

**SEDIMENTATION ENHANCEMENT BY FABRIC INCLINED SETTLING SCREEN  
TO DECREASE DISINFECTION BY-PRODUCT FORMATION POTENTIAL**

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by

LIU CAO

Dr. Enos C. Inniss, Thesis Supervisor

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The undersigned, appointed by the dean of the Graduate School, have examined  
the thesis entitled

**SEDIMENTATION ENHANCEMENT BY FABRIC INCLINED SETTLING SCREEN TO  
DECREASE DISINFECTION BY-PRODUCT FORMATION POTENTIAL**

presented by Liu Cao,

a candidate for the degree of Master of Science in Environmental Engineering,

and hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Enos C. Inniss

---

Professor Baolin Deng

---

Professor John Yang

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## ABSTRACT

The objective of this research is to develop a simple and innovative technology that effectively lowers chemical concentrations to meet Environment Protection Agency (EPA) drinking water regulations. This study focuses on fabric inclined settling screen development for application to small community drinking water treatment systems to help them with compliance, particularly with disinfection by-products (DBPs) through enhanced solids contact. The technology developed combines fabric filters with the traditional inclined plate concept. Fabric material performance and serviceability was first checked by exposure to a drinking water treatment environment and then measuring turbidity, total dissolved organic carbon, and UV254. The study suggests a product like Pureflo (a polyester) is the more appropriate material in acidic and neutral conditions and one like Surefil (rayon/polyester blend) is the more appropriate material in basic conditions. The Pureflo product was used in bench scale systems to determine performance of the designed fabric inclined settling screen. Experiments with different coagulants, different angle, and different layers of fabric screens was conducted. A pilot scale system was set up in Vandalia, MO to test the feasibility of the fabric screen of turbidity, TOC, UV254, and TTHM removal. Results indicated that screens made from pureflo with angles from 30° through 70° under acidic condition have positive effects on sedimentation enhancement.



# 1. INTRODUCTION

## 1.1 DBPs and Sedimentation

Disinfection agents remove organic contaminants which serve as nutrients or shelters for microorganisms. It also prevents pathogenic microorganisms from growing in the plumbing after disinfection, causing the water to be recontaminated. However, it has negative effects. Disinfection byproducts (DBPs) are the large group of possible reaction products produced when organic molecules in water being treated combines with some types of oxidant. Humans are exposed to DBPs through drinking water and oral, dermal, and inhalational contact with chlorinated water. It has been determined that the elevated cancer risk is associated with DBPs rather than the disinfectant that generates them. So the reduction of DBPs becomes urgent.

Total Trihalomethanes Rule was established by EPA in 1979. WHO release guideline values of DBPs in 1993. In 1999, the Stage 1 D/DBP Rule was promulgated in response to the increasing information available about DBPs. The Stage 2 D/DBP Rule came after this to address the issue of average and highest concentration area. It is harder for small water facilities to meet the standards because of lacking of financial support and technology.

The reduction of DBPs can be accomplished in a few ways. One is to try to remove them after their formation. The other is to prevent them from formatting. DBP formation is a function of many variables. One of them is the concentration and types of

source water organic precursors. As a result, one of the THM reduction methods is to enhance coagulation and sedimentation. The effects of an enhanced sedimentation approach, using inclined fabric settling screens, should be included in the considerations.

## 1.2 Research Objectives

The objective of the research is 1) to determine characteristics of fabric materials, especially their intercepting ability of solids and their endurance in water/coagulant solutions; 2) bench scale experiment to determine the feasibility of the design of fabric inclined settling screens in sedimentation tank with different coagulants, different fixing angles, and different thickness of the materials; 3) help small water facility to determine the effectiveness of their process and try to improve their water quality to meet the regulation; 4) pilot scale experiment to determine the feasibility of the design in real utility.

## 2. Literature Review

### 2.1 Disinfection By-Products (DBPs) Formation

Disinfection can be attained by means of physical or chemical disinfectants. The agents also remove organic contaminants from water, which serve as nutrients or shelters for microorganisms. At the same time, it should prevent pathogenic microorganisms from growing in the plumbing after disinfection, causing the water to be recontaminated. Disinfectants should not only kill microorganisms, it must also have a residual effect, which means that they remain active in the water after the initial disinfection stage of treatment.

In the water industry, disinfection has been acknowledged as a key step in production of safe drinking water since the early 1900's. The addition of chemical oxidants to water has been found to disrupt the reproductive processes of pathogens in water through reactions with cellular material such as proteins, DNA, and cell membranes of various microorganisms [1]. Some of these unintended reactions with organic molecules can produce compounds associated with risks to human health after long-term, low-level exposure.

#### 2.1.1 Types of DBPs formed

Disinfection byproducts (DBPs) are the large group of possible reaction products produced when organic molecules in water being treated combines with some types of oxidant. Studies have identified hundreds of disinfection byproducts over the past few

decades, including various aldehydes, haloacetonitriles, trihalomethanes, haloketones, and haloacetic acids. [1-3]

The regulated trihalomethanes (THM) are a group of four chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. EPA has promulgated Disinfectants/Disinfection Byproducts Rule to regulate total trihalomethanes (TTHM) at a maximum allowable annual average level of 80 parts per billion.

Haloacetic Acids (HAA5) are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids, known as HAA5, are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. EPA has promulgated the Disinfectants/Disinfection Byproducts Rule to regulate HAA5 at 60 parts per billion annual average.

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water. EPA has established the Disinfectants/Disinfection Byproducts Rule to regulate bromate at annual average of 10 parts per billion in drinking water. This standard has become effective for all public surface and ground water systems since December 2003. [4]

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. EPA has published the Disinfectants/Disinfection Byproducts Rule to regulate chlorite at a monthly average level of 1 part per million in drinking water. This standard also became effective for all public surface and ground water water systems in December 2003. [4]

#### 2.1.2 DBPs Formation Kinetics

THMs and HAAs are chlorination byproducts, thus were selected as a focus due to the prevalence of these compounds compared with other known chlorination byproducts and large fraction of facilities use free chlorine at some point in their treatment process. [2, 5, 6]

In most chlorinated water, the primary oxidant used is hypochlorous acid (HOCl). Although the reactions that form THMs and HAAs are carried and sometimes complex, the general form of such reactions is as follows:



If the source water contains a measurable concentration of bromide, it can be oxidized by HOCl to form hypobromous acid (HOBr). The HOBr formed also participates in DBPs formation reactions according to available concentrations and reactivity. Zhang [7] et. al. modeled that water temperature has significant effects on the disinfection by-product (DBP) formation and concentration in many water utilities and distribution systems.

### 2.1.3 Health Risks

Richardson [8] identified greater than 600 water disinfection byproducts in chlorinated tap water, including haloacetic acids (HAAs). THMs, and to a lesser extent HAAs, are currently used as indicator chemicals for all potentially harmful compounds formed by the addition of chlorine to water. In many countries the levels of THMs and HAAs in chlorinated water supplies are regulated based on this assumption.

Humans are exposed to DBPs through drinking-water and oral, dermal, and inhalational contact with chlorinated water [9]. In populations who take hot showers or baths, inhalation and dermal absorption in the shower accounts for more exposure to THMs than drinking water [10].

Although both a disinfectant and disinfection byproducts may be found in treated water, it has been determined that the elevated cancer risk is associated with DBPs rather than the disinfectant that generates them. [11] However, obtaining a definitive picture of these health risks posed by exposure to DBPs is still difficult. Table 2-1 shows the adverse effects of exposure to particular THM and HAA species as generally accepted at present.

Table 2-1 THM and HAA Toxicological Summary [12]

	EPA Cancer Classification	Health Risks
THM:		
TCM	B2	Cancer; liver, kidney, and reproductive effects
BDCM	B2	Cancer, liver, kidney, and reproductive effects
DBCM	C	Nervous system, liver, kidney, reproductive effects
TBM	B2	Cancer, nervous system, liver, and kidney effects
HAA:		
DCAA	B2	Cancer, reproductive and developmental effects
TCAA	C	Liver, kidney, spleen, and developmental effects

**Note: B2=Probable human carcinogen, C=possible human carcinogen**

## 2.2 DBPs Related Regulation

DBPs are a fairly new contaminant of concern; the first major publications linking disinfection – most commonly achieved through chlorination – to the formation of halogenated organics in drinking water did not appear until around 1974 [13, 14]. Studies on the relationship between exposure to these compounds and increased likelihood of developing certain types of cancers soon followed. With growing concern about how widespread potentially-hazardous DBP levels might be, the National Organics Reconnaissance Survey (NORS) was undertaken in 1975, with nationwide DBP monitoring as one of its objectives. This 80-system survey, focusing primarily on the occurrence of THMs, found that greater concentrations were generally produced in waters with higher concentration of dissolved organics and in cases where surface water was treated with free chlorine near the beginning of treatment. [15]

The WHO Guideline Values (1993) for the THMs are shown in Table 2. WHO also considers potential health effects caused by exposure to the four compounds simultaneously. In addition to the individual guidelines, there is an additional guideline that states the following: the sum of each individual THM concentration divided by its guideline value cannot be greater than one. This is depicted by equation 2-2: [16]

$$\frac{\text{Chloroform}}{\text{Chloroform GV}} + \frac{\text{BDCM}}{\text{BDCM GV}} + \frac{\text{DBCM}}{\text{DBCM GV}} + \frac{\text{Bromoform}}{\text{Bromoform GV}} < 1.0 \quad \text{Eqn. 2-2}$$

Table 2-2: WHO Guideline Values for Trihalomethanes in Drinking Water (WHO, 1996) [17]

	WHO Guideline Value
Chloroform	200 µg/L
Bromodichloromethane	60 µg/L
Dibromochloromethane	100 µg/L
Bromoform	100 µg/L

Most importantly, the WHO specifically and repeatedly states in the Guidelines (1993) that: “Where local circumstances require that a choice must be made between meeting either microbiological guidelines or guidelines for disinfectants or disinfectant by-products, the microbiological quality must always take precedence, and where necessary, a chemical guideline value can be adopted corresponding to a higher level of risk. Efficient disinfection must never be compromised.” [16] Thus, waterborne pathogens pose a real and immediate threat to health; water disinfection byproducts are certainly the lesser of these two evils.

#### 2.2.1 Total Trihalomethanes Rule

Although some drinking water contaminants had already been regulated since 1974 in the Safe Drinking Water Act, the first national control placed on disinfection byproducts was the establishment of a maximum contaminant level (MCL) of 0.10 mg/L for total trihalomethanes (TTHM) by the EPA in 1979 [18]. TTHM is defined as the sum of the concentrations of all four chlorine- and bromine-substituted trihalomethanes. Under the Total Trihalomethanes Rule, all community drinking water systems were required to analyze representative samples of the water in their distribution system quarterly, regardless of whether surface water or ground water was used as the water supply. Systems using exclusively ground water were subsequently allowed a reduction in monitoring requirements if initial testing showed that the source water did not have a significant potential to generate THMs upon disinfection.



### 2.2.2 Stage 1 and Stage 2 DBPs Rule

Two decades after the Total Trihalomethanes Rule, the Stage 1 Disinfectants and Disinfection Byproducts Rule (or Stage 1 D/DBP Rule) was promulgated in response to the increasing information available about DBPs. All water systems were required to comply with these regulations before 2004, with larger systems meeting earlier compliance deadlines. Stage 1 D/DBP Rule was intended to be only an intermediate step in a more comprehensive plan to reduce DBP concentrations in drinking water. Under this rule, more complex monitoring and reporting requirements were instituted, as well as a 0.080 mg/L MCL for TTHM and a 0.060 mg/L MCL for HAA<sub>5</sub>. [19]

Stage 1 D/DBP Rule also required water treatment plants to remove certain amounts of total organic carbon (TOC), based on source water characteristics. [19] TOC is not considered intrinsically harmful but it contains compounds known to generate DBPs upon chemical oxidation, so reduction of the concentration of DBP source compounds would be expected to reduce final DBP concentrations.

While the Stage 1 D/DBP Rule represented a significant step forward in limiting the concentration of DBPs in drinking water, continuing research findings and discussions among regulators highlighted the need for further regulatory action. The MCLs of 0.080 mg/L for TTHM and 0.060 mg/L for HAA<sub>5</sub> were still deemed appropriate; however, a modification of the method for compliance determination was necessary. The additional requirements set out by the Stage 2 Rule apply to all community water systems (CWS), as well as all non-transient, non-community water systems (NTNCWS)

serving more than 10,000 customers. The complete rule and its implications for drinking water utilities are described in the Federal Register. [20]

In both the Total Trihalomethanes Rule and the Stage 1 D/DBP Rule, concentrations of samples taken within the distribution were averaged over each quarter and split for comparison with the MCLs. With this practice, sites yielding high and low concentration samples for each sampling date can effectively cancel each other out, which does not require the standards to be met at every customer's tap. To address this issue, the Stage 2 Rule changes the reporting and compliance methods such that the quarterly measurement for each location are averaged separately throughout the year, with each average individually compared with the MCL to determine compliance. Using this method, it is no longer possible for utilities to be in compliance while one part of its distribution system is routinely above the established MCLs, provided that the compliance sample collection sites in the highest concentration areas have been selected.

As regulation limiting THM and HAA levels in drinking water have become increasingly strict it has also become increasingly difficult for utilities to find ways to bring their system into compliance with these regulations. Typically, solutions for initial reductions in DBP levels are often more easily found to implement than subsequent modifications to reduce concentrations even further. Modifying treatment to reduce free chlorine usage or switching to a different disinfectant entirely can decrease THM and HAA formation, as can other process modifications that reduce precursors compound concentrations in water prior to chlorination. [1]

## 2.3 Organic DBPs Precursors

DBP formation is a function of many variables. Parameters such as temperature, concentration and type of source water organic precursors, effectiveness of treatment process at removal of organic precursors, disinfection contact time, and types of disinfection practiced all can play important roles in determining DBP concentrations. To understand how water treatment might be able to reduce DBP concentrations, the organic compounds naturally present in surface water from which DBPs are formed must also be better understood.

Although the reaction pathways of THM and HAA formation are numerous and can be complex, laboratory studies of model compounds have shown that aromatic characteristics in NOM, often similar but not necessarily identical to the characteristics monitored by UV absorbance measurements, may be at least partially responsible for DBP formation. [21] Resorcinol (1,3-dihydroxybenzene) and its derivation have been shown to produce chloroform and some HAAs, although other types of molecules that may or may not be associated with UV absorption have also been shown to potentially play a role in the formation of regulated DBPs [22]. Among aromatic compounds, it has been hypothesized that resorcinol-type structures are what reacts quickly to form THMs, while phenolic structures increase in importance with longer formation times [23]. The presence of electron-donating or electron-withdrawing functional groups also appears to affect a molecule's suitability as a DBP precursor, with carboxyl groups having been noted as potentially decreasing the reactivity of a molecule.

Beyond this laboratory data, there is a limited understanding of which molecules found in natural source water are most important as DBP precursors. It was suggested by the calculations of Reckhow et al. [6] that most chlorine consumption observed in natural water samples was involved in the degradation of activated aromatic structures, and the UV-absorbance monitoring illustrated that such degradation appeared to result in the formation of chlorinated organics, including THMs. Although all NOM fractions seem to contain some DBP precursors, hydrophobic fractions tend to produce more THMs and HAAs. Compounds of increasing molecular weight have also been found to have higher THM yields on a mass basis [24].

It was found by Ma, et, al. [25] that chlorine reactivity of Dissolved organic matters (DOM) decreased with the decrease of molecular weight (MW), and MW > 30 kDa fractions produced over 55% of total THMs in chlorinated Membrane bio-reactor (MBR) effluent. Hydrophobic organics had much higher THMs formation reactivity than hydrophilic substances. Particularly, hydrophobic acids exhibited the highest chlorine reactivity and contributed up to 71% of total THMs formation. Meanwhile, low-MW and hydrophilic DOM were susceptible to produce bromine-containing THMs. Of the fluorescent DOM in MBR effluent, aromatic moieties and humic acid-like had higher chlorine reactivity. Conclusively, macromolecular and hydrophobic organics containing aromatic moieties and humic acid-like must be removed to reduce THMs formation. [25]

## 2.4 Small Scale System Facilities

### 2.4.1 Typical Operational Process in Small Communities in Missouri

Small communities of up to 10,000 people typically utilize up to one million gallons of potable water daily. [1] Follow a drop of water from the source through the treatment process, water may be treated differently in different communities depending on the quality of the water which enters the plant. At a minimum, the treatment required to control microbiological contamination must include disinfection to kill disease-causing organisms. The Surface Water Treatment Rule also requires surface water systems to install some form of filtration (the process of removing suspended solids that cause turbidity) unless criteria for exemptions can be met.

As stated in Minimum Design Standards for Missouri Community Water System (effective on December 10, 2013), [26] plants using conventional clarification to treat water prior to filtration shall be designed to provide at least a two-stage treatment process consisting of primary rapid mixing, flocculation and sedimentation and secondary rapid mixing, flocculation, and sedimentation, in series to treat surface water; or provide at least single stage treatment consisting of rapid mix, flocculation and sedimentation for clarification to treat groundwater under the direct influence of surface water. It also points out that requirements for disinfection residuals are found in 10 CSR 60-4.055 Disinfection Requirements and 10 CSR 60-4.025 Ground Water Rule. Disinfection is required at all surface water supplies, ground water sources under the direct influence of surface water, and at any ground water supply of questionable

sanitary quality or where treatment is provided that could potentially result in the water becoming microbiologically contaminated. Usually primary disinfection process is before the filtration step to achieve enough contact time between the water and disinfectant. Disinfection may be accomplished with liquid chlorine, calcium or sodium hypochlorite, chlorine dioxide, or ozone. However, free chlorine using break point chlorination is the preferred method of primary disinfection. Other concerns include sources of water supply, different processes (approaches), chemical application, construction, and waste handling and disposal.

#### 2.4.2 Constraints Small Systems Faced With

The vast majority of community water systems in the United States are small water systems, defined by EPA as those serving up to 3,300 residential customers. EPA requires all community water systems, regardless of size, to meet or exceed its standards on drinking water quality, testing, monitoring and reporting. Hence, each state is required to monitor many community water systems and to ensure their compliance with the federal and state standards. Because of the small size of their customer base, small water systems face greater challenges than larger water systems in meeting those standards while also operating their systems in a sustainable manner. Small water systems that do not meet the standards require corrective action, imposing additional responsibility on the state in monitoring the many small water systems scattered across the state.

The overarching challenges facing small water systems have been documented in numerous reports. A National Research Council committee on small water supply

systems published a book on the conditions of small systems[27], and an Environmental Protection Agency Office of Inspector General evaluation [28] confirmed the findings. Other studies have described similar challenges facing small water systems [29-34]. An inherent problem facing all small water systems is the financial constraint due to the small size of their customer base. Often, the customers of small systems are located in rural areas and have lower household incomes than people living in larger, urban areas who are served by the larger water systems [29]. With low revenues, high unit costs and pressure to keep rates affordable for their customers, small systems are challenged to raise the funds they need for operations, maintenance, and capital improvements.

Failures in small water system management/operation also reflect shortages in technical resources, incomplete understanding of system function, and additional shortcomings that could be alleviated through better planning and communication. Actions that were recommended to preclude these conditions emphasize greater reliance on planning and on clearly-explained procedures and responsibilities, developed with expert advice from technical-assistance personnel or from larger water system. Solid knowledge of the local system is crucial. Also, an ever-changing regulatory environment is very difficult for small water systems, which generally are not well-represented in the regulatory process. Changed rules may be enforced before small systems have the technical expertise or financial capacity to implement them. [35]

Small water systems need considerable help in water source protection, treatment, and distribution, from basic research to community-wide education. Scientists present at the colloquium, for example, identified research needs for lower-

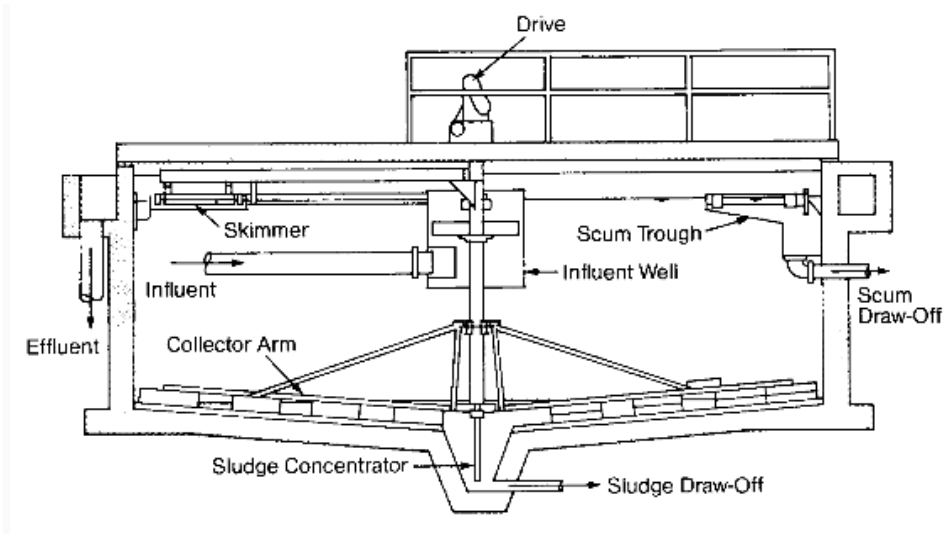
cost monitoring, better treatment methods, public perception of water utilities, and more. Consolidation with larger systems can improve both economics of scale and access to technical expertise. Yet it is clear that better funding or expert advice cannot remove all small-system barriers to safe water delivery. The locally-achievable goals of improved communication, science-based education, and thorough planning by all involved still remain key components of small system success. [35]

## 2.5 Clarifiers

Sedimentation, both rectangular horizontal flow and circular, tanks are an essential process to remove solids from water. With rectangular horizontal-flow tanks, the water to be settled flows in one end, and the treated water flows out at the other end. They are large tanks in which water is made to flow very slowly in order to promote the sedimentation of particles or flocs. In water and wastewater treatment plants, these are so large that they are situated outdoor and usually have an open surface. [36]

Circular tank flow (Figure 2-1) is usually from a central feed (influent) well and moves radially outward to peripheral weirs (effluent). The tank floor is usually slightly conical with a central sludge well (concentration). The floor is swept by a sludge scraper that directs the sludge toward the central wall.





**Figure 2-1. Horizontal flow clarifier image[36]**

Another common clarifier is the up-flow [37] one (Figure 2-2). Following the principles of operation of up-flow sludge blanket clarifiers on entering the bottom of the tank, the flow makes its way upwards through the base of the funnel. As the cross-sectional area of the funnel increases, the velocity of the fluid decreases. At a certain height, the upward forces acting on the floc should balance out with the gravitational forces. In principle, it is in this region that the floc will remain stationary and a floc blanket will form, thickening with time. The residual floc passing the blanket is caught in a polishing filter secured at the top of the unit. Over time, floc accumulation can cause an increase in headloss across the geotextile fabric, which can be measured by fixing a transparent sight tube serving as a manometer across the fabric in which the difference in water level in the tube and the Clarifier indicates the headloss. The clarified effluent of the treatment unit is then usually collected and stored in a treated water reservoir where it undergoes terminal disinfection by free residual chlorination before distribution. [37, 38]

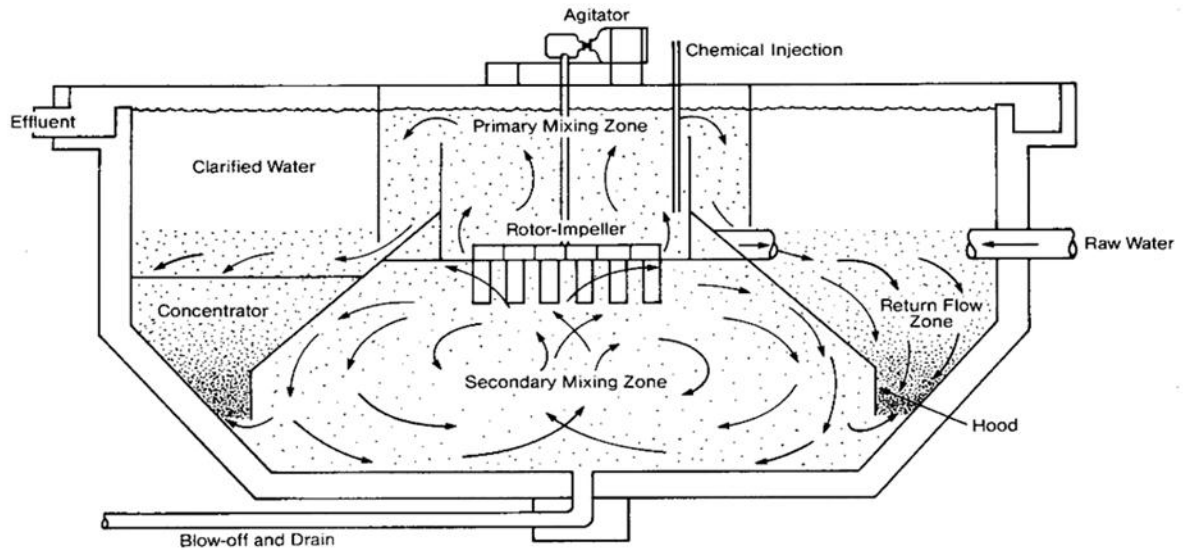
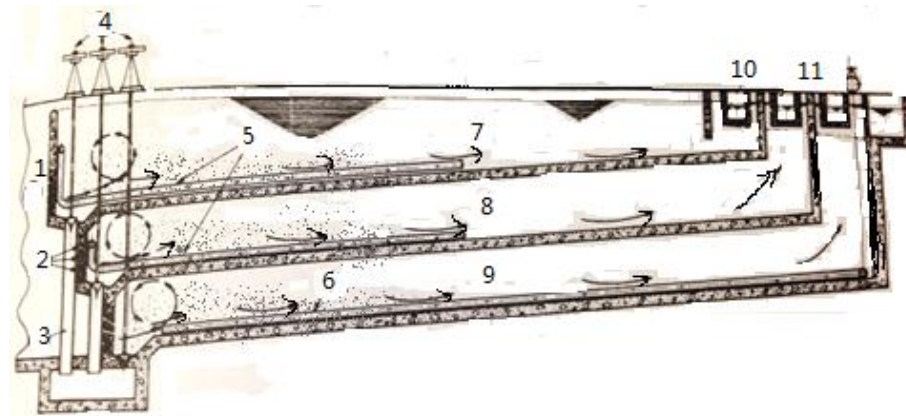


Figure 2-2. Up-flow clarifier image[37]

## 2.6 Inclined Plate Settlers

The tanks described in the former sections have a similar issue that they require large space and the settling efficiency is limited. To overcome this issue, multistory tanks [39] and inclined plate settlers/tubes are coming into use. Multistory (Figure 2-3), or tray, tanks are a result of recognizing the importance of settling area to settling efficiency. Basic flow is arranged into two layers with multistory tanks. The trays may be coupled in parallel with flow divided between them or coupled in series with flow passing from one to the next. The Little Falls Water Filtration Plant of the Passaic Valley Water Commission, Clifton, New Jersey, uses tanks with two layers of reverse-flow (four levels in total) coupled series. [40] Coagulated water enters the lower pass and returns on the level above. Coagulated water is removed using submerged launders. Sludge collectors move in the direction of the flow, scraping settled material to sludge hoppers at the far end of the first pass. Each collector flight is trapped at the effluent end on the

return pass so that collected material drops down into the path of the influent to the bottom pass. Multistory tanks are useful in the place that land is expensive. Its limitations, though, include a limited width of construction for unsupported floors, flow distribution, sludge removal, and maintenance of submerged machinery. [39]

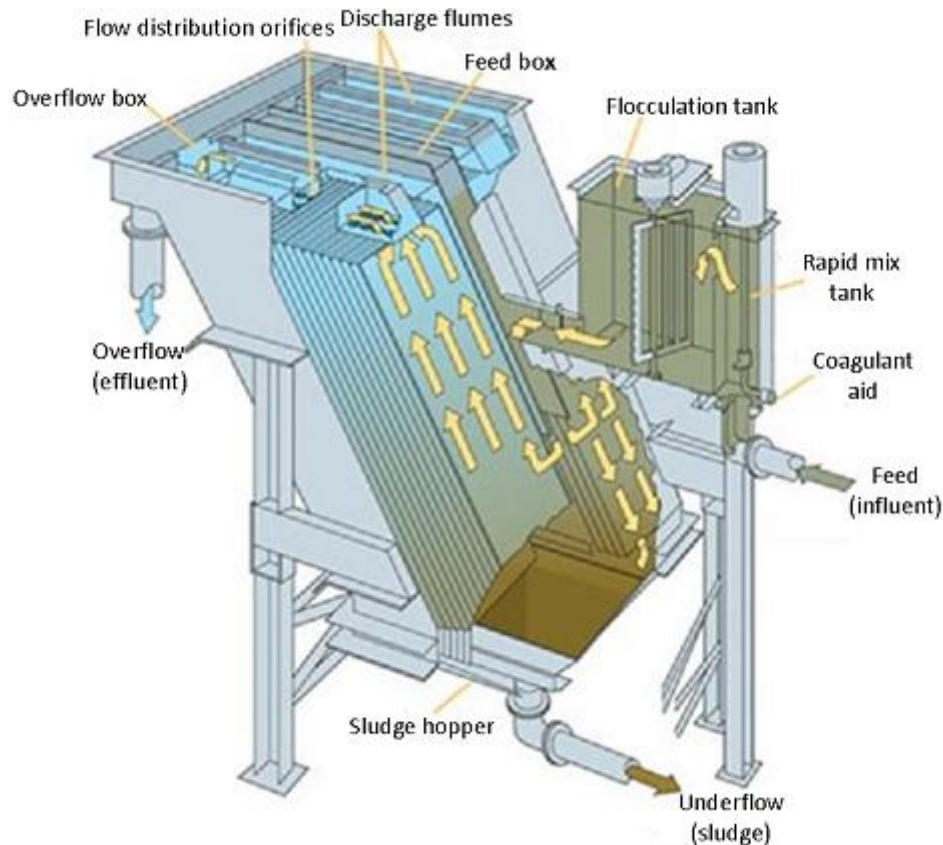


1 Flocculation tank; 2 SPLIT-ROLL inlets; 3 Upper floor sludge drain;  
4 Manually controlled TOP VALVE; 5 COMBECT Sludge suction system  
(optional); 6 WATERINSE: Water flushing system (optional);  
7 Upper clarifying compartment; 8 Intermediate clarifying  
compartment; 9 Lower clarifying compartment; 10 DUCK\_LIPS: Effluent  
collectors; 11 Clarified water collecting channels

**Figure 2-3 Multistory Horizontal Tank with Parallel Flow on Three Levels [39]**

The inclined plate settler has industrial origins [41] of closely spaced inclined plate systems for water treatment resulting from a search for high-rate treatment processes compact enough to be economically housed against winter weather in the 1950s in Sweden. Inclined tube system was spawned in the United States in the 1960s. The most recent developments have involved combining inclined settling with ballasting of floc to reduce plant footprint further [42]. Individual modules of inclined plate or tube settlers can be constructed of appropriate materials. Inclined surfaces may be contained within a suitably shaped tank for countercurrent, concurrent, or cross-flow sedimentation. Adequate flocculation is a prerequisite for inclined settling if coagulation

is carried out. The angle of inclination of the tubes or plates depends on the application, the tendency for self-cleaning, and the flow characteristics of the sludge on the inclined surface. Self-cleaning occurs when the angle of inclination is great enough, typically more than 50° to 60° [43]. Demir [44] found that for inclined plates fitted at the end of a pilot horizontal-flow settler the optimum angle is about 50°, with this becoming more pronounced as surface loading rate increases. The main objective in inclined settler development has been to obtain settling efficiencies close to theoretical. Metso's lamella principle (Figure 2-4 [45]) uses several parallel inclined plates to maximize the available area for any available floor area. In this way, the size and cost of the gravity settler can be minimized by matching the thickening and clarifying requirements more closely. The area needed to clarify a suspension is often greater than that needed for thickening. This means that in a cylindrical thickening tank, the lower section with rakes and drive mechanism can be oversized.



**Figure2-4 Typical inclined plate settler unit ("Lamella Gravity Settler: Inclined Plate Settler" 2009)**

It should be noted that the two basic criteria for gravity settling equipment are good clarity of the over flow liquid and maximum density of the underflow solids discharge. To meet these criteria, an inclined plate settler consists of two main components: the upper tank containing the parallel plates inclined at 55° and the lower cylindrical sludge tank. Raw water enters through an inlet chamber located in the center of the unit and proceeds to the plate chamber through side entry plate slots. As shown in Figure 2-4, the countercurrent design of flow through the system reduces the risk of disturbing previously settled solids. Furthermore, this clarification takes place above the suspension inlet to ensure there is no mixing of the clarified fluid with the incoming feed. As the water flows upward through the plate chamber, the solids settle on the inclined, parallel plates and slide into the sludge tank at the bottom of the unit.

These inclined plates utilize Metso's lamella principle. [46] That is, the floor area is minimized by the use of parallel inclined plates. In this way, the size and cost of the gravity settler can be minimized by matching the thickening and clarifying requirements more closely. This is in stark contrast to traditional clarifier basins where the area required to clarify a suspension is often greater than that needed for thickening. This generally results in a cylindrical thickening tank—i.e. the lower section of the basin—having oversized rakes and drive mechanisms. Further sludge thickening within the inclined plate settler is achieved in the sludge hopper. This inactive zone within the unit is created by the influent side entry plate slots previously mentioned. The clarified water exits the inclined plate settler through orifices or weirs at the top of the unit into collection channels. This creates a pressure drop across the collection channels which ensure uniform flow distribution across the plates utilizing the full area for settling.

