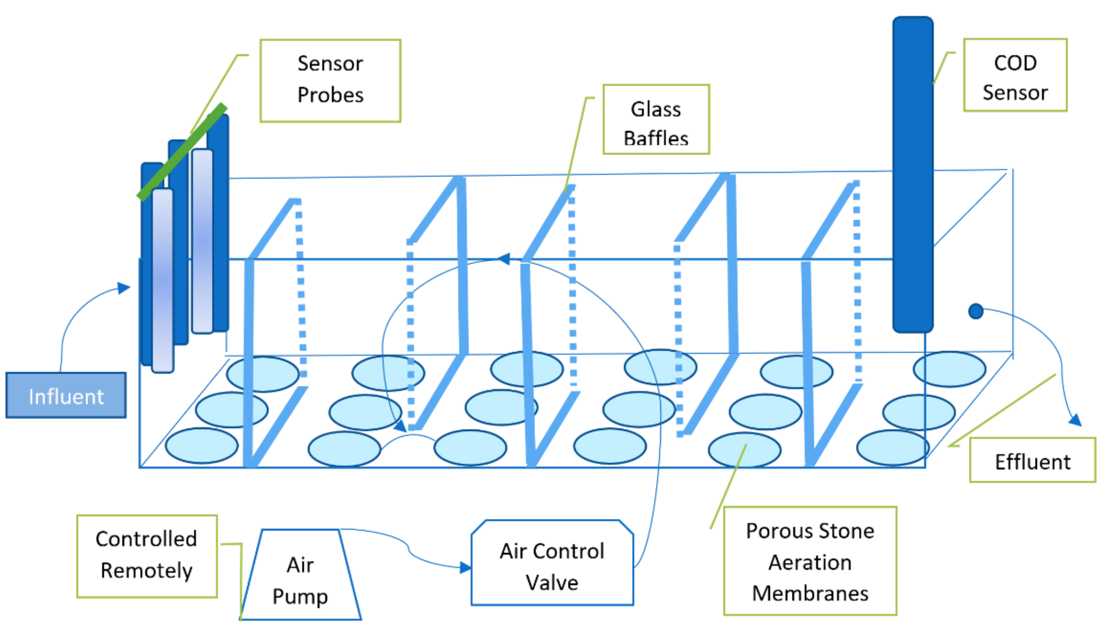

Figure 26: WWTP Microcosm Schematic V3

The laboratory-scale prototype was developed and tested in a bench-scale WWTP system that is shown in the following figure. The prototype system contains digital aeration flow control valve to adjust oxygen delivery to the reactor over time. The system can be used to generate the data needed to develop process models and control algorithms. A successful demonstration of the ability to forecast BOD removal at this scale would provide a justification for the design of a more sophisticated control system in more extensive facilities and an approach to estimate potential energy savings needed to perform a cost-benefit analysis for the product. The logged data are composited into a CSV file and uploaded to a Dropbox folder for retrieval and analysis by the flow-control computer. The flow controller can utilize the data to control the DO delivery while monitoring the concentrations of the various sensor parameters to ensure the DO delivered is still effectively treating the wastewater.

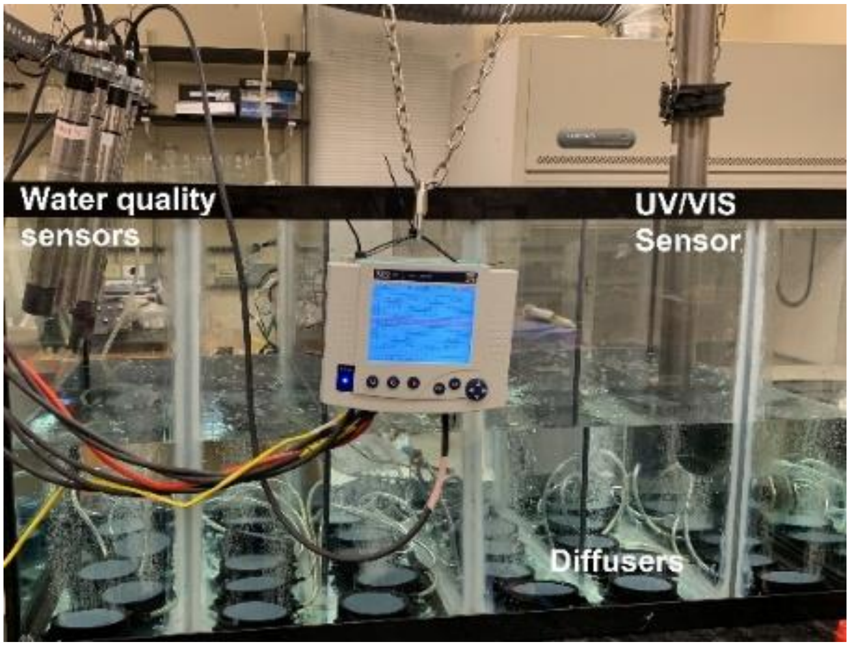

Figure 27: Laboratory Aeration Control

For the synthetic wastewater treated, a straightforward and simple recipe was used of 22.7 g glucose, 22.7 g glutamic acid, and 7.6 g yeast, resulting in a cumulative BOD of 1161 mg O2/ l.

3.5 WWTP Operations Survey

WWTPs within the target range were directly surveyed for water quality data, flow rates, and electric consumption data. The direct emissions from each WWTP were estimated to create a total carbon footprint profile for each WWTP. These emission values were normalized by the functional unit of one MG of wastewater treated. For this investigation, a total of 28 WWTPs serving populations between 10,000 – 100,000 people were surveyed for existing energy consumption and WWTP operational data.

To assess energy and emissions savings potential for these WWTPs within the target range, various in-person and phone interviews were conducted with WWTP operators and city government officials. For municipalities that did not respond to requests for information, the Oklahoma Department of Environmental Quality (ODEQ) was contacted to obtain effluent water quality data from the Discharge Monitoring Reports (DMRs) that each plant is required to submit monthly. The specific data requested from each plant included monthly flow rates, influent BOD, effluent BOD, and energy consumption for 2017.

Since all surveyed municipalities own their respective WWTP, city officials in their utility billing department were also contacted for energy consumption data. Out of the 28 WWTPs interviewed, 11 provided all of the requested information, while the remaining 16 provided enough information about their average daily flow rates and unit processes to provide a basis to extrapolate savings estimates. Record-keeping was a major limiting factor in data collection. Although WWTPs are required to send a DMR to ODEQ monthly, surveyed facilities did not always maintain these records. Data received from each of the 28 studied plants appear in the following table.

Table 4: OK WWTP Survey Data

Municipality	Population	Daily Flow (MGD)	Unit Processes	Bio-Gas Recapturing	Total Energy (MWh/MG)	BOD Removed (Kg)
Ada	17303	2.00			2.00	
Altus	19214	2.01	AS	No	1.98	30933
Ardmore	25176	3.50			2.00	
Bartlesville	36595	7.00		Yes	1.72	
Broken Arrow	106563	4.20			1.79	
Chickasha	16488	2.00	AS		1.79	
Duncan	23231	2.50			1.91	
Durant	17286	1.30	AS, UV	No	1.61	
Edmond	90092	7.33	AS, UV		1.62	112960
Guymon	11921	1.15	AS, CL, AE		5.38	31451.52
Jenks	20740	1.50	AS, UV, AE	No	1.61	
Lawton	96655	9.90			2.49	231098
McAlester	18310	1.50	AS, CL, AE	No	1.79	
Miami	13611	2.29	AS, UV, AE		2.99	39419
Midwest City	57249	6.52	UV, AN	Yes	1.61	139939
Moore	60451	6.00	AS, UV, AE	No	2.00	
Muskogee	38456	7.00		Yes	1.79	
Norman	120284	10.57	AS, UV, AE	No	1.60	151848
Okmulgee	12244	2.14	AS, CL, AE		4.39	32255
Owasso	34542	3.50			2.00	
Ponca City	24758	3.90	AS, CL, AE		1.16	53805
Sand Springs	19783	2.09	AS, UV, AE		2.78	36017
Sapulpa	20579	2.60			2.00	
Shawnee	31286	1.54	TF			19364
Stillwater	48967	4.63	AS, UV, AN	Yes	2.02	
Tahlequah	16598	2.47	AS, UV, AE		1.77	45191
Weatherford	12126	0.91	AS, CL, AE		1.82	20812
Woodward	12993	2.00			1.61	

3.6 Unit Process Energy Consumption Breakdown

Out of the eleven WWTPs that provided all of the requested data, only three had sub-metering specific unit processes. The total energy consumption from the surveys was allocated into four categories: pumping and miscellaneous (lights, heating, air conditions, etc.), aeration processes, solids reduction processes, and disinfection. The energy consumption for aeration systems was extrapolated using data from the sub-metered facilities.

ASP is used for aeration at all surveyed WWTPs except one in the target range. The Shawnee, OK WWTP, uses a trickling filter (TF), which uses biofilms attached to a packed bed medium to remove BOD. TF technologies have been primarily replaced by ASP as they do not always meet treatment goals, require regular operator attention, and have high clogging incidence. The solids reduction process in each facility was categorized as either aerobic digestion (AE) or anaerobic digestion (AN), while the disinfection process can either be ultraviolet (UV) or chlorine (CL). Anaerobic digestion requires natural gas inputs, while chlorine disinfection requires chlorine inputs, both of which add indirect energy consumption and GHG emissions to wastewater treatment.

The survey data were used to estimate five energy consumption factors (ECFs) for each unit process (aeration: AS or TF; solids reduction: AE, AN, or None; disinfection: UV or CL; and all others, OTH) by MWh consumed per MG of wastewater treated. The twelve WWTPs with energy consumption data had four unique configurations (aeration/disinfection/solids reduction): TF, AS/UV/AE, AS/CL/None, AS/CL/AE, AS/UV/AN.

The average daily flow rates, Q, and total energy consumption data for each facility were used with their configurations to estimate energy consumption factors (MWh/MG) for each unit process. The observed total energy expenditures across the year are the sum of the ECFs for each configuration times the total flow:

AS/UV/Ae: Total Energy MWh=Q*(AS+UV+Ae+OTH)

AS/UV/An:Total Energy MWh=Q*(AS+UV+An+OTH)

AS/Oth/Ae: Total Energy MWh=Q*(AS+Ae+OTH)

AS /Oth/An: Total Energy MWh=Q*(AS+An+OTH)

TF: Total Energy MWh=Q*(TF+OTH)

Multiple linear regression was performed using survey data to estimate unit process ECFs. These ECFs were then used to estimate the amount of energy consumed by the ASP, given each plant's average daily flow rate and specific unit processes. Direct energy consumption for chlorination was assumed to be negligible relative to UV processes and was ignored. However, the indirect emissions for the production of chlorine are accounted for with obtained chlorine usage survey data.

The energy consumption for unit processes in facilities that reported energy data were finally adjusted to ensure consistency between the declared energy consumption and that predicted by the individual ECFs. Energy consumption in 14 WWTPs that did not provide energy data was estimated from the unit process ECFs, mean flow rates, and unit process survey data determined from the regression on the other 11 facilities. The WWTPs were compared based on their energy efficiency and specific operations associated with those efficiencies.

3.7 Data Sources Used to Estimate the Current Emissions of Wastewater Treatment

3.71 Direct Emissions of CH4 and N2O

WWTP direct emissions vary across the wastewater industry because various factors such as climate, biogas recapturing, unit processes, and operating DO levels have profound effects. The emission factors used for estimating direct emissions for N20 and CH4 (kg/MG) differ based on unit processes present. The system boundary observed for this study is shown in the figure to the right. If a WWTP utilizes anaerobic sludge digestion, which is the most common, the biogas produced is flared off. This common practice includes burning the produced gas so that the resulting gases (primarily CO2) escaping into the atmosphere have less global warming potential and, therefore, less adverse environmental effects. The assumption that 5% of produced gas

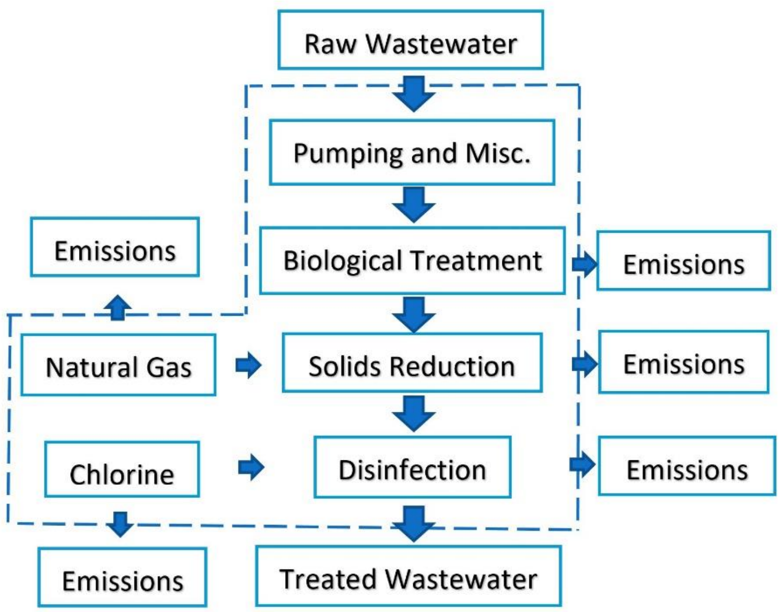

Figure 28: WWTP System Boundary

within sludge digesters is leaking into the atmosphere, and thus not combusted into CO2, comes from Metcalf and Eddy [2]. Direct CH4 emissions are estimated by applying CH4 emission factors on a per-volume basis for each unit process present at the individual WWTP. These direct CH4 emission factors come from long-term emissions monitoring of separate unit processes at a full-scale A/A/O WWTP in Jinan, China [35]. The total N2O emission factor was calculated using EPA's calculation method applied to obtained detailed daily data from Stillwater, OK's WWTP across four years [27], [33]. This estimation method takes into account the flow rate of the water, the concentration of TKN (Total Kjeldahl Nitrogen), and the emission factor of 0.0050 g N emitted as N2O/ g TKN, and is shown in the following figure.

$$N_2O_{WWTP} = Q_i \times TKN_i \times EF_{\mathrm{N2O}} \times \frac{44}{28} \times 10^{-6}$$

where:

N_2O_{WWTP} = N_2O emissions generated from WWTP process (Mg N_2O/hr)
Q_i = Wastewater influent flow rate (m^3/hr)
TKN_i = Amount of TKN in the influent (mg/L = g/m^3)
EF_{N2O} = N_2O emission factor (g N emitted as N_2O per g TKN in influent),
= 0.0050 g N emitted as N_2O/g TKN (Chandran, 2010)
44/28 = Molecular weight conversion, g N_2O per g N emitted as N_2O
10^{-6} = Units conversion factor (Mg/g).

Figure 29: N20 Calculation Equation EPA 2016

No seasonal variability of direct N2O and CH4 emissions was quantifiable within the study. The following tables exhibit all values used in N2O emission calculations.

