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Direct Potable Reuse of Wastewater

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Reflections and Contributions

This semester I was a member of a competition team participating in the New Mexico State University WERC Design Contest to complete my honors thesis requirement as well as my Design 2 requirement. My team worked on task 6 with the given problem of creating potable water from wastewater treatment effluent. Our team was required to design a full-scale treatment plant that would provide drinking water for a city of 5,000, create a bench-scale model to prove the efficacy of the full-scale design, and create written report, a presentation, and a poster.

To complete the task, we began over winter break with research of current processes we could implement. At that point, I focused my research on towns in the United States currently using direct potable ruse or indirect potable reuse of wastewater. Examples of areas that my research focused on were Las Vegas, Nevada; Cloudcroft, New Mexico; El Paso, Texas; and Big Springs, Texas.

Once we came back to campus after winter break, my team and I spent the first week reviewing the research we had completed over the break and eliminating options that did not fit the task requirements or were too expensive. From there, options that were deemed potentially feasible in the final process were researched in depth. I specifically researched reverse osmosis and ultrafiltration, attempting to determine all of the potential pros and cons of using them for our water treatment process. Both reverse osmosis and ultrafiltration were chosen for implementation in our final process due to their capability of removing pathogens, viruses, bacteria, and dissolved salts.

After determining our final general process scheme, I was very involved in the creation of a full-scale process that would effectively treat 500,000 gallons of water per day. This involved using a process simulator called WAVE to create a PFD. Through several iterations of varying pressure vessel numbers, different ultrafiltration modules, and reverse osmosis membranes, a final process was landed upon. This process allowed for effective treatment within the EPA guidelines for drinking water, along with the guidelines from the competition.

A bench scale process was also created that treated both well water, as well as actual wastewater treatment plant effluent from Silver City, New Mexico. The analytical result proved that the process was effective, and that the final product would be safe drinking water.

As Quality Control Coordinator, one of my major roles was in writing the paper. Completion of the paper was a collaborative effort between Molly Churchwell and myself, with some input from other team members. The report is attached, and outlines the final process we landed upon along with the steps taken to reach that point. I ensured that the final paper was a quality product, as it counted as 25% of our final judging in the competition.

Another major role I held was in the implementation of the public involvement aspect of our project. I created both a sample flier that would be mailed to members of community, and a pamphlet that overviewed our process. I discussed the public involvement aspect during the bench scale presentation, and spearheaded the research behind what would make a successful public involvement plan.

Finally, we travelled to Las Cruces, New Mexico to compete and present our final project. The oral presentation team excelled the first day, and the second day I held a major role in the bench scale/poster presentation. Finally, at the awards ceremony, we were recognized as the first place winners of our task, and second place in the combined tasks (with another Arkansas team winning first).

Overall this experience was overwhelmingly beneficial, and I feel much more prepared to work on large-scale projects in a career setting. We created a design that works, and were able to sell it better than any of our competitors, proving our ultimate success.

DIRECT POTABLE REUSE OF WASTEWATER

WERC 2018

Task #6

Poo Pig Sooie!

Ralph E. Martin Department of Chemical Engineering

University of Arkansas

Direct Potable Reuse of Wastewater

WERC 2018

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1. EXECUTIVE SUMMARY

Water is essential to our societies and mankind. Currently, 844 million people across the globe lack access to potable water. By 2025, it is projected that half of the world population will be in a region of water stress.[5] The water crisis is often thought of as a problem limited to places that have always struggled to have clean water, but it is now affecting new areas such as the southwest United States. With increasing population demands and drought, the feasibility of direct potable reuse (DPR) of wastewater is being considered. According to an EPA report in 2017, there are only four operational or planned DPR facilities in the United States. Of these, the El Paso Advanced Water Purification Facility will be the only one to send treated water directly into the distribution system without blending or continuation onto conventional treatment.[1] As demand and water costs increase, we believe that the implementation of our DPR process for wastewater effluent is a viable option for many communities.

The primary contaminants in wastewater treatment plant (WWTP) effluent that must be targeted for potable reuse are organics, bacteria, pathogens, viruses, and suspended and dissolved solids. Our process consists of ozone treatment, granular activated carbon (GAC) treatment, a cartridge particulate filter, ultrafiltration, reverse osmosis, and ultraviolet disinfection. Ozone is used to kill microorganisms in the secondary WWTP effluent before it enters the rest of the system to prevent bio-fouling on the equipment. GAC is used to remove the majority of organic contaminants. A cartridge filter is between the GAC and ultrafiltration (UF) to prevent plugging of the UF membrane. Ultrafiltration is used as pretreatment for the reverse osmosis unit. UF was chosen for its ability to remove pathogens and viruses. Reverse osmosis will remove dissolved solids, a necessary step for the contaminated water to become potable. The final step is disinfection by ultraviolet treatment to ensure no live pathogens reach distribution.

Experiments were performed to determine if this combination of steps could effectively treat contaminated water. The necessary treatment must be able to reduce the total dissolved solids (TDS) level from 1,200 parts per million to less than 500 parts per million and reduce TOC from 10 parts per million to less than 0.1 parts per million. Fecal bacteria such as coliform must not be present for the water to be considered potable.[15]

A full size plant was designed based on the needs of a community of 5,000, using an average water demand of 100 gallons per person per day.[18] The Poo Pig Sooie team has found Silver City, New Mexico (population ≈ 10,000) to be an ideal city for implementation of the

DPR process. This plant would be able to supplement 50% of the potable water (equivalent to a city with a population of 5,000) demands of the city for as little as $1.27 per 1,000 gallons.

2. OVERVIEW OF TASK

2.1 Purpose

The purpose of this task is to design a process that will effectively treat municipal wastewater treatment plant effluent streams for the purpose of direct potable reuse. The primary challenge faced by this idea is not a lack of technology, but rather the affordability of a solution and the social stigma surrounding "Toilet to Tap."

