

Indiana University-Purdue University Fort Wayne

Department of Engineering



**DESIGN AND BUILD A MULTIMEDIA FILTRATION
SYSTEM FOR SUSTAINABLE WATER SUPPLY**

CE 488: Senior Design II Project

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Abstract:

The development of a sustainable water supply can serve many needs around the world. Developing nations where conventional water treatments are not available require a sustainable water supply for their daily water needs. Sustainable water supply systems are ideal because of their minimal chemical usage, low start-up and operation costs, and the ability to be built economically for a small or large scale water supply. This project investigated the ability of a slow sand filtration (SSF) system to be a sustainable alternative to conventional drinking water treatment and also its' ability to provide high quality effluent. The SSF system consisted of a pretreatment stage that involved the use of three gravel roughing filters followed by a sand bed with a depth of 2.5 ft. The SSF system was provided with a continuous water supply to filter through the sand bed for approximately six weeks, with the effluent from the system collected twice daily. The effluent and raw water was then tested and compared to determine the ability of the SSF to improve the turbidity, pH, and the UV absorbance of the water.

To compare the SSF system to conventional and unsustainable water treatment, two different coagulants were used in the jar test. The jar test shows the optimum dosage of coagulant that will result in the highest turbidity removal. Both aluminum sulfate and ferric chloride were used in the jar test and compared to the turbidity removal capabilities of the SSF system.

The results of the jar test showed the optimum dosage for the aluminum sulfate as 50 mg/L with a turbidity removal rate of 83.7%. The ferric chloride had an optimum dosage of 30 mg/L and a turbidity removal rate of 78.3%. The effluent from the SSF system had an average turbidity of 1.49 NTU while the raw water had an average turbidity value of 27.6 NTU. This results in the SSF system having a turbidity removal rate of 94.6% which is higher than what both coagulants could achieve. The comparison of the SSF system's effluent to the influent raw water also showed an improvement in all three of the water quality parameters tested. The average pH in the raw water was 8.3 while after filtration it was an average of 7.99. UV absorbance for the wavelengths of 254 nm, 280 nm, and 400 nm also showed a drop after filtration. In all tests completed, the SSF system showed an improvement in water quality from the initial raw water and proved to be a viable option as a sustainable alternative to conventional chemical coagulants.

Problem Statement:

The objective for this project involves investigating alternative approaches to riverbank filtration (RBF) in order to supply water in a sustainable manner. In the previous semester, RBF was chosen as the primary design to investigate as a source for sustainable water supply. The requirements of the previous semester involved using RBF as a way to supply drinking water to IPFW's campus utilizing the St. Joseph River. It was discovered in the previous semester that RBF would be an unsuitable system for supplying water to IPFW due to site constraints. As an alternative to RBF, slow sand filtration (SSF) was investigated for its ability to be a sustainable water supply for IPFW. While it was found that SSF would not be an ideal alternative for IPFW due to the size of the filter and the limited space available for such a system, it was decided that a SSF would be suitable for a location with a smaller water demand. It was determined to investigate the ability of a SSF to improve the quality of the raw water supply and compare the quality and sustainability of the system to more conventional treatment options.

Scope of Project:

In order to accomplish the objective for this project, a bench-scale SSF was designed, built, and tested. The results of the SSF testing were compared to the quality of the raw water in order to determine the SSF's filtration efficiency. To compare the quality and sustainability of the SSF to more conventional treatment options, two different types of coagulants were tested utilizing the jar test method. The jar test method allows the determination of the optimum coagulant dosage to be determined that results in the highest quality of water. The quality level that both coagulants could attain was compared to that achievable by the SSF. The quality of the water was tested in regards to pH, turbidity, ultraviolet (UV) absorbance, and chemical oxygen demand (COD). With these quality parameters, the filtration efficiency of the SSF was compared to the effectiveness of the coagulants.

Background of Slow Sand Filtration:

Slow sand filtration (SSF) has been used for hundreds of years to provide a means to improve the quality of water. While SSF has a long history behind it, the different scenarios where it can be utilized are still being discovered. SSF's sustainable approach to purifying water with minimal

use of chemicals, low electricity requirements, and marginal operation and startup costs have made it desirable in developing countries who have poor water purification capabilities and also in developed countries with technically advanced water treatment plants. The benefits of SSF make it an ideal water treatment option in a world where more and more emphasis is being placed on providing safe and sustainable approaches to our everyday needs.

SSF operates by allowing untreated water to slowly percolate through a bed of porous sand, with the influent water source introduced over the top surface of the filter area, and effluent collected and drained from the bottom, as seen in Figure 1, below. The ability of SSF to purify water through this method is the result of several mechanisms that occur during filtration. SSF requires a continuous filtration of raw water through the sand bed. As the raw water filters through the sand grains, particles in the raw water are removed by transport and attachment processes. The most basic transport mechanism that occurs in SSF is the straining of particles out of the water by the sand grains. Straining occurs when the particles in the water larger than the voids in the sand grains become trapped and lodged in the sand bed. As more and more particles become lodged in the sand bed, the pore size between the sand grains and the particles decrease, allowing for a larger percentage of particles in the water to be removed. The majority of this screening process occurs at the surface of the filter. Sedimentation of the particles onto the sand grains is another transport mechanism. The settling action occurs as gravity forces the particles to move downward onto the top surfaces of the sand grains. Since the flow rate through SSF is gradual, the particles will remain settled on top of the sand grains and removed from the effluent of the SSF system. (Introduction to SSF)

The sedimentation removal of the particles is enhanced by attachment processes. Once the particle has made contact with the sand grains, Van der Waals forces can help maintain that particle on the sand grain. Another and stronger attachment mechanism is the adhesion of particles to the *schmutzdecke* layer or “dirt cover”. The *schmutzdecke* layer consists of the organic matter that settles on the filter surface and becomes the breeding ground for bacteria and microorganisms. As the *schmutzdecke* layer develops it becomes a sticky, gelatinous film and adheres a great deal of the particles from the raw water. The layer takes several weeks to form and can consist of bacteria, fungi, protozoa, algae, and microscopic aquatic organisms, once fully developed. The organic matter in the raw water is trapped by the *schmutzdecke* layer and

utilized by the bacteria and microorganisms as a food source, thus reducing the organic matter into water, carbon dioxide, and inorganic salts. The schmutzdecke layer provides the primary means for eliminating organic matter in the SSF effluent. (Introduction to SSF)

The transport and attachment processes in an established SSF have the ability to greatly improve the quality of the raw water. No other single process in typical drinking water treatment plants has the ability to improve the physical, chemical, and bacteriological quality of the raw water as an established SSF. The impressive capability of SSFs to improve the raw water quality has encouraged numerous communities in the United States and around the world to implement SSFs as their primary drinking water treatment. According to Slezak and Sims, there are 47 SSF facilities in the United States. The majority of these SSF facilities serve communities with populations under 10,000 people and have been in operation for up to 100 years. These facilities show the ability of SSF to provide potable water to communities while serving an impressive life span. Although the success of SSF has been proven in various applications around the world, each new application of SSF should be tested with a bench scale model of the raw water to be used in the system. Since each raw water source will be unique, the ability of the SSF to purify the raw water will be different in each case. Creating a bench scale model allows the efficiency of the SSF to be evaluated with each raw water source. (Introduction to SSF)

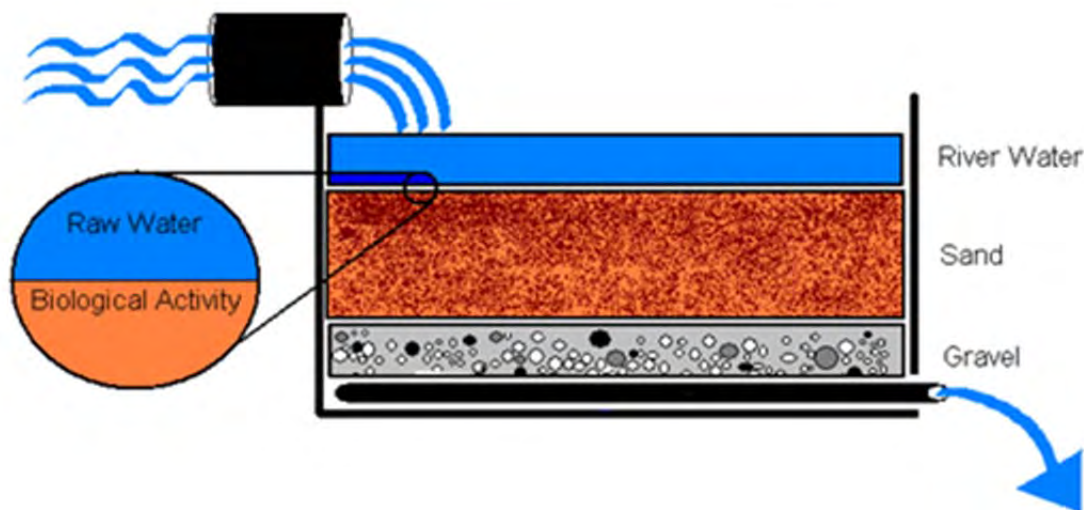


Figure 1: Basic Design of SSF (Source: City of Salem)

Design of a Bench-Scale SSF Model:

The design, build, and testing of a bench-scale SSF model will provide a way to monitor the ability of the SSF to improve the raw water quality. For this project, the raw water utilized was from the St. Joseph River. The water was collected from along the bank of the river at IPFW's campus and transported from the river to a heated lab where the water was allowed to come to room temperature before being introduced to the system. This allowed the influent water to have a consistent temperature and prevent any shock to the system due to abrupt temperature changes.