Table 5: Flow (Qi) for N2O Emission Calculations

Qi					
JAN	inflow avg	4.851	MGD	765.15	m3/hr
FEB	inflow avg	4.777	MGD	753.48	m3/hr
MAR	inflow avg	4.851	MGD	765.06	m3/hr
APR	inflow avg	5.692	MGD	897.85	m3/hr
MAY	inflow avg	4.601	MGD	725.66	m3/hr
JUNE	inflow avg	4.334	MGD	683.61	m3/hr
JULY	inflow avg	4.293	MGD	677.1	m3/hr
AUG	inflow avg	4.518	MGD	712.57	m3/hr
SEP	inflow avg	4.659	MGD	734.79	m3/hr
OCT	inflow avg	5.043	MGD	795.35	m3/hr
NOV	inflow avg	5.410	MGD	853.31	m3/hr
DEC	inflow avg	5.071	MGD	799.86	m3/hr

Table 6: TKNi Used for N2O Emission Calculations

TKN			
JAN	NH3 - N avg	24.629	mg/l
FEB	NH3 - N avg	27.181	mg/l
MAR	NH3 - N avg	26.552	mg/l
APR	NH3 - N avg	26.055	mg/l
MAY	NH3 - N avg	24.770	mg/l
JUNE	NH3 - N avg	23.718	mg/l
JULY	NH3 - N avg	22.195	mg/l
AUG	NH3 - N avg	28.009	mg/l
SEP	NH3 - N avg	29.010	mg/l
OCT	NH3 - N avg	29.669	mg/l
NOV	NH3 - N avg	28.914	mg/l
DEC	NH3 - N avg	23.591	mg/l

Table 7: Direct N2O Calculations

	Kg N2O/hr	hr/mo	Kg N2O/mo.	Kg N2O/MG
JAN	0.148	744	110	0.733
FEB	0.161	672	108	0.808
MAR	0.160	696	111	0.790
APR	0.184	744	137	0.775
MAY	0.141	720	102	0.737
JUNE	0.127	744	94.8	0.705
JULY	0.118	720	85.0	0.660
AUG	0.157	744	117	0.833
SEP	0.167	720	121	0.863
OCT	0.185	744	138	0.882
NOV	0.194	720	140	0.860
DEC	0.148	744	110	0.702
	kg N2O/yr:	1373	Avg.:	0.779

Detailed measurements of CH4 and N2O emissions were beyond the scope of this analysis. Still, they are included here to analyze the importance of various other sustainability components on the wastewater life cycle. The following table highlights the values used for calculating direct WWTP emissions along with providing a direct comparison to estimates from the EPA, University of Toronto, National Autonomous University of Mexico, University of New Hampshire, Shandong Jianzhu University, Tohoku University, and Delft University [28], [30], [30], [34]–[36].

Table 8: Comparison of Direct Emissions from WWTPs

Gas	Emission Factor	Literature Source
N2O	0.12	EPA Avg. [28]
N2O	0.02	Hallym Uni. (AN) [30]
N2O	0.502	Hallym Uni. (AE) [30]
N2O	8.82	University of Girona, Spain [58]
N2O	0.779	Final Avg. Exhibited
CH4	242.3	Mexico UNAM [32]
CH4	12.9	Uni. Of New Hampshire [33]
CH4	43.5	Tohoku Uni. [35]
CH4	130.2	Delft Uni. [36]
CH4	11.3	Final Avg. Exhibited

Natural gas consumption at facilities that utilize anaerobic digesters requiring supplemental heating was estimated using Stillwater OK's WWTP's 2017 natural gas consumption documentation. Natural gas consumption was, on average, 140.2 kg/MG, combusting to 385 kg CO2/MG, but consumption varies seasonally. This variation is accounted for with seasonal variation factors, shown in the following table. Indirect emissions caused by natural gas production are discussed in the next section.

Table 9: Natural Gas Consumption

Season	Kg Natural Gas / MG	Kg CO2 / MG	Seasonal Difference
Fall	164	451	0.772
Winter	213	584	1.0
Spring	142	389	0.665
Summer	48.6	133	0.228
Avg.	142	389	

3.72 Indirect Emissions

GHG emission factors for electric power sources, emissions from chlorine and natural gas production, and other inputs to specific unit processes were analyzed to explore the potential for emissions reduction. WWTPs in Oklahoma get their electricity from the SPP generation mix. The SPP generation mix includes production from source categories of coal, natural gas, nuclear, solar, wind, hydroelectric, landfill gas, and other (biomass and petroleum). Daily on and off-peak data for various power generation categories for the 2017 SPP generation mix are publicly available [37].

Table 10: GREET Emission Factors

GREET Emission Factors for Electric Power Generation Kg CO2 / KWh	
Coal	1.03
Natural Gas	0.47
Nuclear	0.002

Using the GREET database, the carbon emission factors for electricity powered by coal, natural gas, and nuclear sources were found to be 1.03, 0.47, and 0.002 kg CO_2 per kWh, as shown in the table right [39].

These factors were then applied to OK electric power source averages for peak and off-peak hours. Peak energy use occurs between the hours of 2:00 and 7:00 PM, especially during summer months. The difference between power generation during peak and off-peak times is that in order to supply the increase in power demand for peak hours, the electricity is generated at higher priced and less efficient power facilities. OK electric power source averages are from 2016 accessed on SPP's website and shown in the table below to the left [37].

Table 11: On and Off Peak Power Production

ON PEAK / OFF PEAK VALUES FOR COAL, NATURAL GAS, AND NUCLEAR ELECTRIC POWER GENERATION		
ON - PEAK		
COAL	NATURAL GAS	NUCLEAR
46.49%	21.47%	6.36%
OFF - PEAK		
COAL	NATURAL GAS	NUCLEAR
41.84%	15.51%	6.73%

Solar power and landfill gas power only have emissions related to infrastructure, so their GHG emissions were ignored. Wind and hydroelectric power were also disregarded due to their negligible carbon footprints once the associated infrastructure is disregarded. The database estimates the life cycle GHG emissions and energy consumption, including the fuel cycle and transportation costs for each energy source [39]. Since infrastructure emissions were not considered in this analysis, renewable power sources, including wind, solar, and hydroelectricity, have no energy consumption or associated emissions. A transmission efficiency value of 0.935 was used to account for the 6.5% in line losses during energy transfer throughout the grid [39].

Other indirect sources of GHG emissions in WWTPs include the production of chlorine gas for disinfection along with the recovery and consumption of natural gas for anaerobic digesters. The life cycle GHG emissions of 1.87 g CO2e per kg chlorine and 0.79 g CO2e per kg natural gas from GREET were used to estimate the emissions from upstream production activities [39]. WWTPs that reported using chlorine for disinfection or natural gas for anaerobic digestion were surveyed for daily usage. These data were used to estimate resource consumption factors by kg per million gallons of wastewater treated. Average chlorine usage from the three surveyed facilities that add chlorine was 2.23 kg/MG. From records obtained from Stillwater OK's WWTP, natural gas usage for anaerobic digesters that do not use captured gas was 141.9 kg/MG. Seasonal natural gas variability was accounted for using factors shown in Table 11.

These resource consumption factors are extrapolated to the remaining WWTPs that use chlorine disinfection or anaerobic digestion to estimate the associated emissions based on average daily flow rates.

3.8 Emission Savings for Reduced Aeration

Potential electricity and GHG emissions savings were calculated by reducing each WWTP's ECF to that of the most efficient surveyed facility, Ponca City, whose ECF was 0.84 MWh/MG treated. Each facility's ECF was compared to 0.84 to calculate both potential savings and cost (in MWh) if the facility could reduce their energy usage for aeration to that of Ponca City. Energy savings were converted into GHG emissions savings using the emissions factor for distributed electricity from SPP [39].

CHAPTER IV

RESULTS

4.1 Goal

Although rooted within the activated sludge basin, this analysis has spanned various aspects key to the understanding of both inputs and outputs to and from municipal wastewater treatment. The study of the wastewater sensors will hopefully provide insight into both the advances and limitations in using modern sensing technology to characterize wastewater. The goal for mimicking a municipal activated sludge basin was that the results from the laboratory-scale WWTP microcosm would provide a clear relationship of external and changeable factors to the wastewater's characteristics and treatment efficiency. Both sampled and synthetic wastewater was utilized for the inquiry of synthetic wastewater being a more straightforward and more time-efficient method of laboratory experiments. Analysis of surveyed WWTP water quality and energy consumption data will hopefully provide information on a previously under-reported section of our societal infrastructure. This information could aid all influencers of treatment facilities, such as operators, city councils, and facility managers, in the decision-making process of potentially optimizing their respective facilities' energy consumption as well as carbon footprint. Results from the use of commercial wastewater sensors used in the lab are presenting in this chapter, followed by those from simulating municipal wastewater treatment within the lab. Next are the results from comparing synthetic to sampled wastewater, and in the conclusion of this chapter is the analysis of surveyed OK WWTP water quality and energy consumption data.

4.2 Wastewater Sensors Utilized in a Laboratory Setting

This section will review the individual assessment of each sensor used, including manufacturer information and laboratory quality assurance testing.

4.21 pH Sensor

The pH sensor used was that of YSI Xylem Analytics SensoLyt 700 IQ. The theoretical calculation for the following figure was the following equation: M1V1+M2V2=M3(V1+V2) with the experimentation of adding 0.0001 HCl in increments of 10mL.

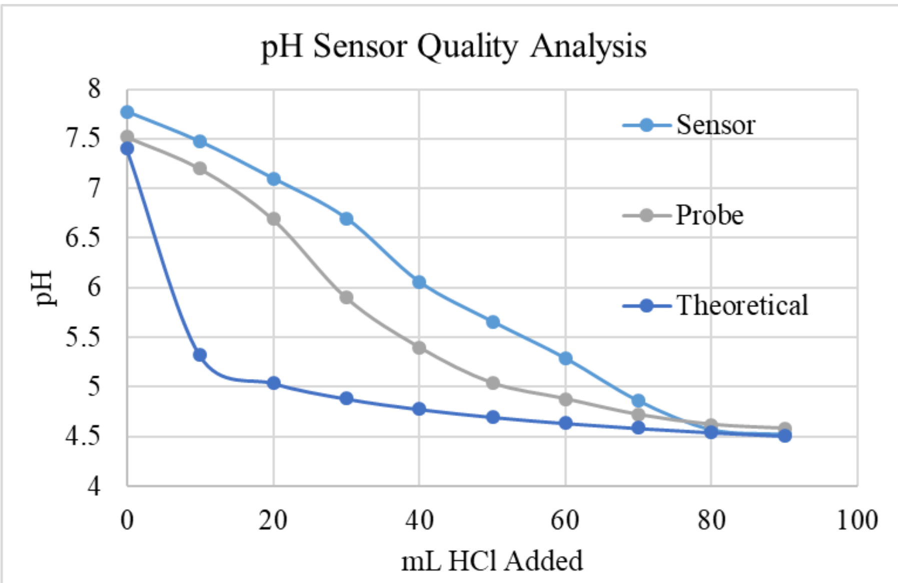

Figure 30: Comparison of Sensor, Hand-Held Probe, and Theoretical Values

This figure shows that although the pH sensor exhibits a significant lag time, it does accurately read the pH eventually. This is significant because if an activated sludge tank is acidifying, the operator will need to know as soon as possible to remedy the reaction by adding sodium bicarbonate ($NaHCO_3$). This inaccuracy in timing should not impede lab work, but will be considered before the planning of any full-scale municipal implementation.

4.22 Conductivity Sensor

The ability to pass electricity in wastewater, directly correlated to the concentration of ions present, can be used to assess the dissolved substances, salts, and heavy metals, within the water in microsiemens per centimeter (symbolized as μS/cm). The Xylem YSI 700 IQ conductivity sensor was chosen to monitor experimentations within the lab-scale WWTP microcosm and said sensors quality assessment was performed with the following equation.

$$Salinity\ (g/L) = 0.4665 \times [Conductivity\ (mS/cm)]^{1.0878}$$

Williams WD (1986) Conductivity and salinity of Australian salt lakes.. *Marine and Freshwater Research*

The sensor analysis was performed by consistently adding salt to the reactor and using the previously mentioned salinity correlation equation. The observed and theoretical conductivity are shown in the following figure.

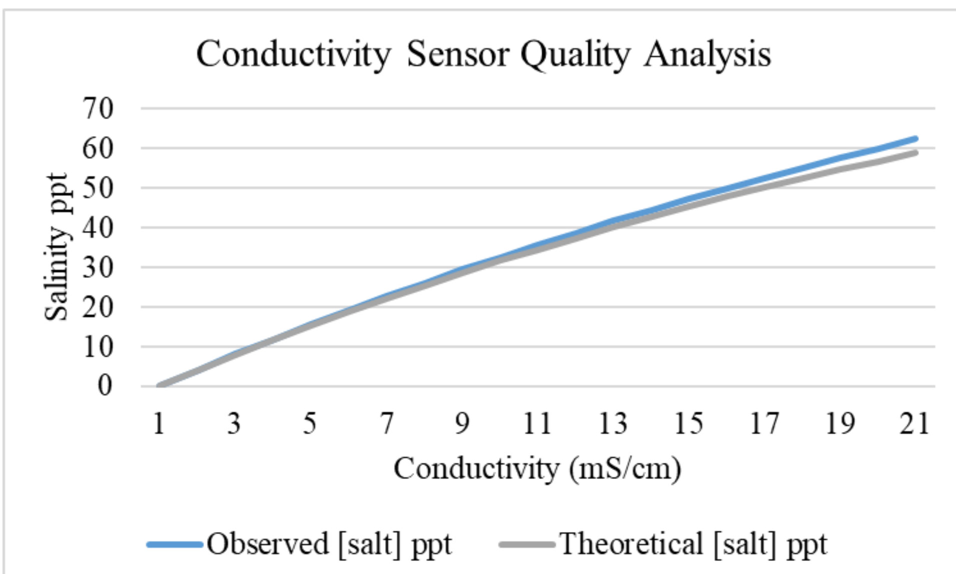

Figure 31: Comparison of Observed and Theoretical Salinity

This figure conveys the conductivity sensor's high accuracy that only begins to fade once salinity concentrations not found in municipal wastewater are reached.

4.23 Turbidity Sensor

The turbidity sensor used, IQ SensorNet VisoTurb 700, measures light scattered by suspended solids or total suspended solids (TSS) in units of mg/l SiO_2. Unlike the conductivity sensor, which measures dissolved particles, turbidity quantifies the water's opaqueness. Quality analysis of the sensor was performed by increasing the concentration of soil in well-mixed water while monitoring the sensor's measurements. The theoretical concentration of TSS was calculated by sampling wastewater during each soil addition increment, filtering the samples, then drying and weighing the filters.

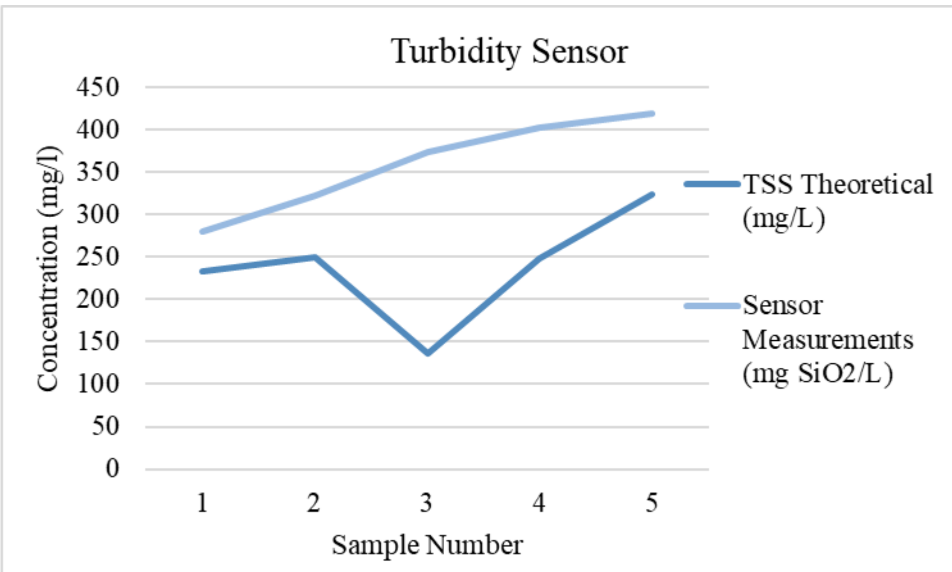

Figure 32: Comparison of Observed and Theoretical Turbidity Concentrations

Turbidity is considered an approximation of biomass present within a reactor, so as treatment of wastewater occurs, the turbidity should increase as the oxygen demand decreases. The experimentation of this relationship using sampled wastewater is shown in the following figure.