The following criteria were considered in completing this task:

- Following standards under the Clean Water Act and Safe Drinking Water Act to define potabilty
- Creating a reliable, affordable process that could be implemented as an advanced treatment for any municipal wastewater effluent
- Minimizing waste streams and ensuring safe disposal of these streams
- Maintaining safety of the process with respect to operation and public health
- Maintaining feasibility of process implementation and addressing the need for public acceptance
- Creating a business plan and cost analysis of the full-scale design
- Creating a bench-scale apparatus that can process five gallons of contaminated water to demonstrate the capability of the selected technology

2.2 Site Description

Silver City, New Mexico is an ideal location for implementation of the full scale process. Silver City has a population of approximately 10,000 people, and the Silver City Wastewater Treatment Plant treats an average of 1.3 million gallons per day. Currently, a portion of the treated effluent is sent to a golf course for irrigation purposes. The remainder is discharged to San Vincente dry creek, where it percolates into the soil and enters the groundwater. After construction of the DPR plant, a third of the wastewater treatment effluent would be sent to our designed tertiary treatment. Our process would be able to provide 500,000 gallons of potable water each day, supplementing approximately 50% of the city's water demand.

Two members of the team traveled to Silver City, New Mexico to discuss the project and design with the town manager, Alex Brown, and the utilities director, Robert Esqueda. Beginning in the early 2000s, Silver City started a water conservation plan in which they increased water rates to discourage overuse of water. Increasing rates was extremely beneficial to decreasing usage. Silver City also conducted a study of their regional water to determine where the effluent from the wastewater treatment plant was going after it was discharged. The town proved that the effluent ends up in the aquifer that the town pulls its water from through the well fields. As a result, Silver City was granted recharge water rights. Investigating the endpoint of the WWTP effluent, Silver City saved and essentially gained $4.4 million of water rights. After Silver City's water conservation plan and rate increases, the town is only using about 50% of their water rights. As a result, investing the necessary money for DPR is not currently necessary for Silver City. In the future, if Silver City's needs outgrow their water rights or if the quality of water from the wells decreases, it will be necessary to consider DPR as a solution.

While in Silver City, the team members also visited the wastewater treatment plant to talk to the employees and collect samples. Treating the Silver City wastewater effluent with the bench scale apparatus will prove that a system such as this could be used to make the wastewater effluent potable.

3. TERTIARY WASTEWATER TREATMENT METHODS

In order to remove contaminants found in wastewater to create drinking water, the secondary treatment effluent must go through tertiary treatment. Tertiary treatment is the most advanced water treatment that will remove *Cryptosporidium*, *Giardia lamblia*, coliforms, dissolved solids, and other contaminants under the EPA National Drinking Water Regulations.[15] Tertiary treatment is any treatment beyond secondary treatment and can include a number of different phases including adsorption, filtration, reverse osmosis, and disinfection/advanced oxidation.

3.1 Adsorption

Adsorbents used in wastewater treatment are capable of removing dissolved organic material, heavy metals, biologics, and reducing turbidity. Typical adsorbents include clay, fly ash, sawdust, and activated carbon.[17] Granular activated carbon (GAC) is made from carbon rich raw organic materials like coconut shells and coal. GAC is also capable of adsorbing and removing chlorine specifically, which is beneficial when treating previously chlorine disinfected water. For this reason, a GAC system was implemented into our final design to both serve as a pretreatment for further filtration and to remove any chlorine added during secondary treatment that would foul an RO system.

3.2 Filtration

Filtration utilizes the spacing between particulate solids or the size of holes in membranes to reject material that is too large to pass. This process allows for the rejection of material regardless of type, and typically serves as a pretreatment for RO. Examples of different types of filtration include mixed media filtration, microfiltration, ultrafiltration, and biofiltration.

- Mixed Media Filtration: A three-layer filter made up of anthracite, sand, and garnet. The density of the particles increases down the filter, while the particle size decreases. This type of filtration is used in conventional filtration, however it is not capable of handling the high requirements of TOC reduction necessary in this case.[14]
- Microfiltration/Ultrafiltration: Membranes with pore sizes of 1 micrometer for microfiltration and 0.01 micrometer for ultrafiltration reject contaminants larger than the respective pore size. Therefore, microfiltration is able to remove all particles except for viruses and dissolved salts, while the only particle able to pass through ultrafiltration is dissolved salts. The high rejection of ultrafiltration makes the process ideal, and allows for a needed redundancy when treating wastewater for drinking water use when placed before an RO system.[23]
- Biofiltration: Biofiltration includes introducing a biofilm onto the surface of a filter in order to decrease water-borne diseases, turbidity, and TOC. However, these filters are subject to clogging and flow channeling due to the purposeful buildup on the membrane, making replacement costs add up and requiring a high amount of backwashing. For this reason, biofiltration was not included in the designed process.[3]

3.3 Reverse Osmosis

RO uses an applied pressure to force a concentrated solution through a semipermeable membrane that is selective against contaminants. Typical industrial RO systems are spiral wound and made with a polyamide thin film composite (TFC) sheet membrane. Feed water is separated as the permeate flows through the membrane, and the concentrated reject stream bypasses the membrane. RO systems require several pretreatment steps in order to decrease fouling but are exceptional at rejecting dissolved salts in the feed water. Typical salt rejection ranges from 95-

99% of salts in the influent.[19] RO also serves as a needed redundancy for the rejected viruses, bacteria, and organics in the pretreatment steps. Therefore, RO was included in the process as the final step before disinfection.