This is primarily because the effective gravity settling area of the inclined plate equals each plate's area projected on a horizontal surface as shown in Figure 2-5. [46]

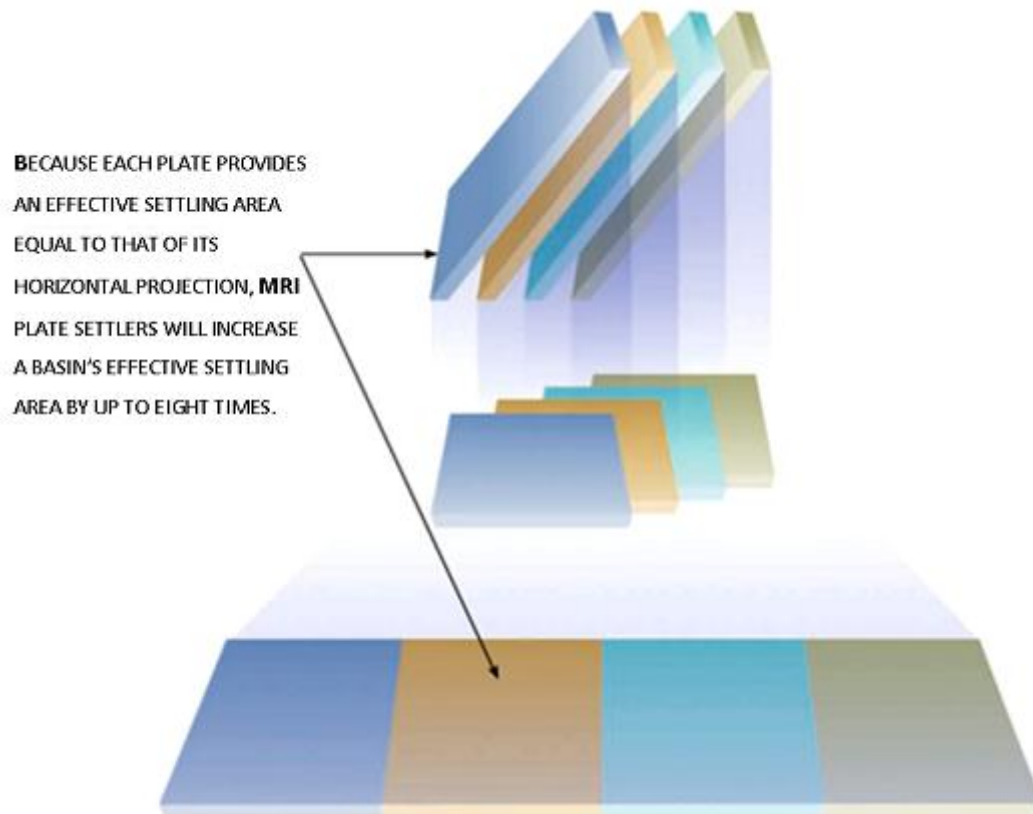


Figure 2-5. Effective gravity settling area in terms of projected horizontal surface ("Advanced Water & Wastewater Treatment Systems: Plate Settler Installations" 2011)

## 2.7 Fabric Materials

As a proof of concept, six fabrics were acquired from the Hanes Product List [47]. They can be classified into three categories, polyester, polypropylene, and a 50/50 blend of polyester and rayon. Polyester is a category of polymers which contain the ester functional group in their main chain. The main characteristics of polyester fabric include being strong, durable, resistant to stretching and shrinking, resistant to most chemicals, wrinkle resistant, mildew resistant, and abrasion resistant. In the case when polyester composites are immersed in water, the voids and cracks in the material will be gradually filled with water molecules, and the capillarity effect would encourage the water

penetration. This increases the mass weight of the material. Prolonged immersion induces chemical reaction between the water molecules and the fiber as well as the matrix causing some elements to leach and dissolve in the water, which causes a decline of the mass weight. Rayon is a manufactured fiber composed of regenerated cellulose in which substitutions have replaced less than 15% of the hydrogens of the hydroxyl groups. Its main characteristics include being highly absorbent, soft and comfortable, easy to dye, and to drapes. Polypropylene is a thermoplastic polymer made from the propylene monomer; that is rugged and unusually resistant to many chemical solvents, bases and acids. Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. Its main characteristics include generation low static and being abrasion resistant, resistant to deterioration from chemicals, mildew, perspiration, rot and weather, thermally bondable, stain and bondable, stain and soil resistant, and having a strong structure. Compared to polyester, it is more hydrophobic meaning that it does not absorb as much water. It also has a much lower melting point and is less UV resistant than polyester. Mao [48] studied the relationship between water permeability and fabric structure, and indicated that the water permeability rate of filter cloth decreases with the increase of fabric tightness and the decrease of yarn twist.



## 2.8 Filtration

### 2.8.1 Membrane Filtration Flux

Filter fabric is used in this research to settle down some solids in the water in order to increase turbidity reduction. The primary function of filter fabric is to act as an inclined plated screen, reducing flow velocity, causing deposition of suspended sediment behind the structure. The fabric also acts as a filter for suspended solids in the water.

The idea is borrowed from situations where high sediment loads in runoff cause severe environmental problems when deposition eventually occurs, so preventing sediment movement beyond controllable locations is a very important issue. [49] While other methods may be equally effective in controlling sediment, the filter fabric fence is a low cost, easy-to-install practice, if properly designed, installed and maintained.

Limited laboratory and field data exists of flow through filter fabric. One article about the high sediment loads mentioned above did report on the development of an equation presenting the relationship between water discharge through the fabric and the hydraulic head upstream of the filter fabric fence for the given fabric parameters. [50]

The relationship between flow rate and hydraulic head for filter fabric was found by applying the Bernoulli equation to the flow. [51] The derived formula equation defines an opening coefficient, where  $\phi(n)$  is called the opening coefficient, a constant

for a specified hydraulic head, but it changes with head. The greater the head, the greater the opening coefficient is.

$$\varphi(n) = \sum_{i=1}^n \sqrt{1 - \frac{2i-1}{2n}} \quad (\text{Eqn. 2-3})$$

The important contribution of equation 2-4, which defines the flowrate  $Q$  through the fabric, is that it gives a universal hydraulic relationship to all kinds of fabric so that it is not necessary to develop an individual one.

$$Q = C_m d_1 d_n \varphi(n) \sqrt{2gHe} \quad (\text{Eqn. 2-4})$$

The fouling mechanism of a woven fabric membrane, when treating kaolin suspension, was investigated by Muhammad [52] with and without the use of a ferric coagulant that was produced using an electrochemical cell. The investigation was carried out at different kaolin concentrations and crossflow velocities (CFV). Without coagulation, the process performance showed that the flux decline with time proceeded exponentially. The effect of CVF on the permeate flux was clear, particularly, when the crossflow velocity was increased to 2 m/s. The fouling mechanism investigation showed that membrane fouling proceeded in accordance with the standard law of filtration, which is attributed to the infiltration of colloidal particles into the pores of the membrane[52]. With coagulation, membrane fouling was found to proceed according to the classical cake filtration model (Figure 2-6).

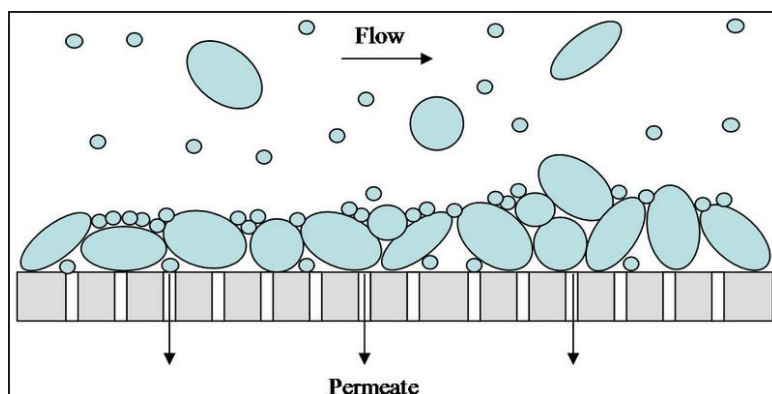


Figure 2-6 Cake filtration model

## 2.9 Chemical Treatment

### 2.9.1 Coagulation

Coagulation was originally used for removal of colloidal matter and color, but its purpose has been expanded to remove some of the organic material that may generate DBPs upon chlorination. With coagulation as a conventional treatment process already in widespread use in surface water treatment facilities, it seems a logical focus for study in efforts to reduce THM and HAA formation. Since the beginning of concern about and regulation of trihalomethanes, maximizing the effectiveness of the traditional coagulation process for removal of organic precursors has been of interest [53].

Although the removal mechanism for comparatively large colloidal material involves physical processes of destabilization [54], most organic molecules are considered to be dissolved and as such not removable by these processes. Instead, organics have been generally considered to be removed by co-precipitation [55]; here, the molecules either adsorb onto the polymeric compounds generated when coagulants are added to water or become associated with other molecules in the solution that adsorb the organics.

Coagulation has been practiced and studied in water treatment for many decades, well before the discovery and regulation of disinfection byproducts as potentially harmful compounds [56]. Earlier interest was in more efficient removal of particulate matter prior to filtration that could not easily be removed by sedimentation alone and also ways in which the color naturally present in some water sources might be removed; this color was the result of dissolved organic molecules, some of which would later be identified as potential precursors to DBPs.

Coagulation, if properly designed and operated, can be effective at helping to remove particles of 1  $\mu\text{m}$  or less in diameter [54] early in treatment. Presumably because of the high effectiveness of particulate removal by coagulation, little data exists describing removal of particle-bound organics [55]. More importantly from what would become an interest in DBP precursor removal, it was shown by many that color is also effectively removed by coagulation with metal coagulants such as ferric chloride or aluminum sulfate, although perhaps by a chemical precipitation mechanism associated with coagulant addition rather than the physical processes which govern particulate coagulation. [56-58] As might be expected based on the fact that the organic molecules most associated with color tend to be large and more hydrophobic in nature, it was soon found that these larger organics are the compounds most effectively removed by coagulation[59].

Because of its prior effectiveness in reducing concentrations of organic molecules associated with color, coagulation emerged as a likely technology to help with reducing TTHM formation. In 1977, Narkis and Rebhun [60] found that coagulation

was most effective at reducing humic and fulvic acids in solution at a lower pH; the changes in ionization of the compounds formed by the coagulant in solution and dissociation of organic functional groups resulted in more effective and efficient removal.

### 2.9.2 Softening

Coagulation is not the only type of process that may remove dissolved organics through a sedimentation process. For facilities already interested in water softening for other reasons, some removal of DBP precursors has been noted in conjunction with the involved chemical precipitations. It has been observed that softening may interact with DBP precursors differently than does coagulation, although both types of treatment have been shown to have a similar potential for effectiveness overall [59]. Liao and Randtke [61] showed that the primary mode of removal of organic molecules during lime softening was co-precipitation; that is, that organics were being removed through adsorption to the softening precipitate as it was forming rather than as a separate precipitation or coagulation effect.

Softening processes may be operated such that only calcium or both calcium and magnesium are removed. Calcium is typically precipitated as  $\text{CaCO}_3$ , while magnesium forms  $\text{Mg(OH)}_2$ . Calcium carbonate is known to be a less-effective adsorbent than magnesium hydroxide because of its solid structure and several studies have demonstrated greater removal of dissolved organics with increased magnesium precipitation; however, calcium carbonate alone does appear to remove at least some DOC [62]. Kalscheur et al. [63] confirmed that observed decreases in DOC

concentrations do indeed parallel decreases in both TTHM and HAA9 formation potential, although the similarities are less pronounced in high-bromide waters due to increased formation of bromine-substituted DBPs. Bob and Walker [64] extended the investigation of calcium vs. magnesium effectiveness further by selecting lime with varying levels of magnesium content to use in softening experiments and found that magnesium impurities in lime may even assist with removal of organics, and particularly those organics responsible for THM formation.

### 2.9.3 Adsorption (Activated Carbon)

Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. Similar to surface tension, adsorption is a consequence of surface energy. In a bulk material, all the bonding requirements (ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms and therefore can attract adsorbents. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (characteristic of weak van der Waals forces) or chemisorption (characteristic of covalent bonding). It may also occur due to electrostatic attraction. [65]

Activated carbon has been used in drinking water treatment to adsorb taste and odor-causing compounds from solution. However, it may also be used to remove dissolved organic material, particularly some organics not removed by coagulants. There are two categories of activated carbon: powdered activated carbon (PAC) and granular

activated carbon (GAC). As the name imply, the distinction between these two is based on size. GAC is often used in filter media or in a separate packed-bed contactor due to its larger size while PAC is typically added to a basin like other solid chemical and settled or filtered out of solution. Generally, the smaller size of activated carbon, the shorter pore length of it, and thus the equilibrium adsorption can be reached more quickly. [66] Both PAC and GAC are currently used in water treatment because of their relative advantages and disadvantages for specific facilities.

The effectiveness of activate carbon adsorption is known to be influenced by a few properties, both of the carbon itself and of the solution from which DOC removal is desired. Activated carbon is known to be more effective at a lower pH[67], with pH values as low as 3.5 and 3.0 clearly more effective than a pH of 7.0 or 9.0. [68] It has been suggested that this pH dependence may be related at least as much to the organic molecules themselves, some of which contain weakly acidic functional groups that become less charged and thus more hydrophobic with decreasing pH as it is related to the carbon itself. [69] Limited adsorption of organic matter has been found in low ionic water [70, 71]; these researchers have suggested divalent ions such as  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in solution become associated with functional groups and facilitate better adsorption to the carbon's surface sites. Properties of activated carbon itself are also important. Pore size distribution may effect removal efficiency[68, 72], as molecules must be able to access the available surface area; however, adsorptive properties have been shown not to be solely a function of the pore size distribution. Surface acidity also affects polarity of the surface, in turn affecting how well a carbon may remove more hydrophobic

structures such as aromatic rings. For PAC, allowing sufficient contact time to reach approximate equilibrium with organics in the water is also key; 30 minutes has generally been found sufficient for at least the initial rapid adsorption of smaller molecules. [73, 74]

As noted by Bishop et al. [75], different activated carbons can have very different efficiencies at removing organic matter, and this efficiency is difficult to accurately predict from standard measurements of carbon properties. As would be expected, studies of organic matter adsorption have shown that all activated carbon is not equally effective at removing DOC [74]; however, properties such as pore size and surface charge do appear to at least influence effectiveness[72]. It also should be noted that effectiveness of adsorption processes can very much be a function of adsorbent vs. adsorbing-species concentrations, which can vary even at the same location as a function of time [76]. Additionally, humic and fulvic acids from different sources have been found to be removed to different extents by the same carbons [68, 69], perhaps because of differing amounts of carboxyl functional groups. Consequently, considerable variation has been reported in effectiveness of activated carbon for removal of DBP precursors and the dosages required to be able to observe such removal[67].



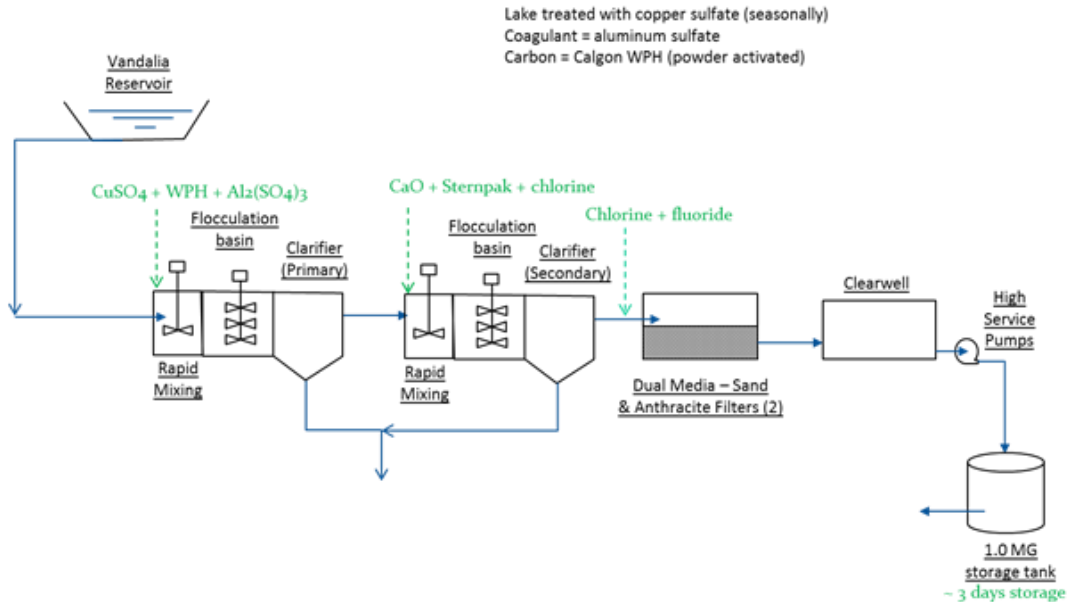
### 3. MATERIALS AND METHODS

#### 3.1 Water Samples

Samples of raw water, water in intermediate treatment stages, and water from distribution system were collected from certain facilities under study. Sampling locations within a treatment facility were selected to be before and/or after major treatment processes, with the objective of determining the effect, if any, that phase of treatment may have had on water quality and disinfection byproduct precursor concentrations. The primary facility studied is in Vandalia, MO.

##### 3.1.1 Vandalia Water Treatment Facility

The Vandalia treatment process starts at Vandalia Reservoir where copper sulfate (now EarthTec) is added seasonally (Figure 3.1). The influent pump station then moves water to the mechanical treatment process at a rate of X gallons per minute. The initial stage of the process includes the first-stage rapid mix, flocculation, and sedimentation, where an additional copper sulfate, a coagulant (aluminum sulfate, alum), and the powder activated carbon (Calgon WPH) is added. Next the second-stage rapid mix, flocculation, and sedimentation process begins with the addition of quick lime (CaO), of the polymer Sternpak, and with some chlorine, and then fluoride and more chlorine is added just before granular filtration. Contact time is achieved through a clearwell. The high service pumps then send the water to an on-site 1.0 million gallon (MG) storage tank before it enters to the Vandalia distribution systems. The storage time of the 1.0 MG tank is approximately 3 days.



**Figure 3.1: Schematic of the Vandalia drinking water treatment process**

The water used in this research was from Vandalia Reservoir or from the primary sedimentation (before the lime and first stage of chlorine is added).

### 3.1.2 Synthetic River Water

Due to the large demand (100 L per run) of raw water, it seems to be difficult to use real river water every time. As a result, simulated water with high turbidity and organic (similar to river water) is required.

Parallel experiments are being used in the determination of simulated water.

The two main purposes for simulated water are to add the turbidity and add the organic dose in water. The reason for this phase of tests is to make sure the simulated water has similar turbidity, TOC and UV254 as common raw waters (i.e. river water) in a drinking water treatment plant.

Kaolin clay is widely used in making water of high. Humic acid is a principal component of humic substances, which are the major organic constituents of soil

(humus), peat, coal, many upland streams, dystrophic lakes, and ocean water. [77] It is produced by biodegradation of dead organic matter. It is not a single acid; rather, it is a complex mixture of many different acids containing carboxyl and phenolate groups so that the mixture behaves functionally as a dibasic acid or, occasionally, as a tribasic acid. Humic acids can form complexes with ions that are commonly found in the environment creating humic colloids. Humic and fulvic acids (fulvic acids are humic acids of lower molecular weight and higher oxygen content than other humic acids) are commonly used as a soil supplement in agriculture, and less commonly as a human nutritional supplement[78]. In this experiment, only humic acid was used to make the synthetic water; that means it only modeled the DOC amount in the water, not necessarily modeled the chemistry conditions in the water.

Different dose of the two chemicals are added into water and 3 hours later, the solutions are tested as well as blank samples to see the turbidity, TOC and UV254 values. The one with closest parameters as river water was used in the followed experiment. The specific amount chemicals using in the experiment will be discussed in Chapter 5.

### 3.1.3 Water sample and chemical sample collection

Water that had been used in this research included water from Missouri River, Vandalia Water Treatment Plant (their source water and the water from different part of process). Chemicals used in the research were provided by several water treatment plants, including lime from Columbia, aluminum chloride from Vandalia, activated

carbon from Vandalia, polyaluminum chloride from Hamilton, aluminum sulfate from Monroe City, ferric chloride from Trenton, etc.

## 3.2 Analytical Methods

### 3.2.1 Turbidity

There are several practical ways of checking water quality, the most direct being some measure of attenuation (that is, reduction in strength) of light as it passes through a sample column of water. Standard Method 2130B (APHA, et al., 1998) was followed to measure turbidity using a Hach 2100P turbidimeter.

### 3.2.2 Total Organic Carbon or Dissolved Organic Carbon

To quantify the amount of natural organic matter in a water source, dissolved organic carbon (DOC) analysis is performed (Standard Method 5310 B: high temperature combustion method (APHA, et al., 1998)). Non-purgeable organic carbon (NPOC) analysis was performed on a Shimadzu TOC-Vcpn instrument with an ASI-V auto sampler and reported as DOC. The NPOC procedure adds 2N hydrochloric acid to the sample and then purges it for 1 min with zero-air (no carbon) to volatilize any carbonates that may have been present in the sample. Water sample is filtered by 4.7 cm glass fiber filter (WHATMAN) before being tested for DOC. DOC was mainly tested in the experiment introduced in Chapter 4 and Chapter 6 and TOC was mainly tested in the experiment described in Chapter 5

### 3.2.3 UV254

Samples were collected for determination of their absorbance of light at 254 nm (UV254) following Standard Method 5910 B. Samples were transferred to a 1-cm quartz cuvette using a syringe and filtered prior to measurement using a 0.45- $\mu$ m syringe filter. UV254 absorbance values were obtained using a Hach DR/5000 spectrophotometer in the plant's laboratory; for all other samples, a Varian Cary 50 Conc UV-Visible Spectrophotometer in the university's laboratory was used.

### 3.2.4 THM Species

The samples collected for TTHM analysis were analyzed with a Varian 3800 gas chromatography (GC) system equipped with a Saturn 2000 mass spectrometer (MS) for detection. An analysis method similar to that described by EPA method 524.2 and Standard Method 6232 C was used. For samples taken in the field and brought back to the laboratory for analysis, a 40-mL water sample was collected, of which approximately 5 mL was used for each analysis. Samples with no headspace were loaded on an autosampler which sent each sample to a purge and trap system for concentration of the volatile TTHM species before carrier gas carried them to the GC.

### 3.2.5 Chlorine Residual

A Hach DR/2400 spectrophotometer was used for these measurements. Duplicate or triplicate measurements of free chlorine residual were taken, with the average of the two values in best agreement recorded. For samples containing a free chlorine residual of greater than 2.0 mg/L, a fresh aliquot was diluted with DI water such

that the measured concentration fell within the 0.02-2.0 mg/L range and the original concentration calculated for reporting or use in chlorine demand determination, as appropriate.

### 3.2.6 Quality Assurance

All the parameters were tested triplicate. Average was taken if the range of the three results were within 5%; otherwise, another test was conducted. Calibration curve for TOC was generated at range from 0 to 10 mg/L. With each run of TOC (DOC), a sample of the standard solution (10 mg/L) and a blank sample (0 mg/L) were tested by side to make sure the calibration curve was still valid. Turbidimeter was calibrated by its program every two months.

For data collected in Chapter 5, five to seven samples were taken at every 20 or 30 minutes. Results show the average with the error bars showing the maximum and minimum number.

## 3.3 Statistical Methods

To compare two entities experimentally and deciding whether differences that are found are likely to be genuine or merely due to chance, the method of statistical inference called significance testing (equivalently hypothesis testing) was conducted. Suppose a particular result is produced by making some experimental modification to a system, one needs to determine whether the result is easily explained by mere chance variation or whether it is exceptional, pointing to the effectiveness of the modification.

To make this decision, one must produce a relevant reference distribution that represents a characteristic set of outcomes which could occur if the modification was with or without effect. The actual outcome may then be compared with this reference set. If it is found to be exceptional, the result is called statistically significant. [79]

In this research, an experiment was performed on a settling tank by taking samples from tank A with our design of inclined fabric settling screen followed by samples from an unmodified tank B which is without the design. What evidence does the data provide that method A gives higher removal rate than method B? To answer this question, one should properly plot the data from the outlet and calculate the averages obtained for methods A and B. Because of the considerable variability in the two tanks, one may worry about whether it could be reasonably claimed that method A is better or whether the observed difference in the averages could just be a chance event. Comparison with the t Test was used to determine the difference. Writing  $\delta$  for the difference in means  $\eta_A - \eta_B$  on the NIID assumption of random sampling from a normal population, the quantity calculated from equation 3.1 would be distributed as t with  $v = n_B + n_A - 2$  of degrees of freedom. Then Pr (%) could be generated and the result obtained could be found from the randomization distribution. [79] In this research, all the results of t Test were generated in the Microsoft Excel program.

$$\frac{(y_A - y_B) - \delta}{s \sqrt{\frac{1}{n_A} + \frac{1}{n_B}}} \quad (\text{Eqn.3.1})$$

Compute from the data some relevant criterion (statistic) to test a particular hypothesis of interest against some alternative hypothesis.

$$\text{Statistic: (e.g., } \bar{y}_B - \bar{y}_A \text{)} \quad (\text{Eqn. 3.2})$$

$$\text{Null hypothesis: } y_B - y_A = 0 \quad (\text{Eqn. 3.3})$$

$$\text{Alternative Hypothesis: } y_B \neq y_A \text{ (two-tail) or } y_B - y_A > 0 \text{ (one-tail)} \quad (\text{Eqn. 3.4})$$

Refer the criterion to an appropriate reference distribution, which shows how the criterion would be distributed if the tested hypothesis were true.

Calculate the probability that a discrepancy at least as large as the one that occurred would occur by chance if the null hypothesis were true.

In this research, 95% significance level was assumed and the probability tail is the main variable of interest. If it is sufficiently small ( $<0.05$ ), we can discredit the null hypothesis and assert that a statistically significant difference has been obtained. [79]



## 4. MATERIAL CHARACTERISTICS TEST AND THEIR FEASIBILITY ANALYSIS

### 4.1 Introduction

The fabric screen presented here combines the inclined plate settler with fabric material instead of the traditional steel/plastic. Apart from adding more surface area by 50% to 500% depending on the number of layers, it allows water to go through the material so that the material itself plays the role of a filter which can separate solids from water and enhance the sediment process. For each layer of the fabric, the up side provides more surface area while the down side stops solids from going through. The cost of fabric is low, and it is easy to maintain or change. The choice of fabric material is important for reasons. First, it should allow water easily pass through while it can intercept some solids. Second, the material itself should not introduce additional pollutants to the water being treated. For the materials chosen for the proof of concept, several material tests have been done.

### 4.2 Material and Method

#### 4.2.1 Fabrics Considered

As a proof of concept, six fabrics were acquired from the Hanes Product List. They can be classified into the three categories, polyester, polypropylene, and a 50/50 blend of polyester and rayon. The specific characteristics of the fabric selected are shown in Table 4-1. Their characteristics are described by weight, thickness, air

permeability, tensile strength, and micron rating. The unit of weight is oz/yd, which stands for ounce per yard, being equal to 0.031 kilograms per meter (kg/m). Thickness is in mils, where 1 mil equals one thousandth of an inch. Air permeability has units of cubic feet per minute per foot (cfm/ft), which equals to 0.001548 square meters per second (m<sup>2</sup>/s). Tensile strength is expressed by md\*cd, meaning both machine directions and cross directions. A micron rating for a fluid filter is a generalized way of indicating the ability of the filter's media to remove contaminants by the size of particles it is exposed to. A filter that is marked or rated "10 microns" has some capability to capture particles as small as 10 micrometers (the average size of a floc particle is around 100-1000 micrometers).

Table 4-1 Fabric Information

Product ID	Fiber	Weight (oz/yd)	Thickness (mils)	Air Perm (cfm/ft)	Tensile (md*cd)	Micron Rating
<b>Pureflo 50</b>	Polyester	0.5	5	957	9*5	300
<b>Pureflo 75</b>	Polyester	0.75	7.4	800	18*17	200
<b>Surefil 50</b>	Rayon/Polyester	0.5	5	966	6*3	100
<b>Surefil 70</b>	Rayon/Polyester	0.7	7.5	690	12*4	70
<b>Regiment 50</b>	Polypropylene	0.5	5	707	8*8	85
<b>Polyfab 500</b>	Polyester	5	unknown	unknown	unknown	unknown

Polyester is a category of polymers which contain the ester functional group in their main chain. The main characteristics of polyester fabric include being strong, durable, resistant to stretching and shrinking, resistant to most chemicals, wrinkle resistant, mildew resistant, and abrasion resistant. In the case when polyester composites are immersed in water, the voids and cracks in the material would be gradually filled with water molecules, and the capillarity effect would encourage the water penetration. This would increase the mass weight of the material. Prolonged

immersion would induce chemical reaction between the water molecules and the fiber as well as the matrix causing some elements to leach and dissolve in the water; this would cause the decline of the mass weight. Rayon is a manufactured fiber composed of regenerated cellulose, in which substituents have replaced not more than 15% of the hydrogen of the hydroxyl groups. Its main characteristics include being highly absorbent, soft and comfortable, easy to dye, and able to drape well. Polypropylene is a thermoplastic polymer made from the propylene monomer. It is rugged and unusually resistant to many chemical solvents, bases and acids. Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. Its main characteristics include being abrasion resistant, resistant to deterioration from chemicals, mildew, perspiration, rot and weather, thermally bondable, stain and soil resistant, and structurally strong. Compared to polyester, it is more hydrophobic, meaning that it does not absorb as much water. It also has a much lower melting point and is less UV resistant than polyester.

#### 4.2.2 Determination of Fabric performance

**Fabric performance with solids.** One of the functions that the fabric inclined screen plays in the water treatment process is to remove particles as a filter when water is going through it. With no pressure other than the water flow, the fabric should have a permeability that minimizes head loss. Lime solids (sludge) collected from a local drinking water treatment process was used in this experiment to test the ability of the fabrics to filter drinking water solids out of the water.

The equipment used in this experiment is shown in Figure 4-1. The procedure starts with the need to weigh the fabric and record that number as  $m_1$ . Weigh a glass filter and record that number as  $m_2$ . Dilute the sludge of the rate of 1:20 into the water. Measure 100 mL of the diluted suspension and put it into the first funnel and wait for it to naturally go through the fabric (using only gravity). After almost all the water is in the second funnel, turn on a vacuum pump to pull the water going through the glass filter. Remove the fabric and filter and place them into the oven and at 105 °C for 24 hours (or until completely dry). Weigh the fabric and filter as  $m_{t1}$  and  $m_{t2}$  respectively. Since the expectation is that whatever is not captured by the fabric will be captured by the glass fiber filter, calculate the removal rate of the fabric as

$$\text{Percent Removal} = (m_{t1} - m_1) / [(m_{t1} - m_1) + (m_{t2} - m_2)] \quad (\text{eqn.4.1})$$

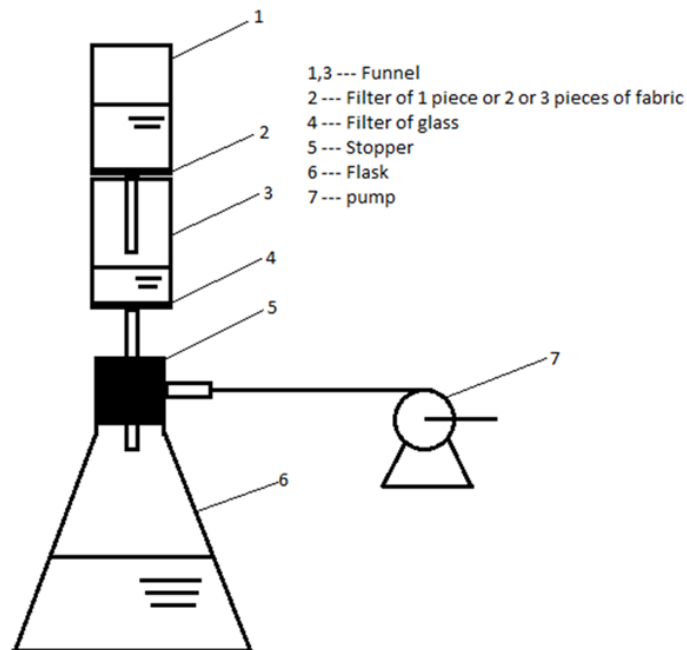


Figure 4-1 Equipment used in determination of fabric performance with solids

**Fabric endurance in solution.** The purpose of the introduction of the fabric inclined settling screen is to help enhance solids removal thereby reducing particles that may react with disinfectant added later in the process. It is essential that the material itself is unreactive and does not introduce additional pollutants/chemicals into water. Jar testing is used to determine the endurance of fabric diluted coagulant solutions (indicative of the environment at a drinking water treatment facility). The coagulants used include aluminum sulfate, sodium aluminate, and ferric chloride. The characteristics color and preferred pH range of each coagulant are shown in Table 4-2.

Table 4-2 Coagulant Information		
Coagulant	Color	pH
Aluminum sulfate	Transparent	4-6
Sodium aluminate	Transparent	10-12
Ferrous chloride	Orange	4-6

In this experiment, the coagulant solution was prepared as 10 mL (milliliters) of coagulant into 1.0 L of deionized water, which was much higher than the real usage in treating the water. If it does not react with the fabric under this high concentration, it is assumed it will not react with fabric under normally used concentration. A 20 centimeter (cm) by 20 cm swatch of each material was placed in individual 250 mL glass jar filled with 200 mL water/coagulant solution and the jar was capped. After 24 hours, a 10 mL water sample was immediately tested for turbidity and then 100 mL water sample was filtered through a 0.45  $\mu\text{m}$  glass fiber filter disk (FisherBrand 09-719-2E), and tested for DOC and UV<sub>254</sub>. This process was repeated for another 24 hours test with a new diluted coagulant solution. The percent reduction is calculated as the original

leaching solution concentration ( $c_1$ ) minus the concentration after leaching ( $c_2$ ) and then divided by the original concentration (eqn. 4.2).

$$\text{Percent reduction} = (c_1 - c_2) / c_2 * 100\% \quad (\text{Eqn. 4.2})$$

#### 4.2.3 Chemical Analysis

**Turbidity.** There are several practical ways of checking water quality, the most direct being some measure of attenuation (that is, reduction in strength) of light as it passes through a sample column of water. This turbidity was measured following Standard Method 2130B (APHA, et al., 1998) using a Hach 2100P turbidimeter.