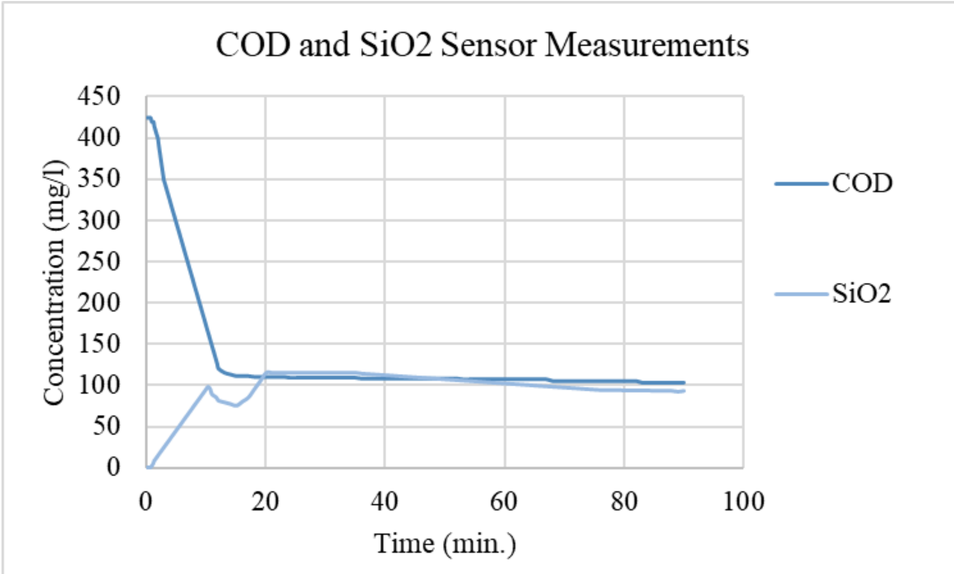

Figure 33: Change in Organic Matter and Turbidity

Because SiO2, the measurement made by the turbidity sensor, is an approximation of biomass, a comparison of SiO2 concentration to theoretical biomass was performed using the assumption of a biomass yield coefficient of 0.4 g cell formed/ g substrate consumed.

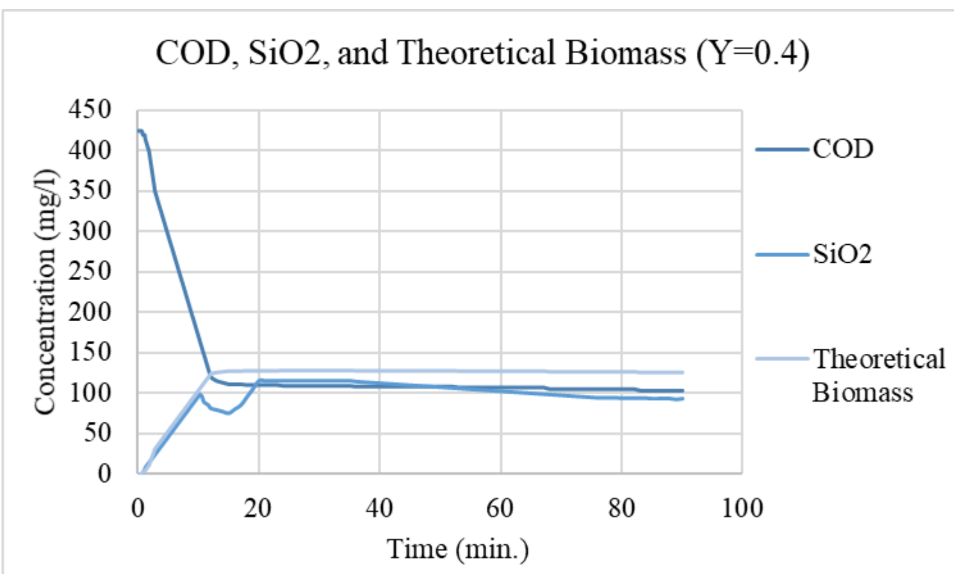

Figure 34: Change in Organic Matter Turbidity and Theoretical Biomass

That same relationship was monitored throughout the treatment process of a simple recipe synthetic wastewater, and results are shown in the following figure where turbidity is shown in mg/l SiO_2.

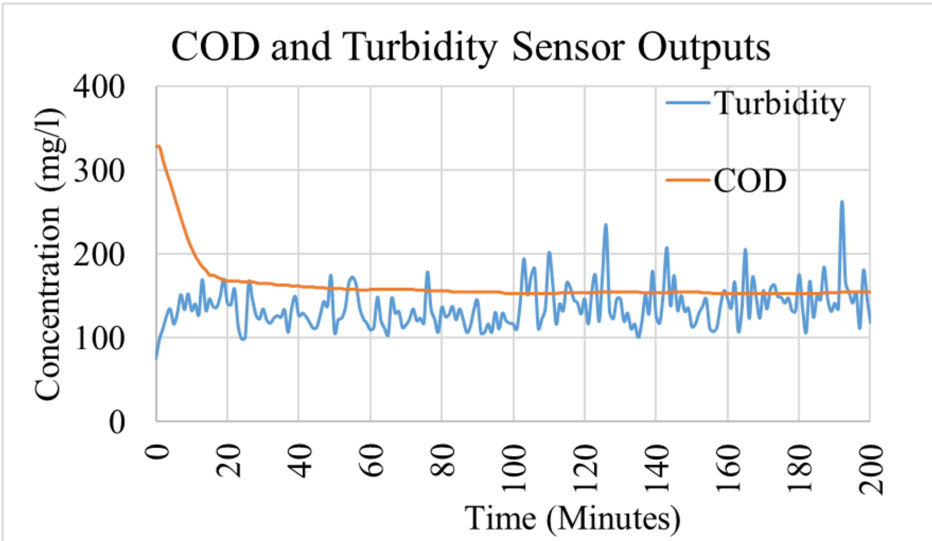

Figure 35: Change in Organic Matter and Turbidity in Synthetic Wastewater

4.24 Dissolved Oxygen Sensor

A key parameter in describing the wastewater treatment process is the dissolved oxygen (DO). The microbial communities within activated sludge consume oxygen at a rate directly correlated to the amount of organic matter it is consuming. The DO sensor used in the lab was the Xylem YSI TriOxmatic Digital Electrochemical Probe.

The following figures compare a model of expected concentration of dissolved oxygen throughout the batch treatment process to what was observed through the use of the DO sensor.

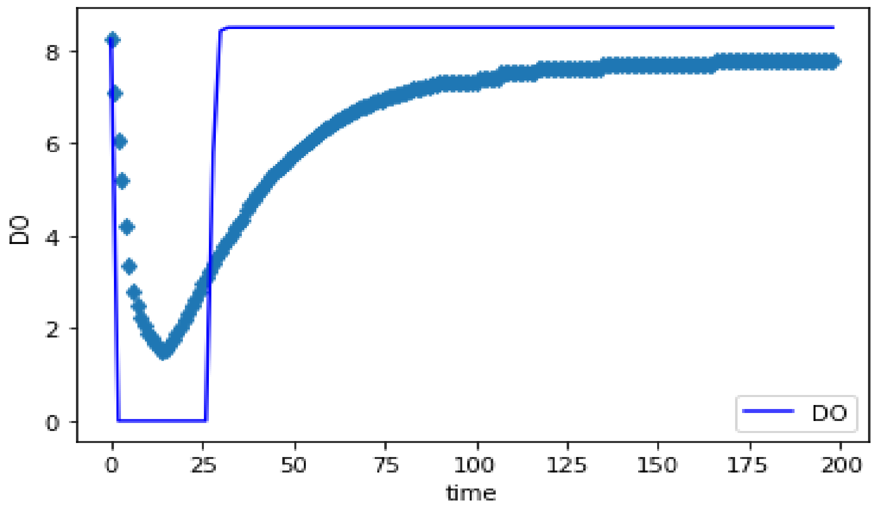

Figure 36: Theoretical Model of DO Changing During Batch Treatment

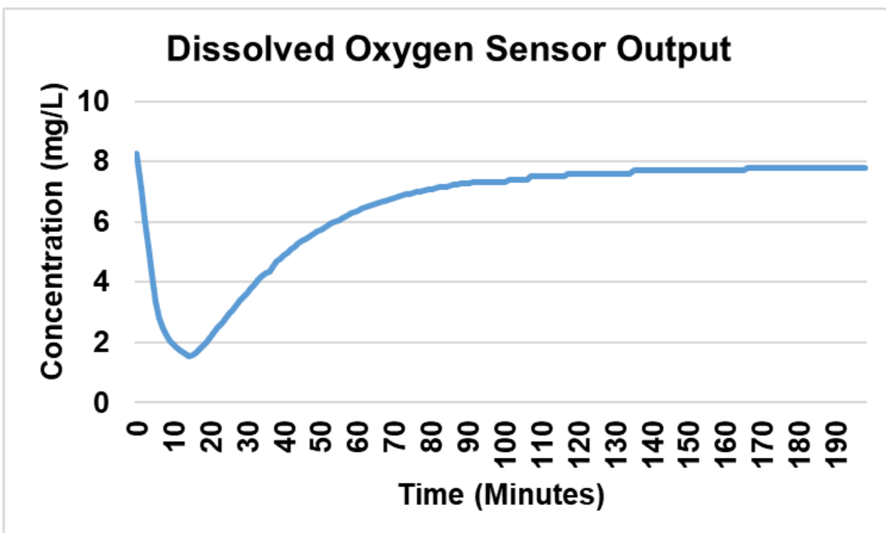

Figure 37: DO Change During Batch Treatment

These figures characterize identical dissolved oxygen drops, signifying high sensor accuracy as well as a functioning microbial community.

4.25 UV/ VIS Absorbance Sensor

Although BOD is a 5-day biological reaction quantified through the observed change in dissolved oxygen concentration, the use of UV absorbance monitoring can provide immediate insight into this otherwise time prohibitive parameter.

Difficulties in solids accumulation or bio-fouling over the spectral reader caused data drifting exponentially to unrealistic concentrations. To quantify the accuracy of the sensor's manufacturer algorithmic estimation of the water's oxygen demand, a highly concentrated (2,600 mg O2/ l) solution was diluted in two broad steps. Follows is a visual comparison of theoretical and observed COD concentrations in the said experiment.

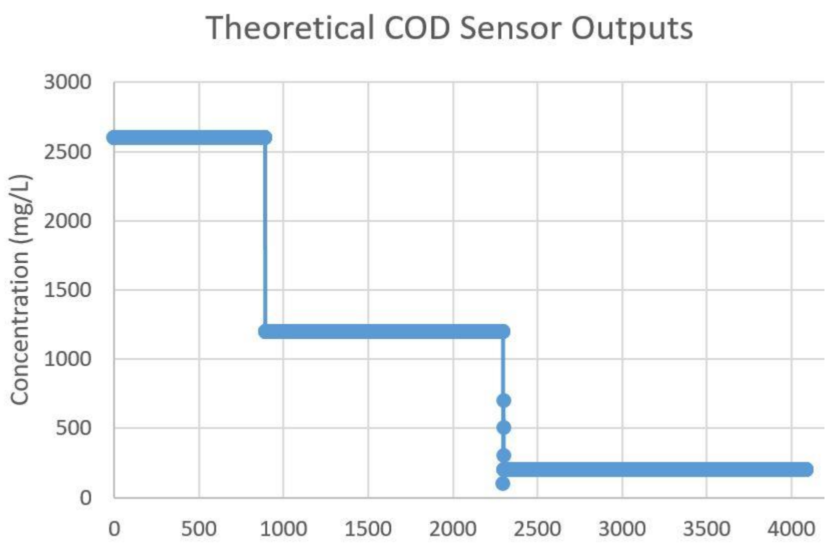

Figure 38: BOD/ COD/ UV VIS Sensor Theoretical Outputs

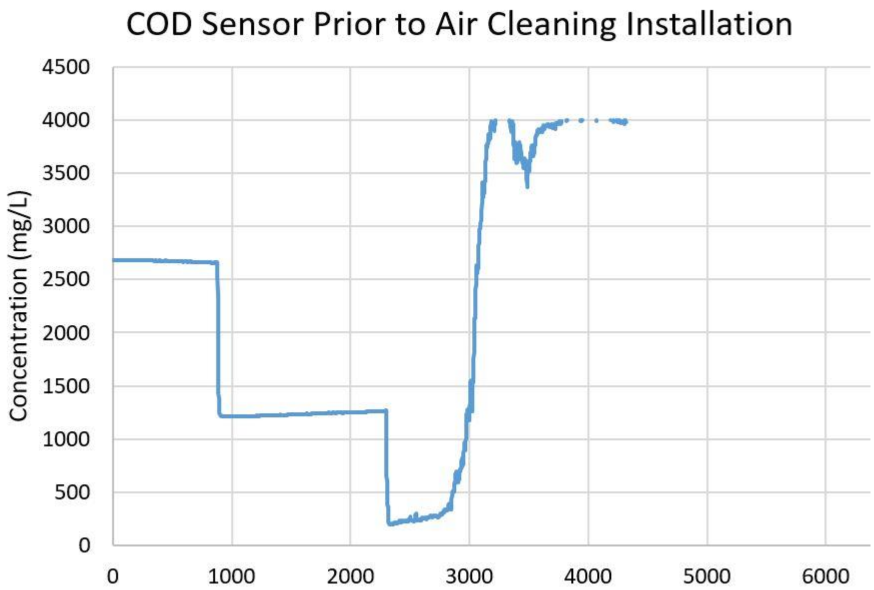

Figure 39: BOD/ COD/ UV VIS Sensor Observed Outputs due to Solids Accumulation

To combat this consistent issue, the first more turbid water was used in hopes that the increased turbidity or mixing of the water would prevent solids from accumulating. This method did not work, and data drifting remained unchanged. Following this technique, the technical support branch of the Xylem YSI manufacturer was contacted for instructional assistance. Because this sensor is meant to be utilized in wastewater conditions with high solids concentrations, the sensor's large hardware comes pre-equipped with an air-entry hole [41].

The previously described instructions were followed with minor changes to utilize pre-existing laboratory items. The following figures show the air cleaning installation process. The red circle denotes where accumulation occurs, and the green circle indicates where the air enters the sensor.

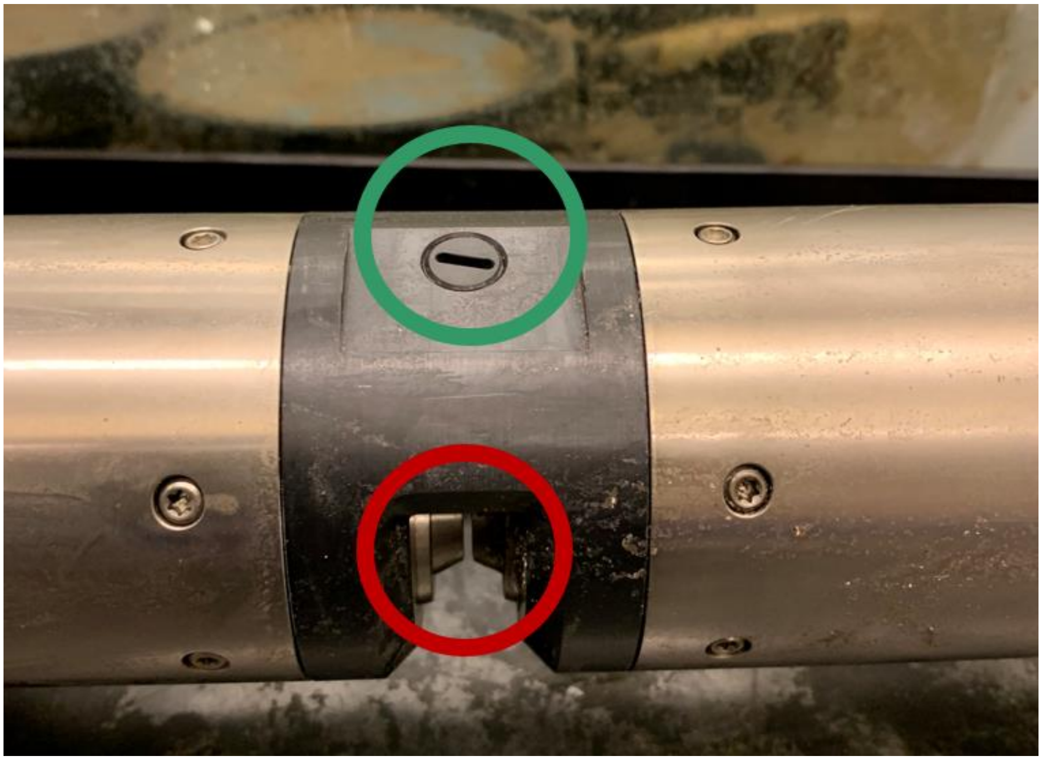

Figure 40: BOD/ COD/ UV VIS Sensor Air Cleaning Installation

Installing an air cleaning system is shown in the following figures.