It was ideal and practical to develop the bench scale model in a similar fashion to a real-life SSF model. One of the first components considered in designing the SSF was the quality of the raw water entering the sand bed. Determining the quality of the raw water helped to decide if any pre-treatment steps were needed before the influent water entered the SSF. Raw water with high turbidity and color values would result in the filter becoming clogged quickly and having to be cleaned. Cleaning the filter results in more maintenance and less effluent being produced from the system. According to the Great Lakes-Upper Mississippi River Board (GLUMRB) 10 States Standards, "slow rate gravity filtration shall be limited to waters having maximum turbidities of 10 units". Since the water source for the project was a river with large fluctuations in the water quality, research was completed to determine the range of turbidity throughout the year. Testing was also completed in the lab with a Hach 2100N Turbidimeter to determine the current turbidity levels. The turbidity levels in the St. Joseph River on September 6, 2012 can be seen below in Table 1.

Table 1: Turbidity Levels in the St. Joseph River on Sept. 6, 2012

	Turbidity (NTU)
River Sample Reading #1	7.05
River Sample Reading #2	6.97
River Sample Reading #3	6.97
Average River Sample Reading	7.00
Standard Deviation of River Samples	.04

According to Yavich, the turbidity levels of the St. Joseph River in Fort Wayne from May 2002 to December 2011 ranged drastically as seen in Figure 2, below. The turbidity levels have an approximate range of 5 NTU to 325 NTU showing that the turbidity levels vary significantly.

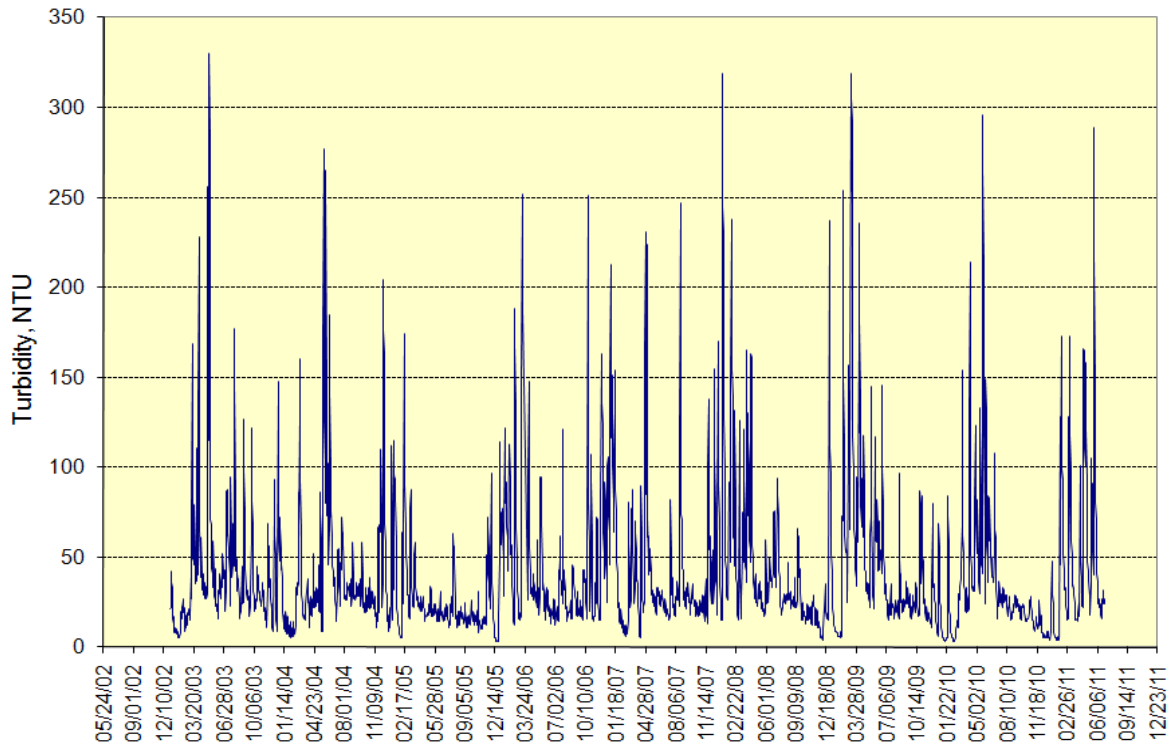


Figure 2: Turbidity Level in the St. Joseph River from May 2002 to December 2011 (Source: Yavich)

To account for the large fluctuations in the turbidity levels, it was decided to implement a pre-treatment stage before slow sand filtration. The pre-treatment would be needed to remove the particles from the water that were contributing to high turbidity. There were several options considered for the pre-treatment stage including a sedimentation tank, roughing filters, or rapid sand filters. The sedimentation tank would consist of a large tank where the particles in the water could settle out and collect on the bottom of the tank. This option would be easy to implement and also inexpensive. The problem with the sedimentation tank is the turbidity removal efficiency which could be below satisfactory for the SSF if the turbidity levels were high. Another concern was the potential to disturb the collected particles on the bottom of the tank when transferring water from the sedimentation tank to the SSF. Due to these concerns, the sedimentation tank was eliminated as a pre-treatment option.

The second option for pretreatment involved using a series of roughing filters to remove the turbidity from the raw water. Roughing filters consist of gravel arranged in a tiered sizing arrangement. The first filter would consist of the largest sized gravel followed by two other filters with decreasing sized gravel. The arrangement of sized gravel allows the largest particles to collect in the void spaces of the first filter while the smaller particles travel on to the second and third filter. This design prevents any of the filters from becoming clogged quickly and lessens the maintenance on the system.

The last option available for pre-treatment was the use of a rapid sand filter. This filter operates similar to a slow sand filter except the filtration rate is much greater and the sand grains are larger. This option proved to be problematic if the turbidity levels were considerably high. It would also require more maintenance than the other options since backwashing would have to occur more frequently than with the roughing filters.

The roughing filters were chosen as the preference for pre-treatment. In designing the roughing filters, the size of the filter, type of gravel, gravel size, filtration rate and the hydraulic flow through the system were determined. The gravel size was selected through research done on other roughing filters. It was discovered that almost all roughing filters were composed of gravel following the size arrangement shown in Table 2.

Table 2: Typical Sizes of Gravel for Roughing Filters

Filter Material	Size of Filter Materials (mm)		
Characteristics	1st Fraction	2nd Fraction	3rd Fraction
Course Filter	16-24	12-18	8-12
Normal Filter	12-18	8-12	4-8
Fine Filter	8-12	4-8	2-4

It was decided to use three filters for the roughing filter setup. The first filter would have gravel sized at 3/8" by 5/8", the second filter at 1/4" by 1/2", and the third filter with gravel sized at 1/8" by 1/4". This sizing followed very closely to the recommended sizes proposed in Table 2. The filtration rate for the roughing filters would be between .3-.6 m/hr. for optimum

performance. The depth of the filters would be at least 18 inches to provide a sufficient volume of voids in the filters to collect the particles out of the raw water.

With the basic setup of the roughing filters as a pre-treatment, the design components of the SSF were decided. The design of the SSF followed the GLUMRB 10 State Standards. The standards followed in the design of the SSF model can be seen below:

- The nominal filtration rate shall be 45 to 150 gallons per day per square foot of sand area (1.8 - 6.1 m/day)
- The effective size of sand shall be between 0.15 mm and 0.30 mm.
- Uniformity coefficient of sand shall be between 1.3-1.8
- Sand Porosity: .4-.47
- Sand Specific Gravity: 2.55-2.65
- Sand Sphericity: .7-.8

The sand for the SSF was selected from a drinking water media supplier with the effective size of the sand being .25 mm. A sieve analysis of the sand can be seen below in Figure 3 and the properties of the sand in Table 3. The depth of the sand filter bed was selected as .75 m. While the biological surface layer of the sand bed provides the primary purification of the raw water, the additional depth helps to remove color from the raw water.

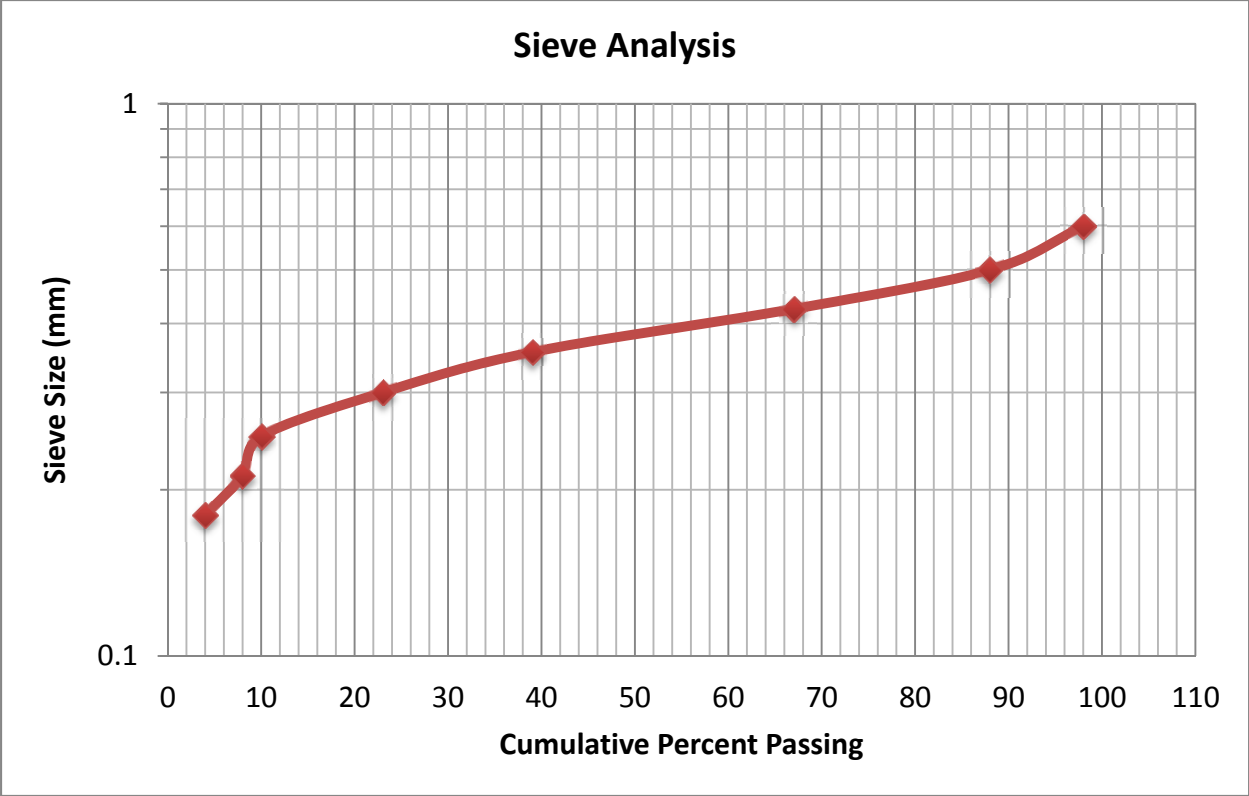


Figure 3: Sieve Analysis of Sand Used in SSF (Data: Red Flint Sand and Gravel)

