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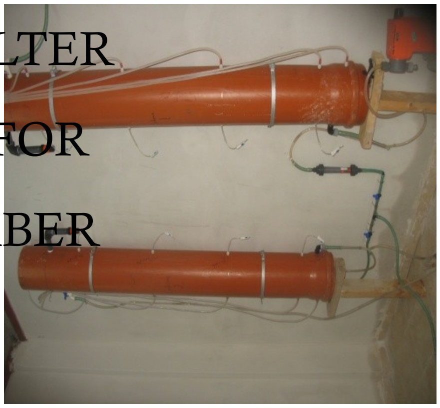
ASSESSMENT OF A ROUGHING FILTER AS A PRE- TREATMENT SYSTEM FOR SLOW SAND FILTER AT AQBAT JABER REFUGEE CAMP



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Supervised By: Dr. Nidal Mahmoud

August, 2010

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Supervised by

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in Water And Environmental Science from the Faculty of Graduate Studies at Birzeit
University- Palestine

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This thesis was prepared under the main supervision of Dr. Nidal Mahmoud and has been approved by all members of the examination committee

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The findings, interpretations and the conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the MSc committee or the views of their respective employers.

DEDICATION

To my mother and father immaculate soul

To my sister that give all the effort to support me

To my wife for her efforts, encouragement

To my lovely daughters

AKNOWLEDGMENT

I would like to express my thanks to my supervisor Dr. Nidal Mahmoud for his guidance and supervision during the period of my study.

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ABSTRACT

Slow sand filtration is one of the most effective surface water treatment methods because of its low cost and simplicity in operation and maintenance especially for rural areas in developing countries.

In Aqbat Jaber WTP this method is used to treat water coming from Al-Qilt and Al-Fawwar springs transported through 13 Km open canal.

However, above raw water turbidity of 20 NTU, pretreatment is required. Direct roughing filtration (a modification of roughing filtration in which coagulant is added to the influent water before filtration with the aim of improving particle removal) is a promising pre treatment method for slow sand filtration.

Several jar tests were conducted in order to assess the optimum operating conditions for roughing filter to find the optimum coagulant dose needed to simulates coagulation and flocculation processes, up flow roughing filters in layers (4 layers) was used in this study, different flow rates (1, 1.5) and coagulant doses (10 to 50) were applied to achieve the best way of particle removal.

The roughing filters effluent quality met the influent requirement of SSF in this study of less than 20 NTU, implying that under the given process conditions a filtration rate of 1.5 m/hr and 0.5 m/hr produces a good results without addition of any chemical with turbidity range 20 to 100 NTU.

It was observed that coagulation in roughing filtration could be effectiveness with more than 100 NTU canal turbidity.

The results of this study also showed a high polluted of Total and Fecal coliform bacteria of raw water open canal due to a different pollution sources.

ملخص

من احدى الطرق الرائدة في معالجة المياه السطحية(slow sand filters) تعتبر المرشحات الرملية
بسبب تكلفتها القليلة وسهولة تشغيلها والتحكم بها خاصة في المناطق الريفية والقرى .

في بلدة عقبه جبر (اريحا) تستخدم هذه الطريقه في معالجة المياه السطحية القادمة من عين القلط
وعين الفوار والتي تنتقل عبر قناة اسمنتيه مفتوحه مسافة 13 كيلو متر حتى تصل الى محطه المعالجه.

خاصة في فصل الشتاء لذلك NTU 20 تصل المياه عبر القناه الى محطة التنقيه معكره اي تبلغ اكثر من
عن طريق بناء فلاتر pre-treatment كان لابد من معالجه هذه المياه قبل دخولها الى المحطة الرئيسية
وهي الهدف الرئيسي من هذه الدراسه لازالة كافة الملوثات والشوائب (Up-flow roughing filters)
slow sandوهي النسبه الملائمه لتشغيل الفلاتر NTU 20 المسببه للعكاره وتقليل نسبتها الى اقل من
filters داخل المجطه الرئيسيه بصوره جيده وفعاله .

المناسبه coagulant لمعرفه كميه المواد الكيميائيه Jar tests تم اجراء العديد من التجارب المخبريه
لتطبيقها على فلاتر التنقيه الاوليه والتي تساعد على التخلص من العوالق والملوثات بشكل اكبر وتم
تحديدها .

وتركيبها في الموقع ووصلها Up-flow roughing filters)) تم تصميم الفلاتر الخاصه بعمليه التنقيه الاوليه
الازمه للمساعده في عمليه تجميع الاوساخ coagulantمع القناه المفتوحه وتم اضافه المواد الكيميائيه
ليسهل التخلص منها داخل الفلتر ,وتم ايضا من خلال التجارب تحديد سرعه التدفق (coagulation)
وكانت 1.5 م/ساعه و 0.5 م/ساعه حيث حققت النتائج اهداف هذه الدراسه في (flow rate) المناسبه
تقليل العكاره الى اقل من 20 NTU .