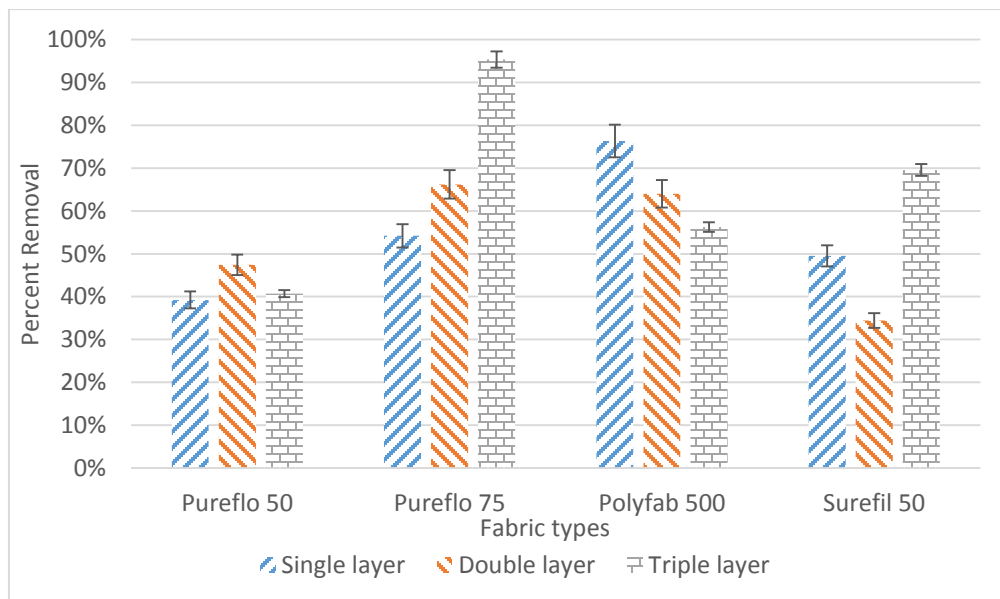
**TOC or DOC.** TOC means total organic carbon and DOC means dissolved organic carbon. Treated water samples from each of the jars are filtered through a 0.45  $\mu\text{m}$  glass fiber filter disk (FisherBrand 09-719-2E) is ready to be analysis with DOC. To quantify the amount of natural organic matter in a water source, TOC and DOC analysis was performed (following the Standard Method 5310 B: high temperature combustion method (APHA, et al., 1998) on a Shimadzu TOC-Vcpn instrument with an ASI-V auto sampler.

**UV<sub>254</sub>.** Measurements of ultraviolet light absorbance at 254 nanometers indicate aromatic organic content (Standard Method 5910 B). Treated water samples from each of the jars are filtered through a 0.45  $\mu\text{m}$  glass fiber filter disk (FisherBrand 09-719-2E), poured into a 1 cm quartz cell or cuvette (Fisher Scientific #14385902C), and then run on a UV-Visible Light Spectrophotometer (Cary 50) at a wavelength of 254 nm.

## 4.3 RESULTS AND DISCUSSION

### 4.3.1 Fabric Performance with Solid

Fabric filtration efficiency can be expressed by percent reduction (equation 4-1). Single, double, and triple layers of fabrics have been tested respectively on four of the fabric sample (Figure 4-2): Pureflo 75, Polyfab 500, Surefil 70, and Regiment 50. It is expected that as the number of layers increase that the percent removal will also increase. Since multiple samples were tested the results shown are the average numbers while the error bars are the maximum and minimum numbers obtained from the tests.



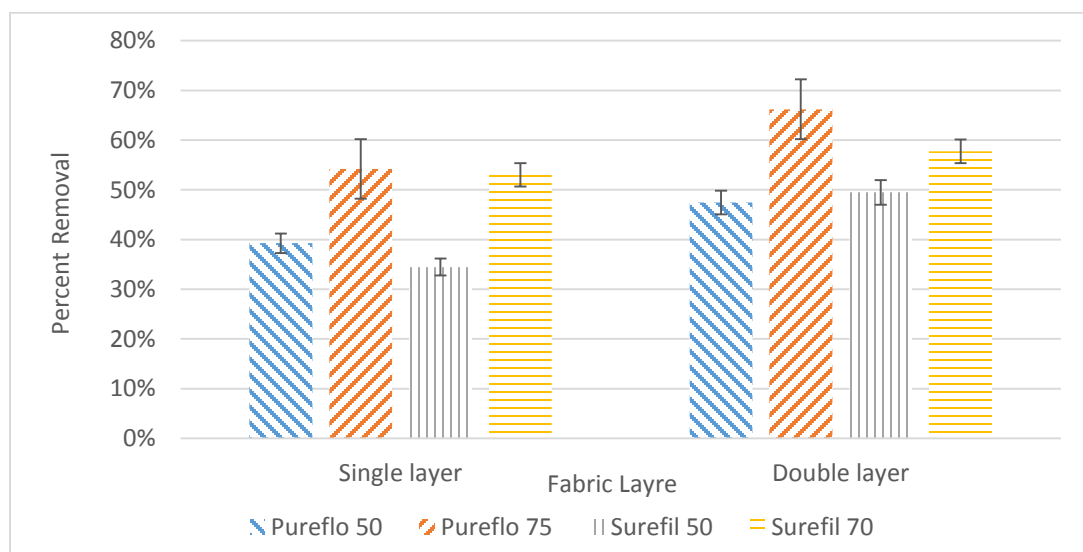
**Figure 4-2. Percent removal of particles through different layers of fabric filter**

The percent removal of pureflo 75, surefil 70, and regiment 50 increased with the increase of layers. For pureflo 75 and surefil 70 the triple layer provides the best filtration efficiency at 95% and 73% respectively. However, the performance difference between single layer and double layer appeared to be limited, with a 10% improvement

for pureflo 75 and a 5% improvement for surefil 70. For regiment 50 filtration efficiency improved a lot from the single layer to the double layer (40% improvement) while it did not change much from double to triple layer (3% improvement). For polyfab 500 the triple layer at 55% performs worse than the single layer (75%).

According to the micron rating shown in table 4-1, surefil should have the better ability to remove contaminants (as small as 70-100 micrometers) than pureflo does (as small as 200-300 micrometers). However, the size of lime solids used in this test was approximately 500 micrometers, which can be stopped by both materials. In this case, the percent removal of pureflo and surefil was close to each other.

Figure 4-3 shows the percent reduction of different fabrics in different thickness. The percent removal increased from 39% for pureflo 50 to 55% for pureflo 75 as well as from 35% for surefil 50 to 53% for surefil 70 because of the thickness increases. At the same time, pureflo 50 and surefil 50 has similar filtration efficiency at the same thickness.



**Figure 4-3. Percent removal of particles through different thickness of materials**



Overall, the results fluctuated somehow due to the uneven surface of the fabric. These tests confirm that the fabrics stop some of the particles so that it is feasible to use it in the settling screen design. However, it is worth mentioning that it took a long time for water to go through regiment 50 (approximately 5 minutes compared to others of 10 to 20 seconds) likely due to its hydrophobicity.

#### 4.3.2 Fabric Endurance in Solution (Turbidity and DOC values)

Table 4-3 and 4-4 respectively show the reduction of turbidity and DOC of different material existing in diluted solution of aluminum sulfate, sodium aluminate, and ferric chloride for 48 hours. Percent reduction, based on equation 4-1, was expected to be positive for it meant the fabric itself has some functions of cleaning the water, or at least does not release additional pollutant to the water. On the other hand, negative numbers (highlighted in red) meant that the fabric added some turbidity or TOC to the water, which was not wanted in our next step of experiment. Materials with negative results were ruled out after these test.

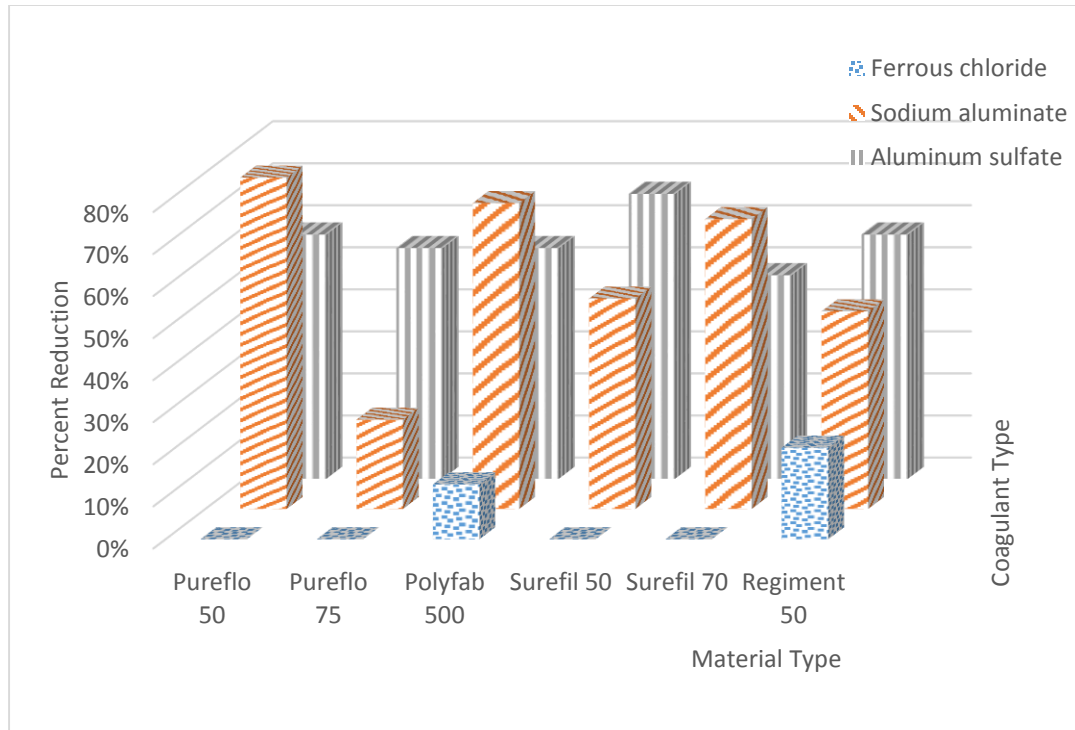
**Table 4-3 Reduction of Turbidity of Different Material and Coagulant Solutions**

	Aluminum sulfate	Sodium aluminate	Ferrous chloride
Pureflo 50	0.581	0.788	-0.174
Pureflo 75	0.548	0.212	-0.043
Polyfab 500	0.548	0.727	0.130
Surefil 50	0.677	0.500	-0.130
Surefil 70	0.484	0.689	-0.069
Regiment 50	0.581	0.470	0.217

Table 4-4 Reduction of TOC of Different Material and Coagulant Solutions			
	Aluminum sulfate	Sodium aluminate	Ferrous chloride
Pureflo 50	0.371	-1.041	0.120
Pureflo 75	0.355	-0.369	0.224
Polyfab 500	0.233	-0.246	0.499
Surefil 50	-0.526	0.612	0.267
Surefil 70	-0.407	0.510	0.348
Regiment 50	0.200	0.683	0.170

In this case, we discarded all the negative numbers in the table when we made the figures for we are only interested in the materials giving the positive number and the material chosen for next step of experiment would be among those. Materials with positive results were used to make incline settling screens in next a few steps of research.

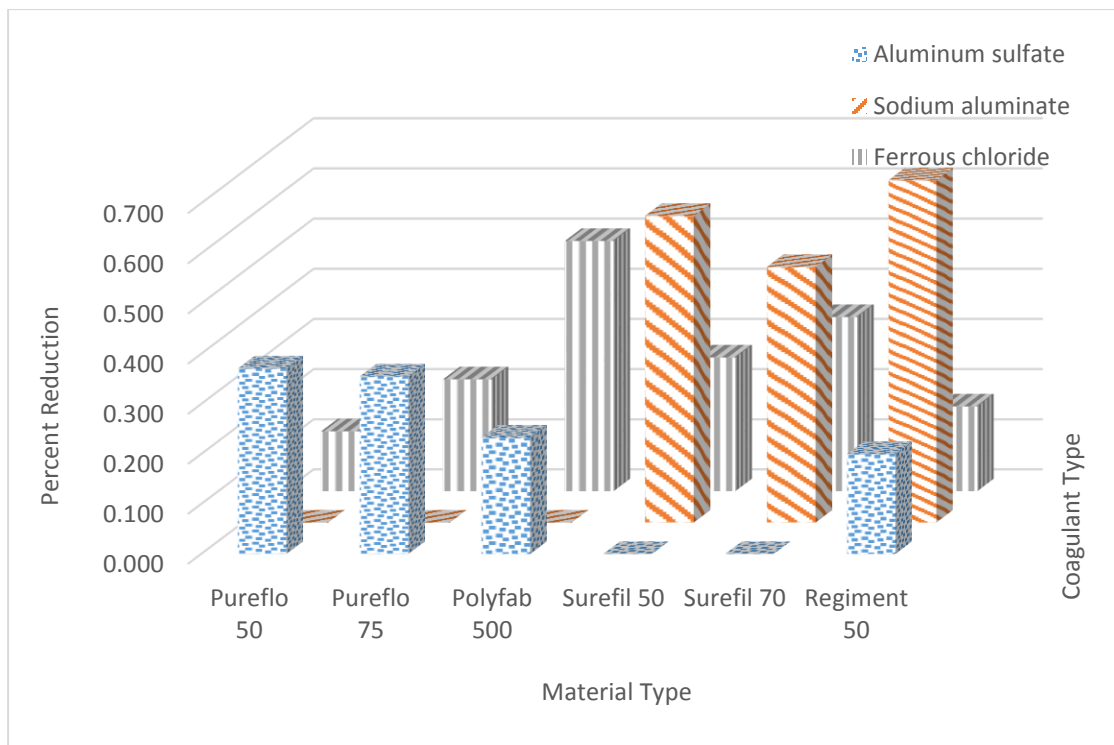
In most case as can be seen from Figure 4-4, turbidity got lower after 48 hours of incubation with the fabrics in sodium aluminate and ferric chloride, likely because the pores of the materials can adsorb some suspended particles and settling of the particles occurs in the jars themselves.



**Figure 4-4 Percent Reduction of Turbidity of Different Material and Coagulant Solutions**

TOC values (figure 4-5 provides performance numbers) indicate the concentration of organics in water. The three polyester (polyfab 500, pureflo 75, and pureflo 50), were affected sodium aluminate the most for the reduction of TOC is a negative number (in figure 4-5, 0 stands for negative as mentioned before) while they performed well in other coagulant. On the contrary, sodium aluminate rarely reacts with the two rayon materials (surefil 50 and surefil 70) while other coagulants were greatly affected by the two materials. As to polypropylene (regiment 50), it did an excellent job in every condition. It added few (and probably removed some) organic chemicals into the water according to the result of TOC test. But it is worth mentioning that this material is so hydrophobic that it does not absorb much water which is a possible reason for this result. These results suggest that the polyester (polyfab 500, pureflo 75, and pureflo 50) can be used in water process using ferric chloride and aluminum sulfate

while rayon materials (surefil 50 and 70) can be used in sodium aluminate and ferric chloride.



**Figure 4-5 Percent Reduction of TOC of Different Material and Coagulant Solutions**

In the point of view of pH, both aluminum sulfate and ferrous chloride are acid while sodium aluminate is basic. So it can be generalized that polyfab 500 and pureflo 75 are safe to be used in acidic or neutral conditions while surefil 70 are good for basic condition. The regiment material rarely react with any solutions, which is qualified for all the condition but in practice, it is limited for its hydrophobicity. It is hard for water to pass through and may cause huge head loss.

#### 4.3.3 Fabric Performance in Different Coagulant Solutions

Tables 4-5, 4-6, and 4-7 show the results of parameters after the material contact with the solution for 24 and 48 hours in aluminum sulfate, sodium aluminate,

and ferrous chloride respectively. Again positive numbers were expected. Negative numbers were discarded (expressed as 0) when being plotted on figures for the materials with negative results were no longer used in the next sets of experiment.

For the aluminum sulfate (Table 4-5) all fabrics show turbidity contributions during the first 24 hours. This is likely an acclimation/ripening to the environment. The surefil product (rayon/polyester blend) did not perform well in this environment.

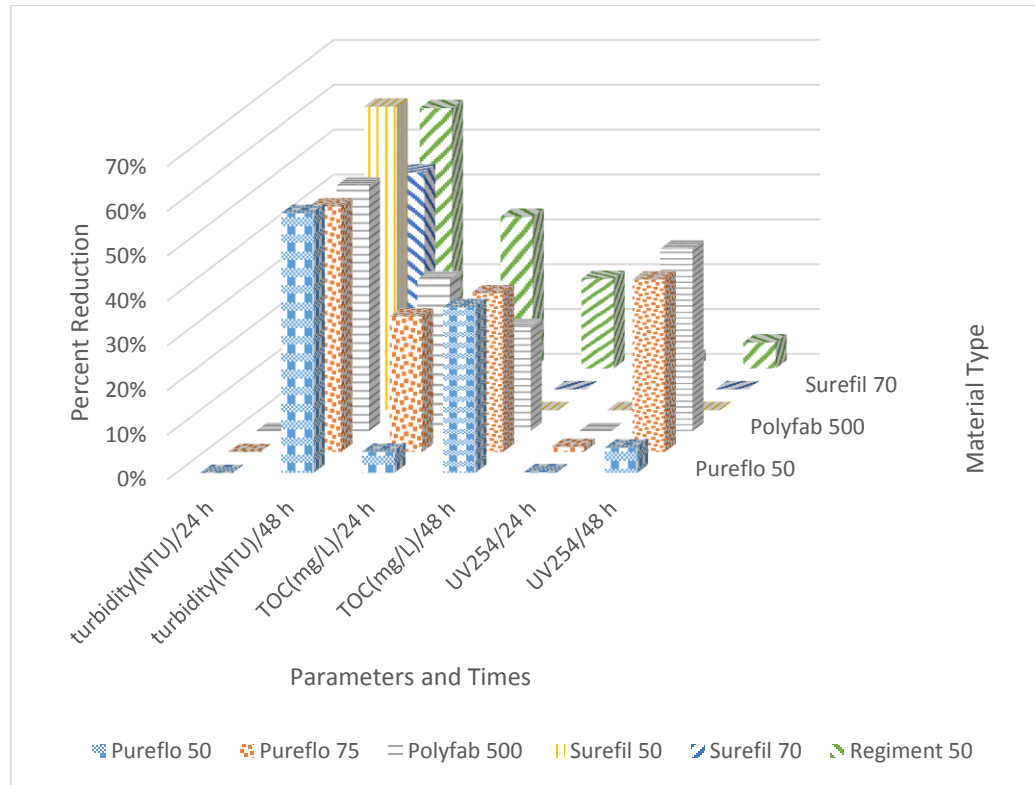
Table 5 Reduction of Select Water Parameters in Aluminum Sulfate

	turbidity (NTU)/24 h	turbidity (NTU)/48 h	TOC (mg/L)/24 h	TOC (mg/L)/48 h	UV <sub>254</sub> /24 h	UV <sub>254</sub> /48 h
Pureflo 50	-0.818	0.581	0.048	0.371	0.001	0.056
Pureflo 75	-0.455	0.548	0.303	0.355	0.011	0.386
Polyfab 500	-0.455	0.548	0.339	0.233	-0.003	0.407
Surefil 50	-1.545	0.677	-2.096	-0.526	-3.792	-1.075
Surefil 70	-0.727	0.484	-1.842	-0.407	-3.092	-1.007
Regiment 50	-0.091	0.581	0.338	0.200	0.024	0.058

As can be seen from the Figure 4-6 that the liquid's turbidity gets higher after 24 hours' time period but starts to get lower after 48 hours' period of exist of fabrics. It is mainly because the pores of the materials that can adsorb some suspended particles.

The two rayon materials (surefil50 and surefil70) seem to affect the water quality the most (Figure 4-6, TOC and UV254 number for surefils were all negative) in aluminum sulfate. But the effect did become less obvious (Table 4-5) in another 24 hours. This may indicate that after a certain time of period, it will not affect the water quality any more. So before the running of the tank, it is suggested to leach the materials into the water for some time (according to this test, the time period should be

longer than 48 hours). As to the three polyesters (polyfab500, pureflo75 and pureflo50) and the polypropylene (regiment50), they perform well in aluminum sulfate.



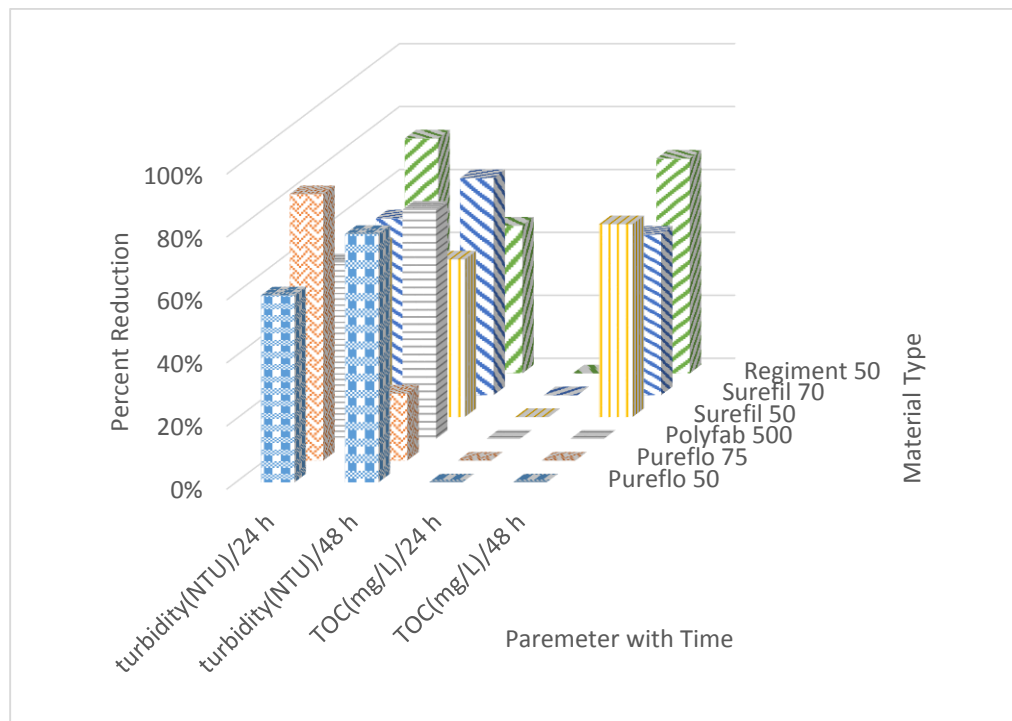
**Figure 4-6 Percent Reduction of Select Parameter in Aluminum Sulfate**

For the aluminum sulfate (Table 4-6) all fabrics show TOC contributions during the first 24 hours. This is likely an acclimation/ripening to the environment. The pureflo and polyfab products (polyester) did not perform well with respect to TOC in the this environment.

**Table 6 Reduction of Select Water Parameters in Sodium Aluminate**

	turbidity(NTU)/24 h	turbidity(NTU)/48 h	TOC(mg/L)/24 h	TOC(mg/L)/48 h
Pureflo 50	0.593	0.788	-0.520	-1.041
Pureflo 75	0.846	0.212	-0.375	-0.369
Polyfab 500	0.759	0.727	-0.124	-0.246
Surefil 50	0.543	0.500	-0.507	0.612
Surefil 70	0.562	0.689	-0.195	0.510
Regiment 50	0.747	0.470	-0.141	0.683

The fabric performance in the sodium aluminate solution (figure 4-7) appears almost opposite to alum; with the three polyester (polyfab 500, pureflo 75, and pureflo 50) affecting the water quality the most during the first 24 hours, but the effect becomes less obvious in another 24 hours (but still very high) while the two rayon materials (surefil 50 and surefil 70) perform better. The polypropylene (regiment 50) is still the best one and is not affected much by the coagulant solution. The turbidity tendency is all good but this parameter is not as important as TOC.



**Figure 4-7 Percent Reduction of Select Parameter in Sodium Aluminate**

For the ferric chloride solution fabric performance (Table 4-7) all fabrics show turbidity contributions and some show TOC contributions during the first 24 hours likely due acclimation/ripening to the environment. Because of the color of ferric, it was hard to eliminate the interference when testing the  $UV_{254}$ . As a result, only turbidity and TOC concentrations have been tested.

Table 4-7 Reduction of Select Water Parameters in Ferrous Chloride

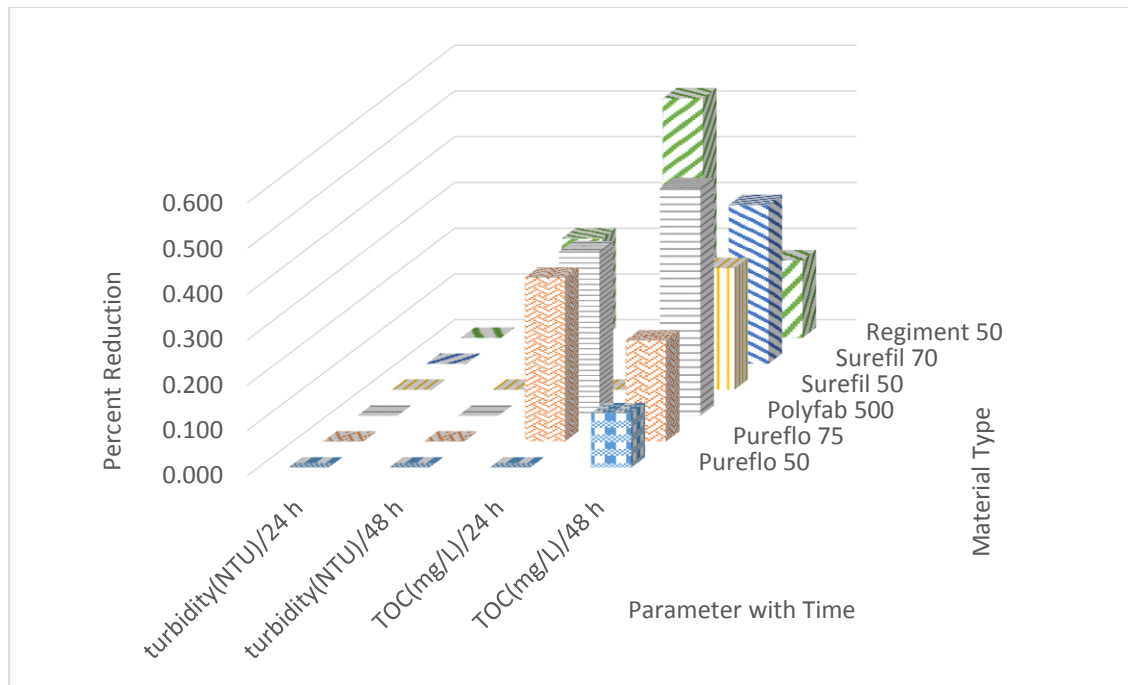
	turbidity(NTU)/24 h	turbidity(NTU)/48 h	TOC(mg/L)/24 h	TOC(mg/L)/48 h
Pureflo 50	-0.512	-0.174	-0.106	0.120
Pureflo 75	-0.435	-0.043	0.361	0.224
Polyfab 500	-0.217	0.130	0.361	0.499
Surefil 50	-0.435	-0.130	-1.480	0.267
Surefil 70	-0.391	-0.609	-0.931	0.348
Regiment 50	-0.043	0.217	0.524	0.170

The blank solution has a TOC greater than alum but much lower than sodium aluminate. The tendency of the TOC is similar to alum as can be found in Figure 4-8. In the first 24 hours, water quality is severely affected by the two rayon materials (surefil50 and surefil70). But after the second 24 hours, the percent reduction of all the materials became positive, which meant the materials have a positive effect to water quality.

As to turbidity, almost all the data were negative probably due to the color in the samples. But in real treatment process, the dosage of the coagulant will be far less than was used in this test so that we don't need to worry about this issue.

Regiment 50, as with all the other results, performed well again in this coagulant for the same reason that it is hydrophobic.





**Figure 4-8 Percent Reduction of Select Parameter in Ferrous Chloride**

#### 4.4 CONCLUSION

Conceptually the fabric inclined screen adds additional surface area for solids to settle on as well as play a role of filter to stop some particles from going through. Use of the fabric screen was determined to be feasible through material testing. All of the material provided successfully removed 40%-90% of particles in the test of the fabric's filtration efficiency. But one (regiment 50, a polypropylene product) had difficulty letting water go through because of its hydrophobicity. In the test of their endurance in dilute coagulant solutions, the polyester (polyfab 500, pureflo 75 and pureflo 50) may be more appropriately used in acidic or neutral environment while the rayon/polyester blend (surefil 50 and surefil 70) were better in basic/alkaline conditions. Regiment 50 is the only one that did not react (release turbidity or TOC) in any conditions. Over an

extended period of time, some of the material even adsorbs some pollutant due to its loose structure and large surface area.

## 5. CONTINUOUS FLOW TESTING OF FABRIC SCREENS

### 5.1 Introduction

In the United States, more than 94 percent of the nation's 156,000 public water systems serve fewer than 10,000 persons. These systems are classified as very small (0-500), small (501-3,300) or medium (3,301-10,000) by the United States Environmental Protection Agency (EPA) and face unique financial and operational challenges in supplying drinking water that meets EPA standards. These water systems do not have the large customer base needed to provide the necessary financial assistance and cannot easily develop or access the technical, managerial and financial resources needed to comply with the increasing number of EPA regulations and rising customer expectations [20].

The inclined plate settler has industrial origins [41]. Closely spaced inclined plate systems for water treatment resulted from a search for high-rate treatment processes compact enough to be economically housed against winter weather in the 1950s in Sweden. Inclined tube system was spawned in the United States in the 1960s. The most recent developments have involved combining inclined settling with ballasting of floc to reduce the plant footprint further [42]. Individual modules of inclined plate or tube settlers can be constructed of appropriate materials. Inclined surfaces may be contained within a suitably shaped tank for countercurrent, concurrent, or cross-flow sedimentation. Adequate flocculation is a prerequisite for inclined settling if coagulation is carried out. The angle of inclination of the tubes or plates depends on the application,

the tendency for self-cleaning, and the flow characteristics of the sludge on the inclined surface. Self-cleaning occurs when the angle of inclination is great enough, typically more than  $50^\circ$  to  $60^\circ$  [43]. Demir [44] found for inclined plates fitted at the end of a pilot horizontal-flow settler the optimum angle is about  $50^\circ$ , with this becoming more pronounced as the surface loading rate increases. The main objective in inclined settler development has been to obtain settling efficiencies close to theoretical. Metso's lamella principle using several parallel inclined plates to maximize the available area for any available floor area. In this way, the size and cost of the gravity settler can be minimized by matching the thickening and clarifying requirements more closely. The two basic criteria for gravity settling equipment are good clarity of the overflow liquid and maximum density of the underflow solids discharge. The area needed to clarify a suspension is often greater than that needed for thickening. This means that in a cylindrical thickening tank, the lower section with rakes and drive mechanism can be oversized.

The fabric screen presented here combines the inclined plate settler with fabric material instead of the traditional steel/plastic. Apart from adding more surface area by 50% to 500% depending on the number of layers, it allows water to go through the material so that the material itself plays a role of filter which can separate solids from water and enhance the sedimentation process. For each layer of the fabric, the up side provides more surface area while the down side stops solids from going through. The cost of fabric is low, and it is easy to maintain or change.

In an effort to develop a methodology for determination of optimal use of fabric screens for reducing the amount of DBPs formed in the distribution systems several fabric materials were selected and tested. Appropriate strategy considerations for improving treatment plant performance were based on their coagulant type and dose, and on the characteristics of the fabric. The systems most likely to make use of this technology are ones which have finished water trihalomethane (THM) and/or haloacetic acid (HAA) levels in excess of forthcoming Stage 2 Disinfectants and Disinfection By-Products (DDBP) drinking water standards.

A THM formation reaction is described in equation 5-1. [80] Strong formation depends on water temperature, pH, organic content and chlorine dosage while weaker formation depends on water age of residence time and bromide concentration. Among these, pH, organic content, chlorine dosage, and water age (storage and system residence) are the parameters that are under operational control. In contrast, water temperature and bromide concentration cannot be controlled. As a result, one of the THM reduction methods is to enhance coagulation and sedimentation. The effects of an enhanced sedimentation approach, using inclined fabric settling plates, should be included in the considerations. [80]

$$\text{TTHM, } \mu\text{moles/L} = 0.00309 * (\text{UV}_{254} * \text{TOC})^{0.44} * \text{Cl}_2^{0.409} * \text{RXN}^{0.265} * \text{TEMP}^{1.06} * (\text{pH} - 2.6)^{0.715} * (\text{Br} + 1)^{0.0358}$$

*(Eqn. 5-1)*

UV<sub>254</sub> = UV absorbance at 254 nanometers, cm<sup>-1</sup>

TOC = Total organic carbon, mg/L

Cl<sub>2</sub> = Chlorine dosage, mg/L

RXN = Coefficient related to water age

TEMP = Water temperature, °C

pH = Water pH, s.u.

Br = Bromide, mg/L

## 5.2 Material and Methods

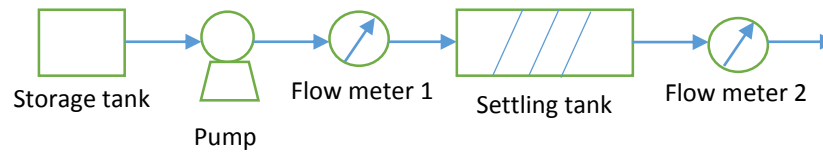
### 5.2.1 Flow through the fabric

The Bernoulli equation (equation 5-2) can be used to describe the water passing through an arbitrarily selected opening in the fabric. Taking the fabric characteristics (opening shape, opening size in both vertical and horizontal direction, weave depth in both direction, total numbers of opening below the water surface along the vertical direction, etc.) into consideration, the discharge ( $q$ ) can be determined based on what is known as orifice discharge equation (equation 5-3), where  $C$  is the coefficient of discharge, ranging from 0.61 to 0.98 according to the shape of the orifice. A simple horizontal channel can be designed to check the flow rate before and after water passes through the fabric (Figures 5-1 and 5-2).