Table 3: Characteristics of Sand Media

Density	100 lbs./ft ³
Size	.2-3 mm
Acid Solubility	<1.0%
Specific Gravity	2.67>2.60
Hardness	6.0-8.0 on MOH scale
Uniformity Coefficient	1.3-<1.65
ANSI/NSF 61 Approved	
AWWA Standard B100-01	

The sizing of the entire SSF system was determined through the amount of water that could be supplied to the system daily. It was also desirable to maximize the ratio of the surface area of the sand to the surface area of the surrounding container in order to lessen the percentage of the water taking the path of least resistance along the side of the container. It was decided that the most reasonable amount of water that could be supplied to the system in a day would be 15 gallons. With this value in mind along with the filtration rate, the surface area of sand to provide that quantity of water was determined. The size of the roughing filters was also determined in a similar manner. Table 4, below, shows the different sizes of the SSF and the daily output for each along with the size of the accompanying roughing filters.

Table 4: Flow Output for Various Sized SSF and Corresponding Sizes of Roughing Filters

Diameter (in)	SSF		RF	
	Filtration Rate (m/hr.)	Flow Rate (gal/d)	Filtration Rate (m/hr.)	Diameter (in)
12	0.17	78.55	0.4	7.82
10	0.17	54.55	0.4	6.52
8	0.17	34.91	0.4	5.22
5.75	0.25	26.52	0.3	5.25
5.75	0.16	17	0.3	4.20
5.75	0.15	15.93	0.6	2.88
4.75	0.17	12.32	0.4	3.1
4.25	0.17	9.86	0.4	2.77
3.75	0.17	7.68	0.4	2.44

The SSF was selected to have a diameter of 5.75 inches, a filtration rate of .16 m/hr., and a daily output of 17 gallons. To accompany this size of SSF, the roughing filters would need to be 4.2 inches in diameter with a filtration rate of .3 m/hr. The roughing filters were selected to have a size of 4.25 inches since this was a more conventional size.

The next component to be designed in the system was the available depth of the water head over the SSF. This is required since the SSF will experience more resistance to flow as time progresses due to the clogging of the voids in the sand grains. Near the end of the filter's run

time the headloss will increase in the filter until terminal headloss is reached. The ability to increase the pressure head of the water over the SSF will allow longer run times before this scenario occurs. By calculating the clean filter headloss, the level of clogging in the filter can be determined by comparing the headloss at that time to the clean filter headloss. The clean filter headloss will be the minimum amount experienced by the filter during its filter run time. The Carmen-Kozeny equation along with the Rose equation were both used to calculate the clean filter headloss. Both equations can be seen below:

$$\text{Carmen-Kozeny Eq: } h_L = \frac{1}{\phi \varepsilon} \frac{1 - \varepsilon}{\varepsilon^3} \frac{L v_a^2}{g} \sum f \frac{p}{d_g}$$

$$f = 150 \frac{1 - \varepsilon}{R} + 1.75$$

$$R = \frac{\phi d v_a \rho}{\mu}$$

$$\text{Rose Eq: } h_L = \frac{1.067 v_a^2 D}{\phi g \varepsilon^4} \sum C_D \frac{f}{d_g}$$

$$d_g = (d_1 d_2)^{.5}$$

$$C_D = \frac{24}{R} + \frac{3}{R^{.5}} + .34$$

Equation Terms:

ϕ =particle shape factor

ε =porosity

L,D=depth of filter bed (m)

v_a =filtration velocity (m/s)

g=acceleration due to gravity (m/s²)

p=fraction of particles (based on mass) within adjacent sieve sizes

d_g = geometric mean size of successive sieves

d=grain size diameter (m)

μ =viscosity (Pa-s)

ρ =density of water (kg/m³)

The Carmen-Kozeny equation resulted in a clean filter headloss of approximately 3 cm/s and the Rose equation resulted in an approximate clean filter headloss of 4 cm, using a filtration rate of 4.72×10^{-5} m/s (3.8 m/d) A table of calculations for both equations can be found in the Appendix.

Table 5: Clean SSF Headloss Using Carmen-Kozeny Equation

US Mesh	Size (mm)	% Passing	% Retained	d,m	R (v=.0000472m/s)	f	p (%)	d _g (mm)	f*(p/dg)
30	0.6	98	2	0.00055	1.49E-05	5538137	0.1	0.547723	1011121
35	0.5	88	10	0.000463	1.25E-05	6585893	0.21	0.460977	3000230
40	0.425	67	21	0.00039	1.06E-05	7810193	0.28	0.388426	5630036
45	0.355	39	28	0.000328	8.87E-06	9300687	0.16	0.326343	4559952
50	0.3	23	16	0.000275	7.45E-06	11076273	0.13	0.273861	5257828
60	0.25	10	13	0.000231	6.26E-06	13186039	0.02	0.230217	1145530
70	0.212	8	2	0.000196	5.31E-06	15540688	0.04	0.195346	3182190
80	0.18	4	4		0				
								Total	23786885

$$h_L = \frac{1}{.75} \frac{1-.45}{.45^3} \frac{.76 * .0000472^2}{9.81} * 23,726,885 = .0285 \text{ m} = 2.85 \text{ cm}$$

Table 6: Clean SSF Headloss Using Rose Equation

US Mesh	Size (mm)	% Passing	% Retained	d,m	R (v=.0000472m/s)	Cd	f	Cd*f/d
30	0.6	98	2	0.00055	0.01489671	1636.014	0.1	297457
35	0.5	88	10	0.0004625	0.012526779	1943.04	0.21	882245
40	0.425	67	21	0.00039	0.010563122	2301.585	0.28	1652420
45	0.355	39	28	0.0003275	0.008870314	2737.847	0.16	1337574
50	0.3	23	16	0.000275	0.007448355	3257.289	0.13	1539809
60	0.25	10	13	0.000231	0.006256618	3874.205	0.02	335429
70	0.212	8	2	0.000196	0.005308646	4562.442	0.04	931110.5
80	0.18	4	4		0			
							Total	6976045

$$h_L = \frac{1.067 * .0000472^2 * .76}{.75 * 9.81 * .45^4} * 6,976,045 = .041 \text{ m} = 4.1 \text{ cm}$$

In order to control the filtration rate through the SSF and each roughing filter, flow control valves were added to the design of the system. These valves allow the optimum filtration rate to be set in each filter. Implementing flow control valves after the SSF will also result in an increased resistance in the system which will result in additional headloss. To ensure that there is a large enough pressure head to compensate for the SSF clogging and the resistance developed in the flow control valve, a water reservoir above the SSF will be implemented. This reservoir will also allow slight fluctuations in the water levels without causing the SSF to run dry or overflow.

Final Design:

The preliminary design of the roughing filters and the SSF system can be seen below in Figure 4 with the final design of the system shown in Figure 5. Figure 6 shows the roughing filters and the SSF can be seen in Figure 7. The flow control valves used to control the filtration rate through each filter can also be seen in Figure 7. The columns for the SSF and the roughing filters were composed of clear extruded acrylic. The roughing filter cylinders had an overall height of three feet with 2.5 feet of the column containing gravel. The SSF cylinder was composed of two-three foot sections of extruded acrylic that were held in place by a rubber pipe coupling. Both the roughing filters and the SSF had an acrylic base attached to the bottom of the columns with JB WaterWeld. The hose connecting the filters together was 3/8" I.D clear plastic.