3.4 Disinfection/Advanced Oxidation

The EPA requires a final disinfection step before effluent can be supplied as drinking water.[13] Disinfection protects public safety and ensures no potentially harmful microorganisms pass through the process. Similarly, advanced oxidation processes serve to both disinfect and oxidize the effluent water to decrease chemical oxygen demand (COD) and biochemical oxygen demand (BOD) contributing compounds. Considered options included Chlorine, UV, Hydrogen Peroxide, and Ozone treatment. Chlorine is destructive to membranes, and also produces carcinogenic disinfection byproducts that then have to be removed prior to distribution if the levels exceed regulations.[5] While ozone is capable of producing byproducts in the presence of bromine, the GAC that follows would then remove these byproducts. UV is capable of disrupting the DNA of microorganisms based on the wavelength of light emitted in non-turbid water.[11] Hydrogen peroxide and ozone are both typical oxidizers, however ozone has a higher oxidizing potential.[9] Ozone can also be generated on site with an ozone generator, while hydrogen peroxide has to be shipped in. The addition of ozone also is effective regardless of turbidity, which can serve as pretreatment to filtration to reduce biofouling. Ozone was chosen as an optimal oxidation step, and UV was chosen for final disinfection.

4. DESIGN BASIS

4.1 Ozone Treatment

Ozone treatment was chosen as an initial disinfection step due to its effectiveness against pathogens and pharmaceutical residues. This primary disinfection step prevents the chances of biofouling on the following treatment train. Ozone was chosen over the common alternative of chlorine disinfection because it does not produce harmful byproducts. It has also been shown to be more effective than chlorine at killing bacteria and viruses.[4]

4.2 Carbon Treatment

Due to the high reduction of organic matter that is necessary, GAC adsorption was chosen for our process. Granular activated carbon adsorption is successfully used in many wastewater treatment processes and has been shown to greatly reduce organic compounds and heavy metals in water. Ozonated water increases the biological activity on a GAC and any ozone residuals left in the water will also be adsorbed. Enhanced biological activity removes more organic carbon than adsorption alone. The expected life of a GAC filter is increased when ozone is used as a pretreatment.[2] Water is sent through a cartridge filter before going to the ultrafiltration membrane to prevent clogging due to any particulates from the GAC.

4.3 Ultrafiltration

Ultrafiltration was chosen as the final pretreatment step for reverse osmosis. UF has been shown to be the most cost effective and efficient pretreatment.[11] The semipermeable membrane is able to reject colloids and macromolecules larger than 0.01 micron. This includes bacteria, pathogens, and viruses, so only dissolved solids will be able to pass through the UF membrane. This provides protection to the final water product and the reverse osmosis membrane.

4.4 Reverse Osmosis

Reverse osmosis is necessary to reduce the total dissolved solids concentration to potable levels and remove remaining organics. RO also serves as an added layer of protection against any viruses being sent to distribution. The nonporous membrane has the ability to remove particles larger than 0.1 nanometers at a 99% rejection rate. The life of the RO membrane increases when pretreatment steps are in place to remove any chlorine and other foulants.

4.5 Ultraviolet Disinfection

Ultraviolet treatment satisfies the EPA requirement for final disinfection before distribution.[13] UV will disrupt any microbiological activity in non-turbid water. The final product will then meet all EPA regulations to be sent directly into the water distribution system.

5. INDUSTRIAL PROCESS SCALE UP

The system is designed to produce 500,000 gallons of potable water per day. This meets the requirements of the WERC wastewater reuse prompt of supporting a town of 5,000 people with the full scale design. This is based on the average citizen in the southwest United States using 80-100 gallons of water per day. In order to achieve this flow rate, 590,000 gallons per day will be processed to yield a permeate stream at the desired flow rate. The fraction of the feed that is processed into potable water is 86%.