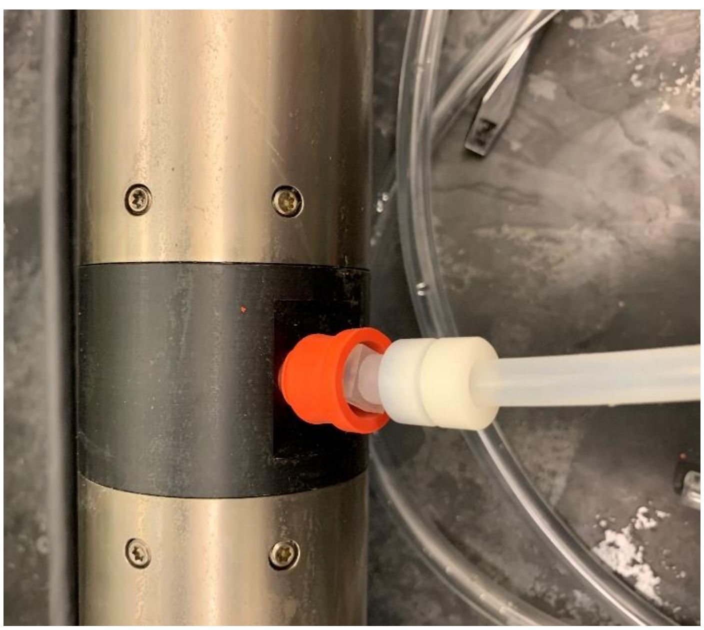

Figure 41: BOD/ COD/ UV VIS Sensor Air Cleaning Input Valve

Figure 42: BOD/ COD/ UV VIS Sensor Air Cleaning Tube Attachment

Once the air cleaning system was successfully installed, the issue of solids accumulating over the measuring gap ceased, no matter the turbidity, as shown in the following figure.

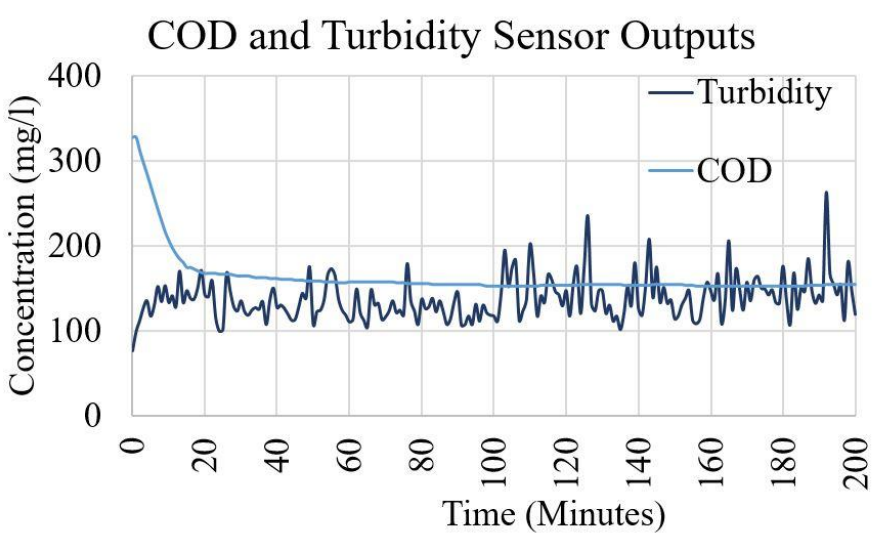

Figure 43: BOD/ COD/ UV VIS Sensor Outputs After Air Cleaning Installation

4.3 Simulating Municipal Wastewater Treatment within a Laboratory Setting

Although used to portray an individual assessment of the UV/ BOD sensor, the previous figure characterizes the successful removal of synthetic organic matter. Although the theoretical BOD was above 1,000 mg O2/ l, the beginning exhibited BOD concentration was 325 mg O2/ l, and the final concentration was 150 mg O2/ l.

When treating sampled wastewater, the beginning concentration was 425 mg O2/ l, and the final exhibited concentration was 105 mg O2/ l.

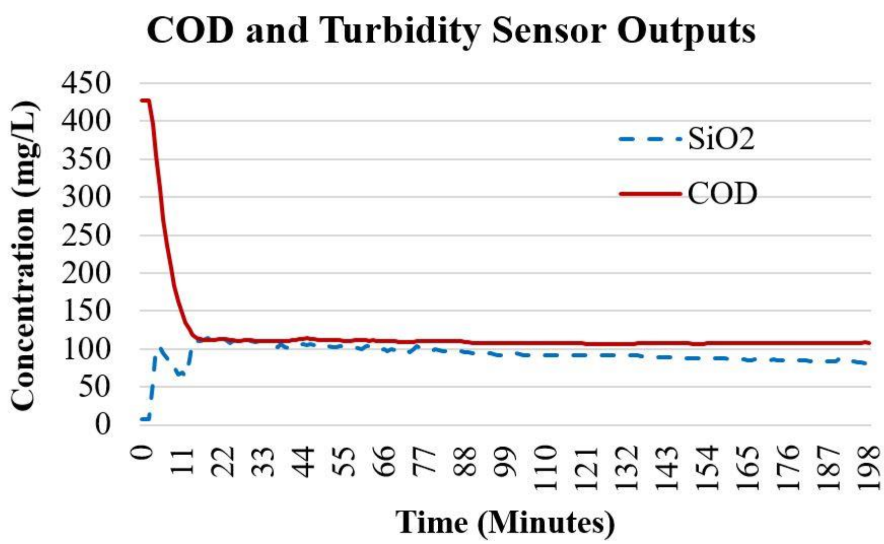

Figure 44: BOD/ COD/ UV VIS Sensor Exhibiting Organic Removal

4.4 Synthetic and Sampled Wastewater Comparison

Although both varieties of wastewater exhibited a decrease in organic matter, as shown in Figure 38 and Figure 39, the observed drop in dissolved oxygen that is typical for activated sludge batch treatment was not exhibited in the wastewater of the synthetic variety. This difference is shown in the following two figures.

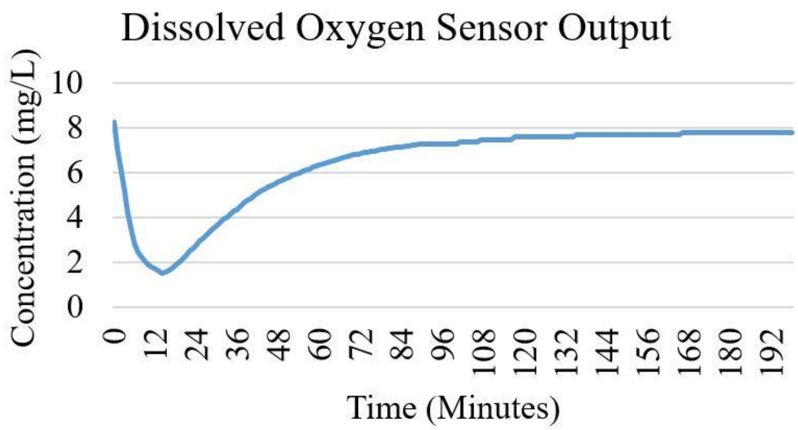

Figure 45: Sampled Wastewater Batch Treatment DO Change

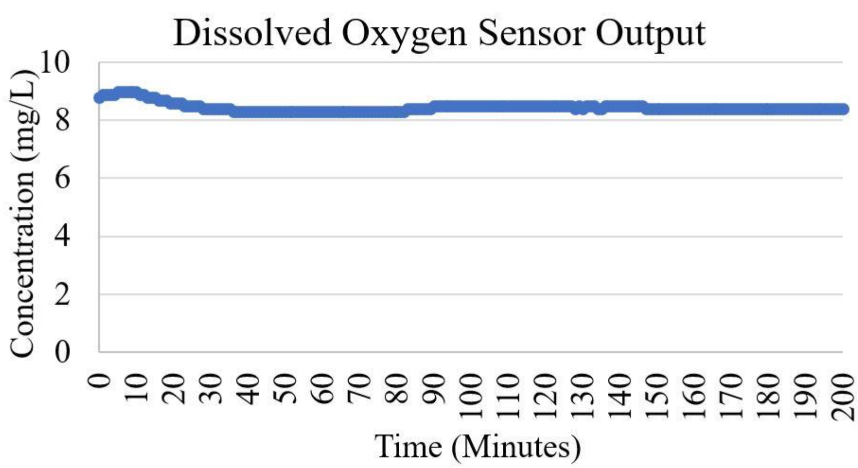

Figure 46: Synthetic Wastewater Batch Treatment DO Change

The difference in DO drops shown in the two previous figures signifies the synthetic wastewater mixture's failure to accurately mimic municipal wastewater.

4.5 Analysis of Surveyed OK WWTP Water Quality and Energy Consumption Data

4.51 Unit Process Energy Consumption

A total of 11 facilities out of the 28 in the target range reported energy consumption data. These ECFs were then used to estimate energy consumption for each of the WWTPs used in the regression. The ECFs for an individual unit process (in MWh/MG), including activated sludge, UV disinfection, aerobic digestion, and anaerobic digestion, are 1,397, 211, 184, and 115, respectfully. A parity plot showing model energy vs. total energy and the correlation coefficient of 0.79 can be found in the following figure.

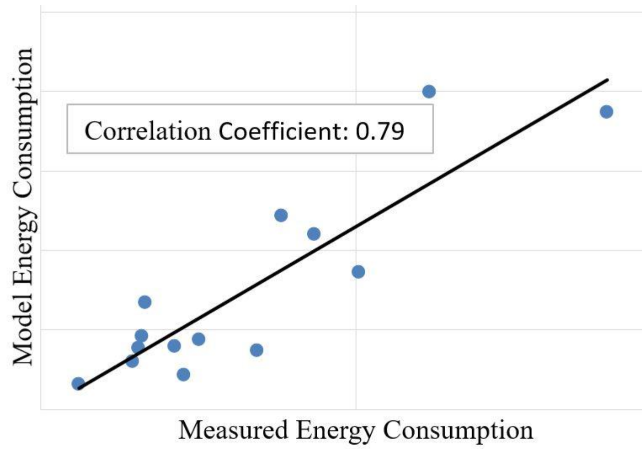

Figure 47: Parity Plot Comparison of Model and Measured Energy Consumption

The unit process energy consumption is shown in Figure 3. The survey results demonstrate that ASPs are the primary energy-consumers in each facility, using 76% of the total. The unit process ECFs in KWh/ MG treated in Table 14 can be used to estimate the total energy consumption for other facilities.

Table 12:Unit Process Electric Consumption Factors (KWh/ MG)

Unit Process	ECF (KWh / MG)
Activated Sludge	1,397
UV Disinfection	211
Aerobic Digestion	184
Anaerobic Digestion	115

The consumption breakdown of each process in surveyed facilities is shown in Figure 44.

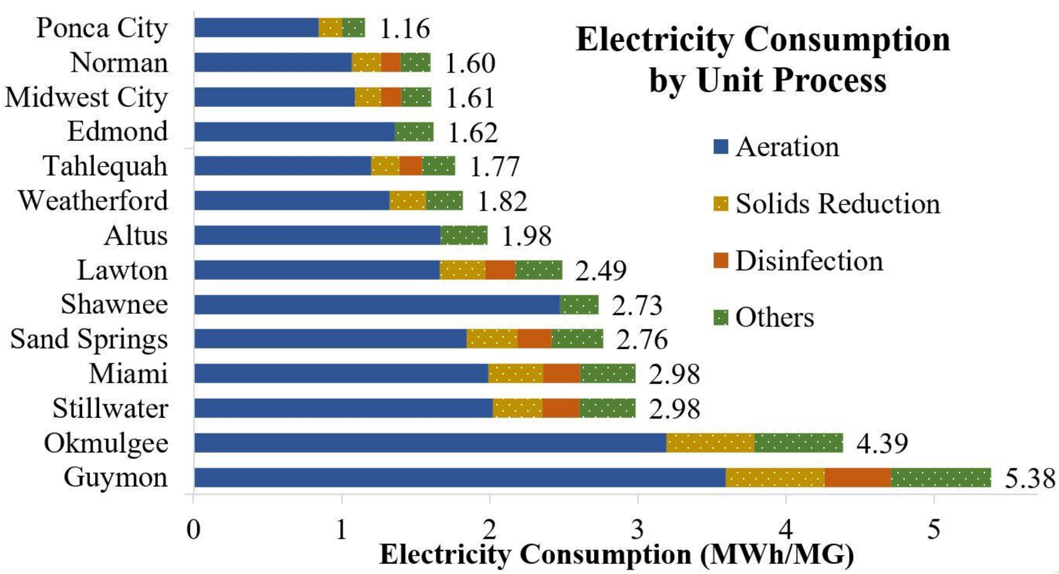

Figure 48: Comparison of OK WWTP Electric Consumption of Unit Processes

4.52 WWTP Direct Emissions

Estimates of WWTP direct CH4 and N2O emissions are relatively sparse, vary substantially across the different facilities and studies, and appear to be continuously changing. For example, from 2000 to 2002, EPA's estimates of WWTP N2O and CH4 emissions in the US increased by over 100% [32]. WWTPs emit GHG's from various reactions, both within the water and the sludge line, under aerobic, anoxic, and anaerobic conditions [42]. Anoxic biological treatment conditions produce approximately 180,000 times less CH4 and 900,000 times less N2O than aerobic biological treatment conditions [43]. Previous studies have found high variability in WWTP direct emissions, mostly dependent on unit processes, biogas recapturing, seasonal changes, climate conditions, and operating DO levels [35]–[37]. The literature indicates that up to 92% of direct WWTP emissions come from aeration tanks [42]. On average, OK WWTPs emit 11.5 kg CH4/MG, making an 8.3% difference from a comparable long-term study of a covered WWTP in Rotterdam, Netherlands [33]. The comparison study's WWTP serves 360,000 population equivalents, and emissions were monitored from October 2010 until January 2012, averaging at 12.5 kg CH4/MG [33]. Total annual direct emissions (CH4 and N2O) for OK

WWTPs is 11.5 kg CH4/MG and 0.779 kg N2O/MG. Direct emissions make up 30% of total emissions.

Table 10 highlights the values used for calculating direct WWTP emissions along with providing a direct comparison to emission estimates from cited literature [35], [37], [37], [44].

The total emissions breakdown is shown in the following figure.