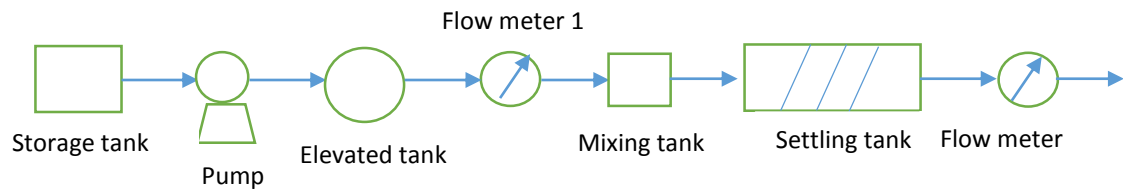
$$E + \frac{P_A}{\gamma} + \frac{v_A^2}{2g} = E + \frac{P_B}{\gamma} + \frac{v_B^2}{2g} + h_1 \quad (\text{Eqn. 5-2})$$

$$q = Ca\sqrt{2gh} \quad (\text{Eqn. 5-3})$$

Relationship between predicted and measured flow rate through different angles of fabric can be plotted according to the flow rate from flow meter 1 and 2. Also, upflow velocity can be calculated by  $v=Q/A$  and detention time can be calculated by  $t=Q/V$ .



**Figure 5-1 Schematic of Phase 1 Experimental setup**



**Figure 5-2 Schematic of Phase 2 Experimental setup**

### 5.2.2 Experimental Premise

Performance of the fabric screen was compared side-by-side with to an identical chamber which does not contain a screen. The treatment studies were conducted using synthetic river water to quantify the efficiency of removing natural organic matter (precursors for DBP production) by measuring the percent reduction of dissolved organic carbon (DOC) and UV254 and comparing that to the reduction in the more commonly measured parameter turbidity.

**Synthetic river water:** Each run would consume 100 liters of water; it was not realistic to use real river water in every run of the experiment. So synthetic water was used modeling the turbidity and TOC of the river water. 100 liters of tap water (in a Rubbermaid container) received 5g Kaolin Clay and 0.5g humic acid to create turbidity and organic precursors, respectively. The experiment of deciding the dosage of the synthetic water is shown in later chapter.

**Bench-Scale Tank design:** A tank was designed for modeling a water treatment process. It contains a quick mixing chamber, a slow mixing chamber, and two settling chambers. One of the settling chambers has a fabric inclined settling screen fixed. By comparing the outlet water parameter from the two settling basins, the performance of the fabric settling screen can be determined. Performance of the fabric screen was compared side-by-side with a control chamber which does not contain a screen. The treatment studies were conducted using synthetic river water to quantify the efficiency of removing natural organic matter (precursors for DBP production) by measuring percent reduction of dissolved organic carbon (DOC) and UV254 and comparing that to the more commonly measure decrease in turbidity. In the data that is presented  $o_1$  stands for outlet of the chamber without fabric inclined plate and  $o_2$  for the chamber containing the screen. Three versions of the tank have been used in this experiment and they will be introduced in the later sections.

**Typical tank operation:** Start the pumps to add in simulated water and chemical (coagulants) into the bottom of the quick mix chamber. Wait for the empty tank being full of water and set the time that the outlet has water to pull out as the time 0. Take sample from the inlet. Take samples from the sedimentation chamber without the fabric as outlet 1 and the sedimentation chamber with fabric as outlet 2 and label them at time 30. Take the sample of inlet as the inlet of outlets the next 30 minutes. Wait for another 30 minutes to take another group of samples.

After the run is over, test the water samples for turbidity. Filter the samples and then test the parameters of TOC and UV254.



### 5.2.3 Data Analysis

**Turbidity:** Standard Method 2130B (APHA, et al., 1998) was followed to measure turbidity using a Hach 2100P turbidimeter.

**UV254 analysis:** UV254 absorbance measurements indicate aromatic organic content (Standard Methods 5910 B). Treated water samples are filtered through a 0.45  $\mu\text{m}$  glass fiber filter disk (FisherBrand 09-719-2E), poured into a 1 cm quartz cell (Fischer Scientific #14385902C), and then run on a UV-Visible Spectrophotometer (Cary 50) at a wavelength of 254 nm.

**TOC Analysis:** To quantify the amount of natural organic matter in a water source, total organic carbon (TOC) analysis is performed (Standard Methods 5310 B: high temperature combustion method (APHA, et al., 1998)). TOC analysis was performed on a Shimadzu TOC-Vcpn instrument with an ASI-V autosampler.

**Data Analysis:** From these results construct a percent reduction (equation 5-4) versus time curve. Equation 5-4 the variable  $c$  stands for the parameter from outlet while  $c_o$  stands for parameter from inlet.

$$\text{Percent reduction} = (c - c_o) / c_o * 100\% \quad (\text{Eqn. 5-4})$$

When percent reduction equals to 1, it means 100% removal. Time interval is every 30 minutes. 30 minutes is the point when the outlet 1 has water go out while outlet 2 has not due to the head loss caused by the fabric. In other words, 30 minutes is the hydraulic detention time. Since the current experiment lasts 3 hours, the fraction

removal trend will be over time. The expectation is that it should remain the same or even increase.

The Improvement Amount is also defined in some experiment as “Percent reduction of outlet 2 – Percent reduction of outlet 1”. This is mainly used to compare the difference between one variable.

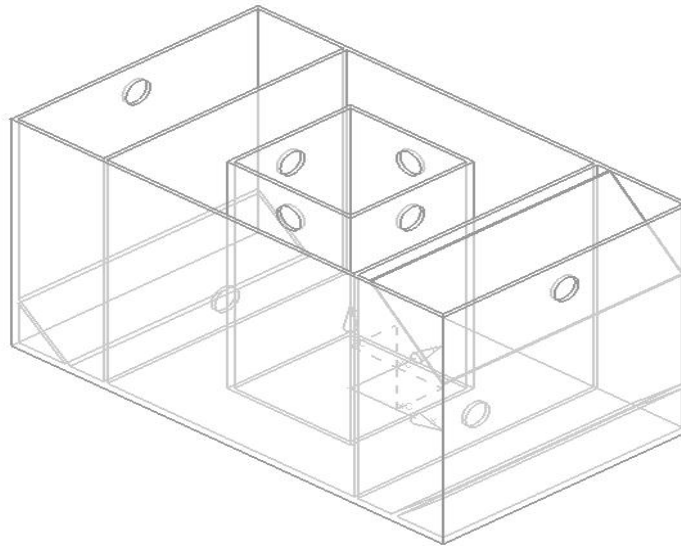
Error bar is used to mark the maximum and minimum values observed. The average values are used to make the graph.

A student t-test is used to determine whether there is a significant difference between sample results.

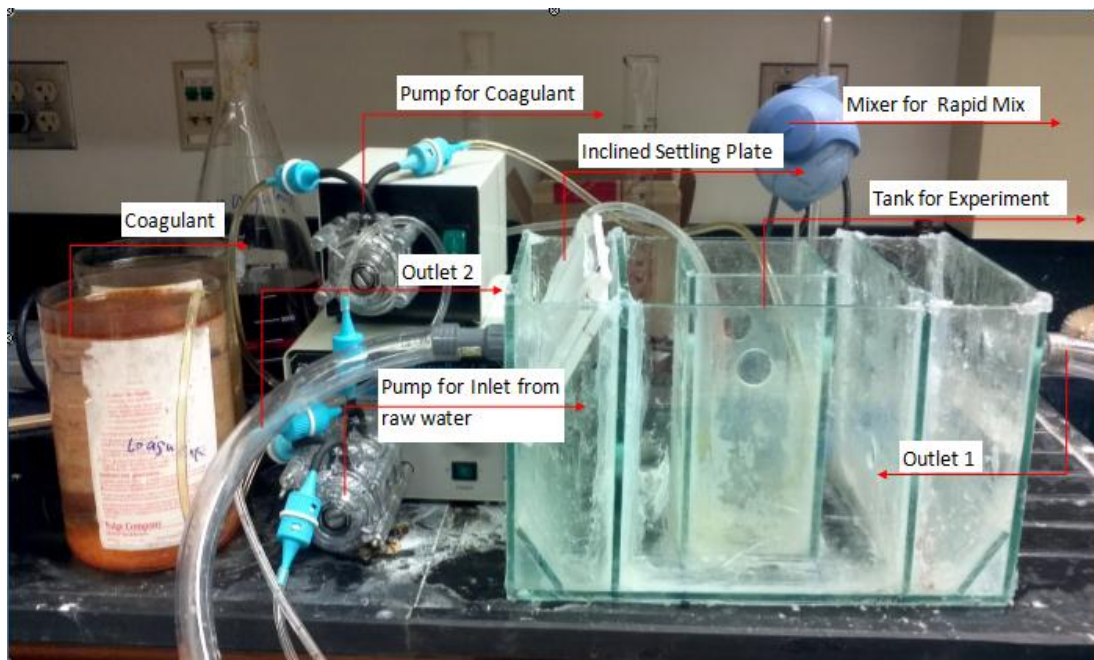
### 5.3 Design of the Tank

There were three versions of the design of the bench-scale tank. The first one is shown in Figure 5-3 and 5-4. The tank constituted has four parts. The central area was the quick mix chamber ( $128 \text{ cm}^3$ ), where chemical and inlet water were added from the bottom. A mixer was required in this area. The outer area was the slow mix chamber ( $384 \text{ cm}^3$ ), which ensured the water and chemical to react thoroughly with each other. The uneven flow and the pressure from the quick mix chamber would force the water to go further so that no mixers were required in this area. The last two parts were two sedimentation chambers ( $480 \text{ cm}^3$  each,  $960 \text{ cm}^3$  total), one with an inclined fabric screen and the other without. In some sets of the experiment in this tank, the inclined fabric screen had not been fixed on; instead, a vertical screen was fixed on one side. The

purpose of the difference was to compare the water quality only with the difference of whether it went through the fabric while other conditions are the same.



**Figure 5-3 Stereogram of the tank**

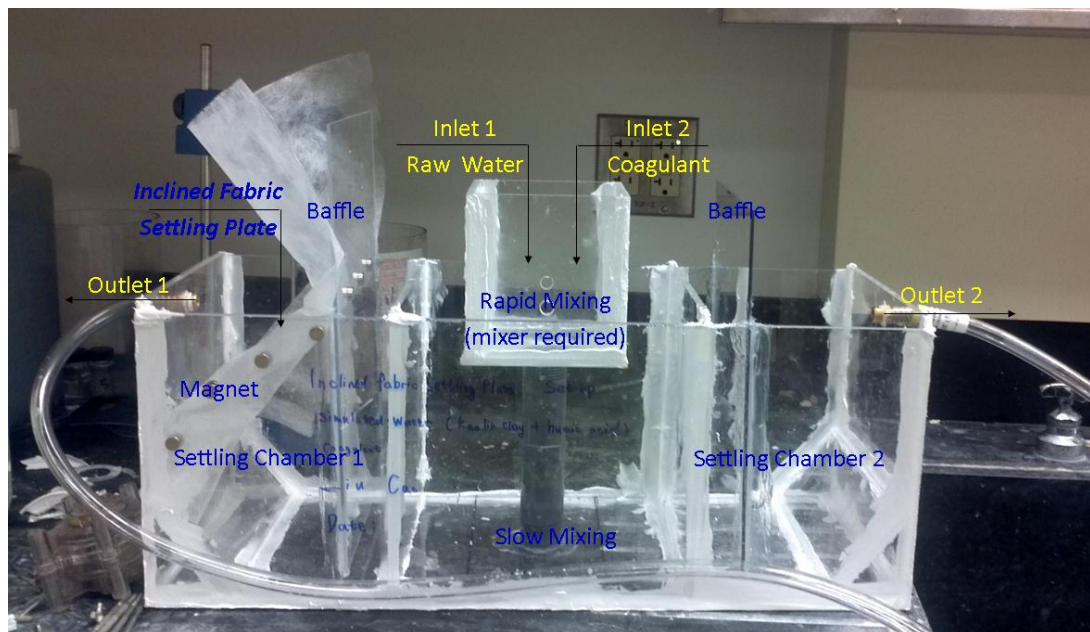


**Figure 5-4 Real Look of the Tank (version 1)**

After running the tank- for some time problems surfaced. Adjusting the structure of the tank was required and the aim of this modification was threefold. Firstly, quick

mixing time was to be reduced to 15-30 seconds. Secondly, slow mixing time was to be increased to 15-25 minutes on average. Finally, by extending the length of the settling chambers, settling time was to increase to 30 minutes so that most of the solids can be settled.

The quick mixing chamber had been significantly reduced while the two settling chambers had been increased and a baffle was added to each chamber to force the water flow. (Figure 5-5)



**Figure 5-5 Real Look of the Tank (version 2)**

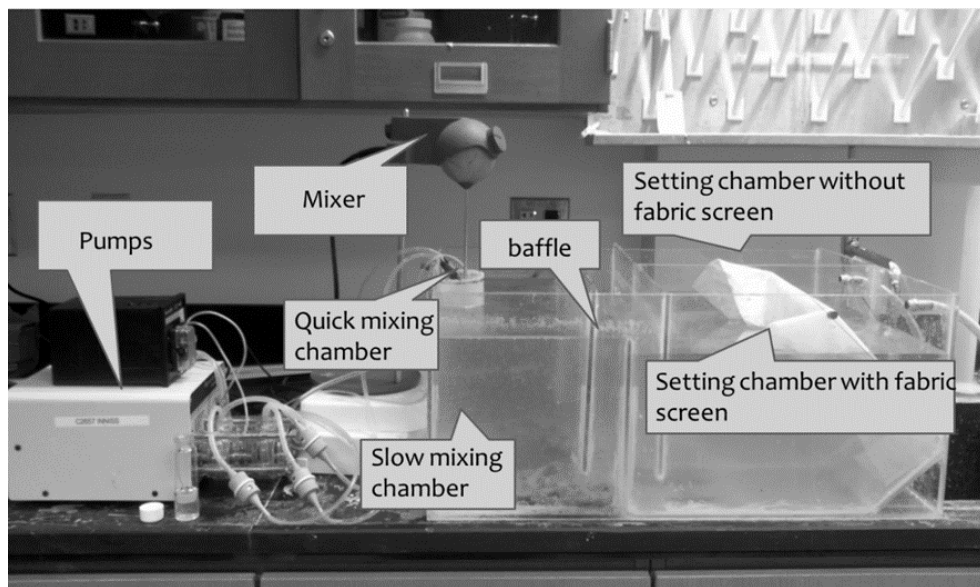
Design of inclined fabric plate screens was the major challenge in the research. A variety of ways to install the screens and the different forms of the screens themselves may all cause impurity of the results.

Magnets were used to help fix the screen in the tank. An important variable to be considered was the different angles to install the inclined screen. Labels on the tank were used to fix the prescribed angles. The screen itself also needed to be taken into

consideration. The thickness of the fabric, the layers of the material, and the pattern of the screens may all lead to different results.

The third version of tank came soon after the second one because of the construction problem that the tank leaked a lot and was hard to fix. With the same concept in mind, the third version did some adjustment and the two settling tanks were moved parallel to each other.

A 3900 in<sup>3</sup> tank (Figure 5-6) was designed for modeling a water treatment process. It contains a quick mixing chamber of 25 in<sup>3</sup>, a slow mixing chamber of 1235 in<sup>3</sup>, and two settling chambers of 1320 in<sup>3</sup> each (2640 in<sup>3</sup> together). One of the settling chamber has a fabric inclined settling screen fixed by magnets. By comparing the outlet water parameter from the two settling basin, the performance of the fabric settling screen can be determined.



**Figure 5-6 Design of the set-up**

Performance of the fabric screen was compared side-by-side with a control chamber which does not contain a screen. The treatment studies were conducted using

synthetic river water to quantify the efficiency of removing natural organic matter (precursors for DBP production) by measuring percent reduction of dissolved organic carbon (DOC) and UV254 and comparing that to the reduction of the more commonly measured turbidity. Start the pumps to add in simulated water and chemical (coagulants) into the bottom of the quick mix chamber. Wait for the empty tank being full of water and set the time that the outlet has water to pull out as the time 0. Take sample from the inlet. Take samples from the sedimentation chamber without the fabric as outlet 1 and the sedimentation chamber with fabric as outlet 2 and label them at time 30.

## 5.4 Results and Discussion

### 5.4.1 Determination of Simulated Water

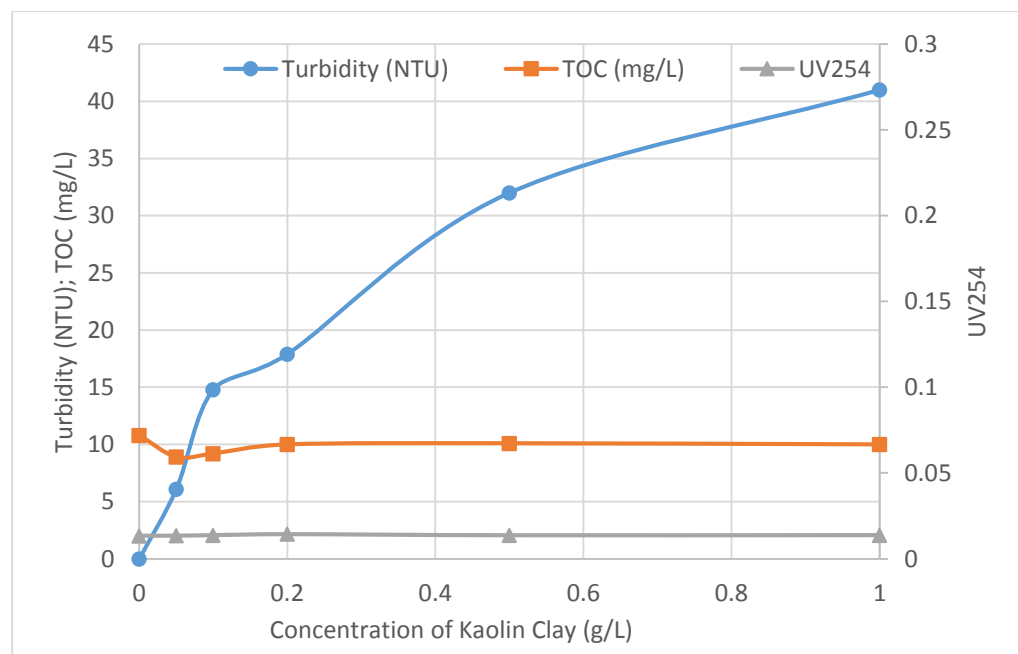
Parallel experiments are being used in the determination of simulated water quality. The two main purposes for using simulated water are to add the turbidity and the organic dose in water. The reason for this phase of tests is to make sure the simulated water has similar turbidity, TOC and UV254 as common raw waters (i.e. river water) in a drinking water treatment plant.

Kaolin clay is widely used in making water of high turbidity while humic acid does a good job in adding organics into water although the color can become an issue.

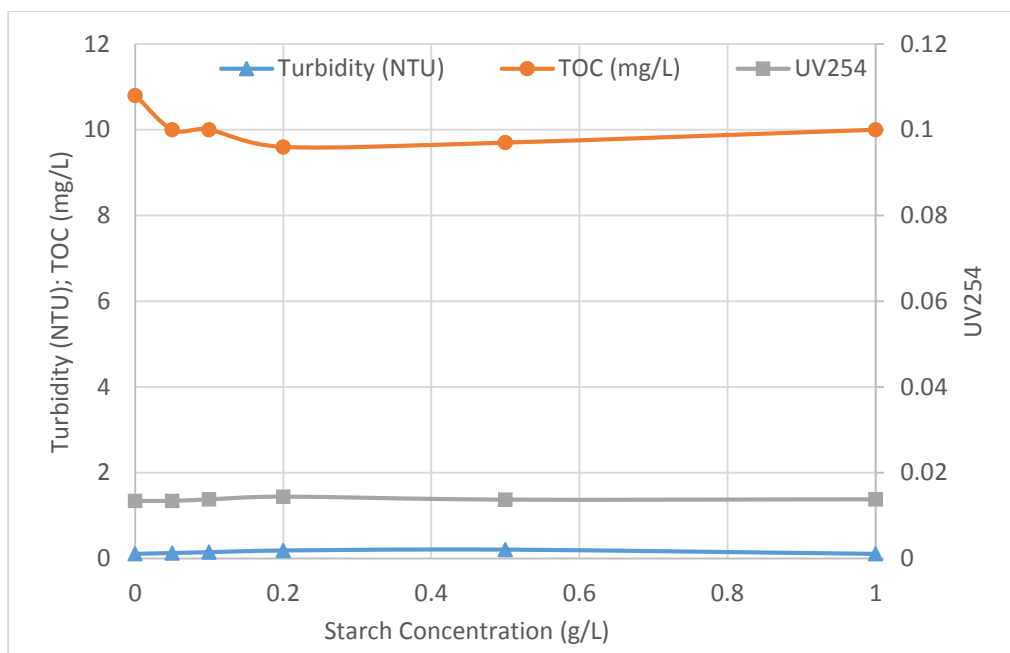
Different doses of the two chemicals are added into water and 3 hours later, the

solutions are tested as well as blank samples to see the turbidity, TOC, and UV254 values.

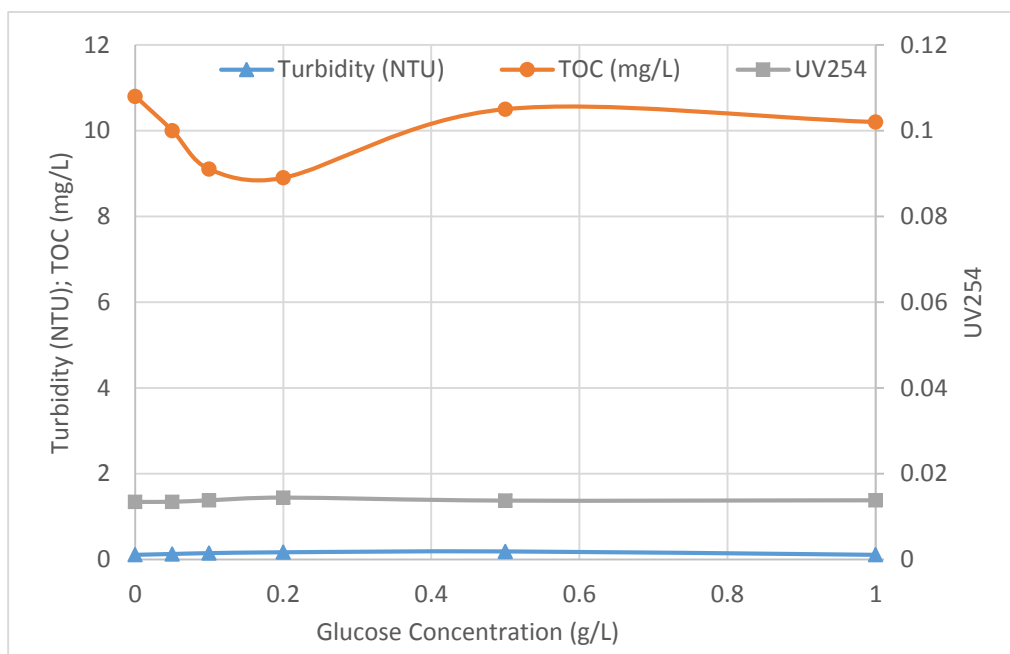
From Figure 5-7 to 5-10 it is obvious that neither glucose nor starch added turbidity or organics into water. That is to say they were not to be chosen to make simulated water in this research. Kaolin Clay added a lot of turbidity into water but did not add any organics. On the other hand, humic acid added very little turbidity but a lot of organics into water. As a result, both Kaolin Clay and humic acid were chosen to make the simulated water. Synthetic river water used was made from 100 gallons of tap water (in a Rubbermaid container) mixed with 4g of kaolin clay and 0.15g of humic acid to create turbidity and organic precursors, respectively.



**Figure 5-7 Effects of adding Kaolin Clay to Water**

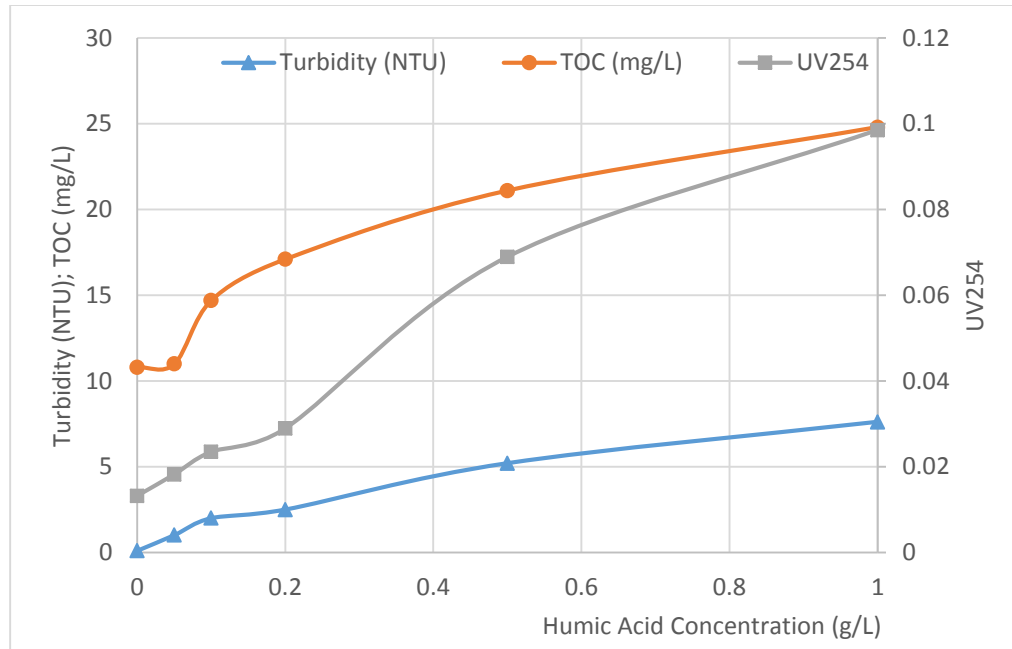


**Figure 5-8 Effects of adding Starch to Water**



**Figure 5-9 Effects of adding Glucose to Water**

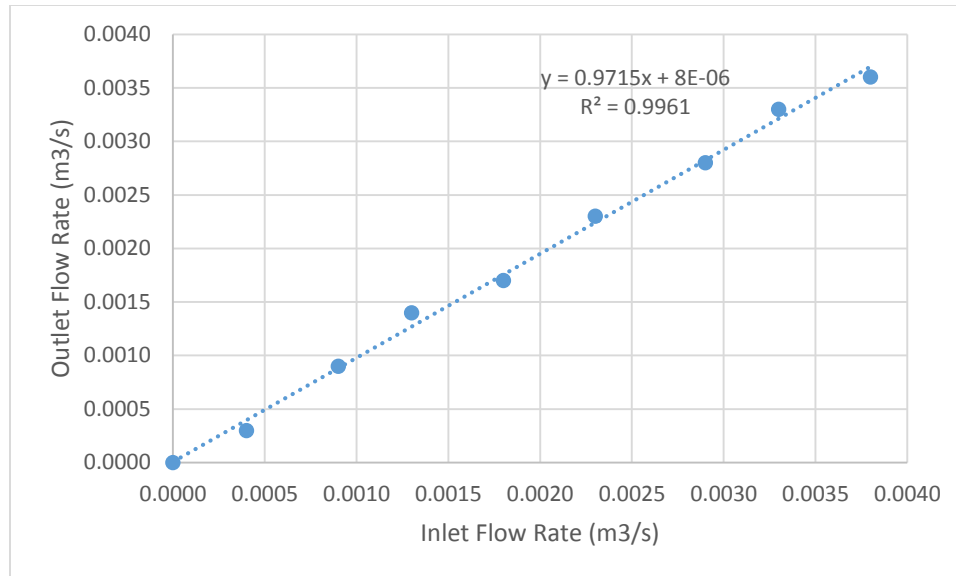




**Figure 5-10 Effects of adding Humic Acid to water**

#### 5.4.2 Flow through the Fabric

This experiment was conducted to verify the hydraulic relationship for filter fabric and to determine the coefficient of discharge ( $C = \text{flow rate of outlet} / \text{flow rate of inlet}$ ). Tests were taken in the third version of the tank, where fabric was fixed on and flow rate of inlet and outlet was measured. Inlet flow rate was adjusted to a certain level through pump; then flow rate of outlet was recorded when it came to steady state. Flow rate was generally increased and the result is illustrated in Figure 5-11. Using linear regression, the coefficient of discharge is equal to 0.972, with a correlation coefficient of 0.9961.



**Figure 5-11 Relationship between outlet and inlet measured flow rate through filter fabric**

#### 5.4.3 Run in the first tank

In the first tank, three runs were conducted with one layer of the screen and two parallel screens under the angle of 60°. The coagulant used was aluminum sulfate from Monroe City and sodium aluminate from Trenton City. Water parameters from the two outlets (outlet 1 is the one without the inclined fabric screen and outlet 2 is the one with the screen) were compared. The results are shown in the Appendix A on Figures 5-12 to Figure 5-20.

The results varied with time, but seemed similar between the two tanks. To verify this, the essential nature of a significance test is to compare two treatments using the following steps:

Compute from the data some relevant criterion (statistic) to test a particular hypothesis of interest against some alternative hypothesis.

$$\text{Statistic: (e.g., } \bar{y}_B - \bar{y}_A \text{)} \quad (\text{Eqn. 5-5})$$

$$\text{Null hypothesis: } y_B - y_A = 0 \quad (\text{Eqn. 5-6})$$

Alternative Hypothesis:  $y_B \neq y_A$  (two-tail) or  $y_B - y_A > 0$  (one-tail) (Eqn. 5-7)

Refer the criterion to an appropriate reference distribution, which shows how the criterion would be distributed if the tested hypothesis were true.

Calculate the probability that a discrepancy at least as large as the one that occurred would occur by chance if the null hypothesis were true.

This is the significance level. If it is sufficiently small we can discredit the null hypothesis and assert that a statistically significant difference has been obtained.

As can be seen from the result of T-test in Tables A1-A9 of Appendix B, a P tail of 0.22, 0.71 and 0.84 for turbidity, of 0.80, 0.81 and 0.41 for TOC, and of 0.97, and 0.51 and 0.99 for UV254 was found. All of the numbers are very high, therefore it can be inferred that the two means are not different.

This result may be caused by the inadequate reaction time in slow mixing tank, a short sediment time, and the leaking of the screen. As it were, a second tank was designed and came into use after this.

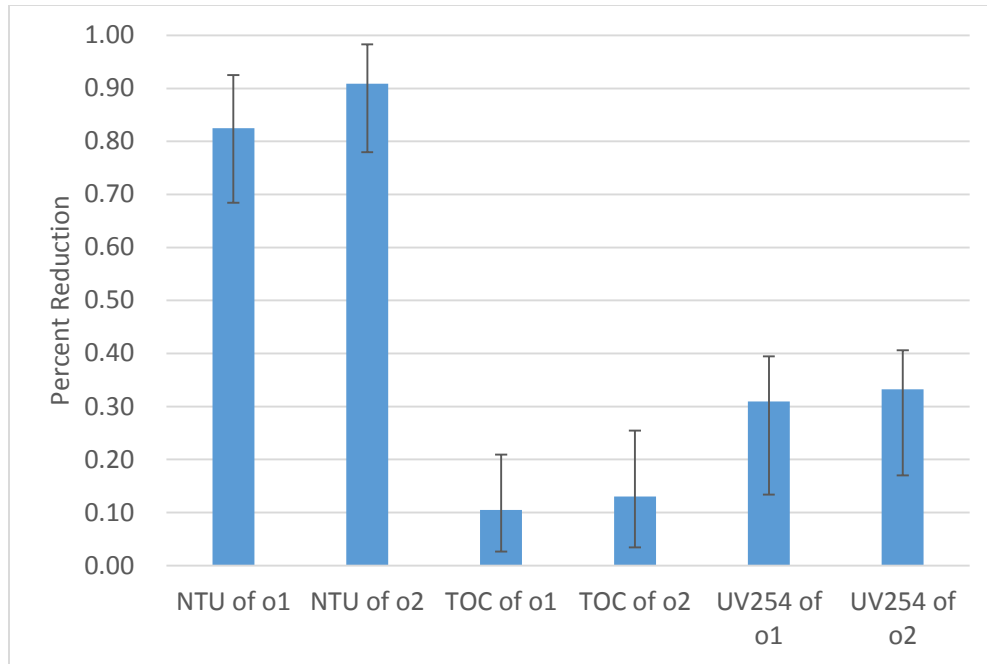
#### 5.4.4 Run in the second tank

Several comparisons have been made in the second tank, including different chemicals (or same chemicals from different source), and different angles of the inclined fabric settling screen.