5.1 Process Flow Diagram

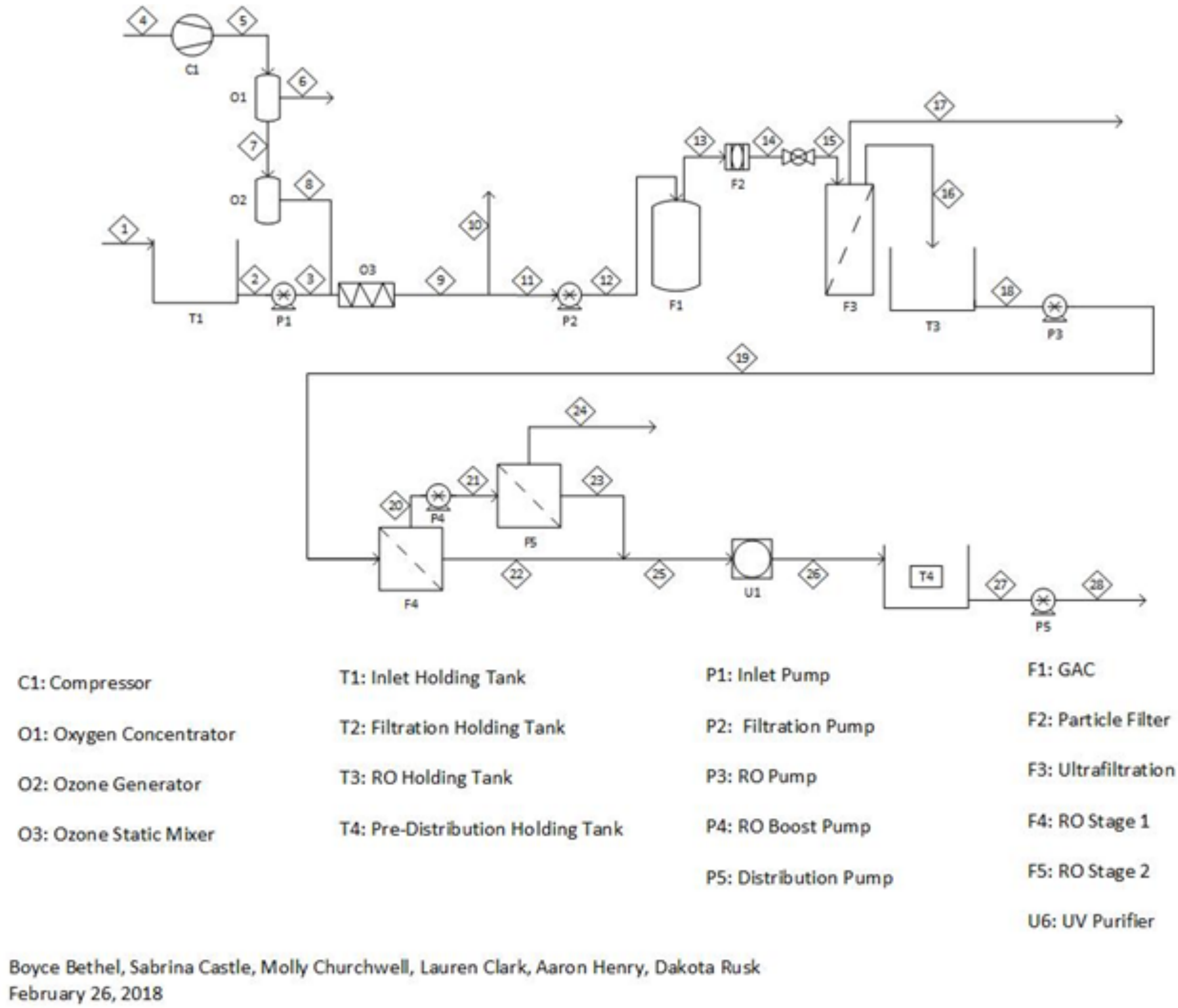

Figure 1: Full Scale Process Flow Diagram

5.2 Oxidation Scale-Up

The industrial ozonation unit is based on a system at Noland WWTP in Fayetteville, AR. The system draws in ambient air (stream 4) and concentrates the stream up to 93% oxygen that is then sent through an ozone generator. The generator produces 790 g/hr of ozone (stream 8) at a dosage of 10 ppm for an hourly flow rate of 20,834 gallons (stream 3). The process also adds oxygen to the water which, along with the ozone decomposition gases, would then be vented (stream 10) after proper residence time.

5.3 Activated Carbon Filtration Scale-Up

The granular activated carbon unit was scaled-up to compare to the recently installed GAC unit at the advanced water treatment facility in Rio Rancho, NM. This dual vessel unit contains 20,000 pounds of virgin GAC per unit with an effective size of 0.8-1.0 mm. For the set flow rate of 410 gpm (stream 12), the empty bed contact time is approximately 20 minutes. Once the activated carbon has been exhausted, it can be returned to the manufacturer for reactivation at a fraction of the cost of new carbon. This allows municipal drinking water facilities to greatly reduce operating costs of the GAC.

5.4 Ultrafiltration Scale-Up

The industrial scale ultrafiltration unit was modeled using WAVE simulation software for membrane systems. The ultrafiltration units are 12 Dow IntegraFlux SFD-2880XP ultrafiltration modules. The input into the system is to be 590,000 gallons per day (stream 15) with an output of approximately 575,000 gallons per day (stream 16). This system has an efficiency of 98%.

5.5 Reverse Osmosis Scale-Up

A single pass system with two stages was designed using WAVE simulation software. The first stage contains eight pressure vessels with six elements per vessel. The inlet pressure of the first stage is 90 psi and the concentrate stream going to the second stage has a pressure of 73 psi. The second stage contains four pressure vessels with six elements per vessel. A booster pump is utilized between the first and second stage to boost the inlet pressure to the second stage to 93 psi. The elements used for the simulation are XLE-440 elements from DOW, which are 40 inch by 8 inch cylindrical elements. The elements have an active surface area of 440 square feet. Using WAVE, this configuration has an expected recovery of 86% giving a permeate flow rate of 350 gpm (stream 25).

5.6 Ultraviolet Scale-Up

The last step of the treatment process is a class B ultraviolet purifier. A class B purifier has an intensity and saturation level of at least 16,000 uW-sec/cm^2. Although all pathogens have been removed, this ultraviolet step is in place to assure that no microorganisms pass to distribution. It also serves as necessary redundancy in a drinking water treatment process. This ultraviolet unit also fulfills the EPA regulation of having a final disinfectant stage.

5.7 Intended Water Reuse

The waste stream produced by ultrafiltration and reverse osmosis will be returned to the WWTP discharge station. After blending with the remaining effluent of the plant, the water will meet regulations of the treatment plant's EPA discharge permit.

5.8 Process Controls and Monitoring

In order to maintain quality control and effectiveness of the water purification system, samples will be taken regularly to insure that each part of the process is performing efficiently. Some parameters will be monitored every four hours, while other parameters, such as temperature and pressure, will be monitored continuously. Daily samples will be taken from the feed and product streams for analysis. Weekly samples will be taken from six sample points, including feed, after ozonation, after the particle filter, after ultrafiltration, after RO, and after UV. Taking routine samples at each of these locations will prevent large problems. If a sample is irregular, the filtration technique preceding the irregular sample will be examined to insure that it is functioning properly. Samples will be tested for all parameters for safe drinking water including total dissolved solids analysis, biological oxygen demand, coliform count, pH, conductivity, and turbidity.

6. ECONOMIC ANALYSIS

A capacity ratio was used to determine the capital cost of the ozonation unit by comparing to the capital cost of the equipment at the Noland WWTP in Fayetteville, AR. This method was also used to calculate the capital cost of the ultrafiltration, reverse osmosis, and UV systems. This calculation is based on the capital cost of the Torreele water plant in Koksijde, Belgium, which has an average RO recovery of 75%.[23] The Torreele plant produces 2,500,000 cubic meters of water per year, which is 3.6 times greater than this design which produces 691,000 cubic meters per year. Using a capacity ratio and the six-tenths-factor rule, the equipment cost for these three stages was determined. The GAC unit recently installed in Rio Rancho, NM gave an appropriate purchase cost estimate due to similar product flow rates.