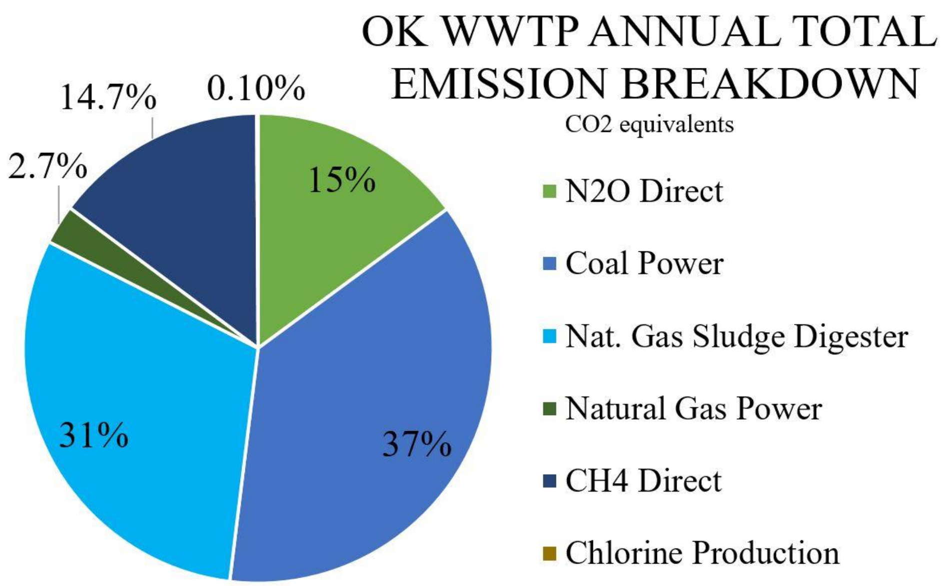

Figure 49: Total WWTP Emission Breakdown

WWTPs that heat anaerobic sludge digesters with natural gas emit 2.744 kg CO2 per kg (CH4 consumed, equating to 385 kg CO2/MG treated, which accounts for 31% of total CO2 emissions. Seasonal natural gas use for anaerobic facilities is shown in the table 15.

4.53 WWTP Indirect Emissions

On average, 70% of total emissions from OK WWTPs comes from indirect sources (electric power, natural gas production, and chlorine production). 29% of total emissions from WWTPs are from electricity used for aeration. Overall, OK WWTPs generate 40% of total life cycle GHG emissions from consumption of electricity, more specifically 37% from coal power plants alone in the supplemental data file. Table 13 represents the average SPP generation mix emissions during on-peak and off-peak hours [45]. "Peak" refers to hours of highest electrical energy usage, making cost/MWh increase [46], [47]. Within the SPP mix, power plants emit more GHGs in the summer months per MWh since the SPP uses the cheapest power plants first, followed by more expensive and less efficient power plants as demand rises in the summer [46], [48]. Because demand peaks primarily occur in the summer, more of the low efficiency, high GHG facilities are dispatched [49], [50]. Monthly power source mix is shown in the following figure, characterizing the increase in coal power during the months that exhibit the highest energy consumption (January and August).

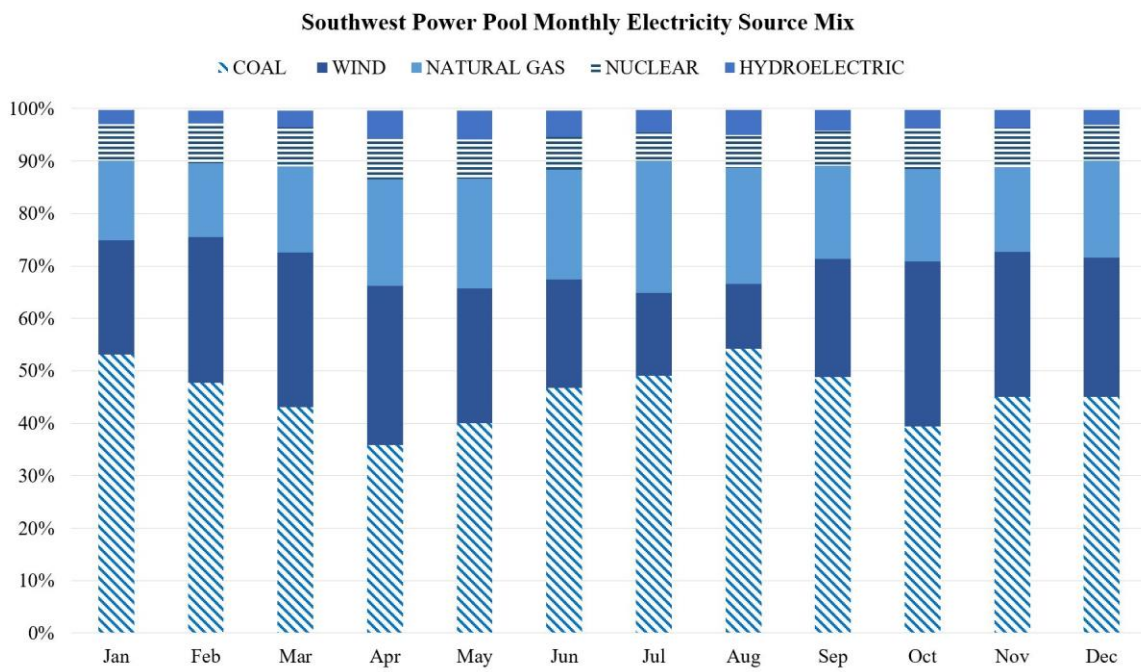

Figure 50: Monthly Power Mix

Emissions from wind and hydroelectric sources are considered negligible for this study. The following figure shows monthly changes in power emissions, with August January and July having the highest emission rates.

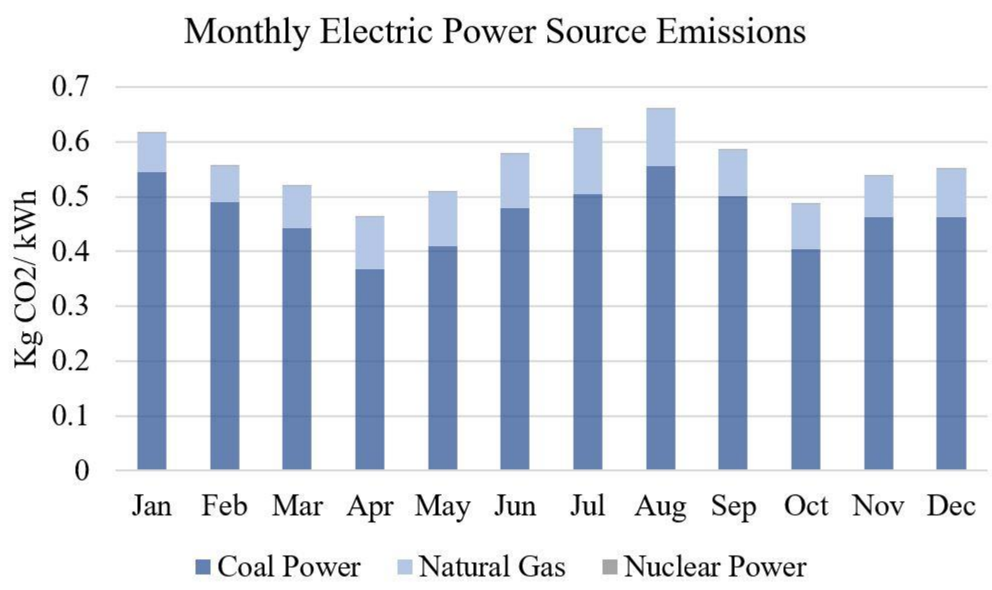

Figure 51: Monthly Power Emissions

Average GHG emissions caused by chlorine and natural gas usage are 1.87 and 0.79 kg CO2 eq./kg on a 100 year GWP basis, respectively, which includes all stages in their product life cycles [51]. Overall, 40% of the total emissions are directly due to power generation, 0.10% due to chlorine, and 31% natural gas production, making indirect emissions account for 70% of total emissions.

4.54 Energy Efficiency Comparisons

Figure 43 shows the electricity consumption for every WWTP surveyed. On average, OK WWTPs consume 1.97 MWh/MG, and 3.31 KWh/Kg BOD removed. The one WWTP utilizing TF treatment, Shawnee OK, exhibited a relatively high electric usage of 2.73 MWh/MG. A comparison of WWTPs with activated sludge and aerobic digestion (AE), activated sludge and anaerobic digestion (AN), and trickling filter (TF) electric energy consumption on both a per volume and per organic removal is as follows.

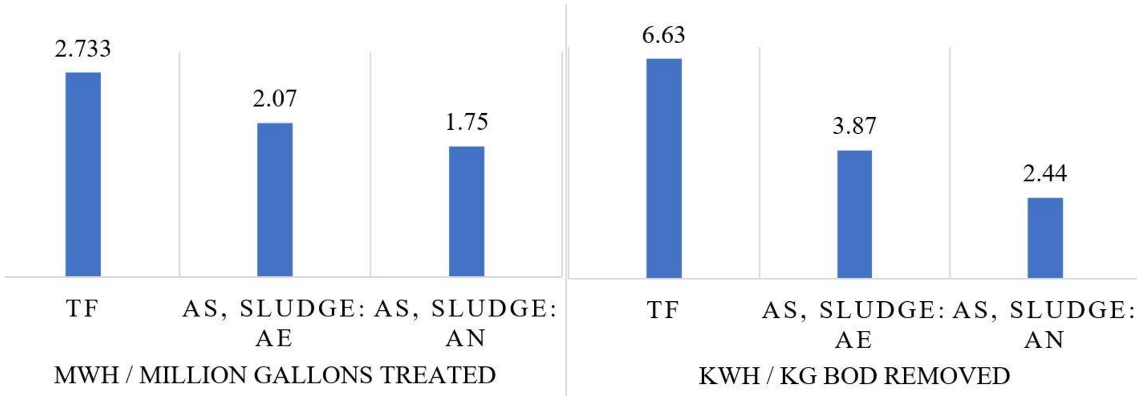

Figure 52: Aerobic, Anaerobic, and Trickling Filter Comparison

The largest energy-consuming facility, found in Guymon OK, consumes 3.59 MWh/MG on average, while the least energy-consuming facility, Ponca City, consumes 0.84 MWh/MG. There are some possibilities as to why these differences are so significant. Personal communications with the Guymon WWTP staff revealed that air blowers are continually running at maximum capacity because they do not possess the technology to adjust airflow levels. Ponca City utilizes a DO control scheme and longer basin retention times to reduce energy consumption.

The consistent operation of blowers at steady rates was observed in over half of the facilities interviewed, which results in wasted aeration energy. Once the oxygen concentration in the wastewater approaches saturation levels, all additional air passes through the water, escaping to the atmosphere without increasing the water quality or the BOD removal rate. WWTP operators need further education and technological means to balance BOD removal with energy costs.

Although aerating continuously at full capacity is common, some WWTPs are working to reduce aeration costs. The Ponca City WWTP uses a DO set-point around 3 mg/L, resulting in a more efficient oxygen transfer while maintaining regulatory compliance. This facility was initially designed for a meat processing plant. Although the meat processing plant was never built, their WWTP can handle higher BOD and nutrient loadings and more massive flows more efficiently. While this facility does not have any extra sustainability enhancing processes such as biogas recapture or land application that might provide indirect GHG emissions savings, it illustrates that placing extra emphasis on the DO set-point can result in energy consumption of 0.84 MWh/MG.

4.55 WWTP Operator Awareness Impact

The reason many WWTPs consume more energy than needed is the lack of incentives for WWTP operators to monitor their energy intake. Every surveyed WWTP operator expressed that their first and foremost concern is meeting water quality permit limits, resulting in energy efficiency losses. During interviews, WWTP operators often indicated that their performance is graded pass/fail based solely on effluent water quality compliance. This disconnect between costs to governing municipalities and knowledge of WWTP energy costs allows efficiency to suffer. In many cases, the facility operators are aware of savings potential, but the institutional structures prohibit changes to reduce energy usage. Officials in municipal governments often lack the expertise to recognize potential energy savings, particularly in smaller communities.

4.56 Potential GHG Savings from WWTP Optimization

During on-peak hours, non-renewable sources account for 68% of the generation mix, while renewable sources only account for 32%. However, during off-peak hours, non-renewable sources drop to 57% while renewable sources increase to 43%. Therefore, one potential strategy to reduce WWTP energy consumption is to shift operations to run during off-peak hours.

GREET factors from various power generation sources are shown in Table 12. An accurate estimation of savings from WWTPs switching to only "off-peak" electricity would require simulating the power grid using economic dispatch modeling and quantifying the different efficiencies of power-producing facilities. Further research is needed to estimate the actual potential benefits of off-peak wastewater treatment.

The following figure separates aeration energy into essential expenditures and potential savings, assuming an aeration optimization strategy was employed.

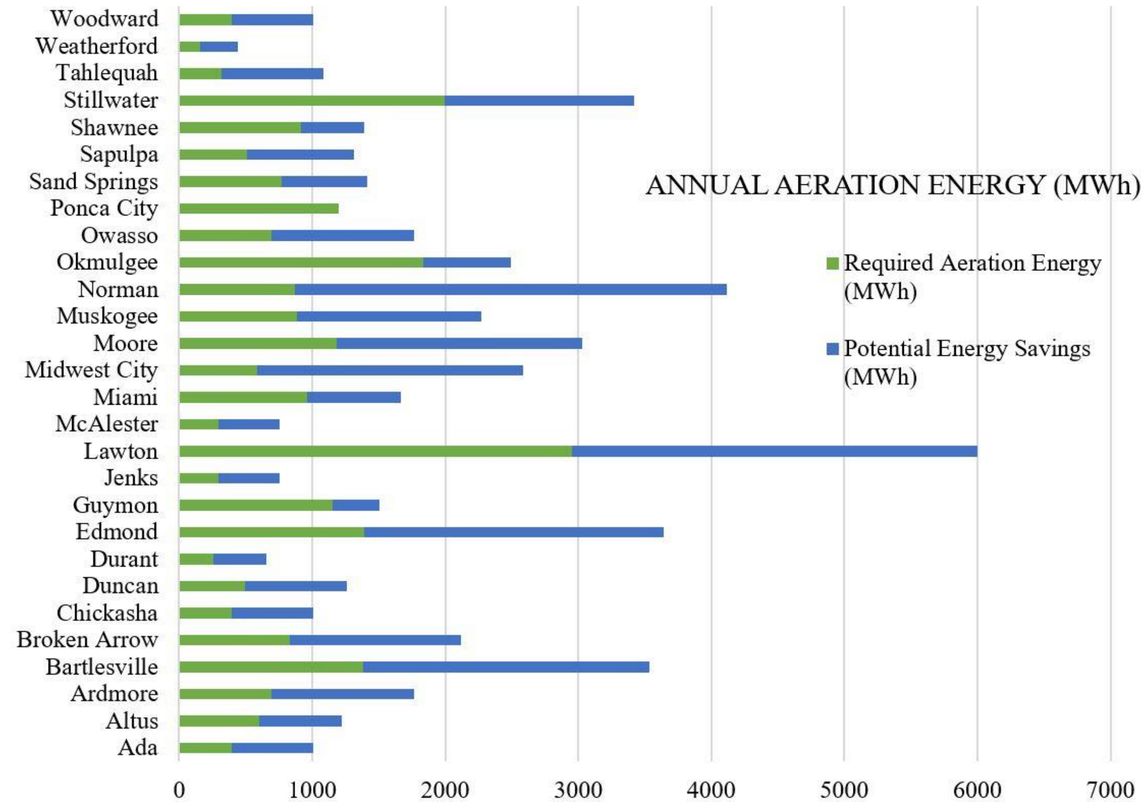

Figure 53: OK WWTP Aeration Energy

These savings are shown in the following table, which directly compares the predicted energy, % error, aeration energy, and percentage, along with potential savings.