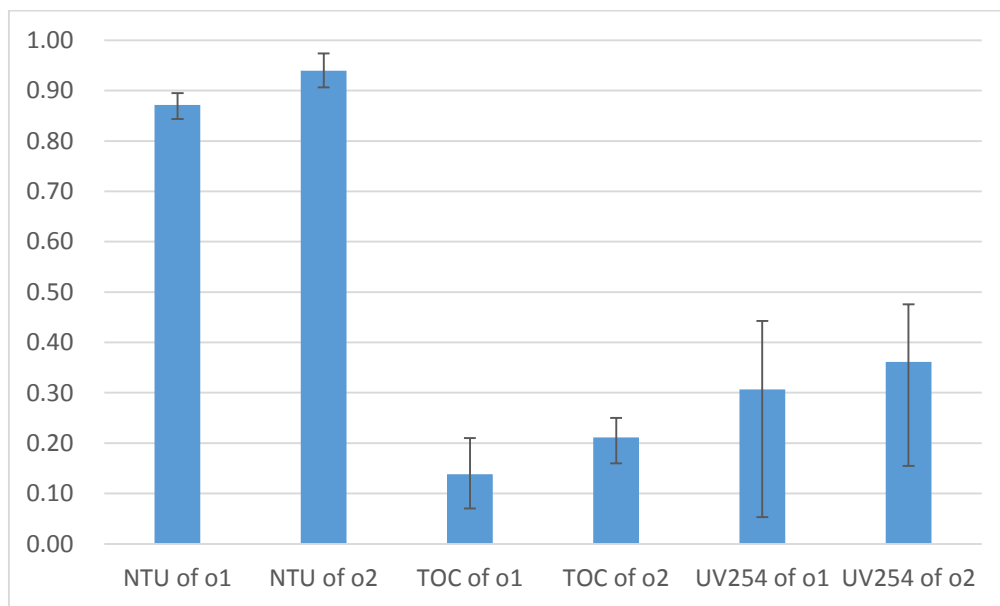
##### 5.4.4.1 Comparison of the results using different source of coagulant

In the first set of experiments, pureflo 50 was used as the fabric screen at a 55° inclination angle. Coagulant from two different treatment plants (polyaluminum

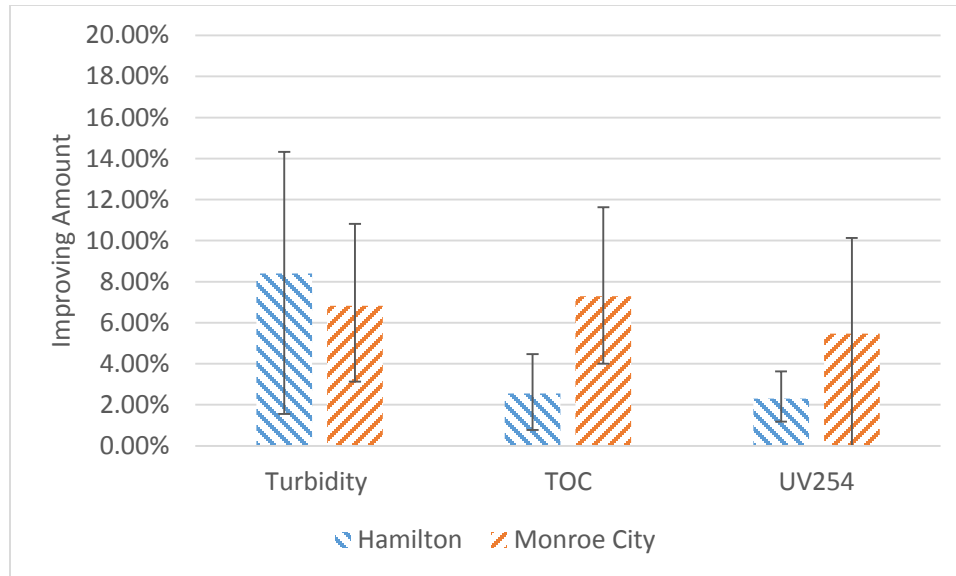
chloride from Hamilton and aluminum sulfate from Monroe City) was used and the results are listed in Tables 5-1 and 5-2 (Appendix A) and in Figures 5-21 and 5-22. Improvement rate of both experiments was compared in Figure 5-23. Figure 5-21 and 5-22 indicated that the water quality from outlet 2 (the one fixed with the fabric screen) seemed to be a little better than outlet 1. But to verify this, t-test had been conducted assuming the same variables and the result of all turbidity, TOC, and UV254 are listed in Tables A-10 to A-15, Appendix B. The P tail of 0.18, 0.67, and 0.72 for turbidity, TOC, and UV254 respectively for the result of the experiment using polyaluminum chloride from Hamilton is observed. It indicated that the two methods are not significantly different. However, the P tail of turbidity, TOC, and UV254 for the one using aluminum sulfate from Monroe City is 0.004, 0.042, and 0.057 respectively. That means that the two methods are different. In other words, the settling tank with fabric inclined settling screen worked better than the one without. Figure 5-23 also brings the same conclusion for the improvement rate of TOC and UV254 of the water treated by aluminum sulfate from Monroe City was higher than it treated by the polyaluminum chloride from Hamilton.



**Figure 5-21 Percent Reduction of parameters in Tank 2, 55° screen angle, Aluminum chloride from Hamilton, one screen, pureflo 50**



**Figure 5-22 Percent Reduction of parameters in Tank 2, 55° screen angle, Aluminum chloride from Monroe City, one screen, pureflo 50**

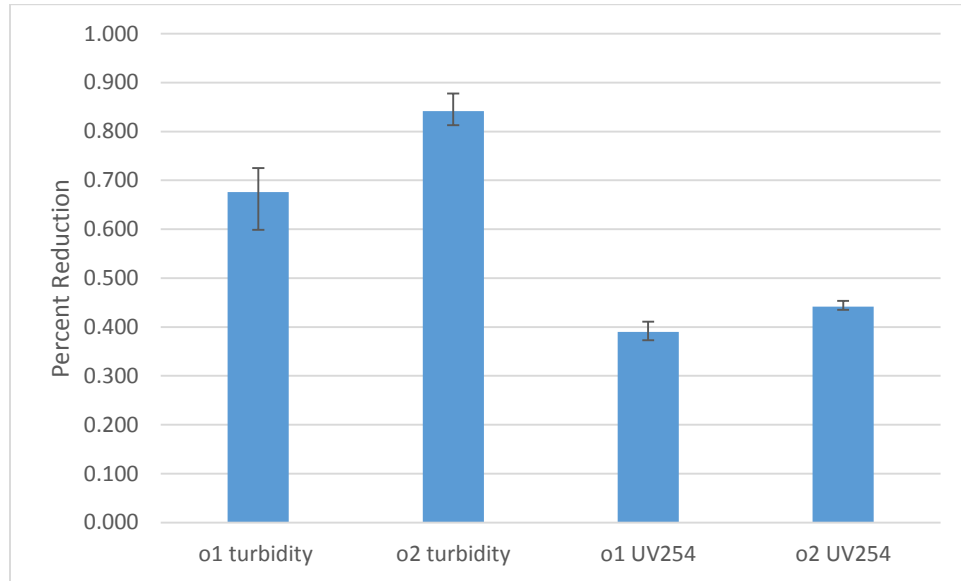


**Figure 5-23 Improvement amount comparison (percent reduction by difference) between the usage of coagulant (Aluminum from Hamilton Vs Monroe City), tank 2, 55°, one screen**

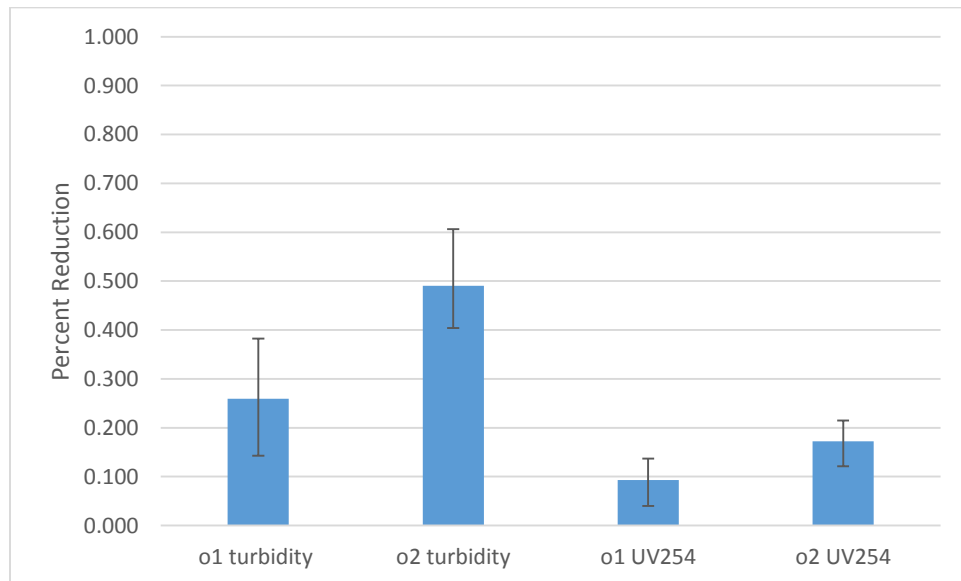
#### 5.4.4.2 Comparison of different angles

In this set of experiments, pureflo 50 was used to make the fabric screen and was fixed in tank 2. Aluminum sulfate from Vandalia Water Treatment was used as the coagulant. The run was conducted using the angles of 55° and 70°. Turbidity and UV254 was tested and the results are shown in Tables 5-3 and 5-4 (in Appendix A) and in Figures 5-24 and 5-25. It seemed to be clear that the water quality from outlet of the settling chamber fixed with the fabric was better than the one without. T-test (Tables A-16 to A-19, Appendix B) indicated the same conclusion for the P tail was 0.0002 and 0.0001 for turbidity and UV254 respectively under 55° and 0.0027 and 0.0069 for turbidity and UV254 respectively under 70°. At 95% confident, the two methods are different.

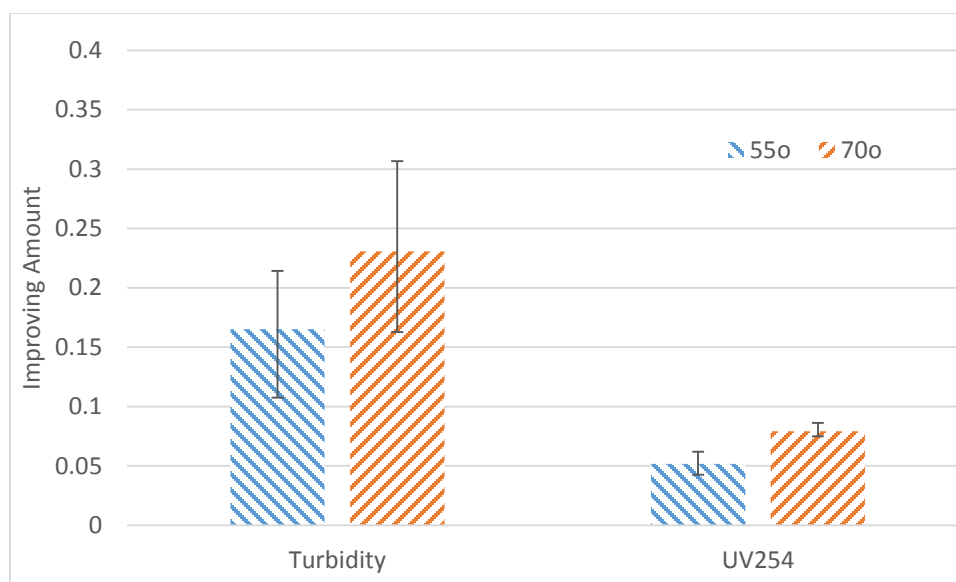
Results of improving amount of different angles were shown in Figure 5-26. It seemed that the performance of the inclined fabric at 70° would be better than 55° based on the higher improvement rate.



**Figure 5-24 Percent reduction in two settling chambers under 55° screen angle with aluminum chloride from Vandalia as the coagulant**



**Figure 5-25 Percent reduction in two settling chambers under 70° screen angle with aluminum chloride from Vandalia as the coagulant**



**Figure 5-26 Improvement amount comparison (Percent reduction by difference) between the different angle (55° Vs 70° screen angle), tank 2, aluminum chloride from Vandalia, one screen**

#### 5.4.6 Run in the third tank (3D comparison)

Twelve sets of experiments have been conducted in the third tank. Comparisons were made by both thickness of the fabric materials and the fixed angles of the fabric screen. Pureflo was used as the fabric material but three different thicknesses were tested. Aluminum sulfate provided by Vandalia Water Treatment Plant was used as the coagulant. Table 5-5 shows other experiment conditions.

**Table 5-5 Sets of experiment been conducted in the third tank**

Angles Material	30°	45°	60°	90°
Pureflo 50				
Pureflo 125				
Pureflo 200				

The results of percent reduction in each run are shown in Tables 5-6 to 5-17 (Appendix A) and Figures 5-27 to 5-38 (Appendix A); the T-test corresponding to the



numerical results are listed in Appendix B. It can be noticed that all the percent reductions from outlet 2 were higher than outlet 1. Except for the turbidity data with pureflo 50 at a 60° inclination angle, and turbidity and UV254 data with pureflo 50 at a 90° inclination angle, the t-tests indicated that the two methods used in all sets of experiment are different (at 95% confident level). It is safe to say the inclined fabric settling screen does have some positive effects on sedimentation enhancement.

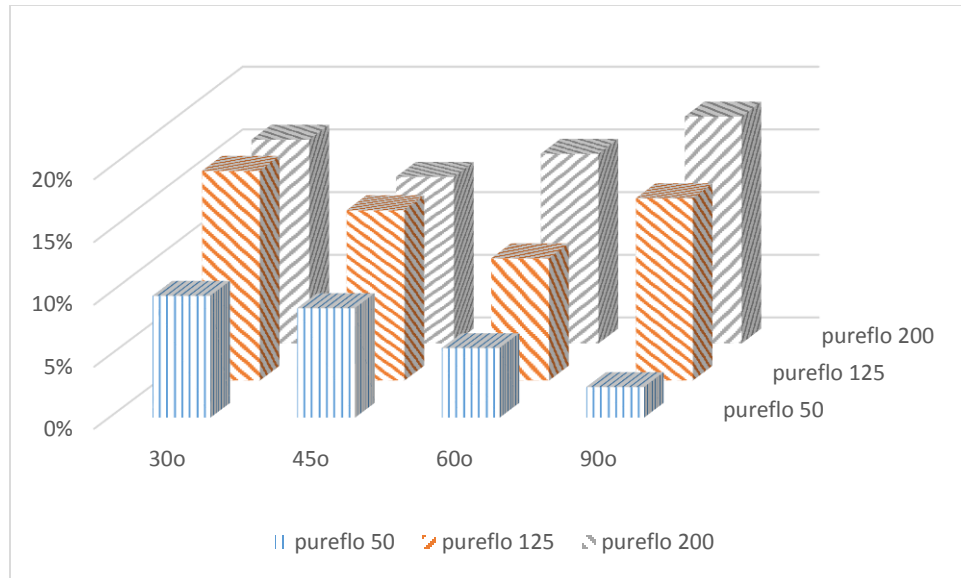
The improvement amounts of turbidity and UV254 of each run are listed in Tables 5-18 and 5-19; they are also illustrated in Figures 5-39 and 5-40. It is clear that the improving amount of turbidity and UV254 grows with the increase of thickness of material. As for turbidity, the improvement amount jumped from pureflo 50 to pureflo 125, but moved slow from pureflo 125 to pureflo 200. The increase tendency for UV254 was always slow. No obvious tendancy can be concluded with respect to angle. In application of regular inclined settling plates, the angle usually depends on the convenience of mechanical cleaning. To determine the best angle for this design, bench scale data is not sufficient. In chapter 6, it will be discussed more with the pilot scale system results.

Table 5-18 Comparison of improvement amount of different angles and different thickness of fabric material, turbidity

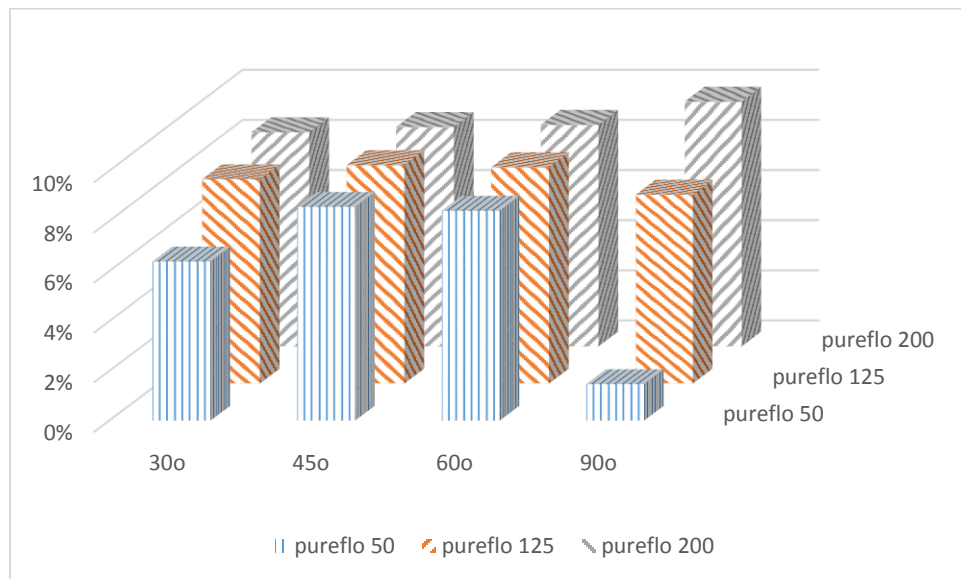
screen angle		30°	45°	60°	90°
pureflo 50	average	9.80%	8.81%	5.60%	2.46%
	max	4.70%	9.21%	11.52%	3.20%
	min	3.55%	3.44%	4.85%	1.48%
pureflo 125	average	16.78%	13.63%	9.80%	14.59%
	max	1.84%	1.95%	4.70%	2.43%
	min	5.84%	4.19%	3.55%	3.17%
pureflo 200	average	16.27%	13.31%	15.15%	18.11%
	max	4.61%	8.64%	11.65%	9.40%
	min	2.84%	4.50%	10.70%	4.95%

Table 5-18 Comparison of improvement amount of different angles and different thickness of fabric material, UV<sub>254</sub>

screen angle		30°	45°	60°	90°
pureflo 50	average	6.38%	8.56%	8.40%	1.47%
	max	3.24%	6.90%	6.88%	1.48%
	min	3.50%	6.65%	6.62%	1.40%
pureflo 125	average	8.17%	8.73%	8.65%	7.56%
	max	2.97%	3.15%	6.83%	1.88%
	min	1.91%	6.37%	3.88%	1.22%
pureflo 200	average	8.55%	8.76%	8.85%	9.77%
	max	9.70%	22.66%	5.19%	3.21%
	min	3.25%	3.52%	2.34%	3.44%



**Figure 5-39 Turbidity improvement amount (Percent reduction difference) of different angles and different thickness of fabric material**



**Figure 5-40 UV254 improvement amount (Percent reduction difference) of different angles and different thickness of fabric material**

## 6. VANDALIA PROCESS ANALYSIS AND IMPROVEMENT

### 6.1 Introduction

The Vandalia treatment process starts at Vandalia Reservoir where copper sulfate (now EarthTec) is added seasonally (Figure 3.1). The influent pump station then moves water to the mechanical treatment process at a rate of X gallons per minute. The initial stage of the process includes the first-stage rapid mix, flocculation, and sedimentation, where an additional copper sulfate, a coagulant (aluminum sulfate, alum), and the powder activated carbon (Calgon WPH) is added. Next the second-stage rapid mix, flocculation, and sedimentation process begins with the addition of quick lime (CaO), of the polymer Sternpak, and with some chlorine, and then fluoride and more chlorine is added just before granular filtration. Contact time is achieved through a clearwell. The high service pumps then send the water to an on-site 1.0 million gallon (MG) storage tank before it enters to the Vandalia distribution systems. The storage time of the 1.0 MG tank is approximately 3 days.

As part of the project, one of the aim is to help treatment plant like this to meet the stage 2 regulations. Several sets of experiment were conducted throughout the process to determine which part of the process can be improved.

### 6.2 Materials and Methods

Several sets of experiments were conducted to determine the improvement potential of the water treatment process in Vandalia.

### 6.2.1 Determination of the effects of coagulant (alum) and carbon

Primary treatment is designed to remove organic and inorganic solids by the physical and chemical processes of coagulation and sedimentation. Both alum and activated carbon are added in the rapid mix tank of the primary process in Vandalia DWTP (Figure 6-1). A reduction of approximately half of the total organic carbon and UV absorbance at 254 nm is witnessed by the outlet of the primary sedimentation tank. In an effort to consider opportunities to improve performance of this system, one must first ask the question “what contribution does each chemical make to the observed decrease?” Therefore, jar testing would help in determining this.

Four 2-Liter jars are each filled with 1 liter of raw water from the Vandalia DWTP. As shown in Table 6-1 the fourth jar is a blank sample. Alum of the same dosage of the DWTP is added in the first jar. Carbon of the same dosage of the DWTP is added in the second jar. Both alum and carbon are added in the third jar. The specific dosage of each chemicals in each jar is shown in Table 6-1. Once the chemicals are added the mixer speed is set at 200 rpm for 30 seconds, and then the speed is adjusted to 45 rpm for 20 minutes. This simulates the rapid mix (coagulation) and slower mix (flocculation) stages of the treatment process. To simulate the sedimentation stage the mixer is turned off, and the solids settle for another 30 minutes. Samples of all the jars are taken for turbidity, DOC, and UV<sub>254</sub> measurements. Removal rate is defined as following

$$\text{Removal Rate} = (C_4 - C_i) / C_4 * 100\% \quad (\text{Eqn. 6-3})$$

Table 6-1 Chemical(s) added to each sample	
Sample	Chemical(s)
1	60 ug Alum
2	30 mg Activated Carbon
3	60 ug Alum & 30 mg Activated Carbon
4	None (blank)

### 6.2.2 Comparison of Three Types of Carbon

Activated carbon (AC) is a form of carbon processed to contain many small, low-volume pores that increase the surface area available for adsorption or chemical reactions. AC is most effective at removing organic compounds such as volatile organic compounds, pesticides and benzene. It can also remove some metals, chlorine and radon. As with any treatment system, it cannot remove all possible drinking water contaminants. The Vandalia DWTP over the past several years has used three different types of activated carbon: Hydrodarco B, Norbit, and Sabre series provided by the Hawkins Chemical Company. Although the current treatment reduces the TOC by 50%, it is expected that the dose of activated carbon used in Vandalia should yield an even greater reduction. Jar testing was used to compare the organic removal achieved by each of the different carbons. The more decrease there is, the more effective the respective carbon is. Various dosages were tested to determine the best dosage of each carbon, which may vary dependent on the carbon. The lowest dosage with the highest organics removal is expected to be the best option.

Six jars were each filled with 1 liter of raw water from Vandalia DWTP. The first jar was a blank sample. Different dosages (one of the dosages should be similar to the one the DWTP is using) of each carbon from low to high are added in the remaining five

jars. Once the carons were added the mixer speed was set at 200 rpm for 30 seconds, and then adjusted to 45 rpm for 20 minutes. The mixer was then turned off, and the carbon was allowed to setke for another 30 minutes. Samples of all the jars were taken and tested for turbidity, TOC, and UV<sub>254</sub>.

Three types of activated carbon were used in this experiment, Sabre provided by Vandalia Water Treatment Plant, WPH, and Hydrodarco B as listed in Table 6-2.

Table 6-2 Types of Carbon Using in the Experiment

Type	
<b>carbon1</b>	Sabre (from Vandalia)
<b>carbon2</b>	WPH
<b>carbon3</b>	Hydrodarco B

### 6.2.3 Different Sequence of Addition of Coagulant and Carbon

As mentioned in the former section, the combination of alum and activated carbon for improved reduction of organics was tested. To try to achieve a better result, jar tests were conducted to determine the influence of using different sequences of addition of the two chemicals. Six jars were prepared and filled with 1 liter of raw water from Vandalia DWTP. The first jar was a blank sample. Different dosages (10, 20, 30, 40, and 50 mg/L) were added in the remaining five jars with 30 mg/L being the actual dosage of Vandalia Water Treatment Plant. After the chemicals were added in, the samples went through 30 seconds of quick mixing, and 10 minutes of slow mixing. Then 60 uL/L alum was added in. The samples then went through 30 seconds of quick mixing, 20 minutes of slow mixing, and 30 minutes of settling. TOC, and UV<sub>254</sub> was tested after the filtration of each sample. The same procedure was repeated with the alum added

first and the addition of carbons 10 minutes later. The last set of experiments was adding the alum and activated carbon at the same time and went through 30 seconds of quick mixing, 20 minutes of slow mixing, and 30 minutes of settling.

#### 6.2.4 Carbon Performance under Different pH

The performance of activated carbon is also affected by pH conditions. The typical pH in water treatment plants varies from 6 to 10 depending on what coagulant they use. Jar tests were conducted to determine the most suitable condition for the Sabre carbon from Vandalia Water Treatment Plant. Five jars were prepared and filled with 1 liter of raw water from Vandalia DWTP. The pH of each jar was adjusted to 6, 7, 8, 9, and 10. Activated carbon at 30 mg/L was added into each jar. The mixer speed was set at 200 rpm for 30 seconds, and then adjusted to 45 rpm for 20 minutes. The mixer was then turned off, and the carbon allowed to settle for another 30 minutes. Samples were taken from all the jars, filtered and the parameters of TOC and UV<sub>254</sub> were tested.

#### 6.2.5 Contact Time

An activated carbon sample must reach adsorption equilibrium to measure its total adsorptive capacity. Normally, a contact time of one hour is sufficient. However, applications involving viscous liquids, low temperatures, or impurities that are difficult to adsorb might require longer contact time. To determine the optimum contact time, a series of liquid samples should be exposed to the same carbon treatment dosage for different time periods using test conditions that match the plant process (impurity type, concentration, pH, temperature, etc.).



Simulated water was used in this experiment. Twelve jars were prepared with 1 liter of simulated water and 30 mg of activated carbon added in each jar. Each jar started with quick mixing for 30 seconds. Then while going through the slow mixing phase, samples were taken at 0 min, 5 min, 10 min, 15 min, 20 min, 30 min, 45 min, 60 min, 90 min, 120 min, 180 min, and 240 min from each jar. The samples were filtered and then tested for TOC and UV254.

Contact time of two dosage of synthetic water (Table 6-3) were tested. The reason of choosing two dosage was that water quality changed a lot under different weather conditions. In summer, the source water (from river) usually has higher turbidity and organics content.

Table 6-3 Two Types of Synthetic Water Samples

	Kaolin Clay (g/L)	Humic Acid (g/L)	Model Season
Water Sample 1	0.003	0.02	Winter
Water Sample 2	0.016	0.08	Summer

#### 6.2.6 Kinetics of TTHM Formation

It is known that the use of chlorine for disinfection purposes of drinking water leads to the formation of many by-products potentially harmful for human health. Among all the chlorinated by-products, trihalomethanes, which exhibit a potentially carcinogenic activity, are certainly the class of compounds that has been investigated most thoroughly during the last 20 years. Kinetics decides how quickly TTHM is formed and is expected to be second order. A TTHM versus time curve can indicate how much

of the formation would be in the storage tank. Both of these are important before further action is taken into the treatment process.

The experiment was conducted with an initial concentration of chlorine higher than the chlorine demand of the sample (20-100% excess with respect to chlorine demand). Immediately after adding chlorine to the solution (250-500 ml), several vials (40 ml) were filled with the chlorinated solutions and sealed with TFE-lined screw caps to avoid volatilization of THM during the reaction time. At the end of each desired reaction time  $\text{NH}_4\text{Cl}$  was added to stop the reaction and chlorine and THM concentrations were analyzed. Two typical time points in this project were the contact time of the secondary treatment process and of the storage tank/clearwell of the DWTP. Contact time can be calculated through Volume divided by Typical flow rate.

A second-order model for the long-term formation of THM from the slowly reacting THM precursors (THMFP) is proposed according to the following expression (Hach Method 10224):



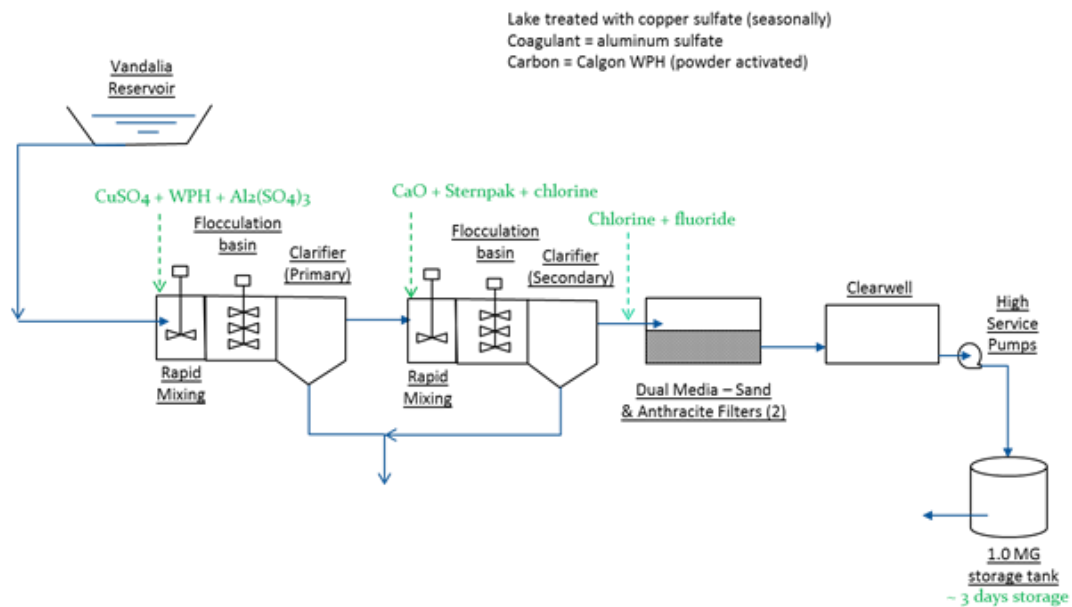
Therefore, the rate of THM formation is given by the following equation:

$$d[\text{THM}]/dt = k * [\text{Cl}_2] * [\text{THMFP}] \quad (\text{Eqn. 6-2})$$

where  $[\text{THMFP}]$  is the concentration of the slowly reacting THM precursors and  $[\text{Cl}_2]$  is the concentration of chlorine at time  $t$ ,  $k$  is the second-order rate constant of the long-term formation of THMs.

### 6.2.7 Pilot Scale System in Vandalia Water Treatment Plant

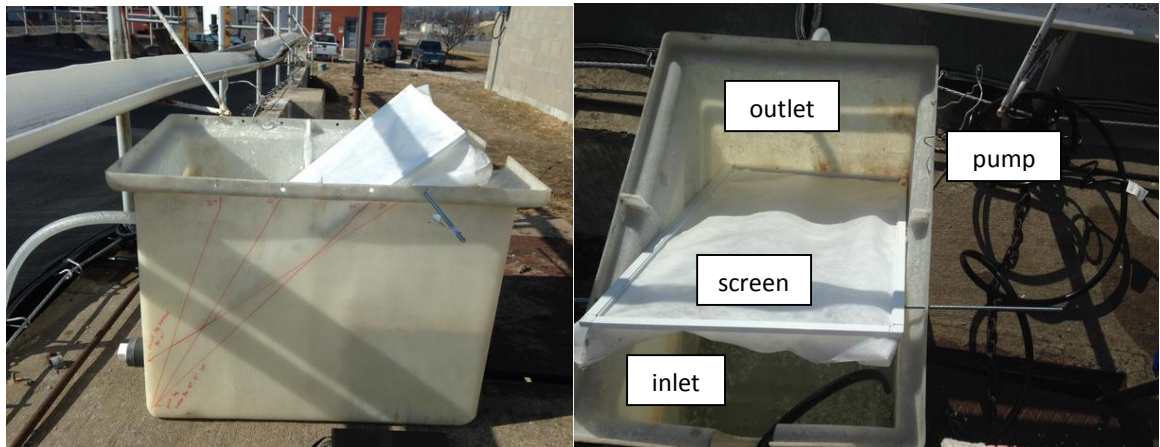
Figure 6-1 is the treatment process in Vandalia. There is two options for locations of a pilot scale set-up: 1) between rapid mix #1 and primary sedimentation, or 2) between rapid mix #2 and secondary sedimentation. Either way water will be pumped from after the flocculation chamber (after addition of chemicals) to the bottom pilot scale tank (around 25 gallon). Fabric inclined settling screens will be fixed at the outlet of the tank and samples will be taken from the outlet before it goes back to the sedimentation basin. Water quality parameters (such as turbidity, TOC, and  $UV_{254}$ ) will be tested for the samples to compare with the water quality in sedimentation chamber.



**Figure 6-1 Water Treatment Process in Vandalia Water Treatment Plant**

The pilot system (Figure 6-2) includes a rectangular tank of 25 gallon, a water pump, several fabric inclined settling screens, and some tubing. Water from flocculator #1 will be pumped to the rectangular tank, then go through the settling screens, and finally flow to the primary sedimentation process. Samples (around 200 mL each) from

outlet of the rectangular tank as well as from the outlet of the primary sedimentation basin will be collected and tested for turbidity, TOC, UV254, and formation potential on a daily basis. The pump can be run continuously or be started 1 to 2 hours before sample collection to receive steady state. Flow rate in the rectangular tank is calculated from the flow rate and volume of the flocculator to maintain a comparable residence time.