The fixed capital investment (FCI) was calculated using the cost of purchased equipment as a basis for other direct costs and indirect costs. Each capital cost category shown in Table 1 was provided by Plant Design and Economics for Chemical Engineers: 5th Edition for a fluid processing plant[20]. There is assumed to be space available for plant construction, so no new land purchase is necessary for the project.

Table 1: Fixed Capital Investment Costs

Fixed Capital Investment		
Direct Costs		
Purchased Eqpt	$	3,087,000
Installation	$	1,451,000
Instrumentation and Controls	$	1,142,000
Piping	$	2,099,000
Electrical	$	339,000
Buildings	$	555,000
Yard Improvements	$	308,000
Service Facilities	$	2,161,000
Total Direct Costs	$	11,142,000
Indirect Costs		
Engineering and Supervision	$	1,018,000
Construction	$	1,266,000
Legal Expenses	$	123,000
Contractor's Fee	$	679,000
Contingency	$	1,358,000
Total Indirect Costs	$	4,444,000
Total FCI	**$**	**15,586,000**

The yearly operating cost includes power consumption and maintenance. Maintenance includes additional labor, anti-scaling chemicals, and lab testing.[23] All of these maintenance components are necessary in monitoring contaminant levels and preventing membrane scaling. These costs are found in Table 2 below and were obtained from the Torreele water treatment plant.

Table 2: Annual Operating Costs

Annual Operating Costs		
Power		
Pump	kWh/m^3	Cost/year
P1	0.07	$5,722
P2	0.12	$6,021
P3	0.57	$23,317
P4	0.07	$5,722
Other		
Labor		$300,000
Chemicals/Lab		$89,801
Membranes/GAC		$17,193
Total		**$447,778**

The annual cost of the system was calculated using three methods over a thirty year payment period. The first cost comparison is calculated under the assumption that a Federal Grant will cover 100% of the fixed capital investment. The second comparison is calculated under the assumption that 50% of the FCI will be covered by a Federal Grant and 50% will be covered by a 0% interest federal subsidized loan. The third comparison assumes that 100% of the FCI is covered by a commercial loan with 6% interest. These three payment possibilities are compared in Table 3 below.

Table 3: Yearly Operating Cost Comparison

Annual Cost Comparison	
FCI Payment Option	**Annual OC**
100% Grant	$447,778
50% Grant, 0% Federal Subsidized Loan (30 years)	$707,671
0% Grant, 6% Commercial Loan (30 years)	$1,580,633
Cost Per 1000 Gallons	
100% Grant	$2.45
50% Grant, 0% Federal Subsidized Loan (30 years)	$3.87
0% Grant, 6% Commercial Loan (30 years)	$8.66

Options for funding water treatment projects in New Mexico include the Clean Water State Revolving Fund (CWSRF) in partnership with the New Mexico Environment Department and the Water Project Fund.[8,24] Both funds include water recycle and reuse projects as an area of focus. The first purpose listed under the CWSRF Act is "to provide loans for the construction or rehabilitation of drinking water facilities." If the community meets the Federal Clean Water Act guidelines, it may qualify for 0% interest.[8] Silver City, NM will need to increase drinking water capacity production by 2021 if a high growth projection of 2.9% is assumed for the city.

7. BENCH SCALE DESIGN

The bench scale apparatus consists of three individual batch processes using six water treatment technologies. The technologies are as follows: ozone, granular activated carbon (GAC), cartridge filter, ultrafiltration (UF), reverse osmosis (RO), and ultraviolet light (UV). The first batch process is the ozone treatment. The second batch process includes GAC, the cartridge filter, and UF. The third batch process includes the RO and UV disinfection.

7.1 System Feed

Two feed sources were tested in the bench scale unit, the feed water specified by the competition as well as the effluent discharged from the Silver City, NM waste treatment plant. The water specified by the competition is water from Well 1 at the Bureau of Reclamation Brackish Groundwater Desalination Research Facility in Alamogordo, NM, that is treated with an unidentified organic matter. Therefore, different samples were prepared and obtained in order to test the bench scale process. A mock solution that mimics the well water was created and tested first to determine the process' ability to remove TOC, TDS, and coliform. The total dissolved solids concentration is approximately 1,200 ppm, made up primarily of sulfates as defined by the competition guidelines. To replicate the organic matter in the water, sucrose was added to the water to a concentration of 10 ppm. After the process was proven to reduce these components within the competition guidelines, samples of effluent water from Silver City, NM were transported to Fayetteville, AR and tested.