Table 13: OK WWTP Energy Prediction

	Predicted Energy (kWh)	% error	Energy (MWh)	Aeration Energy (MWh)	Aeration %	ECF (MWh/ MG)	Aeration Energy Targeted (MWh)	Potential Energy Savings (MWh)
Ada	1,512,721		1,512,721	1,009	0.67	1.38	615	395
Altus	1,205,470	-0.17	1,453,500	1,223	0.84	1.67	617	605
Ardmore	2,647,262		2,647,262	1,766	0.67	1.38	1,076	691
Bartlesville	4,776,905		4,776,905	3,532	0.74	1.38	2,151	1,381
Broken Arrow	2,913,474		2,913,474	2,119	0.73	1.38	1,291	829
Chickasha	1,387,369		1,387,369	1,009	0.73	1.38	615	395
Duncan	1,720,124		1,720,124	1,262	0.73	1.38	768	493
Durant	779,891		779,891	656	0.84	1.38	399	257
Edmond	4,399,933	0.02	4,332,000	3,644	0.84	1.36	2,254	1,390
Guymon	868,260	-0.62	2,256,157	1,505	0.67	3.59	353	1,153
Jenks	899,874		899,874	757	0.84	1.38	461	296
Lawton	7,489,855	-0.17	8,988,000	5,997	0.67	1.66	3,043	2,954
McAlester	1,040,527		1,040,527	757	0.73	1.38	461	296
Miami	1,736,490	-0.31	2,499,719	1,668	0.67	1.99	705	962
Midwest City	4,859,015	0.27	3,821,700	2,588	0.68	1.09	2,004	584
Moore	4,538,163		4,538,163	3,028	0.67	1.38	1,844	1,184
Muskogee	3,121,580		3,121,580	2,271	0.73	1.38	1,383	888
Norman	7,991,519	0.30	6,165,710	4,114	0.67	1.07	3,247	867
Okmulgee	1,483,591	-0.57	3,423,620	2,491	0.73	3.19	657	1,833
Owasso	2,647,262		2,647,262	1,766	0.67	1.38	1,076	691
Ponca City	2,704,609	0.64	1,646,939	1,198	0.73	0.84	1,198	-
Sand Springs	1,586,223	-0.25	2,115,603	1,412	0.67	1.84	644	767
Sapulpa	1,966,537		1,966,537	1,312	0.67	1.38	799	513
Shawnee	1,540,500	0.00	1,540,500	1,393	0.90	2.47	474	919
Stillwater	3,449,772	-0.32	5,043,900	3,416	0.68	2.02	1,423	1,993
Tahlequah	1,846,270	0.16	1,597,637	1,082	0.68	1.20	761	321
Weatherford	634,155	0.05	606,358	441	0.73	1.32	281	160
Woodward	1,199,832		1,199,832	1,009	0.84	1.38	615	395

4.57 Global Warming Potential

The EPA estimates that over 1.6% of N2O emissions are from WWTPs [52]. N2O emissions are highly dependent on an individual WWTP's operations, design, upkeep, and efficiency, making these emissions challenging to estimate [32], [36], [52]. This investigation explored the carbon emissions associated with the treatment of one million gallons of wastewater. The associated system boundary can be seen in Figure 20. Applying the GHG emissions estimation process detailed in the preceding sections, treating wastewater produces 1,622 kg CO2 eq./ MG. WWTPs with anaerobic and aerobic treatment methods are found to emit a total of 1,495 and 1,615 Kg CO2 eq./ MG, respectively. Further research is needed to identify opportunities to decrease

WWTP GHG emissions through different treatment strategies and determine appropriate incentives and regulations.

4.58 Anaerobic and Aerobic Digester Comparison

Two major treatment options exist in sludge reduction: anaerobic and aerobic digestion. For aerobic digestion, oxygen serves as the electron acceptor, making this treatment require aeration blowers [53]. Anaerobic digestion utilizes an alternate electron acceptor (other than oxygen), producing methane that can be captured and burned, and usually requires an outside heat source [53]. An analysis of anaerobic vs. aerobic emissions in Austria, including indirect emissions associated with electrical energy supplied via the power grid, found total anaerobic emissions were 1.52x higher than aerobic [34]. Although generating less direct emissions, the same study found aerobic processes consume 2.54 times the electricity of anaerobic activated sludge [34]. Multiple energy self-sustaining facilities utilize anaerobic digesters, capture the CH4, and use it as fuel for engine generators [23]. Both theoretical calculations and large scale implementation have proven that anaerobic WWTPs can integrate resource recovery processes to accommodate all energy requirements [23], [54]. For colder climates, additional heating energy must be supplied to treatment tanks. Anaerobic and aerobic sludge reduction facilities surveyed were found to consume 1.75 and 2.07 MWh/MG, respectively.

CHAPTER V

CONCLUSIONS

Although a comprehensive knowledge of municipal WWTP energy use and customer segmentation was achieved early-on in this study, understanding the actual microbial communities, how they function, and the technology that can be used to monitor them came much later. Although this knowledge of the bureaucratic and environmental governance of these facilities will be useful in the potential implementation of any optimization technology, it negatively affected the quality of experimentations performed and the broader questions these experiments were attempting to answer.

To accurately simulate a municipal activated sludge tank in a laboratory setting, an understanding of the full-scale variety's inner-workings is required. Energy and water systems are complex and interconnected since energy production relies on water, and water provision and treatment consumes energy. This chapter will discuss this study's main objectives, findings, and what these findings mean in regards to future research.

Each part of this project pertains to one overall goal: increasing the efficiency of municipal WWTPs, especially those with the most potential for energy, and therefore greenhouse gas emission, savings. A laboratory scale WWTP activated sludge tank was constructed for the monitoring and analysis of key water quality characteristics as the water is being treated. In order to utilize this data, an understanding of the sensors, the data they collect, and how best to acquire and store said data was necessary.

For quality assurance and future work, a comprehensive activated sludge model was constructed to allow a comparison of expected and measured sensor values, specifically dissolved oxygen as shown below.

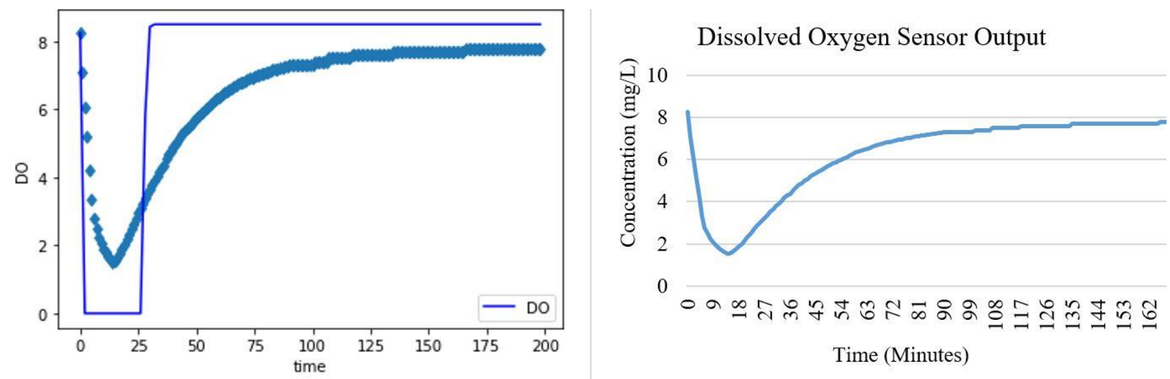

Figure 54: Dissolved Oxygen Model vs Sensor

By monitoring the wastewater while it is being treated, this study created a laboratory environment capable of mimicking a full-scale activated sludge treatment tank so that the system can eventually be used to showcase the direct relationship between water quality measurements, volume of air needed, and electricity saved from the decrease in aeration blower frequency. This study's main objectives and what each objective consists of is shown in the following figure.

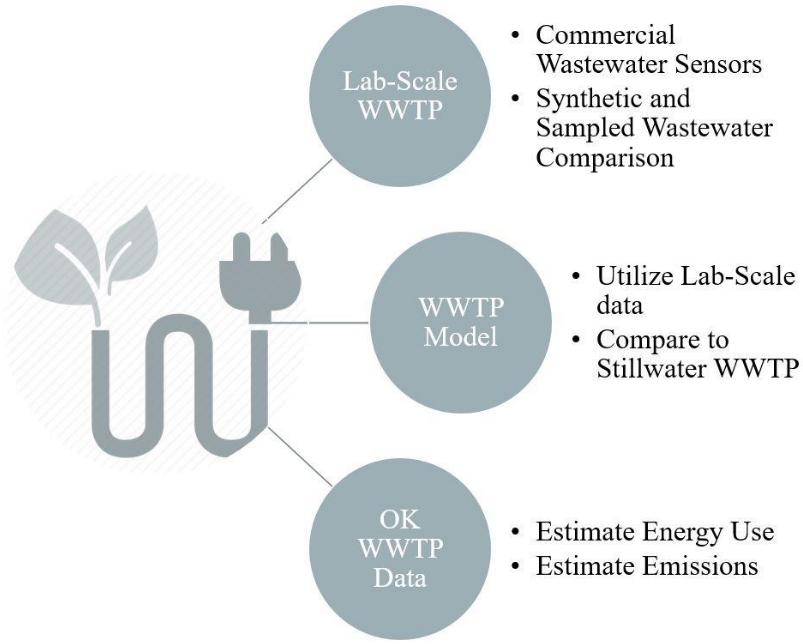

Figure 55: Present Study's Main Objectives

The WWTP microcosm provided insight on multiple ways of creating a microcosm that are not advisable. Using a tank of under five gallons resulted in a complete inability for any decrease in organic matter. A synthetic wastewater mixture of yeast, glucose, and glutamic acid did not exhibit the expected dissolved oxygen or organic matter decrease.

Utilizing on-line wastewater sensors, both sampled and synthetic wastewater were characterized at one minute intervals. The commercial wastewater sensors used were all of the same manufacturer, Xylem Analytics YSI. These on-line wastewater sensors are connected to their respective hub through waterproof cables. The sensor hub is attached to the treatment tank, uploading data once per minute through a local Wi-Fi connection to the Raspberry Pi, which then uploads to a DropBox folder.

Wastewater Sensors Used:

- The pH sensor is less accurate than a hand-held probe
- The pH sensor exhibited a longer lag time than the hand-held probe

- The conductivity sensor is not affected by solids accumulating
- The conductivity sensor is highly accurate, but proved to be less precise at high salinity concentrations
- The turbidity sensor experiences a lag time, but is a valid approximation of biomass concentration
- The turbidity sensor exhibits unstable readings when characterizing synthetic wastewater
- The dissolved oxygen sensor is highly accurate
- The dissolved oxygen sensor is not affected by solids accumulation
- Optical based sensors are effective at characterizing wastewater in real-time
- Optical based sensors require constant air cleaning to combat solid accumulation

Municipal wastewater treatment was simulated effectively within a laboratory setting when using sampled wastewater from the aeration basin at Stillwater, OK WWTP. However, this was not the case when using the simple recipe of synthetic wastewater. A possible solution to this could be allowing the yeast to incubate in water before being added to the treatment tank. When moving forward, a more robust synthetic wastewater mixture will be used. A comprehensive understanding of what each of these key water quality parameters signify, as well as a deeper knowledge into the inner workings of said sensors and the technology that produces their respective measurements, is the greatest result from working with the previously described sensors.

Following a survey of process data from WWTPs serving municipalities between 10,000 and 100,000 people, energy consumption and greenhouse gas emissions were estimated for each facility. Emission estimates show the significance of greenhouse gases produced from power generation, and analyzing variations in power generation mix shows a significant potential for off-peak aeration being a potential solution to increasing overall sustainability. A conservative analysis of potential aeration energy savings provided insight into how the differences in each

WWTP's operation affect energy consumption. This analysis also provided a better understanding of current aeration control practices.

OK WWTP water quality and energy consumption data:

- Aeration consumes 75% of total electricity.
- Average facility over aerates 18%
- 70% percent of total emissions are from indirect sources
- 30% of total emissions are direct emissions (CH_4, N_2O)
- 40% of total emissions are from electricity generation.
- Natural Gas for heating sludge digestion created 30%
- The one trickling filter available for analysis consumed 2.733 MWh/ Million Gallons Treated or 6.63 kWh/ Kg BOD removed
- WWTP's utilizing UV disinfection exhibited higher indirect emissions
- WWTP's utilizing aerobic sludge digestion exhibited higher total emissions due to their increase in electricity consumption
- WWTP's utilizing aerobic sludge digestion consume 2.07 MWh/ Million Gallons Treated or 3.87 kWh/ Million Gallons Treated
- WWTP's utilizing anaerobic sludge digestion consume 1.75 MWh/ Million Gallons Treated or 2.44 kWh/ Million Gallons Treated

This study lead to a better understanding of how choice in unit processes and operational preferences affect resource consumption. The results of this analysis paired with the findings of the literature review has led to the conclusion that the original goal of creating an on-line sensor fed predictive algorithm to estimate required aeration is not needed in order for a facility to be able to substantially increase energy efficiency. Although potential optimization through use of a single water parameter (DO, NH_4) would provide slightly less savings than through use of a multi-parameter method, these savings could be dramatically increased by using less electricity, specifically aeration, during peak hours.

By monitoring the wastewater while it was being treated, this study created a laboratory environment capable of mimicking a full-scale activated sludge treatment tank so that the system can eventually be used to showcase the direct relationship between water quality measurements, volume of air needed, and electricity saved from the decrease in aeration blower frequency.

Looking forward to future work, there will be a greater emphasis on the implementation of aeration control as well as the quantification of energy and emissions savings that said implementation is capable of. A comprehensive knowledge of aeration blowers must be acquired in order to truly analyze the most cost-effective methods for aeration optimization. This deeper understanding of the mechanical aeration blowers will prove incremental for characterizing the direct relationships between water quality measurements, volume of air needed, and electricity saved from the decrease in aeration blower frequency. An exploration into all potential cost-effective remedies for municipal wastewater treatment should be considered in order to provide municipalities with sufficient knowledge for increasing their WWTP's sustainability. An example of such potential remedies include the storage of wastewater during peak hours then treating it primarily at night when ample renewable power is available.

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APPENDICES

Commercialization of aeration technology proposed business plan presentation.