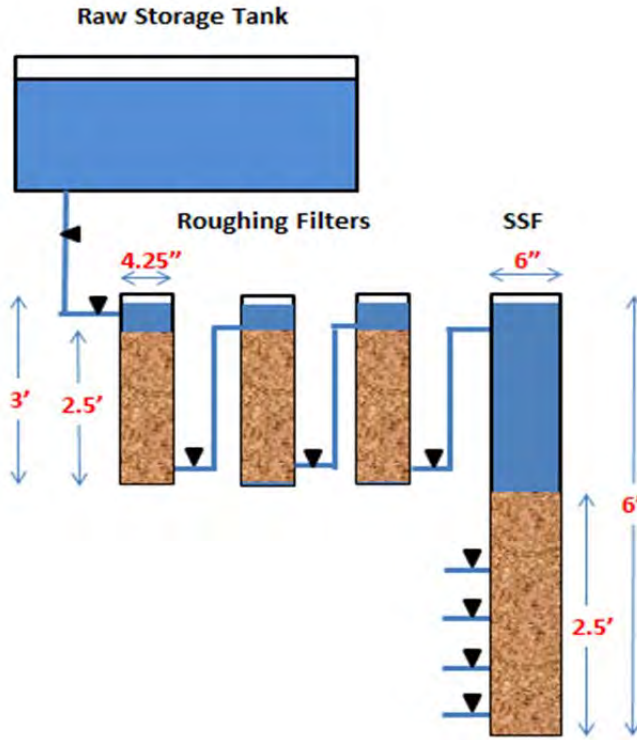


Figure 4: Preliminary Design of SSF System



Figure 5: Final Design of SSF System



Figure 6: Roughing filters

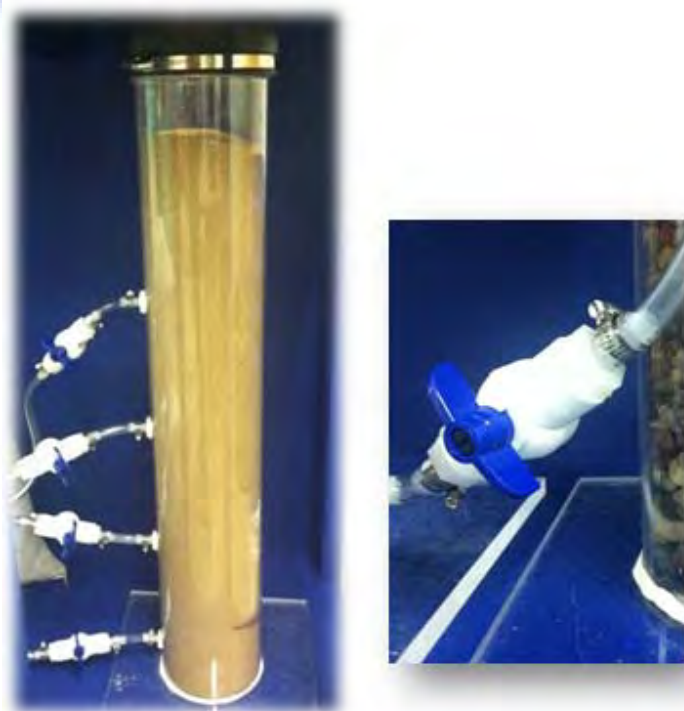


Figure 7: SSF column (left) and shut-off valve (right)

Testing:

The plan developed for testing the SSF allowed for observations to be made regarding the quality and quantity of water produced from the SSF. The goal of the testing was to be able to compare the quality of the SSF effluent to the raw water quality and also observe any changes in the flow rate. The flow rate was observed and monitored for the first 10 hours to observe the initial clogging of the voids in the filter. This change in flow rate also allowed the change in headloss to be observed in the system.

To determine the quality of both the SSF effluent and the raw water, the turbidity, pH, UV absorbance, and chemical oxygen demand (COD) was tested two times daily. A water sample was collected in the morning and in the evening from the SSF effluent. A sample was collected and tested each time raw water was collected from the river. The testing procedures for each parameter can be seen below:

Turbidity (Standard Method 2130)

1. Obtain 75mL of the water sample to be tested. Be sure the sample is well mixed prior to taking the measurement.
2. Turn the turbidity meter on and allow it to warm up for approximately 5 minutes.
3. Using the standard turbidity samples, verify that the turbidity meter is working properly. Be sure to mark down the standard turbidity indicated on the sample as well as the turbidity measured by the instrument. This will be used to determine the standard calibration curve.
4. Place approximately 25 mL of unknown sample into a glass turbidity tube and place the sample in the turbidity meter.
5. Measure the turbidity and repeat.
6. Calculated the average and standard turbidity of your sample using the standard calibration curve generated from 3.

pH:

1. Calibrate the meter (Hach HQ40D) with the standard buffer solution. The red colored buffer solution has a pH of 4.01, the yellow colored buffer solution has a pH of 7, and the blue colored buffer solution has a pH of 10.01.

2. Rinse the pH probe with deionized (DI) water between switching each buffer or sample.
3. Keep stirring the solution when measuring the pH values.
4. Read three times for each sample.
5. Rinse the pH probe again and seal the probe with 3 M KCl solution after the last measurement.

COD:

1. Preheat the digester block to 150°C
2. Remove the cap from a COD vial containing concentrated H₂SO₄.
3. Pipet 2.00 mL of the sample into the vial with caution, as the vial will become hot.
4. Replace the cap onto the COD vial, making certain that it is secured tightly.
5. Carefully invert the vial several times to mix the contents.
6. Prepare the reagent blank by repeating Step 3 using DI water.
7. Wipe the outside of the vials by paper towel.
8. Allow the vials to heat in the digester block at 150°C for 2 hours.
9. Let the vials cool down to room temperature.
10. Measure the absorbance of the vials by a colorimeter and obtain COD reading.

UV Absorbance:

UV-Vis absorbance at 254, 280 and 400 nm was used to determine the concentrations of overall organics, aromatic organics, and color substances, respectively by a UV-VIS spectrophotometer (Lambda 25, PerkinElmer) with a 10 mm quartz cuvette.

Conventional Water Treatment Processes – Coagulation, Flocculation, and Sedimentation:

Influent Water Quality:

Water sources, specifically surface water and ground water under the direct influence of surface water (GWUDI), contain suspended, dissolved, and colloidal particles. In order to provide further purification of the water through filtration, the amount of these particles must first be reduced to in order to avoid constant clogging of the filtration systems. In order to separate the suspended particles from the water a series of steps is used in which the particles are conditioned and removed from the water. This series of steps is known as



Figure 8: Fort Wayne Three Rivers Filtration Plant

coagulation, flocculation, and sedimentation and is currently used in conventional drinking water treatment.

These suspended particles have been in the surface waters for long periods of time as stable discrete units. One of the forces that play a part in the stabilization of these particles is due to the charges that these particles bear. These suspended particles most generally carry a negative charge and since all of the particles have the same charge they are not attracted to one another. Therefore no clumping or settling will occur due to these repulsive forces that the particles bear. In order to overcome this coagulation and flocculation is used as a pretreatment step in which the particles are destabilized and drawn together to form floc.

Coagulation:

The first step in the removal of the suspended particles is coagulation. Coagulation is the addition of chemicals, also known as coagulants, to the water that have opposite charges to that of the suspended particles in the water. The chemicals added neutralize the charges of the particles in the water and allow them to stick together. The larger destabilized particles formed

through this process are called microflocs that are not yet visible to the naked eye. If these microflocs do not form then either not enough coagulant was used or the coagulant was not dispersed properly.

To perform coagulation correctly a rapid mix of the water and coagulant is required to promote the particle collisions necessary to form floc. If the combination is not mixed sufficiently then the coagulation stage will be incomplete while over-mixing is not an issue. A proper contact time of 1 to 3 minutes is required during the rapid mixing of the coagulant.

Several different coagulants are currently available in the market and are selected depending on the conditions of the influent water and the availability of the product. Common coagulants that are used include aluminum sulfate, ferric sulfate, ferric chloride, and polymers. Some of the common properties among these coagulants are that they are metals and typically carry a positive charge of 3+.

After selecting the coagulant that will be used in the treatment of the raw water the best dosage needs to be determined. If not enough coagulant is added to the water then not enough floc will form which is used to aggregate the particles and natural organic matter (NOM's). When too much coagulant is added to the water the charge of the particles in the water is reversed from negative to positive which results in a similar situation to the initial situation. In order to avoid this problem of under or over dosing the water with coagulants a method to determine the best dosage is used.

The Jar Test is a simulation of the water treatment processes that occur in conventional drinking water treatment but at a smaller scale. This provides the necessary information, on a day to day basis, to the system operators so they know how a coagulant behaves with the raw water and how much needs to be used to successfully neutralize the suspended particles.

Flocculation:

The next process, after the rapid mixing of coagulants during coagulation, is flocculation. Unlike the process of coagulation, flocculation is the gentle mixing of the microfloc produced in the previous step. This gentle mixing allows the floc to increase in size from microfloc to visible suspended particles. The increase in size is due to the additional collisions that occur during the gentle mixing of the water. If the mixing velocity, during flocculation, is too high then the floc

will not form well and can possibly be destroyed defeating the purpose of coagulation. Once the floc has reached an optimum size and strength, which typically takes 20 to 45 min, then the water is ready for the next process known as sedimentation.

Sedimentation:

Sedimentation is a solid-liquid separation process, which is driven by greater density of solid particles than water. During the sedimentation process, low Reynolds number is preferred to facilitate the settling of the suspended and colloidal particles to the bottom of the tank. Consequently, supernatant can be harvested from the top of the sedimentation tank.

Methodology:

Jar tests were performed to simulate the conventional drinking water treatment processes including coagulation, flocculation, and sedimentation together in a jar test device from Phipps & Bird as shown in Figure 9. Up to four beakers can be tested at the same time. The rotation speed of each paddle was adjustable from 0 to 295 rpm for different mixing requirements of the treatment processes. The St. Joseph River water was the raw water to be treated, same as the multimedia filtration system. Different dosages of the coagulants (aluminum sulfate and ferric chloride) were tested separately to evaluate the purification efficiency.