7.2 Process Flow Diagram

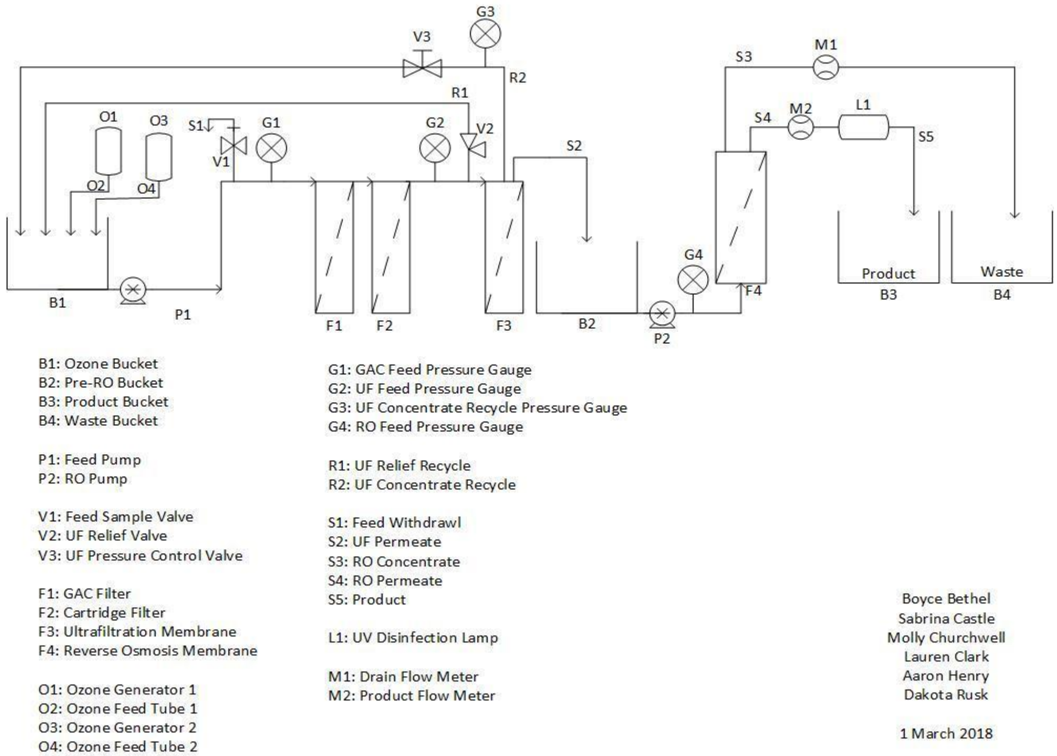

Figure 3: Bench Scale Process Flow Diagram

As seen in Figure 3, the five gallons of feed is initially treated with 10 ppm of ozone in the ozone bucket (B1). Once the ozonation is complete, the water is pumped from the ozonation bucket to the GAC (F1), and the solution goes directly from the GAC to the cartridge filter (F2) and UF (F3). The pressure control valve (V3) on the waste stream is adjusted to maintain the inlet and outlet pressures for the UF. The permeate from the UF (S2) flows into the pre-RO bucket (B2). The waste from the UF (R2) flows to the ozone bucket to reenter the process and mimic a batch ultrafiltration process. When insufficient feed water in the ozone bucket remains, the feed pump (P1) is shut down. The RO pump (P2) is turned on to pump the water from the pre-RO bucket into the RO (F4). The RO concentrate (S3) flows into the waste bucket (B4). The RO permeate flows (S4) through the UV lamp (L1) and into the product bucket (B3).