**Figure 6-2 Real look of the pilot scale system**

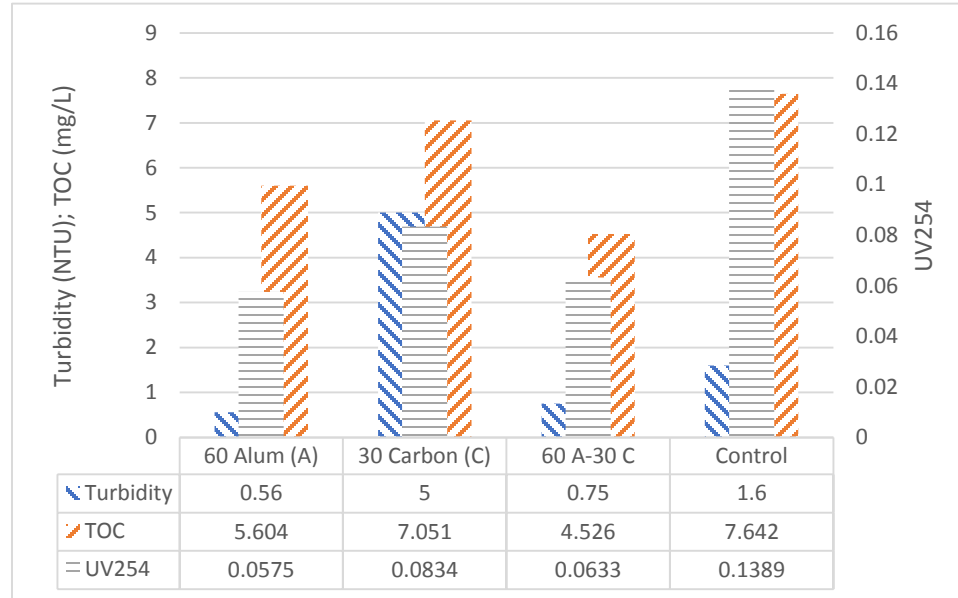
## 6.3 Results and Discussion

### 6.3.1 Determination of the effects of coagulant (alum) and carbon

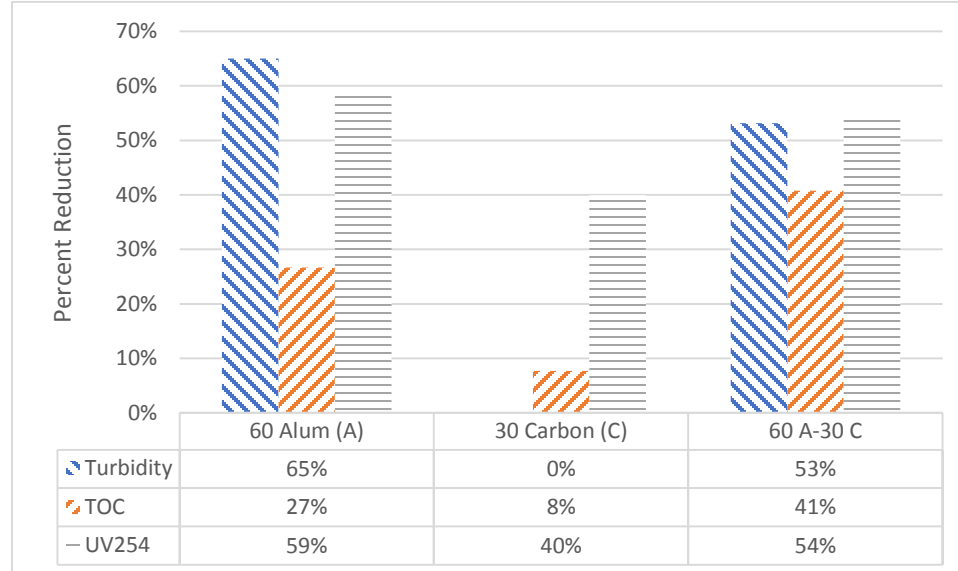
Test results were shown in Figure 6-3 while Figure 6-4 indicated the removal rate of sample 1 to 3 (compared to 4, which is the blank sample). Figure 6-3 shows the raw water turbidity, TOC, and UV254 numbers and compares these measurements to those made after the selected treatments of alum (60  $\mu\text{g/L}$ ) and activated carbon (30  $\text{mg/L}$ ) both individually and together. Because of the powder activated carbon (PAC) does not

readily settle on its own, the presence of the PAC caused an increase in turbidity.

However, then combined with alum both TOC and UV254 were reduced (Figure 6-4).



**Figure 6-3 Test Results of Four Samples**



Note: Removal rate of turbidity of sample 2 was -213%, which indicated that using activated carbon only added turbidity to water. It was discarded when the data was plotted.

**Figure 6-4 Percent Removal of Sample 1 to 3**

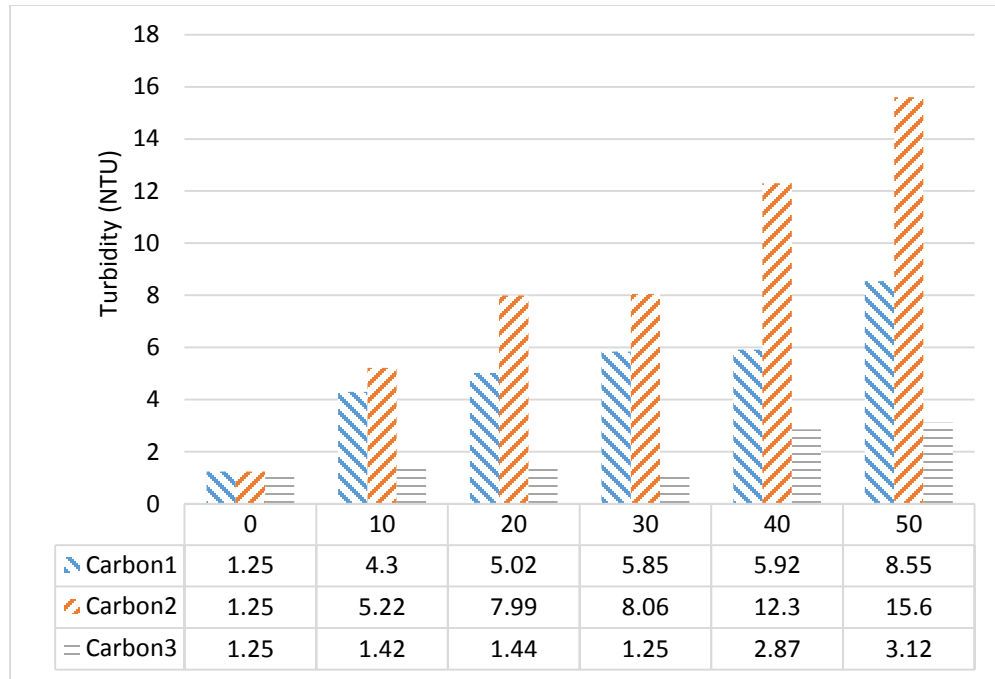
As can be seen from the above figures, alum removed 65% turbidity, 27% TOC and 59% of UV254. Activated carbon added additional 213% turbidity due to its low

density which kept it floating in the water while it removed TOC by 8% and UV254 by 27%. It seemed that alum did a good job decreasing the turbidity and aromatic organic content (indicated by UV254); at the same time, the performance of activated carbon did not reach the expectation. When the two chemicals were combined, the removal rate of turbidity, TOC and UV243 was 53%, 41%, and 54% respectively. It indicates that alum still helped to capture most small particles into bigger ones but there was a little carbon remained floating in the water. The combined chemicals did a better job to remove organics for the percent reduction of TOC was 41% compared to 27% and 8%. UV254 number of the combined chemicals was similar to the one of alum, and both of them reached more than half.

In a word, the combined chemicals helped more to remove organics while getting similar results of turbidity and UV243 as alum. However, activated carbon did not have significant effects on its own.

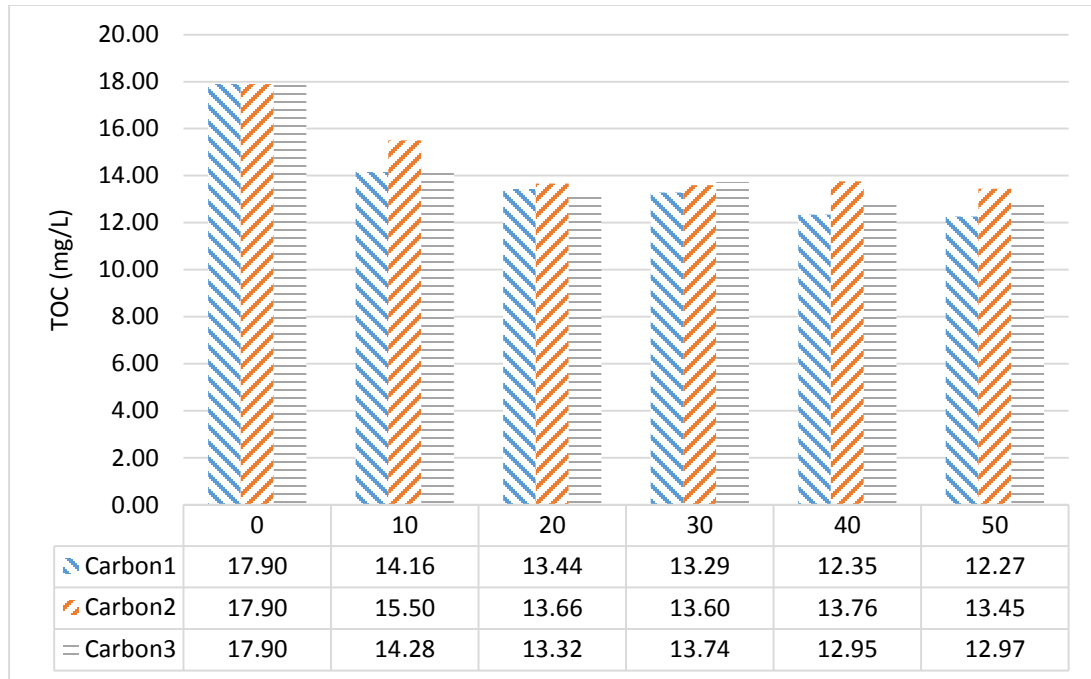
### 6.3.2 Comparison of Three Types of Carbon

Figure 6-5 shows the turbidity result of three carbons. The turbidity increases with the rise of activated carbon dosage with the WPH has the most significant increase rate and Hydrodarco B did not change much. It is because that the activated carbon is too light to settle with larger particles. The lighter the carbon is, the harder it is to settle. In real practice, coagulant is added to help sedimentation so turbidity is not an issue.

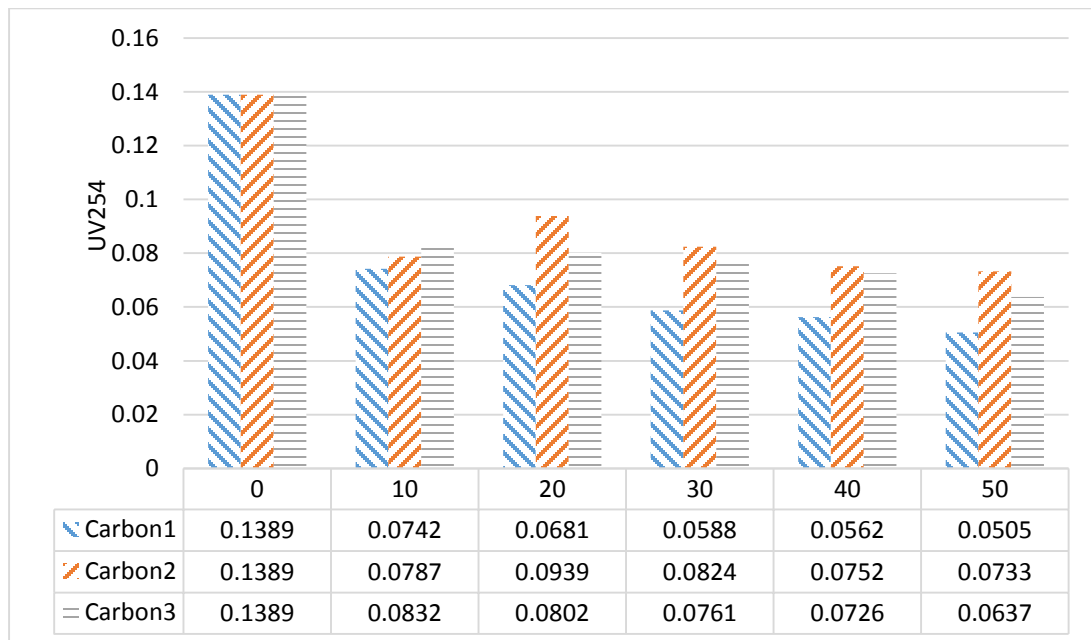


**Figure 6-5 Jar Test Result of Different Carbon-Turbidity**

Figure 6-6 and figure 6-7 show the TOC and UV254 results for the jar test respectively. The three carbons have very similar trend with Sabre views the greatest removal rate and WPH sees the least. The difference, however is scant. And the removal rate of TOC is around 30% while one of UV254 is some 50%. The removal efficiency increases limitedly so there is no point to increase the dosage of activated carbon to expect better result of organic reduction. The possible reason for that is that there is limited organics that can be adsorbed by carbon in the Vandalia water so that after the certain amount of carbon added in, it adsorbed all of them and there is no extra organics in water can be adsorbed by this kind of carbon any more.



**Figure 6-6 Jar Test Result of Different Carbon-TOC**



**Figure 6-7 Jar Test Result of Different Carbon-UV<sub>254</sub>**



### 6.3.3 Different Sequence of Addition of Coagulant and Carbon

Percent reduction is defined as  $[(c_1 - c_i) / c_1] * 100\%$ , where  $c_1$  is the concentration of blank sample and  $c_i$  stands for turbidity, TOC, and  $UV_{254}$ . Figure 6-8 and Figure 6-9 shows the removal rate of TOC and  $UV_{254}$  respectively of the three different sequence. Reductions of both TOC and  $UV_{254}$  increase with the increase of carbon dosage but the slope is close to steady. The result also suggests that the percent reduction of the series of first adding alum being the highest while adding at the same time being the lowest. At a dosage of 10 mg/L, the removal rate of TOC almost doubled when alum was added first than was observed with the other two conditions. However, percent reduction got closer when dosage of carbon is increased. From the result, sequence of addition of coagulant and carbon could be taken into consideration.

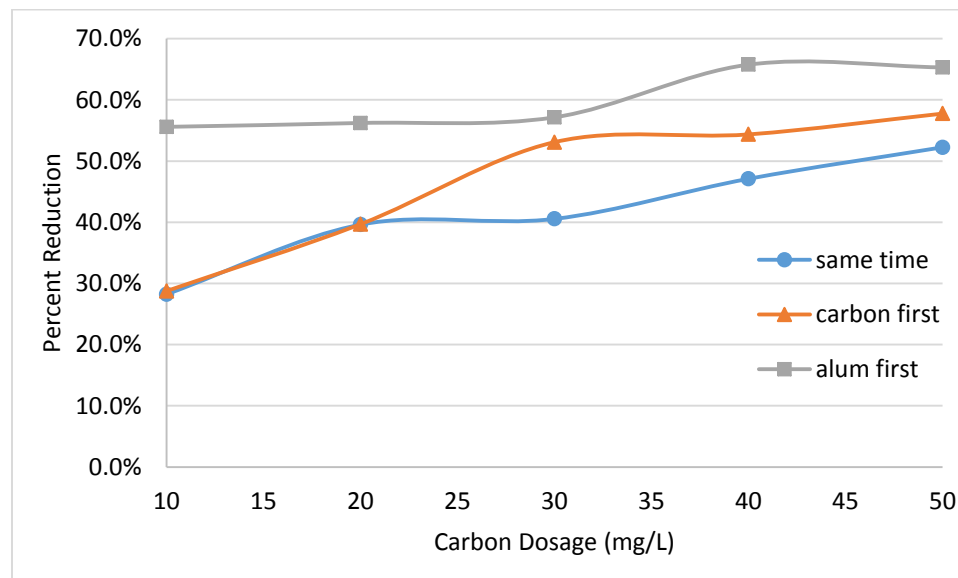
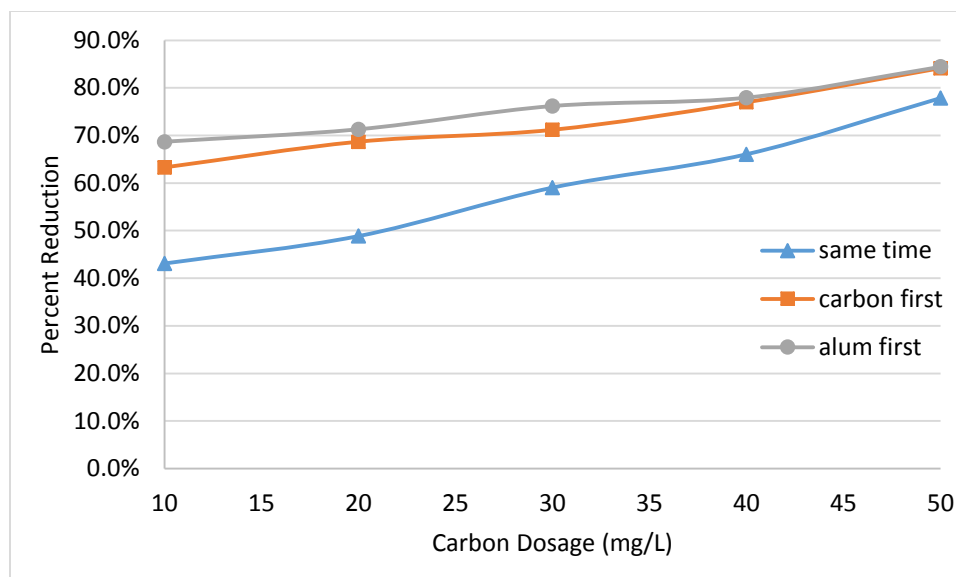


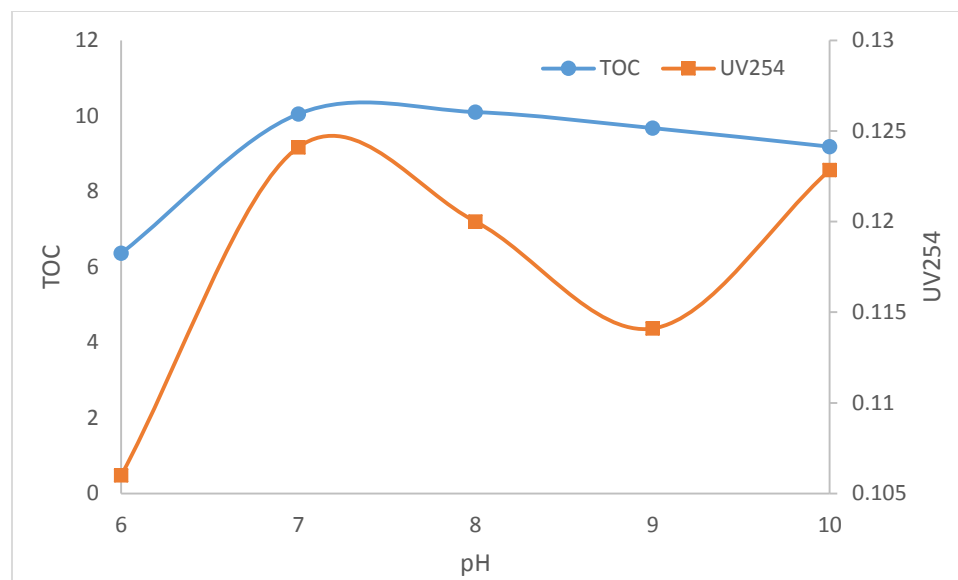
Figure 6-8 TOC Percent Reduction of Different Sequence of Addition of Chemicals



**Figure 6-9 UV<sub>254</sub> Percent Reduction of Different Sequence of Addition of Chemicals**

#### 6.3.4 Carbon Performance under Different pH

Figure 6-10 shows the results of TOC and UV<sub>254</sub> under different pH. At pH of 6, both TOC and UV<sub>254</sub> see the lowest numbers while they reach the highest at neutral condition. When the water was in basic condition, TOC decrease somehow with the increase of pH while UV<sub>254</sub> decreased from pH of 7-9 and increased again from pH of 9-10. It indicates that activated carbon has its best performance at pH of 6 and worst performance at 7. As a result, acidulous coagulant is recommended in the water treatment plant using these types of activated carbon. The coagulant Vandalia currently use is aluminum sulfate, which is sub-acidity so it is good for TOC and UV<sub>254</sub> removal.

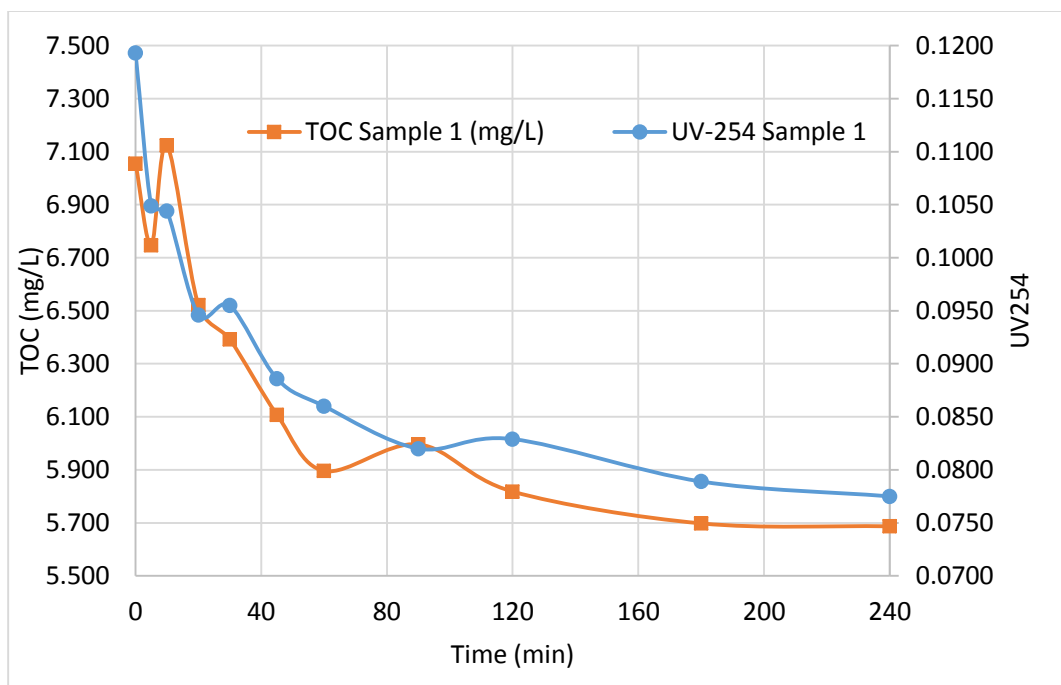


**Figure 6-10 TOC and UV254 Data at Different pH Conditions**

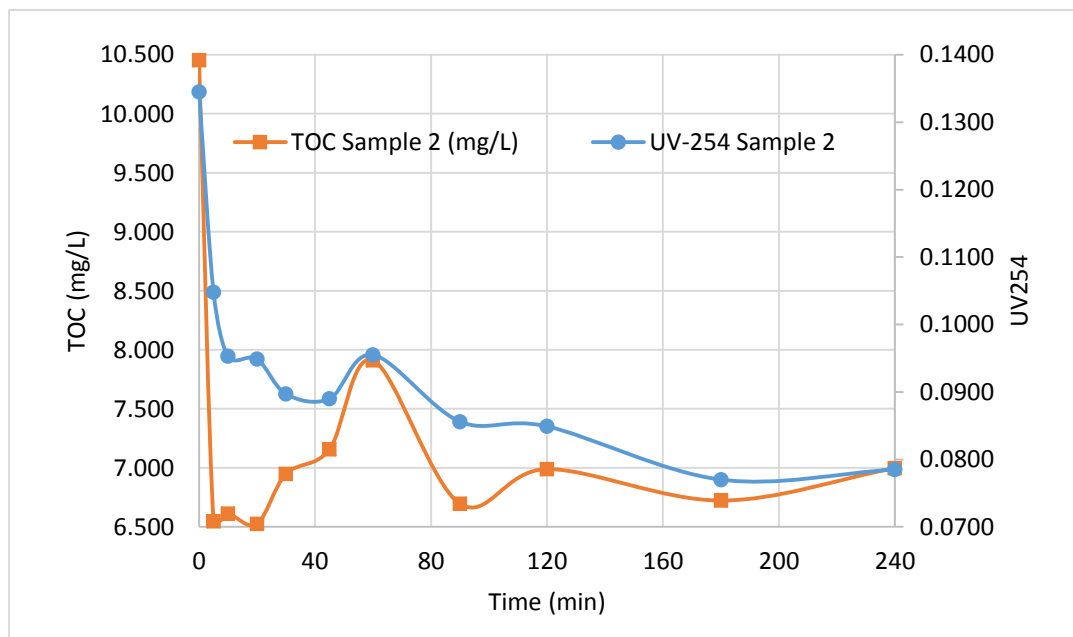
### 6.3.5 Contact Time

Contact time of two dosages of synthetic water (Table 6-3) were tested. The reason of choosing two dosage was that water quality changed a lot under different weather conditions. In summer, the source water (from river) usually has higher turbidity and organics content. The results for winter and summer conditions are shown in Figure 6-11 and Figure 6-12 respectively.

It can be noticed from both figures that tendency of TOC and  $UV_{254}$  was very similar to each other. These trends indicate that the organic content started decreasing soon after the addition of activated carbon and fluctuated a little during the first hour and a half. However, after 90 minutes, it became steady, which suggests that the optimal contact time of activated carbon was close to 90 minutes. The real contact time in Vandalia is nearly 4 hours so it is not an issue in this case.



**Figure 6-11 Contact Time of Synthetic Water Sample 1**

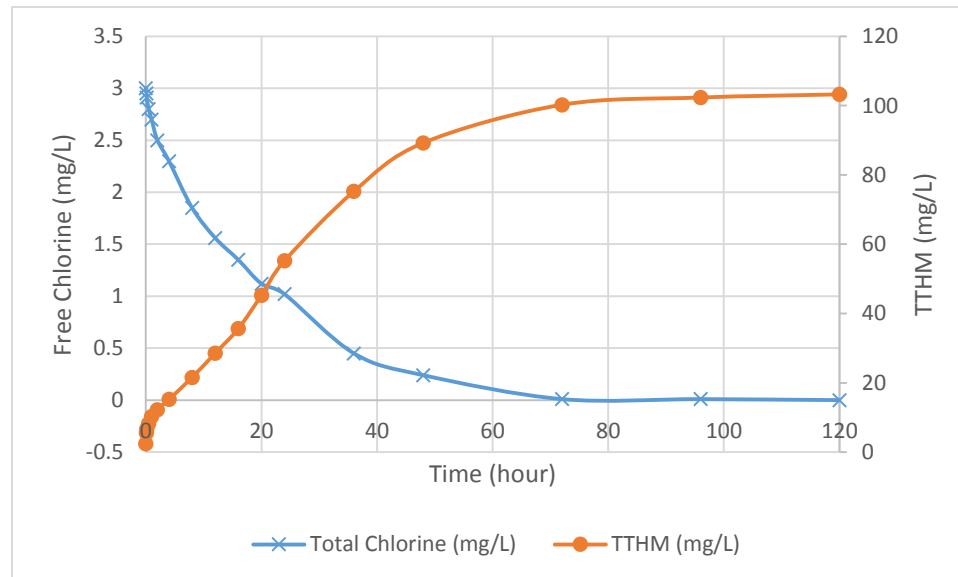


**Figure 6-12 Contact Time of Synthetic Water Sample 2**

### 6.3.6 Kinetics of TTHM Formation

Figure 6-13 shows the total chlorine concentration and TTHM concentration over time (from 0 to 120 hours). The water sample was from Vandalia Water Treatment Plant

after primary sedimentation but before primary disinfection. 3 mg/L of chlorine was added at time 0. Total chlorine concentration started to decline from 3.0 mg/L to 1.02 mg/L at first 24 hours and then slowed the decrease rate and reached 0 after 72 hours. TTHM concentration started to climb from the very beginning through the first 36 hours and reached 75.26 mg/L (the regulation level is 80 mg/L) and continue to increase to around 90 mg/L after 72 hours and became steady to almost 100 mg/L after 120 hours. According to this result, the 3-day (72 hours) storage tanks could be the issue of their DBPs problems. To fix this, the time water stays in the storage time should be reduced.



**Figure 6-13 Total chlorine concentration and TTHM concentration over time**

### 6.3.7 Pilot Scale System in Vandalia Water Treatment Plant

Two sets of data were collected in the pilot system with both the outlet of the pilot system and the primary sedimentation of the treatment process. The first set of experiment was conducted from 3/10/2014 through 3/17/2014 with only one screen under 30°, 45°, 60°, and 75°. Data from each angle were collected twice in the adjacent two days. Weather conditions were taken into account for the system was set up

outdoors. Water quality from source water changed every day thereby changed with the result of primary sedimentation. 3mg/L chlorine was added to samples after it being tested with turbidity, TOC, and UV254. TTHM was tested 24 hours after the addition of chlorine. The results of TTHM were combination of chloroform, bromodich, dibromoch, and bromoform. The second set of experiment was conducted from 3/22/2014 through 3/30/2014. The only change was that two screens were fixed in the system parallel. Results of the first set of experiment is shown in Table 6-4. For most turbidity, TOC, UV254, and TTHM of screen angles of 30°, 45°, 60°, and 75°, have better results from the pilot system then the primary sediment. Exception are turbidity and TOC on 3/13/2014, TOC and TTHM on 3/16/2014, and turbidity on 3/17/2014. Results of the second set of experiment is shown in Table 6-5. Except for turbidity, UV254, and TTHM on 3/26/2013, and UV254 on 3/27/2014, all the results indicated that water quality of the water samples collected in pilot outlet was better than it of primary sediment.

Water quality in the treatment process changed daily so the results from primary sediment varies every day. To better compare the effects of the fabric inclined settling screen, percent reduction is again used here and the result is shown in Figure 14. As to turbidity, two-screen system has a better ability of turbidity removing than one-screen system under each angles. Similarly, two-screen system has better TOC removal under 30°, 45°, and 75°, but under 60°, one-screen system has a better percent reduction. Percent reduction for UV254 in two-screen system is higher under 30° and 45° but lower under 60° and 75°. For TTHM reduction, two-screen system has better effect under most angles except 30°.

Anglewise, 60° seems to have comparatively the highest reduction rate while 75° has the least percent reduction. 30° and 45° screen(s) also have positive effect of removing turbidity, TOC, UV254, and TTHM. As mentioned before that the expectation of the settling screen is for it acting like some kind of filter to stop some particles from going through as well as providing more surface area for the settling of the particle having gone through the fabric. The reason for 75° to be less effective is possible because of the less surface area it provides.

Table 6-4 Data of pilot scale system, one screen, from 3/10/2014-3/17/2014

Date	Data Source	Screen Angle	Turbidity (NTU)	TOC (mg/L)	UV254	24-hour TTHM (mg/L)	T max (F)	T min (F)	Wind Speed (MPH)
3/10/2014	Pilot System	30	0.23	6.307	0.0418	36.523	71.1	38.0	7.3
	Primary Sediment		0.25	6.378	0.0477	42.532			
3/11/2014	Pilot System	30	0.33	5.963	0.0360	26.856	80.2	32.0	9.2
	Primary Sediment		0.50	5.987	0.0372	30.265			
3/12/2014	Pilot System	45	0.28	4.574	0.0306	25.753	41.6	27.7	13.2
	Primary Sediment		0.33	4.657	0.0395	28.654			
3/13/2014	Pilot System	45	0.39	4.975	0.0273	29.818	61.7	24.6	6.0
	Primary Sediment		0.39	4.934	0.0371	35.245			
3/14/2014	Pilot System	60	0.26	4.671	0.0270	33.546	62.2	35.3	10.6
	Primary Sediment		0.35	5.096	0.0296	34.123			
3/15/2014	Pilot System	60	0.31	5.034	0.0276	40.365	71.0	28.6	7.4
	Primary Sediment		0.45	5.454	0.0378	50.066			
3/16/2014	Pilot System	75	0.32	5.234	0.0289	41.256	40.2	19.8	15.8
	Primary Sediment		0.33	5.231	0.0293	40.265			
3/17/2014	Pilot System	75	0.37	5.149	0.0164	29.354	47.8	16.3	4.1
	Primary Sediment		0.36	5.154	0.0189	30.685			

Table 6-5 Data of pilot scale system, two screens, from 3/20/2014-3/27/2014

Date	Data Source	Screen Angle	Turbidity (NTU)	TOC (mg/L)	UV254	24-hour TTHM (mg/L)	T max (F)	T min (F)	Wind Speed (MPH)
3/20/2014	Pilot System	30	0.36	5.897	0.0478	40.347	67.9	33.2	7.3
	Primary Sediment		0.54	6.012	0.0593	46.708			
3/21/2014	Pilot System	30	0.54	6.589	0.0511	40.973	78.2	41.9	8.6
	Primary Sediment		0.87	6.765	0.0581	45.214			
3/22/2014	Pilot System	45	0.44	6.785	0.0522	42.353	48.0	28.6	9.3
	Primary Sediment		0.79	6.953	0.0525	45.214			
3/23/2014	Pilot System	45	0.51	5.248	0.0436	29.934	40.3	22.2	7.3
	Primary Sediment		0.54	5.563	0.0457	34.353			
3/24/2014	Pilot System	60	0.64	6.012	0.0508	48.692	42.4	21.9	4.8
	Primary Sediment		1.05	6.359	0.0635	50.578			
3/25/2014	Pilot System	60	0.57	6.124	0.0525	29.896	39.5	20.7	8.3
	Primary Sediment		0.97	6.578	0.0609	31.256			
3/26/2014	Pilot System	75	0.65	6.325	0.0565	39.327	52.6	20.3	8.2
	Primary Sediment		0.64	6.383	0.0549	38.568			
3/27/2014	Pilot System	75	0.52	6.652	0.0643	40.487	61.5	38.3	11.1
	Primary Sediment		0.56	6.653	0.0608	44.357			

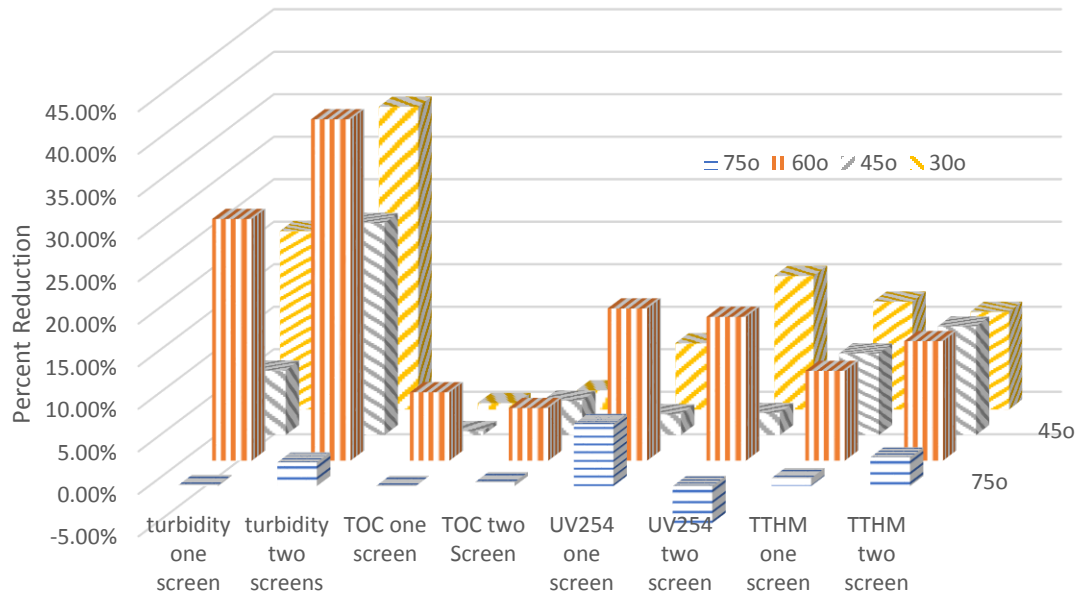


Figure 6-14 Percent reduction of pilot system results of turbidity, TOC, UV254, and TTHM under 30°, 45°, 60°, and 75°



## 6.4 Conclusion

Several tests have been done to test the effectiveness of the process. Alum did a good job to remove turbidity and UV254. Combined chemicals of alum and activated carbon helped more to remove organics but activated carbon did not have significant effects on its own. The results of different sequencing of the addition of alum and carbon indicated that adding one after another had better effects than adding the two together. All the activated carbon tested had effects on turbidity, TOC, and UV254 removal. But the removal efficiency increase was limited so that there appears to be no point to increase the dosage of activated carbon to expect better results of organic reductions. When the performance of activated carbon was tested under different pH, it showed that under acid conditions, activated carbon removes more TOC and UV254 than under basic conditions. It can also be noticed that after 90 minutes, the decrease of TOC and UV254 gained with activated carbon became steady, so a contact time longer than 1.5 hours is adequate. The current contact time in Vandalia is nearly 4 hours so it is not an issue from this view. TTHM was tested after 3 mg/L chlorine had been added. At the first 72 hours, the TTHM value was under 80mg/L (regulated limit), but after that, it approached 100 mg/L. Therefore the control of contact time with the added chlorine is critical. Vandalia has a storage tank with 3-day detention time which creates some concerns. The pilot scale system with the designed inclined fabric settling screen(s), gave positive results of reduction of turbidity, TOC, UV254, and TTHM. It also indicated that a 60° angle has the best result while a 75° angle does not provide much improvement.