CONTRAIRE

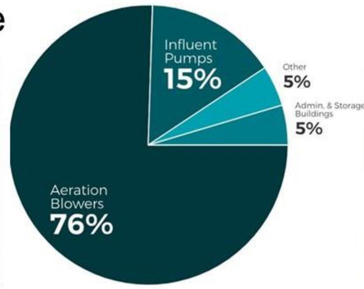
WASTEWATER PLANT TESTING AND AERATION CONTROL SERVICES

We sell outcomes, not products

Rabecca Wiseman
Brooks Robison
contraireservices@gmail.com

Wastewater Treatment Operations

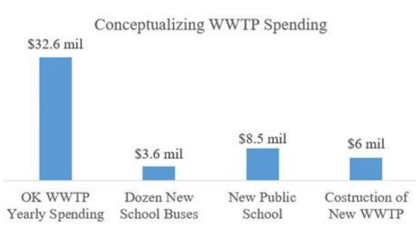
- ➢ Aeration breaks down organic matter
- ➢ Blowers pump air into basins
- ➢ Energy intensive

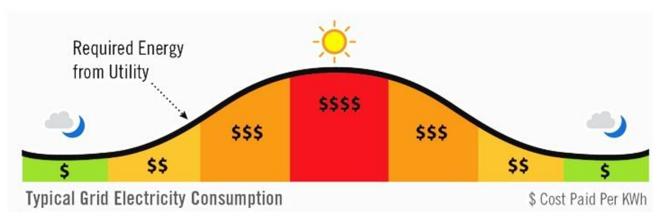


CONTRAIRE

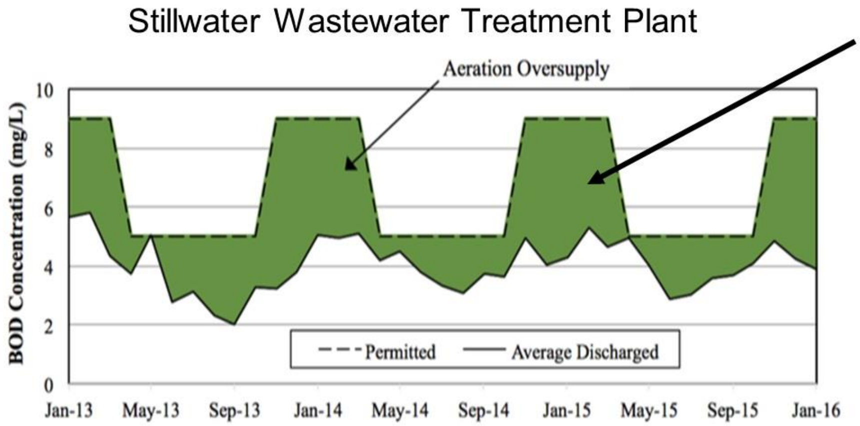
Problem

- ➢ Over Aeration Standard Practice
- ➢ Blowers Run at Full Capacity
- ➢ ~60 % of WWTP Electric Input is Unnecessary
- ➢ Electricity is 25–40 % of WWTP Operating Budgets
- ➢ Excessive Aeration Leads to GHG Emissions





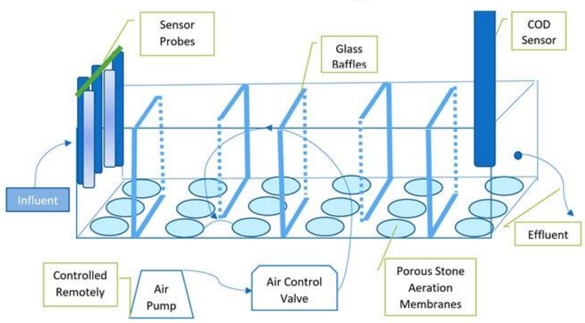
Wasted Aeration Energy



- **45% Excessive Aeration**
- **$300,000/year in Unnecessary Electricity Costs**

CONTRAIRE

Predictive Analysis Solution

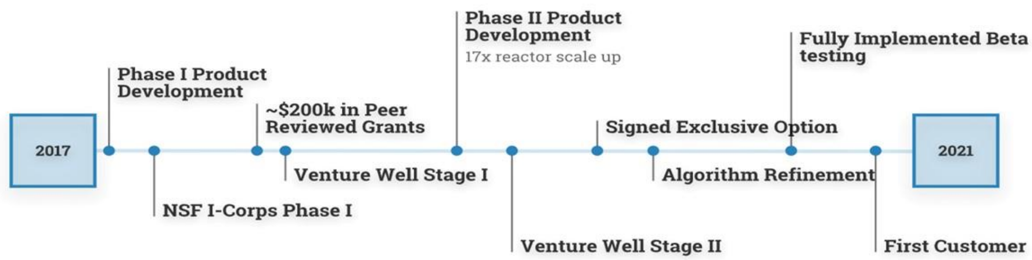


9 Unique Industrial Sensor Outputs → Proprietary Algorithm → "Real-Time" Wastewater Quality & Aeration Control

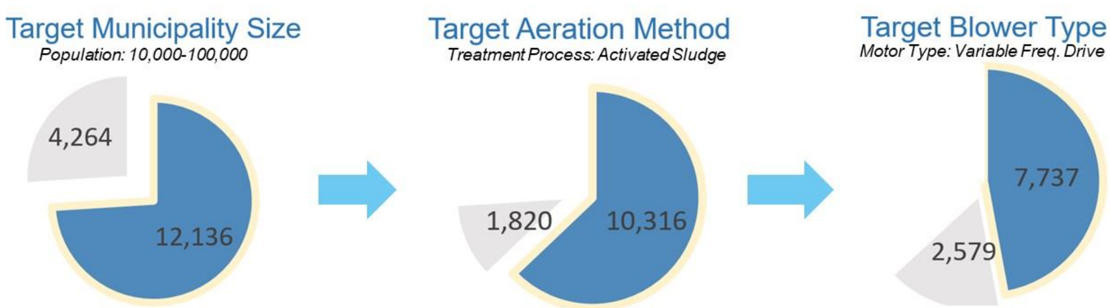
CONTRAIRE

Product Development Status

- ➢ Raised $233,000 in Non-Dilutive Grant Funding
  - o Bench-Scale thru Field Beta testing
- ➢ 50 Market Analysis Interviews
- ➢ Secured Field Beta Municipal Customer
- ➢ Phase II Bench-Scale Upscale: 17x upscale



U.S. Market Opportunity



Total Annual Recurring Market = $370 Million

Pricing Strategy

Pricing Formula:

Average Annual Service Fee = $3,000/Month *(Fixed)* + $250*Avg. Daily Flow *(Variable)*

= **$48,000**

Contraire	Municipalities
➢ Monthly Recurring Fee ➢ Scales to Muni System Size ➢ Simplifies Purchasing Decision ➢ Owns Control System ➢ Captures ~20% Energy Savings	➢ **NO** Upfront Cash Expenditures ○ Month 1 Savings ➢ Real-time Compliance Monitoring

CONTRAIRE

Unit Value Proposition

Contraire		Municipality (WWTP)	
Sales Price	$48,000	Customer Value	$300,000
COS + Commission	$12,500	Customer Cost *(Sales Price)*	$ 48,000
Gross Profit	$35,500	Customer Benefit (NEV)	$252,000
Payback (Months)	*8.1X*	*Benefit/Cost Ratio*	*5.25X*

Additional Benefits

➢ Electricity Usage Peak Demand Management

➢ Reduced Direct & Indirect Greenhouse Gas Emissions
(34% of total WWTP emissions come from aeration electricity)

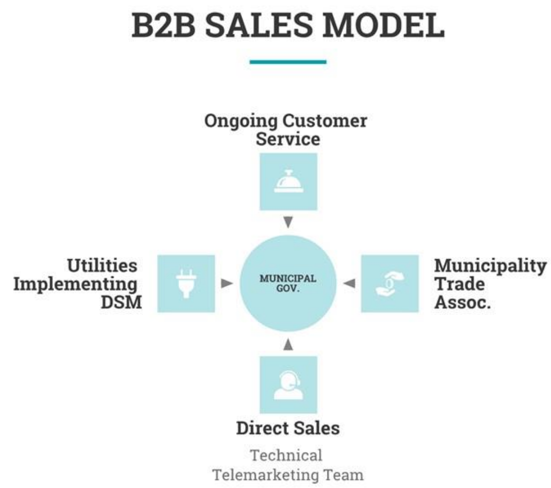
➢ Extends Mechanical Blower Life (~$250K ea.)

CONTRAIRE

Sales Strategy

Decision Making Unit Participants

- Economic Buyer: City Manager & Mayor
- End User: Wastewater Treatment Plant Manager
- Champion: Utility Manager
- Key Influencers: Trade Associations & Regulatory Agencies



CONTRAIRE

Contraire Team

Brooks Robison
M.B.A - Entrepreneurship

- ➢ Business Lead
- ➢ Top 5 Business Senior
- ➢ B.S. Marketing & Entrepreneurship
- ➢ Co-Student Entrepreneur of the Year

Rabecca Wiseman
M.S. Environmental Engineering

- ➢ Technical Lab Lead
- ➢ NSF – I-Corp Team Lead
- ➢ B.S. Civil Engineering
- ➢ Co-Student Entrepreneur of the Year

CONTRAIRE

Financial Information

Sources & Uses of Funds	Year 1-4
($ 000's omitted)	
Sources:	
Grant/Award funding*	$375
Common/Founders Stock	$441
Preferred (Series A)	$1,900
Preferred (Series B)	$3,000
Uses:	
R&D*	($375)
Operational Losses	($1,447)
Working Capital	($126)
WWTP Installation's	($2,904)
Other Assets	($83)
Contingency-Cash	$781

Income Statement	Year 7
($ 000's omitted)	
Revenue	$22,512
COS	$2,819
Gross Profit	$19,693
Pre-Tax Margin	*87.5%*
Overhead	($6,130)
EBITDA	$13,563
Depreciation	$2,341
Pre-Tax Income	$11,222
Pre-Tax Margin	*49.8%*

** Grant Funding Flows thru University*

Strategic Equity Capital Path

(000's $ omitted)	Investment $	Pre-Money	Initial %	Diluted %	Projected ROI
Co-Founders	$41	-	-	23.1%	-
Option Pool	-	-	-	15.4%	-
Common Stock	$400	$1,450	21.6%	10.6%	22
Series A	$1,900	$3,600	34.5%	25.9%	13
Series B	$3,000	$9,000	25.0%	25.0%	8

<u>Projected Exit Value of $90 Million</u>

CONTRAIRE

Potential Applications

- Big data collected on key wastewater metrics
- Generate data useful for Continuous Emissions Monitoring Systems
- Combined-sewer overflow system live measurements
-

CONTRAIRE

Competition & Exit Strategy

SIEMENS
Ingenuity for life

- Large-Scale WWTP Focus
- Aeration Control Air Blower
- No Retrofitting Capability

- Large-Scale WWTP Focus
- Sensor Network
- No Predictive Measurements

Endress+Hauser
People for Process Automation

<u>Distinguishing Competitive Advantages</u>

- Controls aeration levels based on predictive BOD concentrations
- Retrofittable into existing WWTPs
- Unique multi-year, subscription pricing structure

CONTRAIRE

Conclusion

- ➢Tremendous Muni Customer Value Proposition
- ➢Low Risk Product Development
- ➢Large $370 M Recurring Market
- ➢Recession Resistant Industry
- ➢Attractive Investor Risk/Return Profile

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Grant Funding

Funding Acquired (OSU)	Amount	Date
Phase 1 EPA People, Prosperity, & Planet (EPA P3)	$15,000	Aug '17
National Science Foundation (NSF) I-Corp	$3,000	Feb '18
OSU Technology Business Development Program	$25,000	May '18
OK Center for Advancement of Science and Technology	$90,000	June '18
EPA P3 - Phase II	$75,000	Nov '18
Venture Well - Phase I	$5,000	Jan '19
Venture Well – Phase II	20,000	August '19
TOTAL GRANTS AWARDED	**$233,000**	

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Implementation Costs

Item	Quantity	Unit Cost	Total
Sensors	24	$750	$18,000
Control Board	1	$4,500	$4,500
Infrastructure Overhead	1	$1,500	$1,500
Installation Cost (Labor & Travel)	1	$5,500	$5,500
WWTP System Cost			**$29,500**

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Unit Cost Breakdown

Item	$	% of Cost
Unit Annual Subscription (Avg.)	**$48,000**	
System Installation - Labor	$2,933	6.1%
System Installation - Travel	$2,500	5.2%
Annual Maintenance	$1,500	3.1%
Sales Commission	$3,600	7.5%
OSU Royalty	$1,920	4.0%
GOS	**$12,453**	25.9%
Gross Profit	$35,547	
	74.1%	

System Installation - Asset	$24,000
System Payback - Months	8.1

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Sources & Uses of Funds

(000's omitted)	Year 1	Year 2	Year 3	Year 4
Sources:				
Grant/Award Funding*	$100	$125	$150	$0
Common/Founders Stock	$41	$400	$0	$0
Preferred Stock (A & B)	$0	$0	$1,900	$3,000
Uses:				
R&D	$100	$125	$150	$0
Operating Losses	$3	$291	$1,013	$184
Working Capital	($1)	($4)	$21	$110
System Installations	$0	$24	$576	$2,304
Other Assets	$0	$8	$30	$45
Cash Contingency	$39	$114	$386	$782

*Grant funding flows thru University

Income Statement

(000's omitted)	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Revenue	$100	$149	$774	$3,504	$8,688	$15,024	$22,512
COS	$0	$41	$218	$944	$1,487	$2,112	$2,819
Gross Profit	$100	$108	$556	$2,560	$7,201	$12,912	$19,693
Gross Margin		*72%*	*72%*	*73%*	*83%*	*86%*	*87%*
SG&A	$103	$405	$1,556	$2,705	$3,624	$4,731	$6,130
EBITDA	($3)	($298)	($1,000)	($145)	$3,577	$8,180	$13,563
Depreciation	$0	$4	$70	$370	$906	$1,563	$2,341
Pre-Tax Income	($3)	($301)	($1,070)	($516)	$2,671	$6,617	$11,222
Pre-Tax Margin	*(3%)*	*(202%)*	*(138%)*	*(15%)*	*31%*	*44%*	*49%*

Integrated Financial Model - Contraire
Proforma Income Statement

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Revenues:							
Reoccuring System Subscription Fees	$0	$0	$48,000	$1,200,000	$5,808,000	$11,568,000	$18,480,000
New System Subscription Fees	$0	$24,000	$576,000	$2,304,000	$2,880,000	$3,456,000	$4,032,000
Grant Revenue	$100,000	$125,000	$150,000	$0	$0	$0	$0
Total Revenues	$100,000	$149,000	$774,000	$3,504,000	$8,688,000	$15,024,000	$22,512,000
Cost of Good Sold:							
System Installation Costs	$0	$37,700	$130,400	$521,600	$652,000	$782,400	$912,800
System Operation/Maintenance Costs	$0	$750	$19,500	$109,500	$271,500	$469,500	$703,500
Sales Commissions	$0	$1,800	$43,200	$172,800	$216,000	$259,200	$302,400
OSU Royalty Fee	$0	$960	$24,960	$140,160	$347,520	$600,960	$900,480
Gross Profit	$100,000	$107,790	$555,940	$2,559,940	$7,200,980	$12,911,940	$19,692,820
Gross Profit Margin		*72%*	*72%*	*73%*	*83%*	*86%*	*87%*
Operating (Overhead) Expenses:							
Salaries	$0	$121,500	$775,500	$1,313,000	$1,633,000	$1,913,000	$2,308,000
Employee Taxes & Benefits	$0	$34,524	$229,236	$416,024	$517,720	$608,216	$730,912
Marketing Expenses	$0	$41,000	$101,000	$213,000	$303,000	$386,000	$536,000
Sales Travel	$0	$0	$60,000	$120,000	$150,000	$180,000	$210,000
Research & Development	$75,000	$125,000	$150,000	$175,000	$200,000	$400,000	$600,000
Product Certification Expenses	$0	$10,000	$15,000	$30,000	$60,000	$90,000	$120,000
Travel Expenses	$25,000	$10,000	$82,000	$96,000	$96,000	$96,000	$96,000
Telephone/Internet Expenses	$0	$12,600	$16,800	$25,200	$31,200	$37,200	$44,400
Office Rent	$0	$4,800	$25,200	$55,200	$74,400	$91,200	$112,800
Insurance Expenses	$0	$0	$1,680	$42,000	$203,280	$404,880	$646,800
Miscellaneous	$3,000	$10,000	$40,000	$125,000	$200,000	$300,000	$450,000
Accounting	$0	$6,000	$15,000	$25,000	$55,000	$75,000	$100,000
Legal	$0	$30,000	$45,000	$70,000	$100,000	$150,000	$175,000
Total Operating Expenses	$103,000	$405,424	$1,556,416	$2,705,424	$3,623,600	$4,731,496	$6,129,912
EBITDA	($3,000)	($297,634)	($1,000,476)	($145,484)	$3,577,380	$8,180,444	$13,562,908
EBITDA Margin	*-3%*	*-200%*	*-129%*	*-4%*	*41%*	*54%*	*60%*
Depreciation	$0	$3,650	$69,900	$370,400	$906,300	$1,563,233	$2,341,200
Interest Expense	$0	$0	$0	$0	$0	$0	$0
Pre-Tax Income	($3,000)	($301,284)	($1,070,376)	($515,884)	$2,671,080	$6,617,211	$11,221,708
Pre-Tax Margin	*-3.0%*	*-202.2%*	*-138.3%*	*-14.7%*	*30.7%*	*44.0%*	*49.8%*