7.3 Experimental Apparatus

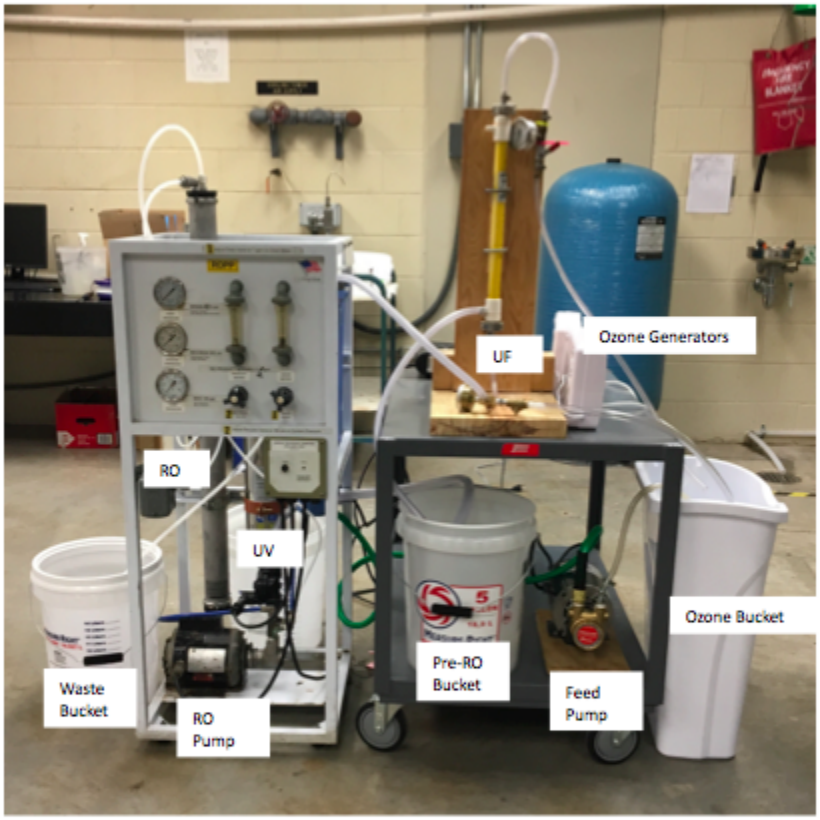

Figure 2: Front of Bench Scale Apparatus

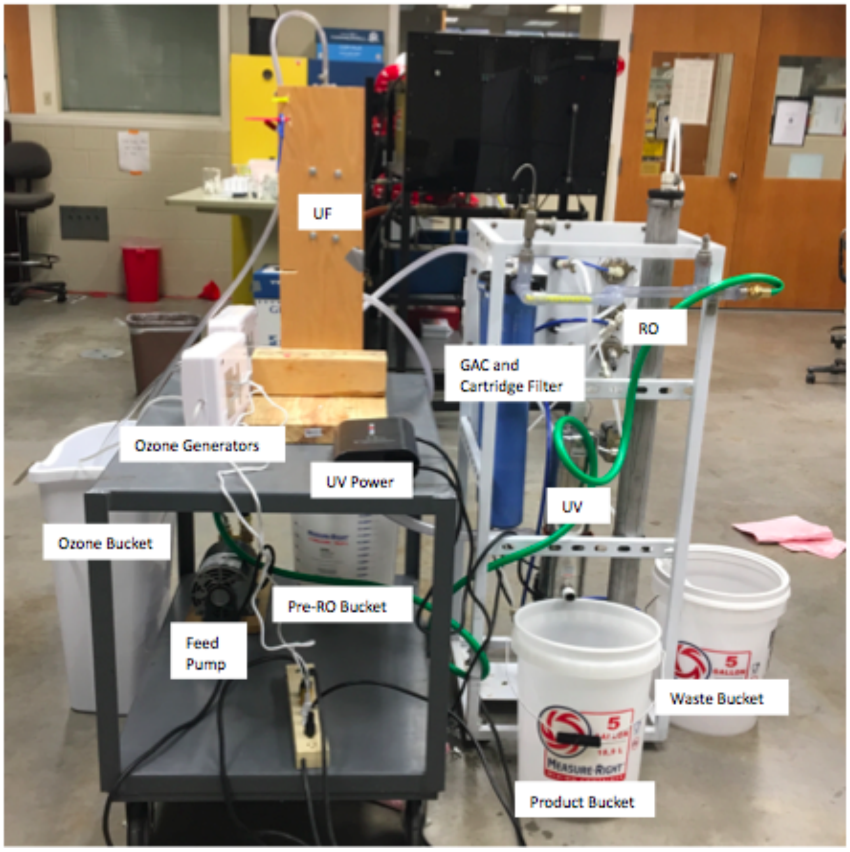

Figure 3: Back of Bench Scale Apparatus

7.4 Bench Scale Procedure

1. Fill the Ozone Bucket.
2. Turn on the Ozone Generator 1 and run for cycle 3 (10 minutes).
3. When the Ozone Generator 1 cycle is complete, turn on the Ozone Generator 2 and run for cycle 3 (10 minutes).
4. When the Ozone Generator 2 cycle is complete, turn on the Feed Pump to pump the water from the Ozone Bucket into the GAC, cartridge filter, and UF.
5. Monitor the inlet pressure for the UF to make sure it stays at 25 psig. Use the pressure control valve on the recycle stream to maintain inlet pressure.
6. Collect the UF permeate in the RO Feed Bucket.
7. Send the UF concentrate back into the ozone bucket to be pumped through the system again.

8. When the Ozone Bucket water level reaches the marked End Line, turn off the Feed Pump.
9. Turn on the RO Pump to pump the water through the RO membrane.
10. Collect the RO permeate after it flows through the UV Disinfection Lamp in the Product Bucket.
11. Collect the RO Concentrate in the Waste Bucket.

8. EXPERIMENTAL TESTING AND RESULTS

The treated water was tested for conductivity, turbidity, and total organic carbon (TOC) content levels. In addition to these criteria, total coliform and E. coli parameters were evaluated to assure our water meets the microbiological standards for drinking water. For experimental purposes, a mock solution was created based on the Well 1 composition data provided by BGNDRF. Effluent from the wastewater treatment plant in Silver City, NM was also treated using the bench scale process.

8.1 Sample Preparation and Analytical Methods

Each sample was collected at a volume of 500 milliliters. Samples were transported to the Arkansas Water Quality Lab where TOC, TDS, conductivity, pH, and total coliform tests were conducted. Table 3 summarizes the target parameters established by EPA regulation and the guidelines of Task 6. The only parameter level not mentioned in either the EPA standards or task description is the required conductivity levels. Since the conductivity and TDS concentration are closely related, the target conductivity reading was determined to be <1000 μS/cm.

Total Organic Carbon (TOC) was measured using the Water Quality Lab's SAN++ Automated Wet Chemist Analyzer from Skalar. This measures TOC by first acidifying the sample with sulfuric acid and sparging the sample with nitrogen. This liberates the sample of any inorganic or volatile organic carbon. The sample is then mixed with tetraborate reagent and passed through a UV coil. This oxidizes the organic carbon, generating carbon dioxide, which is then removed from the solution by acidification and sparging. The carbon dioxide emitted is measured by an infrared system.

TDS was measured by weighing an amount of the sample, passing the sample through a filter to remove any suspended solids, measuring the weight of the removed solids, then evaporating the remaining water and measuring the salts left behind in the solution on a scale.

Conductivity was measured using a conductivity probe. The probe was calibrated with 3 separate conductivity standards of 100, 1000, and 10,000 µS/cm. After the probe was calibrated, measurements of the samples conductivity were recorded and then measurements of the conductivity standards were taken again to ensure accurate readings. Measurements of pH were taken using the same procedure as conductivity utilizing pH standards.

Total coliform and E. coli levels were tests using the Most Probable Number (MPN) test. In this method, 1 mL of the samples were added to a pre-prepared tray with wells that allowed for bacterial growth. Then diluted samples were added to another tray to allow for the use of MPN tables. Once the trays were filled with the samples, they were incubated for 24 hours, and the number of wells that were orange in color and the number of fluorescent cells present under blacklight were counted and referenced to the MPN tables to give an approximation of the coliform colonies and E. coli colonies in the sample.

8.2 Results

The final product requirements are: TDS below 500 ppm, TOC below 0.1 ppm, and pH between 6.5 and 8.5. The results of the bench scale experiments are shown in Table 4 and Table 5.

Table 4: Results from Mock Well Water

Sample	Conductivity (µS/cm)	TDS (mg/L)	pH	TOC (mg/L)
Feed 1 (B1)	2002	1197	7.26	10.96
Feed 2 (B1)	1994	1204.3	7.26	10.64
GAC/UF 1 (S2)	1392	805.8	8.18	0.75
GAC/UF 2 (S2)	1388	829	8.18	0.96
RO 1 (S5)	30.5	28.75	6.95	0.23
RO 2 (S5)	30.9	21	6.93	0.23

As seen in Table 4, the designed process is able to meet the target criteria of TDS and pH. Further experimentation will be conducted to reduce TOC levels even further. The GAC and ultrafiltration units were able to reduce TOC concentration by 75-80% and conductivity by 15%. After reverse osmosis, TOC concentration was reduced to 0.23 ppm. Conductivity and TDS were reduced by 95%, well under the EPA standard. The pH of the final effluent was approximately 7.