## 7. RECOMMANDATION AND OPPORTUNITY FOR FUTURE RESEARCH

All the fabric materials used in this research are not NSF-61 approved. As a result, it cannot be used in real drinking water treatment process. But this research provides a foundation for determining the feasibility of selected material to function in this application. The same method may be used when the NSF-61 material is provided.

During the bench scale experiment, only one dosage of each chemical was used. In the future, experiment can be conducted with different dosages of a chemical and compare the results of them. Five different dosage can be chosen (two smaller than, one equal to, and two larger than the original one) to conduct the experiment. Respective parameters (such as turbidity, TOC, and  $UV_{254}$ ) can be tested as the change of the dosage. Dosage with smallest results is the best.

All bench scale experiment was conducted with only one chemical. But in real water treatment process, it is more usual to have more than one chemicals to add (such as polymer, lime, coagulants, activated carbon, etc.). So in future research, it is suggested to conduct one run with multiple chemicals. For example, Vandalia add both activated carbon and alum in the primary process. Experiment using both of the two chemicals should be conducted to see the effect of the design.

The pilot scale system was only tested at the Vandalia Treatment Plant. Since each facility tends to operate differently, the same system does not necessary work for another one without evidence provided. The concerns include different water quality (different river water has different chemistry composition, hardness of river water and groundwater is different from each other), and process unit design (the fabric settling

screens may more suitable for the process using coagulation and sedimentation). So the pilot system should be moved to other facilities and the same experiment conducted to find out the effectiveness at other locations.

All runs in both bench scale and pilot scale system were 3-5 hours in duration. Tests with longer time should be conducted to see the effect when solids become attached to the screen. It may have a “bridge” effect and provide better “filter” performance or may add more head loss or turbidity to the water.

How to clean the fabric screen(s) is also an interesting question to consider. It will be easier to remove the screens, physical scraping them or wash them by water, and then replace them. Clean in place seems to be unpractical if multiple layers of screens are used.

All runs in both bench and pilot scale systems were conducted with only one or two layer(s) of the inclined fabric settling screens. Since experiments suggests that two layers works better than one, assumption is that more layers will work even better. More layers of screens are expected to be applied into real use. So experiment conducted with more layers of screens are suggested in the future. It should be answered by further experiment that how many layers of screens can be added on without causing huge headloss.

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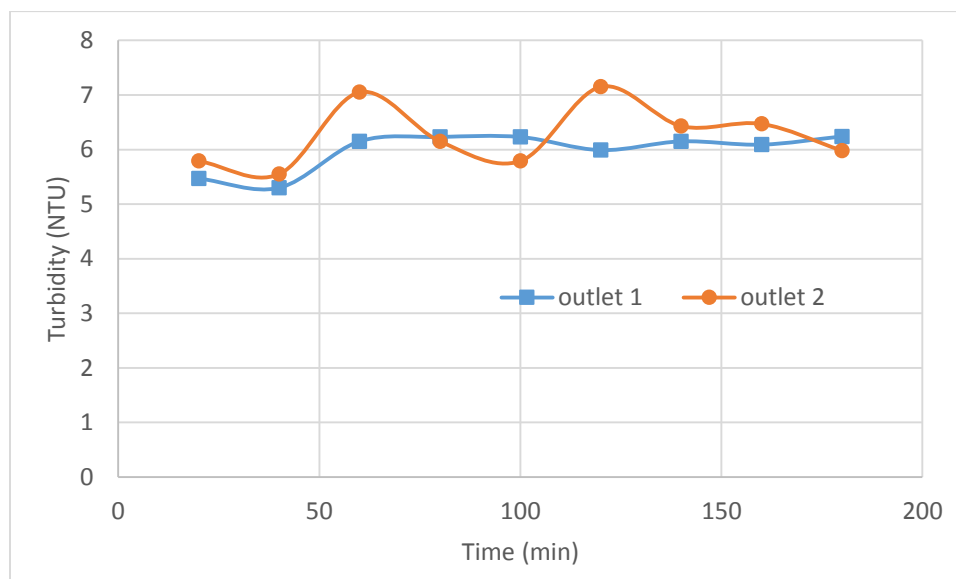
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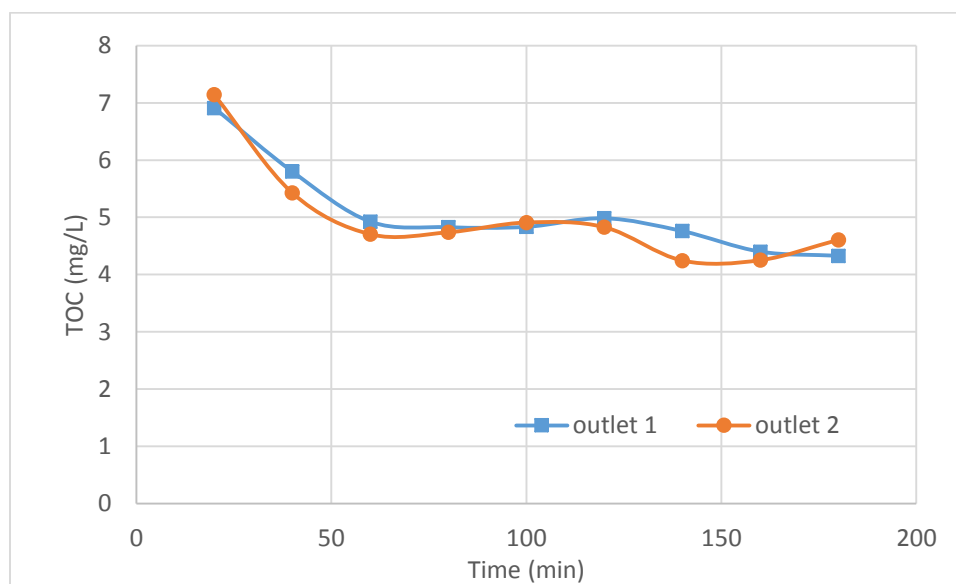
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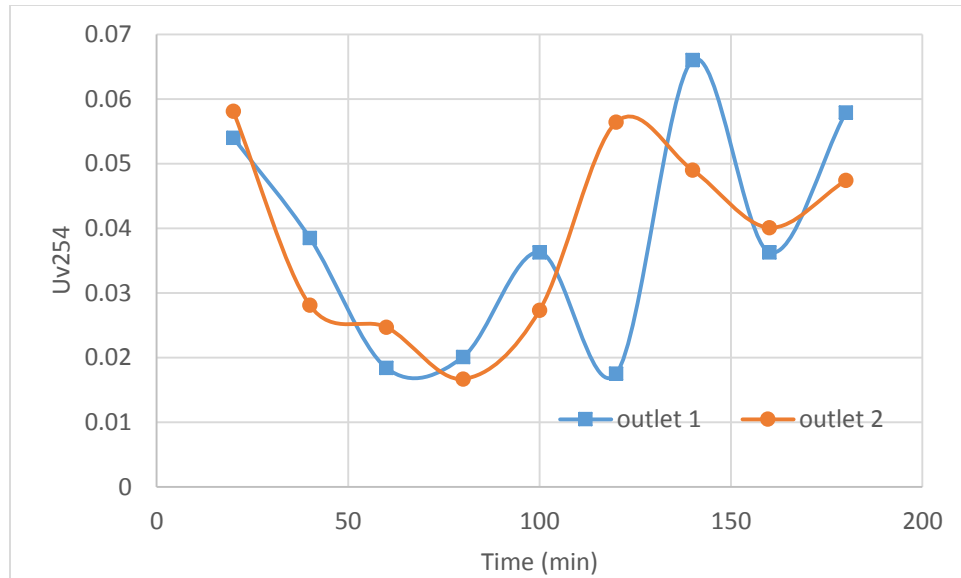
## APPENDIX A. SOME FIGURES AND TABLES OF CHAPTER 5



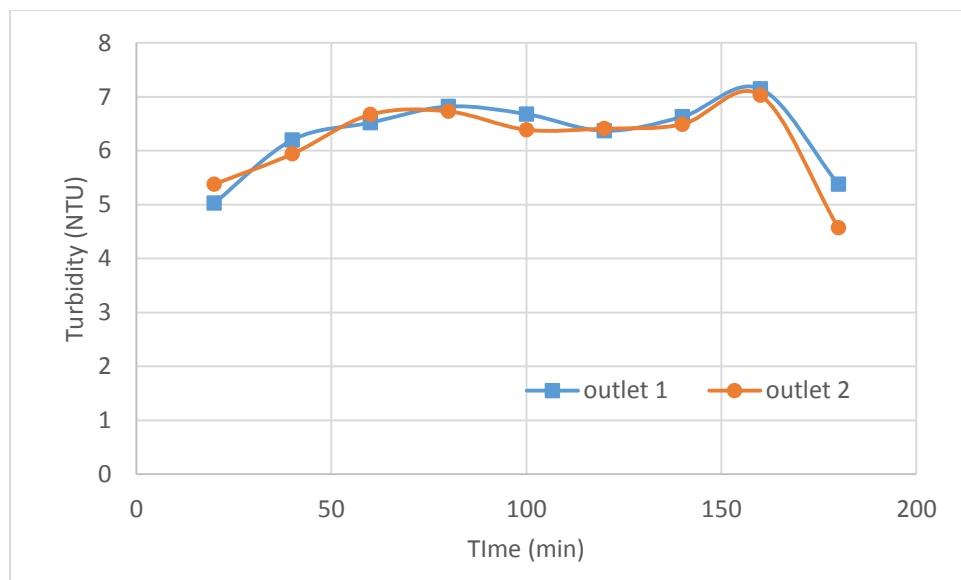
**Figure A-1 (5-12) Tank 1, 60° screen angle, aluminum chloride from Monroe City, one screen, turbidity measurements in outlet 1 (without screen) and outlet 2 (with screen)**



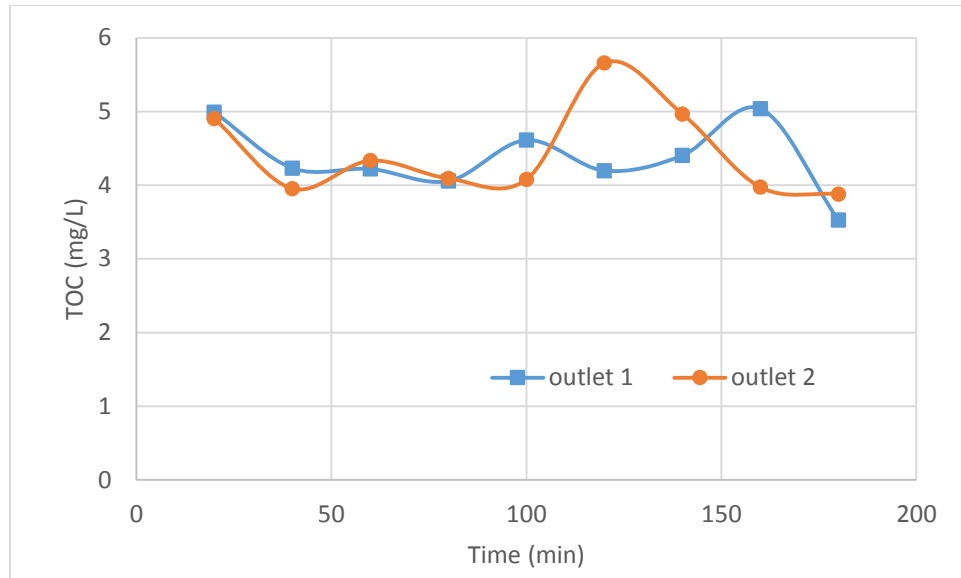
**Figure A-2 (5-13) Tank 1, 60° screen angle, aluminum chloride from Monroe City, one screen, TOC measurements in outlet 1 (without screen) and outlet 2 (with screen)**



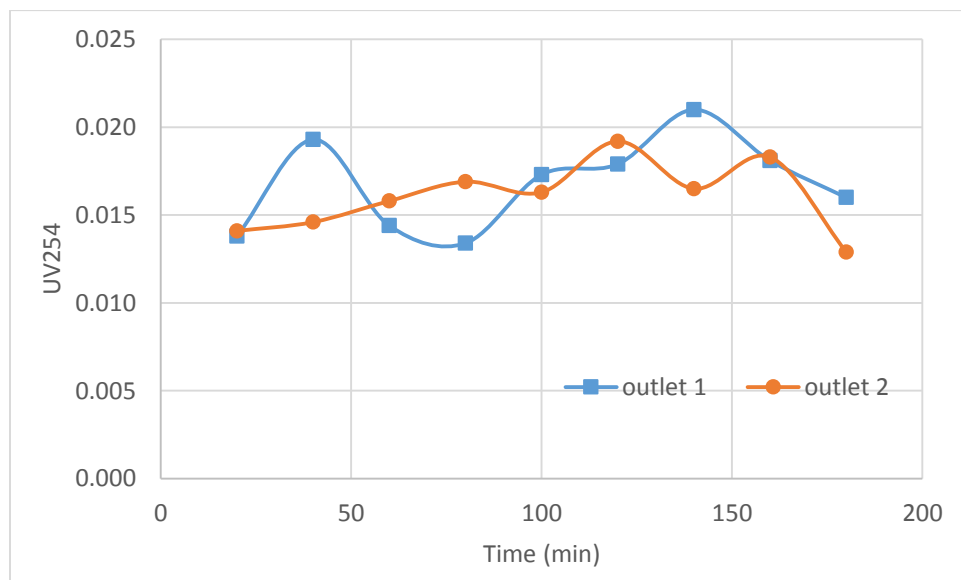
**Figure A-3 (5-14) Tank 1, 60° screen angle, aluminum chloride from Monroe City, one screen, UV254 measurements in outlet 1 (without screen) and outlet 2 (with screen)**



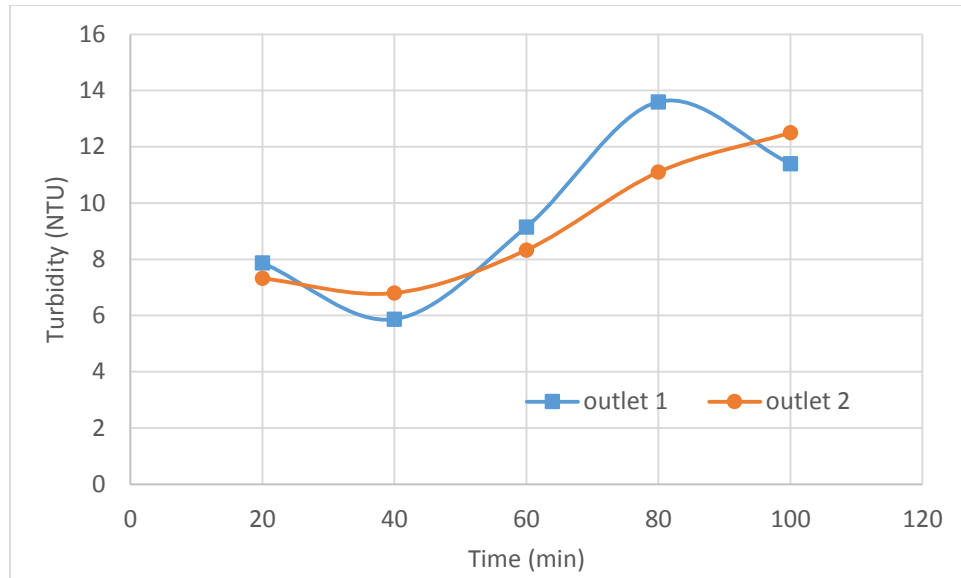
**Figure A-4 (5-15) Tank 1, 60° screen angle, aluminum chloride from Monroe City, two screens, Turbidity measurements in outlet 1 (without screen) and outlet 2 (with screen)**



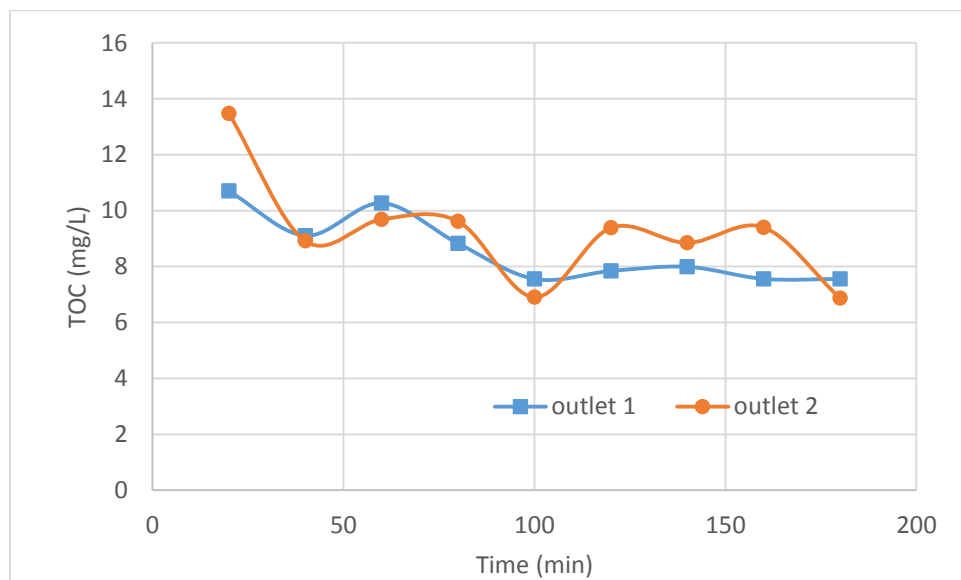
**Figure A-5 (5-16) Tank 1, 60° screen angle, aluminum chloride from Monroe City, two screens, TOC measurements in outlet 1 (without screen) and outlet 2 (with screen)**



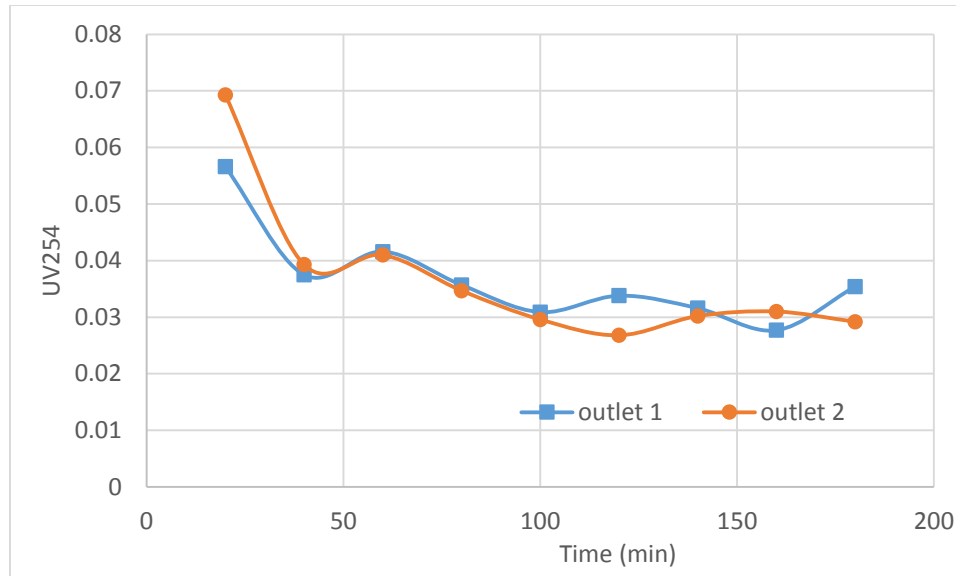
**Figure A-6 (5-17) Tank 1, 60° screen angle, aluminum chloride from Monroe City, two screens, UV254 measurements in outlet 1 (without screen) and outlet 2 (with screen)**



**Figure A-7 (5-18) Tank 1, 60° screen angle, sodium aluminate from Trenton, one screen, Turbidity measurements in outlet 1 (without screen) and outlet 2 (with screen)**



**Figure A-8 (5-19) Tank 1, 60° screen angle, sodium aluminate from Trenton, one screen, TOC measurements in outlet 1 (without screen) and outlet 2 (with screen)**



**Figure A-9 (5-20) Tank 1, 60° screen angle, sodium aluminate from Trenton, one screen, UV254 measurements in outlet 1 (without screen) and outlet 2 (with screen)**

**Table A-1 (5-1) Percent reduction in two settling chambers under 55° screen angle with aluminum chloride from Hamilton as the coagulant**

Time (min)	NTU (o1)	NTU (o2)	TOC (o1)	TOC (o2)	UV254 (o1)	UV254 (o2)
30	0.68	0.78	0.21	0.25	0.13	0.17
60	0.76	0.90	0.03	0.03	0.34	0.37
90	0.86	0.96	0.05	0.07	0.37	0.38
120	0.90	0.92	0.06	0.07	0.39	0.41
150	0.93	0.98	0.18	0.22	0.32	0.34
Average	0.82	0.91	0.10	0.13	0.31	0.33

**Table A-2 (5-2) Percent reduction in two settling chambers under 55° screen angle with aluminum chloride from Monroe City as the coagulant**

Time (min)	NTU (o1)	NTU (o2)	TOC (o1)	TOC (o2)	UV254 (o1)	UV254 (o2)
30	0.89	0.97	0.07	0.16	0.38	0.48
60	0.86	0.97	0.09	0.21	0.28	0.28
90	0.88	0.94	0.14	0.21	0.05	0.15
120	0.84	0.91	0.18	0.23	0.44	0.47
150	0.88	0.91	0.21	0.25	0.38	0.42
Average	0.87	0.94	0.14	0.21	0.31	0.36

**Table A-3 (5-3) Percent reduction in two settling chambers under 55° screen angle with aluminum chloride from Vandalia as the coagulant**

Time (min)	Decrease Rate o1 turbidity	Decrease Rate o2 turbidity	Decrease Rateo1 UV254	Decrease Rate o2 UV254
30	0.668	0.877	0.392	0.445
60	0.677	0.833	0.411	0.453
90	0.599	0.813	0.373	0.435
120	0.725	0.833	0.393	0.440
150	0.713	0.852	0.382	0.435
Average	0.676	0.841	0.390	0.442

**Table A-4 (5-4) Percent reduction in two settling chambers under 70° screen angle with aluminum chloride from Vandalia as the coagulant**

Time (min)	Decrease Rate o1 turbidity	Decrease Rate o2 turbidity	Decrease Rateo1 UV254	Decrease Rate o2 UV254
30	0.382	0.606	0.137	0.215
60	0.239	0.546	0.103	0.189
90	0.143	0.434	0.040	0.121
120	0.241	0.404	0.088	0.163
150	0.292	0.461	0.098	0.173
Average	0.259	0.490	0.093	0.172

**Table A-5 (5-6) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	79.73%	88.72%	60.68%	69.57%
60	70.89%	85.39%	55.66%	58.54%
90	77.13%	85.49%	56.93%	62.95%
120	75.88%	86.78%	60.48%	64.98%
150	80.16%	86.40%	60.92%	70.55%
average	76.76%	86.55%	58.93%	65.32%

**Table A-6 (5-7) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	73.54%	91.56%	13.57%	29.03%
60	76.45%	83.94%	32.92%	38.27%
90	76.74%	83.08%	22.73%	35.26%
120	74.42%	81.23%	29.12%	36.66%
150	70.53%	75.90%	29.96%	31.87%
average	74.33%	83.14%	25.66%	34.22%

**Table A-7 (5-8) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	38.75%	42.75%	11.17%	12.96%
60	36.82%	53.94%	10.50%	20.51%
90	85.51%	86.65%	16.02%	20.19%
120	83.16%	83.91%	5.33%	20.61%
150	75.57%	80.58%	4.41%	15.20%
average	63.96%	69.56%	9.49%	17.89%

**Table A-8 (5-9) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	84.83%	85.81%	47.11%	49.28%
60	86.39%	89.20%	44.55%	47.50%
90	83.84%	89.50%	44.52%	44.59%
120	85.29%	87.17%	43.99%	45.35%
150	83.09%	84.07%	52.61%	53.39%
average	84.69%	87.15%	46.55%	48.02%

**Table A-9 (5-10) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	75.30%	93.73%	28.68%	36.86%
60	78.31%	89.25%	27.49%	33.75%
90	72.32%	90.33%	24.70%	35.84%
120	70.66%	88.54%	29.11%	36.51%
150	69.37%	87.98%	27.50%	35.37%
average	73.19%	89.97%	27.50%	35.67%

**Table A-10 (5-11) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	73.84%	88.96%	20.30%	22.66%
60	65.24%	80.82%	8.97%	18.09%
90	64.81%	79.28%	8.11%	16.96%
120	68.84%	82.37%	10.14%	22.02%
150	72.98%	82.42%	12.03%	23.48%
average	69.14%	82.77%	11.91%	20.64%

**Table A-11 (5-12) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	79.73%	88.72%	59.62%	70.28%
60	70.89%	85.39%	56.24%	61.00%
90	77.13%	85.49%	58.43%	64.25%
120	75.88%	86.78%	63.58%	70.09%
150	80.16%	86.40%	56.99%	72.48%
average	76.76%	86.55%	58.97%	67.62%

**Table A-12 (5-13) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	59.44%	76.46%	18.15%	27.59%
60	65.47%	79.82%	20.77%	27.10%
90	65.44%	80.73%	19.47%	27.66%
120	68.26%	79.68%	23.49%	30.47%
150	64.01%	78.87%	27.75%	34.58%
average	64.52%	79.11%	21.93%	29.48%

**Table A-13 (5-14) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	76.01%	89.44%	9.04%	27.29%
60	75.07%	89.51%	26.90%	32.84%
90	66.07%	86.95%	22.78%	28.08%
120	67.58%	84.21%	19.76%	25.47%
150	58.81%	74.78%	22.85%	30.39%
average	68.71%	84.98%	20.26%	28.81%

**Table A-14 (5-15) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**

Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	83.01%	91.82%	34.46%	37.98%
60	80.16%	91.60%	34.97%	38.82%
90	76.60%	92.12%	28.88%	33.07%
120	68.27%	90.22%	27.26%	36.89%
150	83.86%	92.70%	13.09%	35.70%
average	78.38%	91.69%	27.73%	36.49%

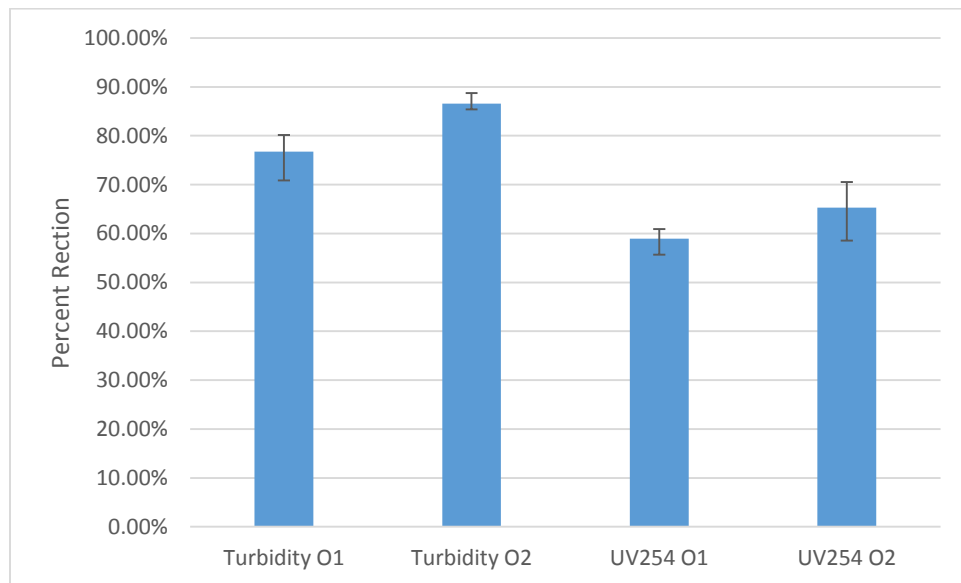


**Table A-15 (5-16) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**

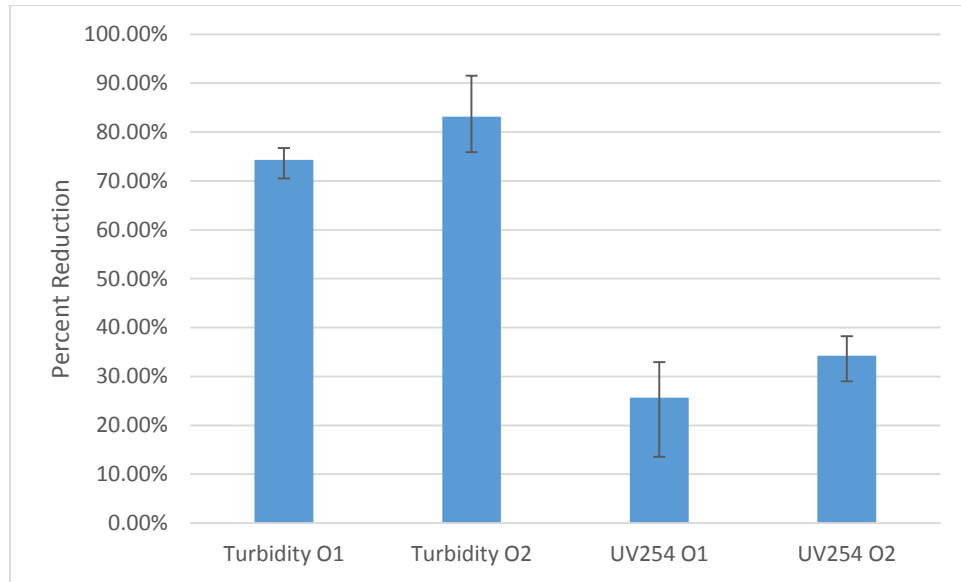
Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	69.87%	96.67%	21.55%	29.88%
60	75.86%	85.90%	19.01%	27.30%
90	60.00%	77.70%	18.37%	25.44%
120	79.00%	95.74%	34.56%	41.06%
150	91.47%	95.91%	29.40%	43.43%
average	75.24%	90.38%	24.58%	33.42%