Jar Test:

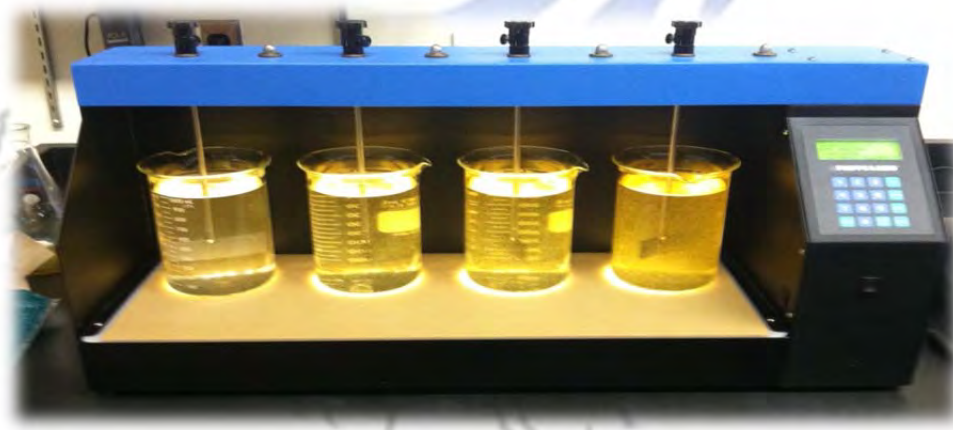


Figure 9: Jar Test Device

Experimental Steps:

- 1) Add 1,000 mL of raw water to each of the jar test beakers. Record the original turbidity of the samples.
- 2) Prepare a stock solution of coagulant by dissolving 100 mg of the chemical coagulant into 10 mL of DI water. Each 1.0 mL of this stock solution will equal 10 mg/L of the chemical coagulant when added to 1,000 mL of raw water.
- 3) Turn on the stirrer to the highest speed of 295 rpm while simultaneously adding stock solution of 0, 2, 3, and 5 mL to beakers 1 thru 4, respectively. Let it stir for ~1 min to simulate the static mixing in the conventional drinking water treatment plant.
- 4) At the end of the coagulation stage, reduce the speed of stirring to 40 rpm to match the conditions of flocculation for 14 minutes.
- 5) At the end of the 14 minutes, turn off the stirrer and allow the settling of the suspended particles for 30 minutes. This is the sedimentation process that occurs after flocculation.
- 6) Take samples of the supernatant of each beaker and measure the turbidity.
- 7) Draw a curve of dosage (x-axis) vs. turbidity removal (y-axis).

Results:

SSF:

After collecting over 90 different water samples throughout the semester and testing them according to the methodology listed above, the results obtained are shown below.

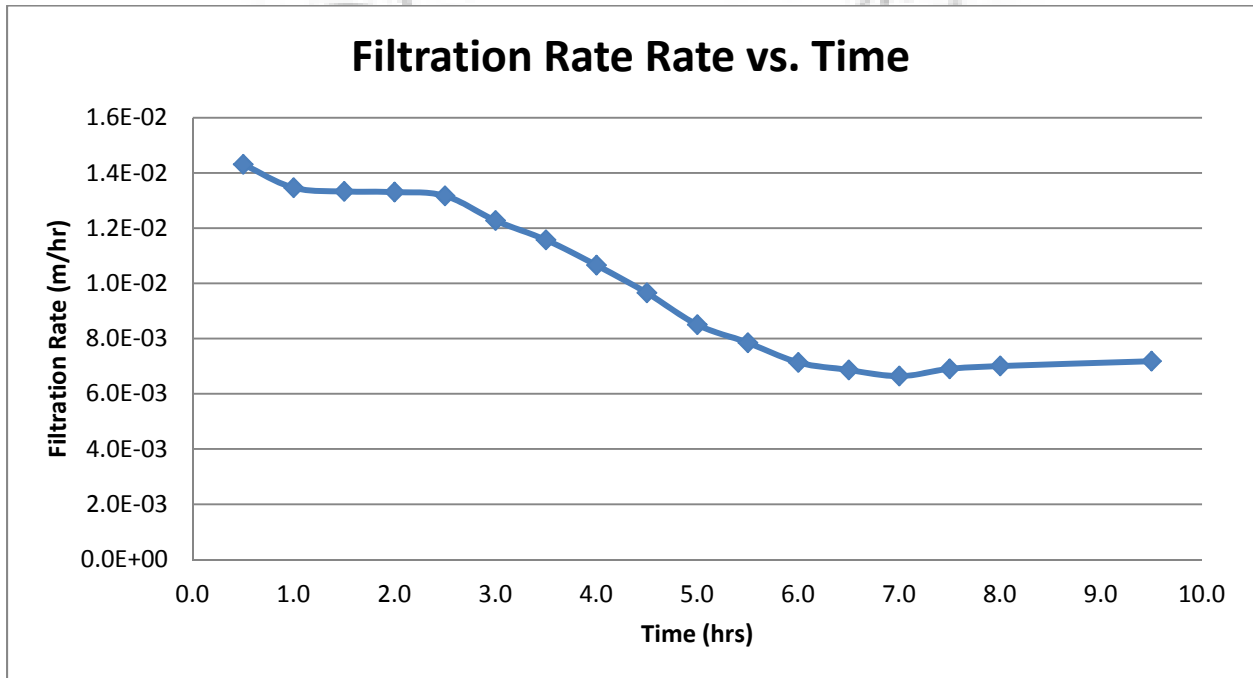


Figure 10: Initial Filtration Rate of SSF System

As seen in Figure 9, the initial filtration rate started at the initial system setting of .0143 m/d. As time went on, the sand grains settled decreasing voids and became clogged with particles from the raw river water. Because of this, a drop in the filtration rate is seen. At around the seven hour mark the system started to level out with the filtration rate around .007 m/d. At this point, the sand was fully settled and saturated.

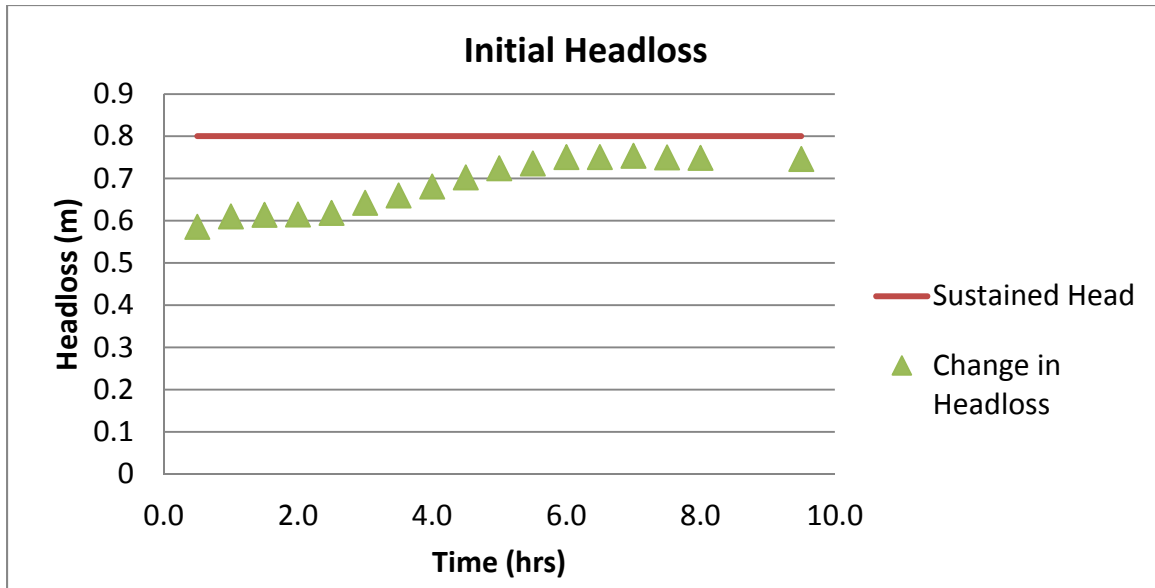


Figure 11: Initial Headloss of SSF System

For the same reasons the flow rate decreased, the headloss in the slow sand filter increased. As seen in Figure 10, the initial headloss is .6 meters and increases till around the seven hour mark where it levels off around .72 meters. Because of this headloss, the SSF column was designed to hold enough water to overcome these losses while still providing the desired flow rate exiting the SSF. The large change in headloss from the calculated clean filter headloss to the initial headloss shown in Figure 11 is due to the resistance provided by the flow rate valves. Since the valve was partially open to control the filtration rate, additional pressure was needed to push the water through the SSF system and out of the control valve. If the SSF column did not have the resistance due to the control valve and the effluent hose, the clean filter headloss value could be used to provide the desired filtration rate.