Integrated Financial Model - Contraire
Proforma Balance Sheet

	Beg.	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Cash	$41,000	$38,572	$113,593	$386,459	$782,136	$628,691	$3,471,693	$9,997,860
Accounts Receivables	$0	$0	$667	$17,333	$97,333	$241,333	$417,333	$625,333
Inventory	$0	$0	$0	$18,111	$86,933	$108,667	$163,000	$190,167
Total Current Assets	$41,000	$38,572	$114,260	$421,903	$966,403	$978,691	$4,052,026	$10,813,360
# of senors inv		*0*	*0*	*6*	*29*	*36*	*54*	*63*
Control System Equipment	$0	$0	$24,000	$600,000	$2,904,000	$5,784,000	$9,240,000	$13,272,000
Office Furniture & Computers	$0	$0	$7,500	$37,500	$82,500	$142,500	$222,500	$317,500
Accumulated Depreciation	$0	$0	($3,650)	($73,550)	($443,950)	($1,350,250)	($2,913,483)	($5,254,683)
Net PP&E	$0	$0	$27,850	$563,950	$2,542,550	$4,576,250	$6,549,017	$8,334,817
Total Assets	$41,000	$38,572	$142,110	$985,853	$3,508,953	$5,554,941	$10,601,043	$19,148,177
Account Payable	$0	$572	$5,394	$19,513	$58,497	$74,464	$91,486	$110,122
Bank Credit Line	$0	$0	$0	$0	$0	$0	$0	$0
Total Current Liabilities	$0	$572	$5,394	$19,513	$58,497	$74,464	$91,486	$110,122
Long-term Debt	$0	$0	$0	$0	$0	$0	$0	$0
Total Liabilities	$0	$572	$5,394	$19,513	$58,497	$74,464	$91,486	$110,122
Equity	$41,000	$41,000	$441,000	$2,341,000	$5,341,000	$5,341,000	$5,341,000	$5,341,000
Retained Earnings	$0	($3,000)	($304,284)	($1,374,660)	($1,890,544)	$780,536	$7,397,747	$18,619,455
Tax Distribution	$0	$0	$0	$0	$0	($641,059)	($2,229,190)	($4,922,400)
Total Equity	$41,000	$38,000	$136,716	$966,340	$3,450,456	$5,480,477	$10,509,557	$19,038,055
Total Liabilities & Equity	$41,000	$38,572	$142,110	$985,853	$3,508,953	$5,554,941	$10,601,043	$19,148,177

Contraire Integrated Financial Model
Income Statement Assumptions

		2019	2020	2021	2022	2023	2024	2025
Unit Sales/Revenue Assumptions:		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
# New Municipal Wastewater Plants		0	1	24	96	120	144	168
# Existing Municipal Wastewater Plants		0	0	1	25	121	241	385
$ Annual Subscription Charge		$48,000	$48,000	$48,000	$48,000	$48,000	$48,000	$48,000
$ Annual COS-Operation & Maintenance		$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500
Grant/Award Revenue		$100,000	$125,000	$150,000				
Staffing Plan/Compensation Assumptions:	Annual Compensation	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Corporate Team								
President/CEO	$175,000	0.00	0.00	0.75	1.00	1.00	1.00	1.00
VP Sales & Marketing	$155,000	0.00	0.00	0.75	1.00	1.00	1.00	1.00
Manager - Brooks	$70,000	0.00	0.50	1.00	1.00	1.00	1.00	1.00
Manager - Rabecca	$75,000	0.00	0.50	1.00	1.00	1.00	1.00	1.00
Technical Sales Professionals	$65,000	0.00	0.00	2.00	4.00	5.00	6.00	7.00
Sales Telemarketer	$55,000	0.00	0.00	0.00	2.00	3.00	4.00	5.00
VP Engineering & Operations	$98,000	0.00	0.50	1.00	1.00	1.00	1.00	1.00
System Installers (1:24 New Systems)	$55,000	0.00	0.50	1.00	4.00	5.00	6.00	7.00
Customer Service Technicians (1:45 Systems)	$50,000	0.00	0.00	1.00	3.00	6.00	9.00	13.00
CFO/Controller	$105,000	0.00	0.00	0.00	1.00	1.00	1.00	1.00
Accountants (1:100 systems)	$65,000	0.00	0.00	1.00	2.00	3.00	4.00	6.00
Procurement	$55,000	0.00	0.00	0.00	1.00	1.00	1.00	1.00
Administrative	$40,000	0.00	0.00	1.00	1.00	2.00	2.00	2.00
Total # Employees		0.00	2.00	10.50	23.00	31.00	38.00	47.00

Sales Commission New Plants	7.5%							
Sales Commission Existing Plants	2.0%							
Employee Taxes & Benefits	28%							
OSU Royalty Cost	4.0%							
Marketing and SG&A Expense Assumptions:		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Sales & Marketing Expenses:								
# National Trade Shows		-	-	1	2	2	4	4
Cost per Trade Show		$5,000						
Marketing Materials (Website & Literature)		$0	$35,000	$80,000	$150,000	$225,000	$275,000	$350,000
Industry Trade Publications		$0	$6,000	$12,000	$45,000	$60,000	$75,000	$150,000
Travel Expense/Trade Show		$4,000						
Monthly Travel Expense/Sales Prof.		$2,500						
Product Development Expenses:								
Research & Development		$75,000	$ 125,000	$ 150,000	$ 175,000	$ 200,000	$ 400,000	$ 600,000
Regulatory Requirements		$0	$10,000	$15,000	$30,000	$60,000	$90,000	$120,000
General & Administrative Expenses:								
Travel Expense/Executive/Month		$4,000						
Travel/Commercialization Research		$25,000	$10,000	$10,000	$0	$0	$0	$0
Travel/Installation		$2,500						
Telephone/Internet Service (Annual Base)		$12,000						
Telephone-Technical Sales & Customer Service per Month		$100						
Office Rent/Employee		$2,400						
Insurance-General (% Rev.)		0.5%						
Insurance-Product Liability (% Rev.)		3.0%						
Miscellaneous		$3,000	$10,000	$40,000	$125,000	$200,000	$300,000	$450,000
Outside Accounting		$0	$6,000	$15,000	$25,000	$55,000	$75,000	$100,000
Outside Legal		$0	$30,000	$45,000	$70,000	$100,000	$150,000	$175,000

Integrated Financial Model - Contraire
Balance Sheet Assumptions

Beginning Balance Sheet:	Beg	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Balances at Time/Year 0								
Cash	$41,000							
Accounts Receivables	$0							
Inventory	$0							
Leasehold Improvements	$0							
Office Furniture & Computers	$0							
Accumulated Depreciation	$0							
Account Payable	$0							
Bank Credit Line	$0							
Long-term Debt	$0							
Equity	$41,000							
Retained Earnings	$0							
Tax Distribution	$0							
Check Figure	*$0*							
Average # Days in Accts. Rec.		10						
Average # Days Inventory		0	0	50	60	60	75	75
Average # Days in COGS Accts. Payable		30						
Average # Days in Operating Expenses Payable		2						
Capital Expenditures:								
Average Control System Cost		$18,000						
Infrastructure Overhead (Wiring/Wi-Fi/Control Board)		$6,000						
Installed Control Systems		$0	$24,000	$576,000	$2,304,000	$2,880,000	$3,456,000	$4,032,000
Equipment Depreciation Schedule (in yrs.)		5						
Office Equipment		$0	$7,500	$30,000	$45,000	$60,000	$80,000	$95,000
Office Furniture & Computers Depr. Sch. (in yrs.)		3						
Bank Credit Line:								
Advance Ratio for Accts. Rec.		0%						
Advance Ratio for Inventory-Finished		0%						
Interest Rate		0.0%						
Equity Capital Raised		$0	$400,000	$1,900,000	$3,000,000	$0	$0	$0
Incremental Tax Rate (Federal + State)		24%						

Capitalization Table Template - Multiple Funding Rounds

Total # Founding Shares Issued	500,000	Pre-Money: Stock Options Pool	40.0%	Common Pre-Money Valuation	$1,450,000	Series A Pre-Money Valuation	$3,600,000
Founders Price per Share	$0.0100			Common Stock Raised	$400,000	Series A Capital Raised	$1,900,000
				Common Post Money Valuation	$1,850,000	Post Money Valuation	$5,500,000
				Common Investor(s) % Equity	21.6%	Series A Investor(s) % Equity	34.5%
				Common Investor per Share Price	$1.7400	Series A Investor(s) per Share Price	$3.3859

Pre-Money Valuation	$9,000,000
Series B Capital Raised	$3,000,000
Post Money Valuation	$12,000,000
Series B Investor(s) % Equity	25.0%
Series B Investor(s) per Share Price	$5.5406

Shareholders:	$ Investment	Initial Shares	Total % Equity	Total Shares	Total % Equity	Common $ Investment	Common #Shares	Total Shares	Total % Equity
Wiseman - Co-Founder	$2,500	250,000	50.0%	250,000	30.0%			250,000	23.5%
Robison - Co-Founder	$2,500	250,000	50.0%	250,000	30.0%			250,000	23.5%
Option Pool - Unissued				333,333	40.0%			180,833	17.0%
CEO - Future Hire								152,500	14.3%
CTO - Future Hire								0	0.0%
VP Marketing - Future Hire								0	0.0%
CFO - Future Hire								0	0.0%
Independent Board								0	0.0%
Common Stock Investor(s):									
Angel(s)						$400,000	229,885	229,885	21.6%
Series A Investor(s):									
Regional Angel Group(s)									
Seed Venture Capital Fund									
Series B Investor(s):									
Venture Capital Fund(s)									
Total	$5,000	500,000	100.0%	833,333	100.0%	$400,000	229,885	1,063,218	100.0%

Shareholders:	Series A $ Investment	Series A # Shares	Total Shares	Total % Equity	Series B $ Investment	Series B # Shares	Total Shares	Total % Equity
Wiseman - Co-Founder			250,000	15.4%			250,000	11.5%
Robison - Co-Founder			250,000	15.4%			250,000	11.5%
Option Pool - Unissued			130,833	8.1%			0	0.0%
CEO - Future Hire			152,500	9.4%			152,500	7.0%
CTO - Future Hire			50,000	3.1%			50,000	2.3%
VP Marketing - Future Hire				0.0%			75,000	3.5%
CFO - Future Hire				0.0%			40,000	1.8%
Independent Board				0.0%			15,833	0.7%
Common Stock Investor(s):								
Angel(s)			229,885	14.2%			229,885	10.6%
Series A Investor(s):								
Regional Angel Group(s)								
Seed Venture Capital Fund	$1,900,000	561,143	561,143	34.5%			561,143	25.9%
Series B Investor(s):								
Venture Capital Fund(s)					3,000,000	541,454	541,454	25.0%
Total	$1,900,000	561,143	1,624,361	100.0%	3,000,000	541,454	2,165,815	100.0%

	Dividend Rate	Years To Exit	Liquidation Multiple	Total $ Preference	
Potental Exit Value					$90,000,000
(imputed $/Share Sales Price)				$41.55	
Liquidation Preferences:					
Series A Investors			1.25	$2,375,000	
Series A Accrued Dividend	8.0%	5		$950,000	
Series A Preferred Liquidation Preference					$3,325,000
Series B Investors			1.00	$3,000,000	
Series B Accrued Dividend	5.0%	4		$600,000	
Series B Preferred Liquidation Preference					$3,600,000
Distributable Equity Value to Common Equivalent (Exit Value after Preferences)					$83,075,000

Sensor Data Log Example

Dropbox, Inc [US] | https://www.dropbox.com/sh/aoy7pdabirzlrv2/AACIMNBaN

sensors_test.csv

Date/Time COND (mS/cm) NH4 (mg/L) O2 (mg/L) NO3 (mg/L) pH TURB (mg/L SiO2) Temperature (C)
2018-11-10 23:37 3.67287e-006 0.1 1.99999 8.30602 5.49729 22.8712
2018-11-10 23:36 3.67523e-006 0.1 8.14257 8.3505 5.47836 22.8712
2018-11-10 23:35 3.67523e-006 0.1 8.14462 8.39606 5.45041 22.8712
2018-11-10 23:34 3.6776e-006 0.1 8.14185 8.44496 5.46579 22.8698
2018-11-10 23:33 3.6776e-006 0.1 8.1452 8.49496 5.48443 22.8698
2018-11-10 23:32 3.68001e-006 0.1 8.14218 8.54719 5.4468 22.8683
2018-11-10 23:31 3.68001e-006 0.1 8.14272 8.60497 5.46291 22.8683
2018-11-10 23:30 3.68001e-006 0.1 8.13973 8.66164 5.49879 22.8669
2018-11-10 23:29 3.68232e-006 0.1 8.14196 8.725 5.51027 22.8669
2018-11-10 23:28 3.68232e-006 0.1 8.14171 8.79279 5.49813 22.8669
2018-11-10 23:27 3.68232e-006 0.1 8.14334 8.86058 5.6241 22.8669
2018-11-10 23:26 3.68473e-006 0.1 8.14549 8.93169 5.42324 22.8669
2018-11-10 23:25 3.68473e-006 0.1 8.14389 9.0084 5.28093 22.8655
2018-11-10 23:24 3.68473e-006 0.1 8.14093 9.09063 5.46159 22.8641
2018-11-10 23:23 3.68709e-006 0.1 8.14194 9.17734 5.50666 22.8641
2018-11-10 23:22 3.68709e-006 0.1 8.14441 9.2674 5.42487 22.8641
2018-11-10 23:21 3.68951e-006 0.1 8.14356 9.36296 5.49879 22.8627
2018-11-10 23:20 3.69186e-006 0.1 8.14359 9.4619 5.4548 22.8627
2018-11-10 23:19 3.69186e-006 0.1 8.147 9.57192 5.46531 22.8613
2018-11-10 23:18 3.69428e-006 0.1 8.14679 9.68194 5.45083 22.8598
2018-11-10 23:17 3.69428e-006 0.1 8.14391 9.79864 5.65703 22.8598
2018-11-10 23:16 3.69663e-006 0.1 8.14554 9.92758 5.49524 22.8584
2018-11-10 23:15 3.69663e-006 0.1 8.14431 10.0576 5.57145 22.8584
2018-11-10 23:14 3.69905e-006 0.1 8.14465 10.1988 5.50053 22.857
2018-11-10 23:13 3.69905e-006 0.1 8.14399 10.3499 5.46171 22.857
2018-11-10 23:12 3.70135e-006 0.1 8.14372 10.5055 5.69225 22.8556
2018-11-10 23:11 3.70377e-006 0.1 8.14246 10.6733 5.57013 22.8542
2018-11-10 23:10 3.70377e-006 0.1 8.14378 10.8534 5.59838 22.8542

VITA

Rabecca Jeanette Wiseman

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF ENERGY AND EMISSIONS FROM MUNICIPAL WASTEWATER TREATMENT

Major Field: Environmental Engineering

Biographical:

Education:

Completed the requirements for the Master of Science in Environmental Engineering, at Oklahoma State University, Stillwater, Oklahoma in December, 2020.

Completed the requirements for the Bachelor of Science in Civil Engineering, Environmental Option, at Oklahoma State University, Stillwater, Oklahoma in 2018.

Experience:

NSF GRADUATE RESEARCH FELLOWSHIP AWARDEE – fall 2020

PRINCETON UNIVERSITY TIGER LAUNCH BUSINESS COMPETITION Winner – spring 2019

QUEEN'S UNIVERSITY TORONTO ENTREPRENEURSHIP CHALLENGE, Winner – spring 2019

VENTUREWELL PHASE 1 & 2 – fall 2019

Professional Memberships:

CHI EPSILON, CIVIL ENGINEERING HONOR SOCIETY
Member since spring of 2017, Pledge Marshall fall 2018 – fall 2020