**Table A-16 (5-17) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**

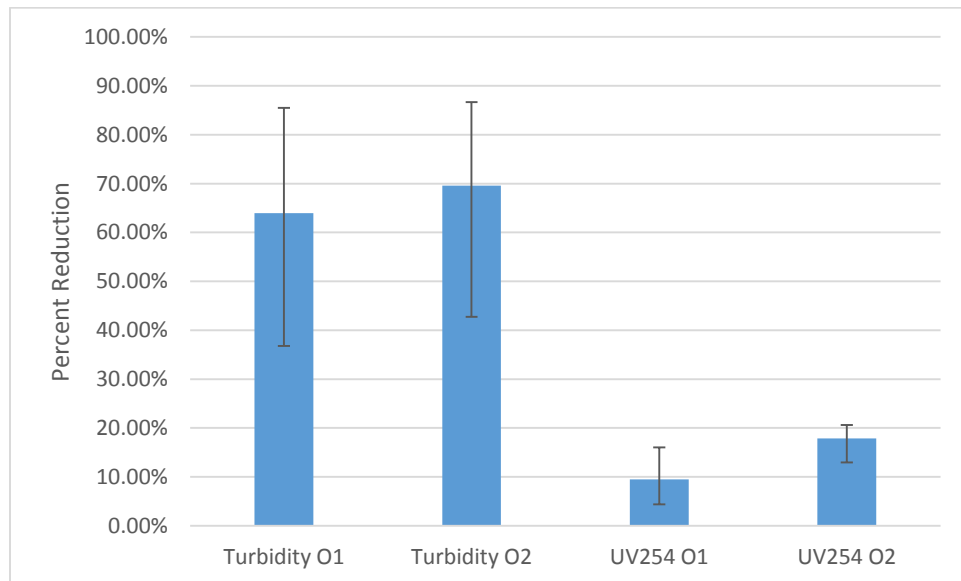
Time (min)	Turbidity Decrease Rate O1	Turbidity Decrease Rate O2	UV254 Decrease Rate O1	UV254 Decrease Rate O2
30	63.99%	91.50%	14.61%	27.59%
60	69.29%	85.32%	20.77%	27.10%
90	67.34%	84.17%	15.94%	27.66%
120	68.26%	81.42%	19.82%	27.49%
150	64.01%	81.01%	24.48%	34.62%
average	66.58%	84.68%	19.12%	28.89%



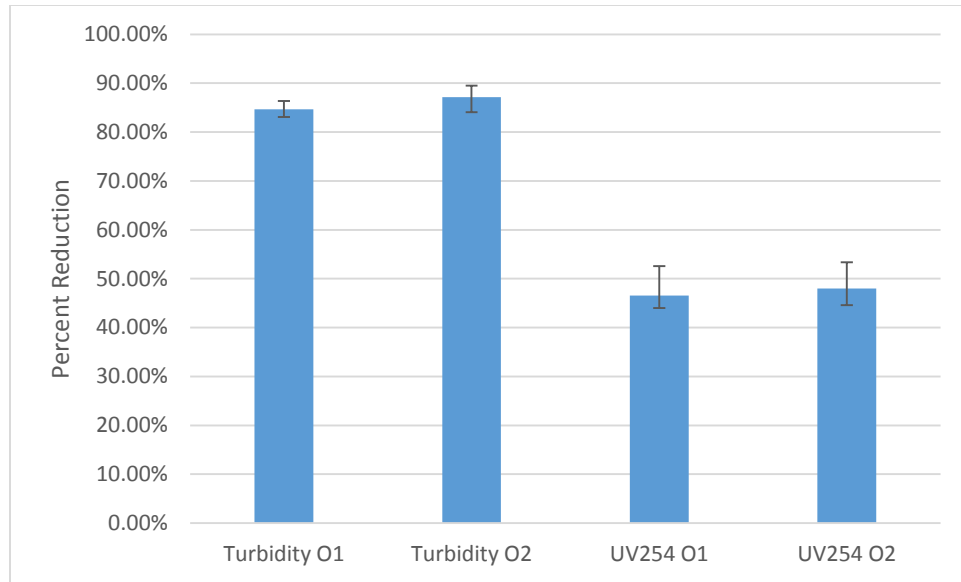
**Figure A-10 (5-27) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**



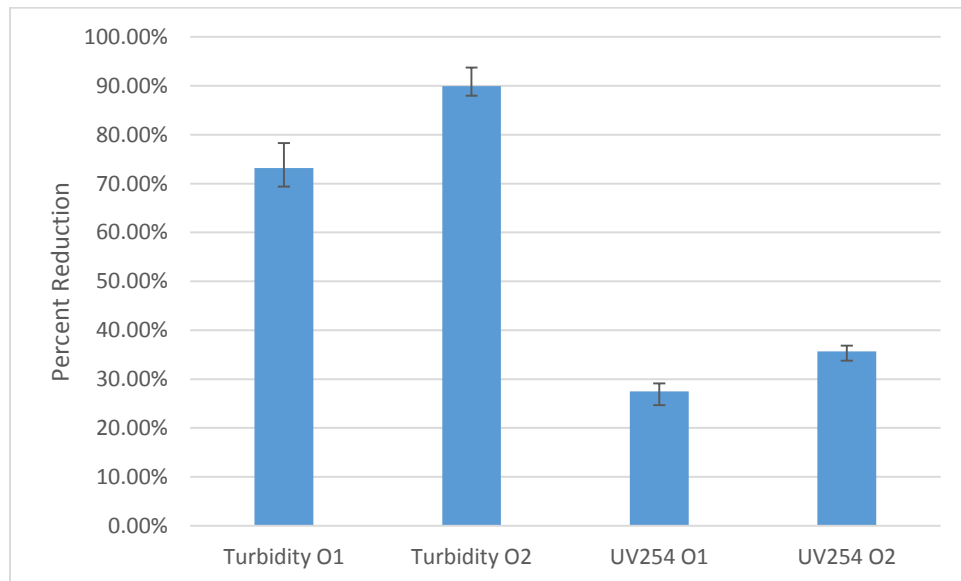
**Figure A-11 (5-28) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**



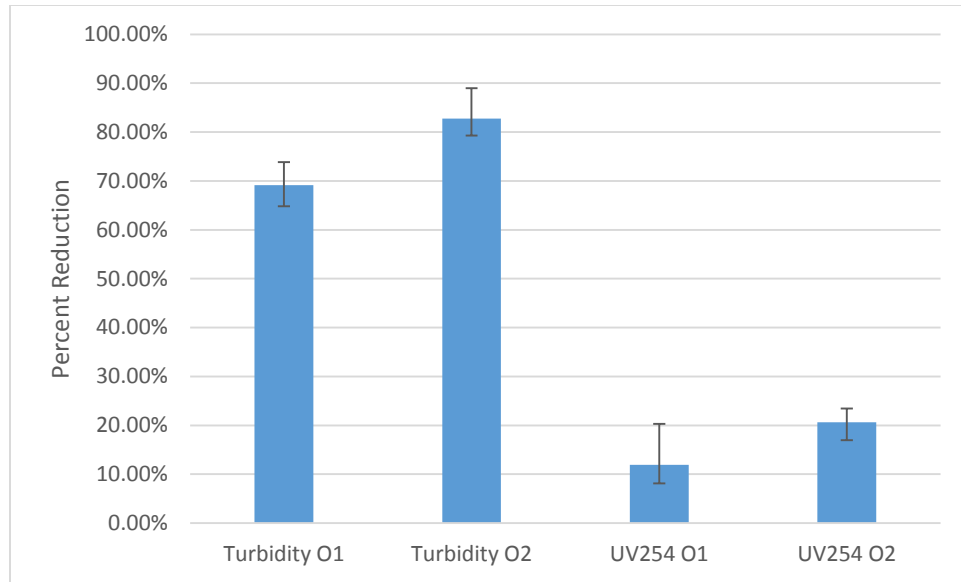
**Figure A-12 (5-29) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**



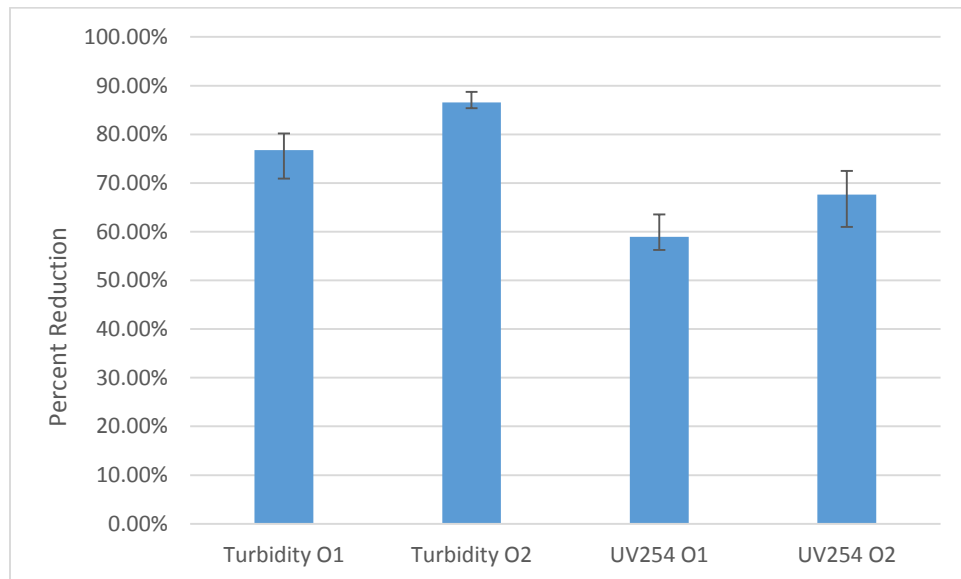
**Figure A-13 (5-30) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material**



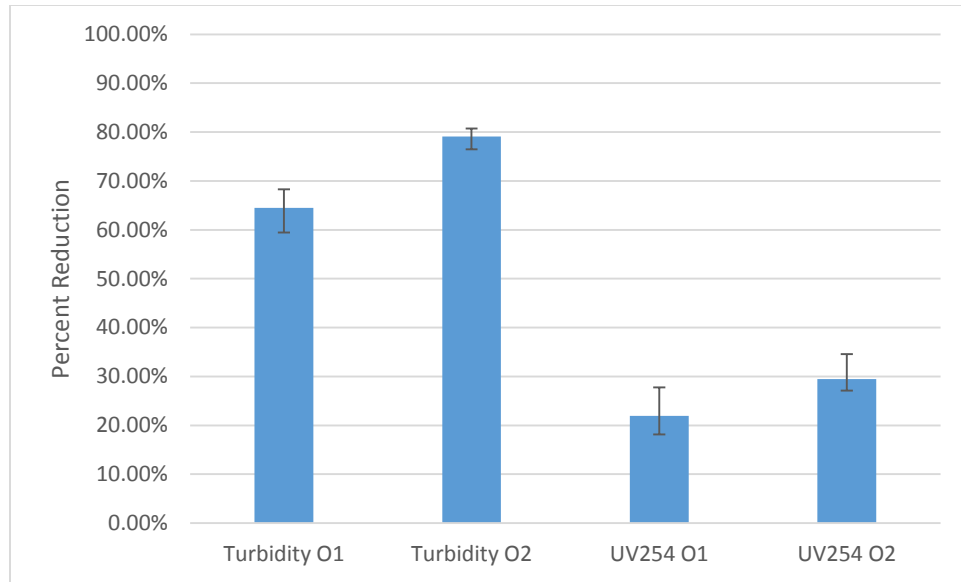
**Figure A-14 (5-31) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**



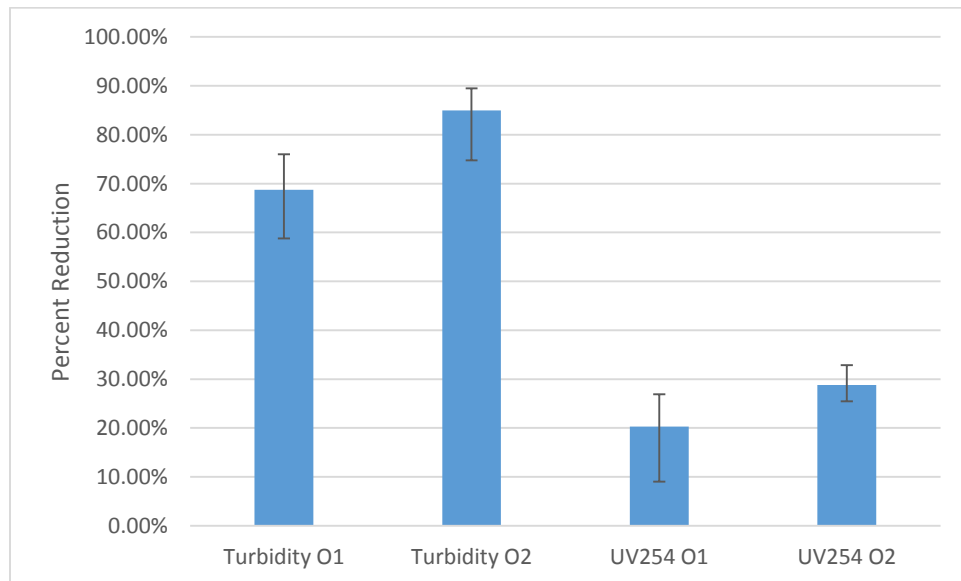
**Figure A-15 (5-32) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**



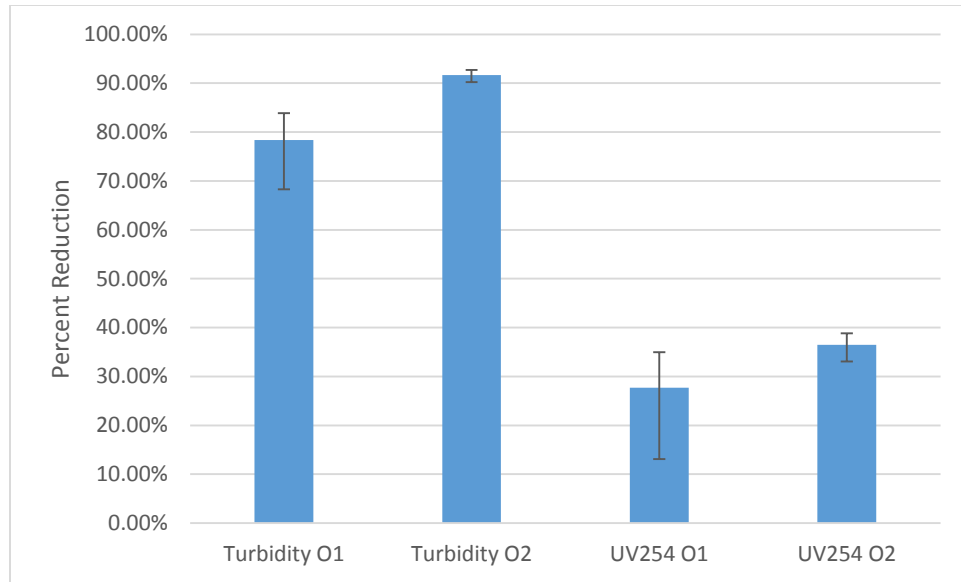
**Figure A-16 (5-33) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**



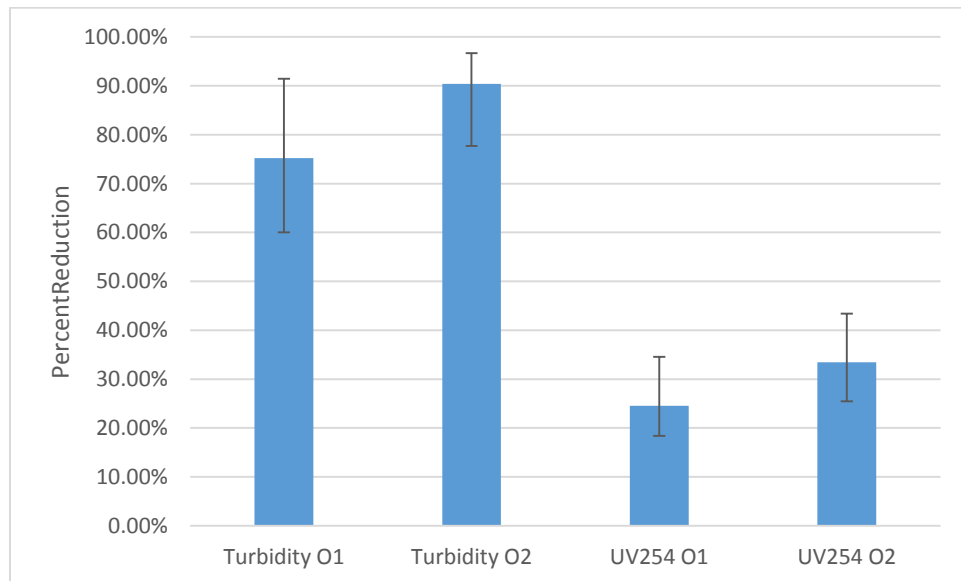
**Figure A-17 (5-34) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material**



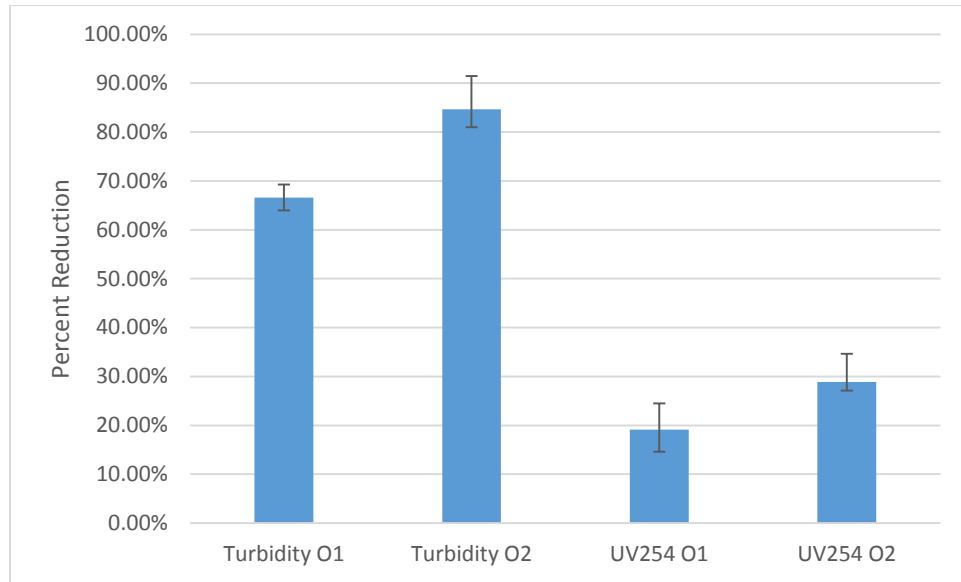
**Figure A-18 (5-35) Percent reduction in two settling chambers under 30° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**



**Figure A-19 (5-36) Percent reduction in two settling chambers under 45° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**



**Figure A-20 (5-37) Percent reduction in two settling chambers under 60° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**



**Figure A-21 (5-38) Percent reduction in two settling chambers under 90° screen angle with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material**

## APPENDIX B. T-TEST RESULTS

Table B-1 tank 1, 60°, aluminum chloride from Monroe City, one screen, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	1	2
Mean	5.98	6.26
Variance	0.12	0.32
Observations	9	9
Pooled Variance	0.22	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	-1.26	
P(T<=t) one-tail	0.11	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.22	
t Critical two-tail	2.12	

Table B-2 tank 1, 60°, aluminum chloride from Monroe City, one screen, TOC

t-Test: Two-Sample Assuming Equal Variances		
	1	2
Mean	5.09	4.98
Variance	0.64	0.78
Observations	9	9
Pooled Variance	0.71	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	0.26	
P(T<=t) one-tail	0.40	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.80	
t Critical two-tail	2.12	



Table B-3 tank 1, 60°, aluminum chloride from Monroe City, one screen, UV254

t-Test: Two-Sample Assuming Equal Variances		
	1	2
Mean	0.04	0.04
Variance	0.00	0.00
Observations	9	9
Pooled Variance	0.00	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	-0.04	
P(T<=t) one-tail	0.48	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.97	
t Critical two-tail	2.12	

Table B-4 tank 1, 60°, aluminum chloride from Monroe City, two screens, Turbidity

t-Test: Two-Sample Assuming Equal Variances		
	1	2
Mean	6.31	6.18
Variance	0.47	0.59
Observations	9	9
Pooled Variance	0.53	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	0.38	
P(T<=t) one-tail	0.36	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.71	
t Critical two-tail	2.12	

Table B-5 tank 1, 60°, aluminum chloride from Monroe City, two screens, TOC  
t-Test: Two-Sample Assuming Equal Variances

	1	2
Mean	4.36	4.43
Variance	0.22	0.38
Observations	9	9
Pooled Variance	0.30	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	-0.24	
P(T<=t) one-tail	0.41	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.12	

Table B-6 tank 1, 60°, aluminum chloride from Monroe City, two screens, UV254  
t-Test: Two-Sample Assuming Equal Variances

	1	2
Mean	0.02	0.02
Variance	0.00	0.00
Observations	9	9
Pooled Variance	5E-06	
Hypothesized Mean Difference	0E+00	
df	2E+01	
t Stat	7E-01	
P(T<=t) one-tail	3E-01	
t Critical one-tail	2E+00	
P(T<=t) two-tail	5E-01	
t Critical two-tail	2E+00	

Table B-7 tank 1, 60°, sodium aluminate from Trenton, one screen, Turbidity  
t-Test: Two-Sample Assuming Equal Variances

	1	2
Mean	9.58	9.21
Variance	9.09	6.14
Observations	5	5
Pooled Variance	7.61	
Hypothesized Mean Difference	0.00	
df	8.00	
t Stat	0.21	
P(T<=t) one-tail	0.42	
t Critical one-tail	1.86	
P(T<=t) two-tail	0.84	
t Critical two-tail	2.31	

Table B-8 tank 1, 60°, sodium aluminate from Trenton, one screen, TOC  
t-Test: Two-Sample Assuming Equal Variances

	1	2
Mean	8.60	9.23
Variance	1.46	3.71
Observations	9	9
Pooled Variance	2.59	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	-0.83	
P(T<=t) one-tail	0.21	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.42	
t Critical two-tail	2.12	

Table B-9 tank 1, 60°, sodium aluminate from Trenton, one screen, UV254  
t-Test: Two-Sample Assuming Equal Variances

	1	2
Mean	0.04	0.04
Variance	0.00	0.00
Observations	9	9
Pooled Variance	0.00	
Hypothesized Mean Difference	0.00	
df	16.00	
t Stat	-0.01	
P(T<=t) one-tail	0.50	
t Critical one-tail	1.75	
P(T<=t) two-tail	0.99	
t Critical two-tail	2.12	

Table B-10 Tank 2, 55°, Aluminum chloride from Hamilton, one screen, pureflo 50, Turbidity  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of NTU of o1</i>	<i>Decrease Rate of NTU of o2</i>
Mean	0.824956948	0.9089539
Variance	0.010197265	0.006358737
Observations	5	5
Pooled Variance	0.008278001	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.459724147	
P(T<=t) one-tail	0.091244598	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.182489196	
t Critical two-tail	2.306004135	

Table B-11 Tank 2, 55°, Aluminum chloride from Hamilton, one screen, pureflo 50, TOC

t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of TOC of o1</i>	<i>Decrease Rate of TOC of o2</i>
Mean	0.104610474	0.130110013
Variance	0.007094727	0.009809651
Observations	5	5
Pooled Variance	0.008452189	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.438548599	
P(T<=t) one-tail	0.336295262	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.672590524	
t Critical two-tail	2.306004135	

Table B-12 Tank 2, 55°, Aluminum chloride from Hamilton, one screen, pureflo 50, UV254

t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of UV254 of o1</i>	<i>Decrease Rate of UV254 of o2</i>
Mean	0.309303062	0.332366886
Variance	0.010529742	0.008868583
Observations	5	5
Pooled Variance	0.009699163	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.370283365	
P(T<=t) one-tail	0.360391476	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.720782952	
t Critical two-tail	2.306004135	

Table B-13 Tank 2, 55°, Aluminum chloride from Monroe, one screen, pureflo 50, Turbidity  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of NTU of o1</i>	<i>Decrease Rate of NTU of o2</i>
Mean	0.871427917	0.939710225
Variance	0.000354844	0.001124979
Observations	5	5
Pooled Variance	0.000739911	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.969066187	
P(T<=t) one-tail	0.00206216	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.004124321	
t Critical two-tail	2.306004135	

Table B-14 Tank 2, 55°, Aluminum chloride from Monroe, one screen, pureflo 50, TOC  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of TOC of o1</i>	<i>Decrease Rate of TOC of o2</i>
Mean	0.138253712	0.211164557
Variance	0.003443389	0.001125615
Observations	5	5
Pooled Variance	0.002284502	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.411939319	
P(T<=t) one-tail	0.021189881	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.042379761	
t Critical two-tail	2.306004135	

Table B-15 Tank 2, 55°, Aluminum chloride from Monroe, one screen, pureflo 50, UV254

t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate of UV254 of o1</i>	<i>Decrease Rate of UV254 of o2</i>
Mean	0.306535001	0.361203228
Variance	0.023326459	0.019553009
Observations	5	5
Pooled Variance	0.021439734	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.590330604	
P(T<=t) one-tail	0.28563183	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.057126366	
t Critical two-tail	2.306004135	

Table B-16 Tank 2, 55°, Aluminum chloride from Vandalia, one screen, pureflo 50, Turbidity

t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate o1 turbidity</i>	<i>Decrease Rate o2 turbidity</i>
Mean	0.676274103	0.841495945
Variance	0.002453278	0.000593944
Observations	5	5
Pooled Variance	0.001523611	
Hypothesized Mean Difference	0	
df	8	
t Stat	-6.692685769	
P(T<=t) one-tail	7.69313E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.000153863	
t Critical two-tail	2.306004135	

Table B-17 Tank 2, 55°, Aluminum chloride from Vandalia, one screen, pureflo 50, UV254  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate o1 UV254</i>	<i>Decrease Rate o2 UV254</i>
Mean	0.390016744	0.441685941
Variance	0.000198775	6.02564E-05
Observations	5	5
Pooled Variance	0.000129516	
Hypothesized Mean Difference	0	
df	8	
t Stat	-7.178615487	
P(T<=t) one-tail	4.72024E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	9.44049E-05	
t Critical two-tail	2.306004135	

Table B-18 Tank 2, 70°, Aluminum chloride from Vandalia, one screen, pureflo 50, Turbidity  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate o1 turbidity</i>	<i>Decrease Rate o2 turbidity</i>
Mean	0.259366097	0.490127995
Variance	0.007605789	0.006983706
Observations	5	5
Pooled Variance	0.007294747	
Hypothesized Mean Difference	0	
df	8	
t Stat	-4.271977722	
P(T<=t) one-tail	0.001358442	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.002716883	
t Critical two-tail	2.306004135	



Table B-19 Tank 2, 70°, Aluminum chloride from Vandalia, one screen, pureflo 50, UV254  
t-Test: Two-Sample Assuming Equal Variances

	<i>Decrease Rate o1 UV254</i>	<i>Decrease Rate o2 UV254</i>
Mean	0.093053533	0.172349929
Variance	0.001220647	0.001196735
Observations	5	5
Pooled Variance	0.001208691	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.606332954	
P(T<=t) one-tail	0.003459197	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.006918394	
t Critical two-tail	2.306004135	

Table B-20 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, turbidity  
t-Test: Two-Sample Assuming Equal Variances

	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.767578018	0.865547113
Variance	0.001394065	0.000181261
Observations	5	5
Pooled Variance	0.000787663	
Hypothesized Mean Difference	0	
df	8	
t Stat	-5.519362676	
P(T<=t) one-tail	0.000280401	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.000560802	
t Critical two-tail	2.306004135	

Table B-21 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.58933726	0.653167289
Variance	0.000603253	0.002424912
Observations	5	5
Pooled Variance	0.001514082	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.593703369	
P(T<=t) one-tail	0.015964383	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.031928766	
t Critical two-tail	2.306004135	

Table B-22 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.743345236	0.831412224
Variance	0.000632804	0.003191334
Observations	5	5
Pooled Variance	0.001912069	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.184427666	
P(T<=t) one-tail	0.006455582	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.0012911164	
t Critical two-tail	2.306004135	

Table B-23 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.256594322	0.342196117
Variance	0.005949795	0.001398485
Observations	5	5
Pooled Variance	0.00367414	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.232929534	
P(T<=t) one-tail	0.028020133	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.0056040265	
t Critical two-tail	2.306004135	

Table B-24 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.639612968	0.695647054
Variance	0.058500318	0.039551298
Observations	5	5
Pooled Variance	0.049025808	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.400138105	
P(T<=t) one-tail	0.349763402	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.699526804	
t Critical two-tail	2.306004135	

Table B-25 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.094878065	0.178915815
Variance	0.002241397	0.001276817
Observations	5	5
Pooled Variance	0.001759107	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.168095623	
P(T<=t) one-tail	0.006616278	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.013232555	
t Critical two-tail	2.306004135	

Table B-26 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.846881096	0.871491779
Variance	0.000164307	0.000525949
Observations	5	5
Pooled Variance	0.000345128	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.094610957	
P(T<=t) one-tail	0.034758897	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.069517794	
t Critical two-tail	2.306004135	

Table B-27 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 50 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.465543167	0.48022951
Variance	0.001292268	0.001239178
Observations	5	5
Pooled Variance	0.001265723	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.65270115	
P(T<=t) one-tail	0.266126302	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.532252603	
t Critical two-tail	2.306004135	

Table B-28 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.731906324	0.899667953
Variance	0.001309934	0.000519931
Observations	5	5
Pooled Variance	0.000914932	
Hypothesized Mean Difference	0	
df	8	
t Stat	-8.769365408	
P(T<=t) one-tail	1.12094E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	2.24189E-05	
t Critical two-tail	2.306004135	

Table B-29 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.274979602	0.356658476
Variance	0.000295948	0.000147736
Observations	5	5
Pooled Variance	0.000221842	
Hypothesized Mean Difference	0	
df	8	
t Stat	-8.670776907	
P(T<=t) one-tail	1.21757E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	2.43514E-05	
t Critical two-tail	2.306004135	

Table B-30 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.69141239	0.827710145
Variance	0.001772586	0.001362467
Observations	5	5
Pooled Variance	0.001567527	
Hypothesized Mean Difference	0	
df	8	
t Stat	-5.443161923	
P(T<=t) one-tail	0.000306833	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.000613666	
t Critical two-tail	2.306004135	

Table B-31 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.119097551	0.206410011
Variance	0.002417509	0.000854097
Observations	5	5
Pooled Variance	0.001635803	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.41334923	
P(T<=t) one-tail	0.004588813	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.009177625	
t Critical two-tail	2.306004135	

Table B-32 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.767578018	0.865547113
Variance	0.001394065	0.000181261
Observations	5	5
Pooled Variance	0.000787663	
Hypothesized Mean Difference	0	
df	8	
t Stat	-5.519362676	
P(T<=t) one-tail	0.000280401	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.000560802	
t Critical two-tail	2.306004135	

Table B-33 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.589722854	0.676203335
Variance	0.000833002	0.00229785
Observations	5	5
Pooled Variance	0.001565426	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.45598451	
P(T<=t) one-tail	0.004309276	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.008618551	
t Critical two-tail	2.306004135	

Table B-34 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.645243028	0.791101667
Variance	0.001046047	0.000263823
Observations	5	5
Pooled Variance	0.000654935	
Hypothesized Mean Difference	0	
df	8	
t Stat	-9.011623169	
P(T<=t) one-tail	9.17808E-06	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	1.83562E-05	
t Critical two-tail	2.306004135	



Table B-35 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 125 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.2192595	0.294823531
Variance	0.001447872	0.00098892
Observations	5	5
Pooled Variance	0.001218396	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.422874234	
P(T<=t) one-tail	0.004524738	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.009049476	
t Critical two-tail	2.306004135	

Table B-36 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.687084876	0.849787068
Variance	0.004997684	0.003724286
Observations	5	5
Pooled Variance	0.004360985	
Hypothesized Mean Difference	0	
df	8	
t Stat	-3.895570866	
P(T<=t) one-tail	0.002286567	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.004573133	
t Critical two-tail	2.306004135	

Table B-37 Result of decrease rate of two settling chamber under 30° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.202644872	0.288148084
Variance	0.00457821	0.000818702
Observations	5	5
Pooled Variance	0.002698456	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.602524085	
P(T<=t) one-tail	0.015747015	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.03149403	
t Critical two-tail	2.306004135	

Table B-38 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.848748359	0.914088782
Variance	0.000349094	5.34174E-05
Observations	5	5
Pooled Variance	0.000201256	
Hypothesized Mean Difference	0	
df	8	
t Stat	-7.28245671	
P(T<=t) one-tail	4.2662E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	8.5324E-05	
t Critical two-tail	2.306004135	

Table B-39 Result of decrease rate of two settling chamber under 45° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances

	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.277327921	0.364929397
Variance	0.007837843	0.000502559
Observations	5	5
Pooled Variance	0.004170201	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.144879643	
P(T<=t) one-tail	0.032142989	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.064285977	
t Critical two-tail	2.306004135	

Table B-40 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances

	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.752393089	0.903846073
Variance	0.0134741	0.00699105
Observations	5	5
Pooled Variance	0.010232575	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.367311286	
P(T<=t) one-tail	0.022718354	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.045436708	
t Critical two-tail	2.306004135	

Table B-41 Result of decrease rate of two settling chamber under 60° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.241450194	0.287082913
Variance	0.004057812	0.004255094
Observations	5	5
Pooled Variance	0.004156453	
Hypothesized Mean Difference	0	
df	8	
t Stat	-1.119141298	
P(T<=t) one-tail	0.14777699	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.29555398	
t Critical two-tail	2.306004135	

Table B-42 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, turbidity

t-Test: Two-Sample Assuming Equal Variances		
	<i>Turbidity Decrease Rate O1</i>	<i>Turbidity Decrease Rate O2</i>
Mean	0.665777179	0.846846003
Variance	0.000601797	0.001780319
Observations	5	5
Pooled Variance	0.001191058	
Hypothesized Mean Difference	0	
df	8	
t Stat	-8.295589548	
P(T<=t) one-tail	1.68E-05	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	3.35999E-05	
t Critical two-tail	2.306004135	

Table B-43 Result of decrease rate of two settling chamber under 90° with aluminum chloride from Vandalia as the coagulant and pureflo 200 as the fabric material, UV254

t-Test: Two-Sample Assuming Equal Variances		
	<i>UV254 Decrease Rate O1</i>	<i>UV254 Decrease Rate O2</i>
Mean	0.19123234	0.288931898
Variance	0.001560053	0.001028881
Observations	5	5
Pooled Variance	0.001294467	
Hypothesized Mean Difference	0	
df	8	
t Stat	-4.293556319	
P(T<=t) one-tail	0.001319322	
t Critical one-tail	1.859548038	
P(T<=t) two-tail	0.002638644	
t Critical two-tail	2.306004135	