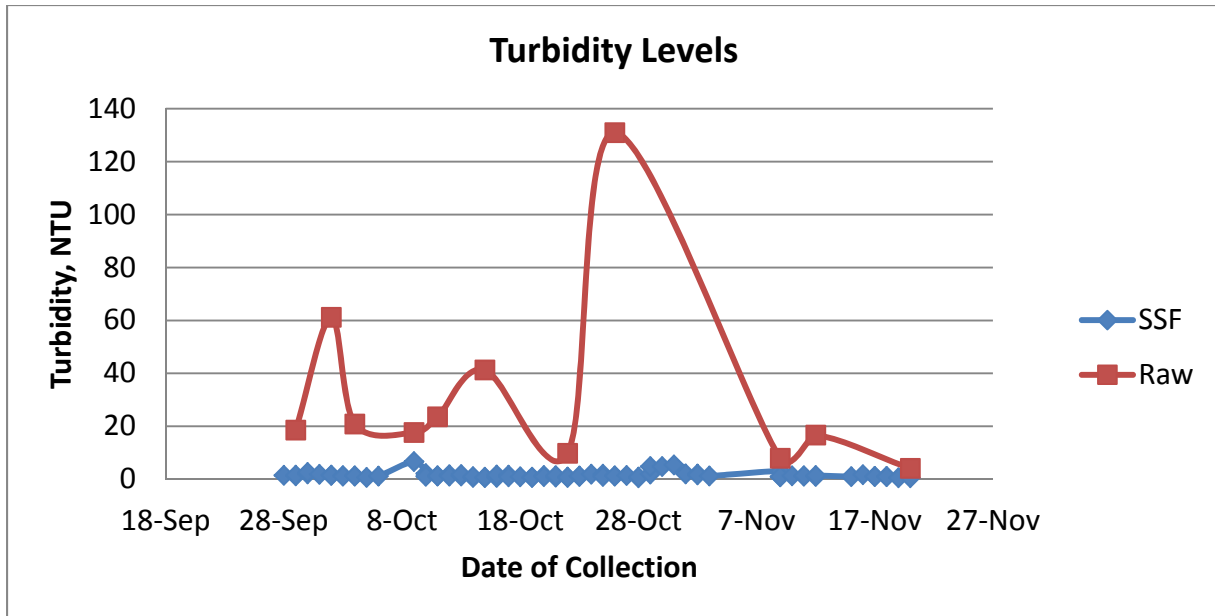


Figure 12: Turbidity levels of SSF system

Figure 11 shows the different turbidity levels of both the Saint Joseph River raw water samples and the effluent from the slow sand filter. From the data shown it can be seen that the raw water turbidity fluctuated significantly over the course of the semester ranging from 4.12 nephelometric turbidity units (NTU) up to 131 NTU. Although the raw water fluctuated, the effluent from the SSF was consistently less turbid than that of the raw water ranging from 0.55 NTU to 6.66 NTU providing an average turbidity of 1.49 NTU with a standard deviation of 1.07 NTU. With the filtration provided by the combination of the roughing filters and the slow sand filter, there was an overall 95.5% turbidity removal rate in the system.

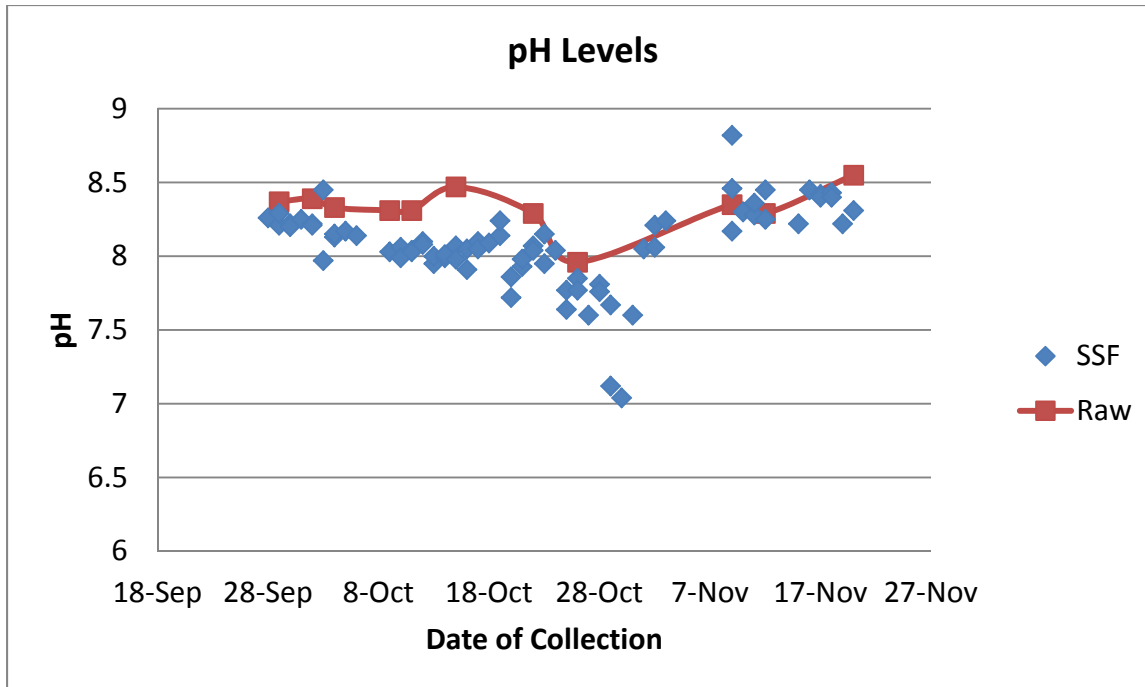


Figure 13: pH levels of SSF system

Figure 12 shows the different pH levels of both the Saint Joseph River raw water samples and the effluent from the slow sand filter. From the data shown it can be seen that the SSF reduces the pH levels from the initial river water. From September 28th to October 30th there was an overall decline in pH levels in the SSF due to microbial degradation provided by the formation of the microbiological layer on top of the SSF (schmutzdecke) as well as throughout the SSF column. These pH levels range from roughly 8.26 to 7.04, providing a standard deviation of 0.25 and an average pH drop of 0.31. After October 30th backwashing had to be done because of a decrease in water quality. This can be seen in Figure 12 because the pH levels start to rise after the backwashing, jumping from a pH of 7.04 to a pH of 8.82. Because of the methods used to backwash the efficiency of the microbiological organisms in the filter column was decreased. This provided a decrease in the pH level difference between the raw water and the effluent of the SSF. The time constraints provided by the semester, however, did not allow the efficiency of the microbial degradation to return to its full potential.

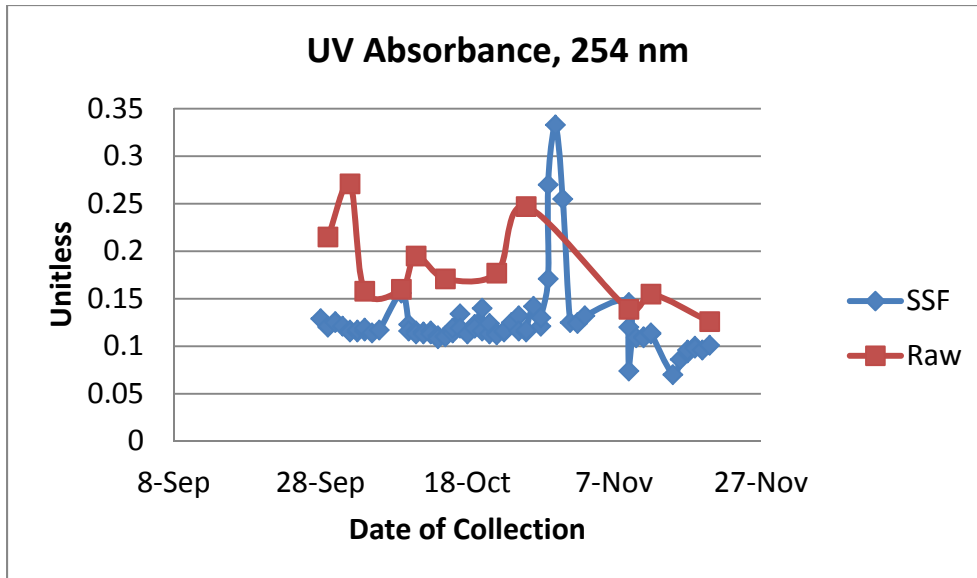


Figure 14: 254 nm UV Absorbance of SSF system

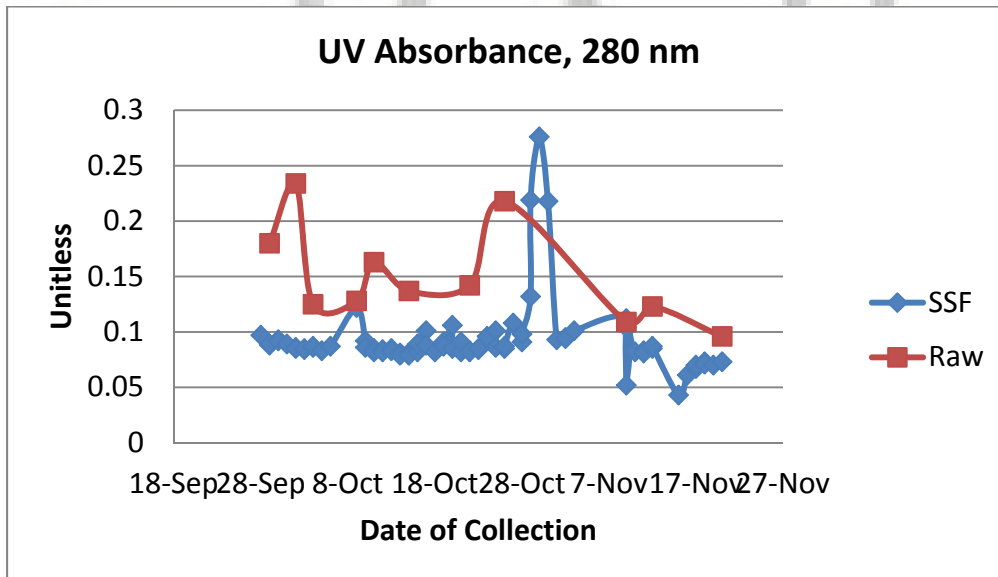


Figure 15: 280 nm UV Absorbance of SSF system

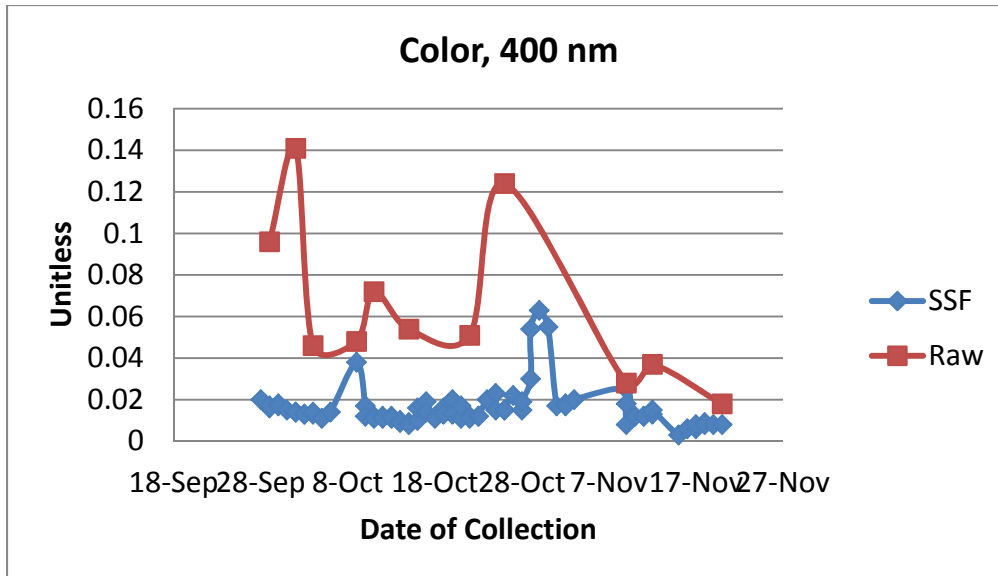


Figure 16: 400 nm UV Absorbance of SSF system

Figures 13, 14, and 15 show the UV absorbance of the SSF compared to the raw water from the Saint Joseph River. All three figures show a significant decrease in UV absorbance provided by the filtering of water through the SSF.