Table 5: Results from Silver City WWTP Effluent

Sample	Total Coliforms (MPN/100 mL)	E. coli (MPN/100 mL)	Conductivity (µS/cm)	pH	Turbidity (NTU's)	TDS (mg/L)	TOC (mg/L)
Feed (B1)	2419.6	461.1	773	7.96	5.96	452.3	3.83
After Ozone (B1)	1119.9	238.2	777	8.19	7.80	455.25	3.02
After UF (S2)	<1.0	<1.0	633	8.35	0.29	375.75	0.88
Product (S5)	<1.0	<1.0	23	7.88	0.16	30.50	0.25

As seen by Table 5, the bench scale system effectively removed coliform and E. coli. The conductivity, pH, and turbidity are also within potable levels in the product. The team is waiting for the laboratory results from TDS and TOC testing.

9. FUTURE EXPERIMENTATION

In the weeks between the report being sent to auditors and the WERC competition, the Poo Pig Sooie team plans to continue running variations of solutions to ensure the validity of the chosen processes. Effluent from the wastewater treatment plant in Silver City, NM will be treated with the ozone process to determine the appropriate dosage and treatment times to reduce coliform colony count to zero.

10. REGULATIONS AND SAFETY CONSIDERATIONS

When determining what process would best accomplish the task of creating drinking water, a clear definition of what constitutes drinking water was necessary. The EPA sets a national limit on 90 different contaminants that could be in drinking water, and the Safe Drinking Water Act gives states the ability to create regulations no less stringent that the EPA's.[7] Therefore, the guidelines for drinking water as outlined by the national regulations were used as a basis to determine whether the effluent water could be qualified as drinking water. The EPA includes both primary and secondary regulations, referring to regulations that are enforceable and unenforceable respectively. Both were taken into consideration while analyzing water samples.

The contaminants that were focused on included TOC, TDS, and total coliform. Based on the EPA national regulations, the maximum limit for total coliform is 5.0% of samples coliform positive per month.[16] Total coliform positive indicates that there is total coliform in the sample, without discrimination between types (such as *E. coli*). To enforce the 5.0% rule on total coliform, sampling regulations are in place based on the number of people serviced. Therefore, on the bench scale process, the EPA public health goal of zero total coliform was used as a benchmark to prove that the water is drinking water. For TDS, there is a secondary regulation at a limit of 500 mg/L. However, the taste and palatability of water is rated as excellent at a level below 300 mg/L, so the goal was to remain at or below this level.[21]

TOC itself is not regulated by the EPA but can result in disinfection byproducts in the effluent if not removed.[6] Therefore a recommended goal of 2 mg/L was used to ensure the effluent water was drinking quality, and then the given requirement of 0.1 ppm was followed.

10.1 Ozone Safety

Due to the production of ozone on site and it's usage in disinfection, ozone safety must be considered. Ozone as a gas ranges from colorless to blue and is characterized by having a strong pungent odor. The odor threshold is 0.02 to 0.05 ppm, however, longer exposure decreases sensitivity. Inhalation of ozone can lead to a headache, coughing, dry throat, heavy chest, and/or shortness of breath which can be combated by exposure to fresh air and oxygen therapy. The NIOSH ceiling exposure limit is 0.1 ppm for light exposure, and the Immediately Dangerous to Life and Health value is 5 ppm. In regards to long-term exposure, ozone is a radiomimetic agent. Similar to exposure to excess sunlight, this can cause aging and drying of the skin. Ozone does not show carcinogenic, teratogenic, or mutagenic characteristics. Ozone is highly reactive, and should not have contact with oxidizable substances including alkenes, benzene and other aromatic compounds, rubber, dicyanogen, bromine diethyl ether, dinitrogen tetroxide, nitrogen trichloride, hydrogen bromide, and tetrafluorohydrazine.[20]

11. PUBLIC INVOLVEMENT

Education and involvement of the public is a vital step towards the implementation of this process. There is currently a stigma associated with converting wastewater to drinking water. It is often viewed as "unsanitary" and "unhealthy," but the multi-barrier filtration and disinfection process removes contaminants within potable levels. The people affected by this water treatment need to be informed of the advantages of direct potable reuse. The main points of discussion would be how DPR is essential in preventing water scarcity in many areas where other options are not available. Many communities, including Silver City, NM, already practice de facto reuse when wastewater treatment plant effluent is returned to a surface or groundwater source and then sent to a drinking water plant. It will be important to illustrate that implementing this process will reduce the cost of their water bill, while delivering higher quality water to their homes. The public will also need to be involved during the implementation process, so the input on how to best serve the community can be considered. One specific way to do this would be to allow members of the public to tour the facility to build their confidence. This is a solution geared toward areas that are struggling to provide water, so the need may outweigh the stigma and the public would be more accepting. However, the same process can be used indirectly as is done in many areas where the public was unwilling to drink DPR water by injecting the effluent into a reservoir or the groundwater prior to distribution.

12. CONCLUSIONS

Implementation of this process will effectively treat wastewater treatment plant effluent to drinking water standards. For communities who struggle during seasons of drought, potable reuse is the most viable option. Our process is cost effective and less expensive than what water currently costs in some places throughout the southwest. The public must be educated and involved throughout the process in order to successfully start up a plant. Should the public not support direct potable reuse, it is important to note that indirect potable reuse is also an option. Although additional treatment would not be necessary, a project without public support will not be successful and the community will be no better off in times of a water crisis.

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