The first wavelength used was 254 nanometers (nm) which helps represent the overall organic matter in the water samples. Similar to the results of pH, the UV absorbance was relatively constant from September 28th till about October 28th. These results provide a minimum UV absorbance of .108 and a maximum of 0.156 with an average of 0.120 and a standard deviation of 0.009. After October 28th the absorbance started to rise because of the extreme buildup of microbial content. In order to remedy this, backwashing was done and as a result lowered the UV absorbance back to the original absorbance levels.

The second wavelength used was 280 nm which helps represent the total aromatic organics, which are the most reactive, in the water samples. The 280 nm wavelength UV absorbance results are very similar visually to the results of the UV absorbance for 254 nm following the same pattern until October 28th. These results provide a minimum UV absorbance of 0.079 and a maximum of 0.122 with an average of 0.088 and a standard deviation of 0.008. Like the 254 nm wavelength, results varied after October 28th because of microbial buildup, but returned to normal after backwashing.

The third wavelength used was 400 nm which represents the color of the water samples. This wavelength has similar visual results to both the 280 nm and 254 nm wavelengths up until October 28th where the microbial buildup changed the results significantly. The results prior to October 28th provide a minimum UV absorbance of 0.008 and a maximum of 0.038 with an average of 0.015 and a standard deviation of 0.005. After backwashing, results were returned to original data.

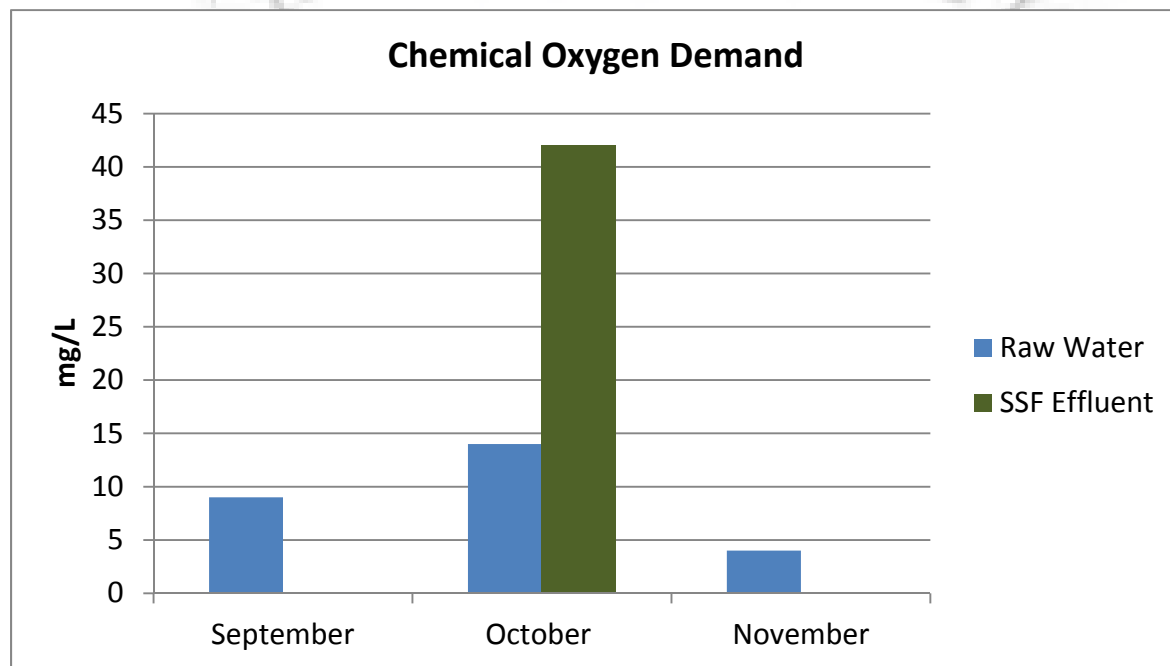


Figure 17: Chemical Oxygen Demand

Figure 16 shows the COD of both the raw water and the effluent from the SSF. Samples were taken at the end September, the end of October, and the beginning of November. Both September and November shows that the oxygen demanding microbes have excess oxygen in the water with a COD of zero mg/L. In October however, the COD is 42 mg/L. This is because the sample was taken right before backwashing took place proving that the buildup of oxygen demanding microbes affected the water quality so much that in respect to COD, the SSF effluent was worse than the raw water from the river. As seen, after backwashing in November though, the COD is back to zero mg/L.

Coagulants:

After testing both aluminum sulfate and ferric chloride coagulants, the following results were obtained and shown below.

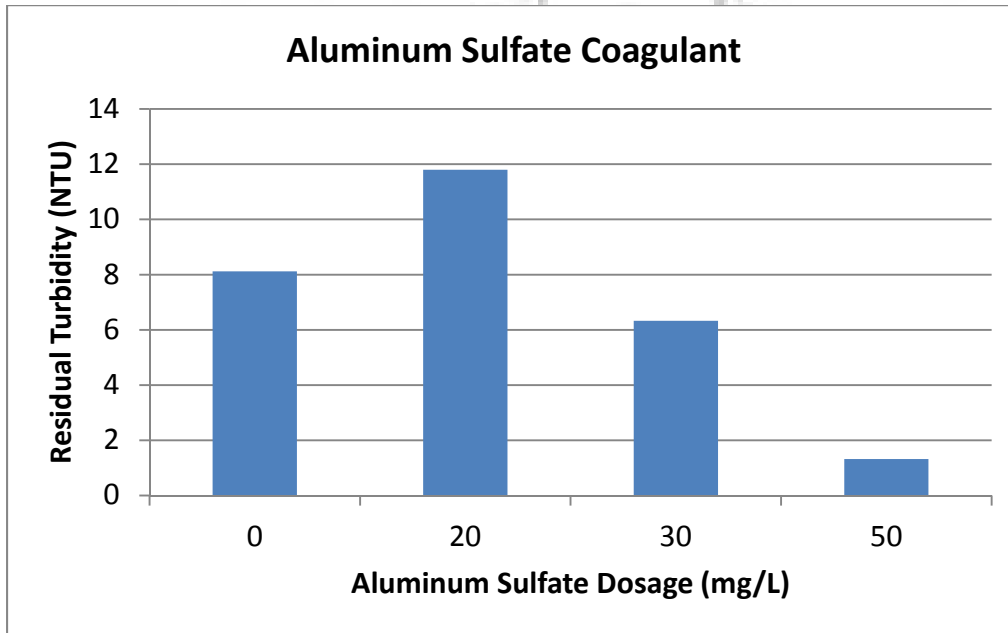


Figure 18: Best Dosage for Aluminum Sulfate

Performing the jar test for aluminum sulfate as a coagulant yielded a best dosage of 50 mg/L providing a turbidity of 1.36 NTU as shown in Figure 17. The UV absorbance for aluminum sulfate is shown below in Figure 18. At the best dosage of 50 mg/L the UV absorbance for 254 nm, 280 nm, and 400 nm are 0.081, 0.056, and 0.006 respectively.

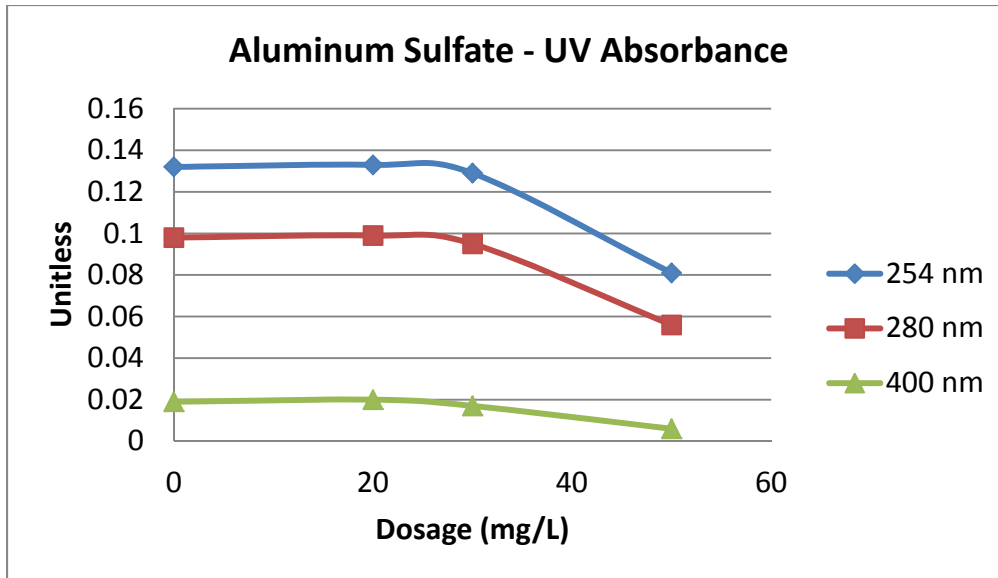


Figure 19: Aluminum Sulfate UV Absorbance

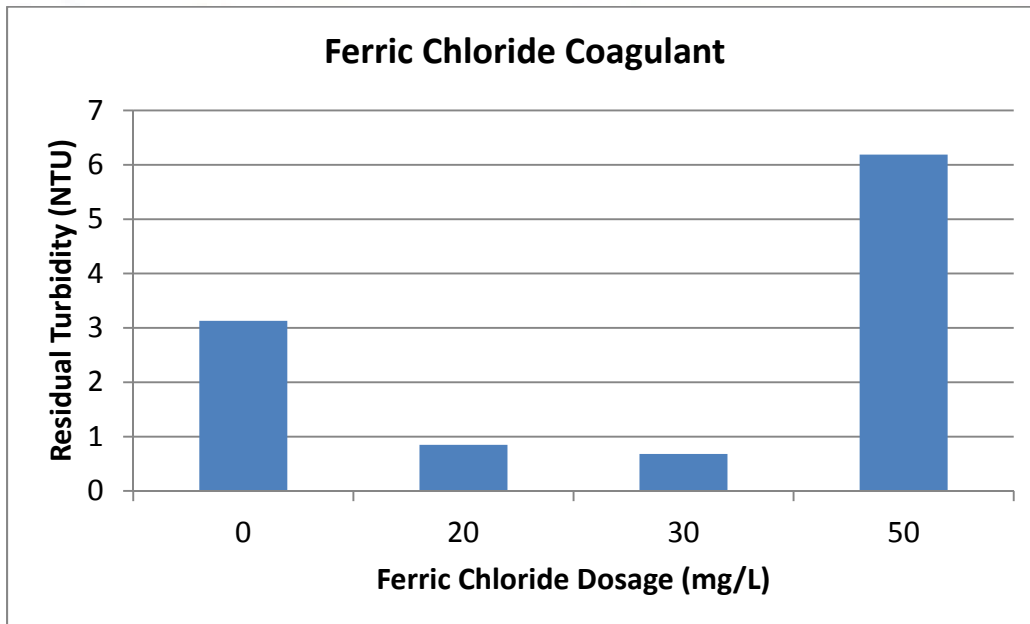


Figure 20: Best Dosage for Ferric Chloride

Performing the jar test for ferric chloride as a coagulant yielded a best dosage of 30 mg/L providing a turbidity of 0.68 NTU as shown in Figure 19. The UV absorbance for ferric chloride

is shown below in Figure 20. At the best dosage of 30 mg/L the UV absorbance for 254 nm, 280 nm, and 400 nm are 0.119, 0.092, and 0.015 respectively.

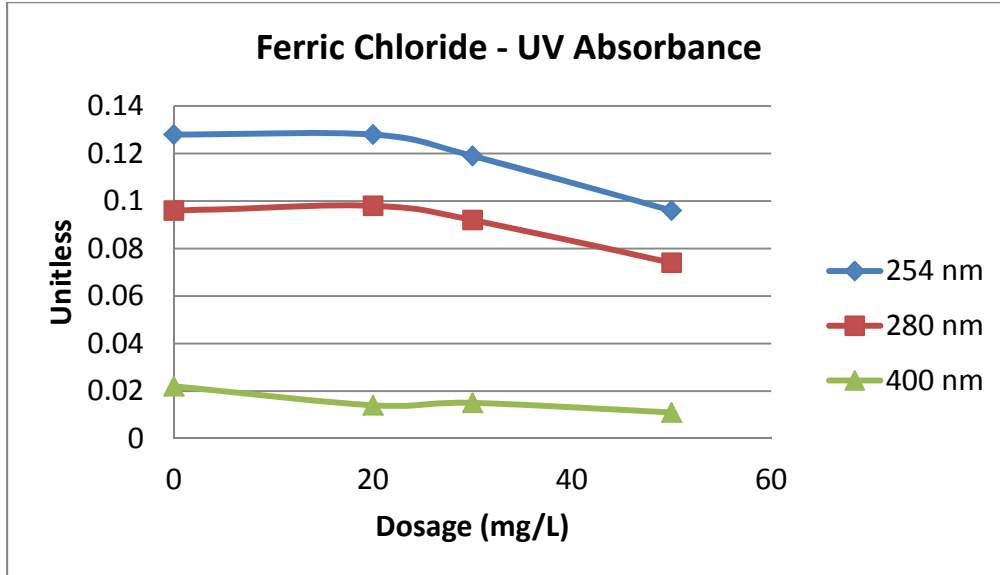


Figure 21: Ferric Chloride UV Absorbance

Comparisons:

In order to get a better representation between alternatives, comparisons are made between aluminum sulfate, ferric chloride, and the slow sand filtration system.

Figure 21 compares the turbidity between all three alternatives. As shown, all three have a high turbidity removal based on the samples used for the tests. Ferric chloride has the lowest end turbidity of 0.68 NTU as shown in Table 7, while aluminum chloride and the SSF have comparable turbidity levels of 1.36 and 1.49 NTU respectively. Although ferric chloride provides the lowest end turbidity, the removal rate is the least of the three at 78.3%. Table 7 shows the removal rates for each alternative. Given the samples of water used, the SSF has the highest turbidity removal rate at 95.5%.

Comparing the UV absorbance at 254 nm wavelength, aluminum chloride provides the lowest total organic matter measurement with a result of 0.081 while ferric chloride and the SSF have almost identical values at 0.119 and 0.120 respectively. The UV absorbance at 280 nm provides similar results as the 254 nm wavelength resulting in aluminum chloride at the lowest aromatic

organics. As shown in Table 7, aluminum sulfate, UV absorbance of 0.056, provides almost double the removal of aromatic organics in the water compared to ferric chloride, UV absorbance of 0.092, while the SSF provides a UV absorbance of 0.088. The color of the water, or UV absorbance at 400 nm, is the clearest with aluminum chloride at a UV absorbance of 0.006. Ferric chloride and the SSF have the same color after testing with a UV absorbance of 0.015.

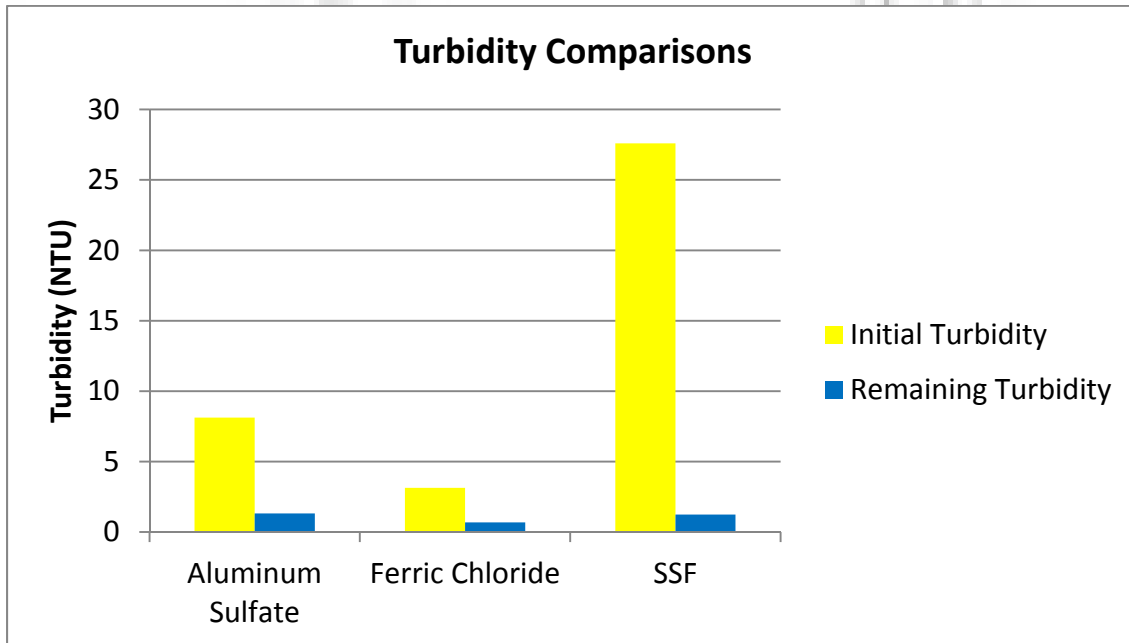


Figure 22: Turbidity comparison between Aluminum Sulfate, Ferric Chloride, and SSF

Table 7: Comparison between alternatives

Alternative	Turbidity NTU	Turbidity Removal Rate (%)	254 nm	280 nm	400 nm
Aluminum Sulfate (50 mg/L)	1.36	83.7	0.081	0.056	0.006
Ferric Chloride (20 mg/L)	0.68	78.3	0.119	0.092	0.015
SSF	1.49	94.6	0.120	0.088	0.015

Given the data obtained for lowest turbidity, ferric chloride provided the best result while the highest turbidity removal rate was provided by the SSF. Aluminum sulfate, however, has the best overall results for UV absorbance.

Conclusions:

Based on the results of this study, while the Slow Sand Filtration system does not provide the lowest end turbidity or the lowest UV absorbance, it has been shown that the SSF's effectiveness is very comparable to the conventional use of coagulants such as aluminum sulfate and ferric chloride. From an economic point of view, this system is ideal being a low cost technology, requiring low initial expenditure, minimal power usage, chemical free, and low maintenance cost.



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