جيد وفعال في تقليل نسبه العكاره الى اقل من 20 FeCl$_3$ coagulant تبين من خلال البحث ان استخدام
وان فلاتر التنقيه , NTU عن 100 influent عندما تزيد نسبه التلوث في القناه او المياه الداخله الى الفلتر NTU
اذا قلت نسبه NTU الاوليه تستطيع العمل دون اضافه اي ماده كيميائيه وتحقيق النسبه الملائمه وهي 20
.في القناة NTU العكاره عن 100

ان ماتوصل اليه البحث يبين ان القناه ملوثه بشكل كبير ببكتريا Total Coliform & Fecal Coliform.

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LIST OF ABBREVIATIONS

SUVA	Specific Ultraviolet Absorbance
WTP	Water Treatment Plant
SSF	Slow Sand Filter

°C	Degree Centigrade
µM	Micrometer
AWWTP	Al Bireh Wastewater Treatment Plant
AJWTP	Aqbat Jaber Water Treatment Plant
cm	Centimeter
FC	Fecal Coliform
hr	Hours
m	Meter
m^3	Cubic Meters
mg/L	Milligram per Liter
mm	Millimeter
m/hr	Meter per hour
m/s	Meter per second
NTU	Nephelometric Turbidity Unit
VRFs	Vertical Roughing Filters
HRFs	Horizontal Roughing Filters
DRFs	Down Flow Roughing Filters
URFs	Up Flow Roughing Filters
PWA	Palestinian Water Authority
SS	Suspended Solids
TC	Total Coliform
min	Minutes
g	Gram

L/hr	Liter per hour
ml	Millimeter
mg	Milligram

CHAPTER 1

INTRODUCTION

1.1 Background

Aqbat Jaber Refugee Camp is located at Wadi Al Qilt area 3km southwest of Jericho city. There are more than 6804 inhabitants living in the camp. The socio-economic conditions in the camp are extremely harsh and the people are living in primary conditions and simple houses. Limited water supply is a significant problem for the refugee camp. The UNRWA supervises the camp and responsible for the water supply and has to take the required actions in case of any disruption of water supply. The estimated average daily demand of the camp is rated at 817 m^3/day assuming water consumption of 120 l/c/d and 20% unaccounted for water.

The water supply system to the camp consists mainly of springs, conveying open canal, treatment plant, and distribution network. In case water supply system fails to provide good water quality, an alternative, but more expensive, is available from Mekorot (Israeli Water Supply Company). The main springs feeding the water supply system are Al Fawwar and Al Qilt springs (Figure 1). The water reaches the treatment plant very polluted and with high Turbidity during the period of November to March.

Daghrah, (2005) conducted astudy to assess the pollution sources.It was found that the soil eroded by rainwater runoff, algae grow along the open canal during summer time and vegetations grow near the canal edges are the main cause of canal pollution and turbidity increased. High SUVA (Specific Ultra Violet Absorption) values have been recorded (more than 2 l/mg-m) for the raw water which indicates high organic content (Daghrah, 2005).

It is worth to mention that the slow sand filter of the treatment plant was rehabilitated during the year 2006; the underlying layers and mechanical system were changed. An automatic on line turbidity meter has been installed to drain the polluted water (reading turbidity over 20 NTU) to the irrigation canal during the rainy season. This means that reduction of the turbidity by adding a pre-treatment unit is recommended to enable continuous and effective function of the treatment plant and to increase the water quantity feeding the camp.

To have a good water quality slow sand filtration applied as surface water treatment which is particularly effective to have a good water quality. However, efficient application of the treatment process requires water of low turbidity. Hence pre-treatment of the surface water is usually necessary. For slow sand filtration, pretreatment is essential if the raw water has a turbidity of more than 20 NTU (Wegelin and Boller, 1991). The selection of the most suitable type of pretreatment for a particular design should be made on the basis of field investigations, in which samples are taken to determine variations in raw water characteristics.

The main problem is the intermittent water supply to the camp as the water treatment plant (WTP) is taken out of operation when the source of water has poor quality (turbidity more than 20 NTU). Consequently, there is no more water for treatment, and then no water supply for domestic use. This requires pretreatment stage to eliminate the turbidity, increase the efficiency of the WTP and then to ensure continuous operation of the plant and then permanent water supply to the camp.

This technology must satisfy the economical factor and not require a high personnel skill for operation. Here a particular experience should be carried out in WTP, which is an interesting example to apply adequate technology for each particular situation and also as an example of transfer of knowledge from a university to the community.

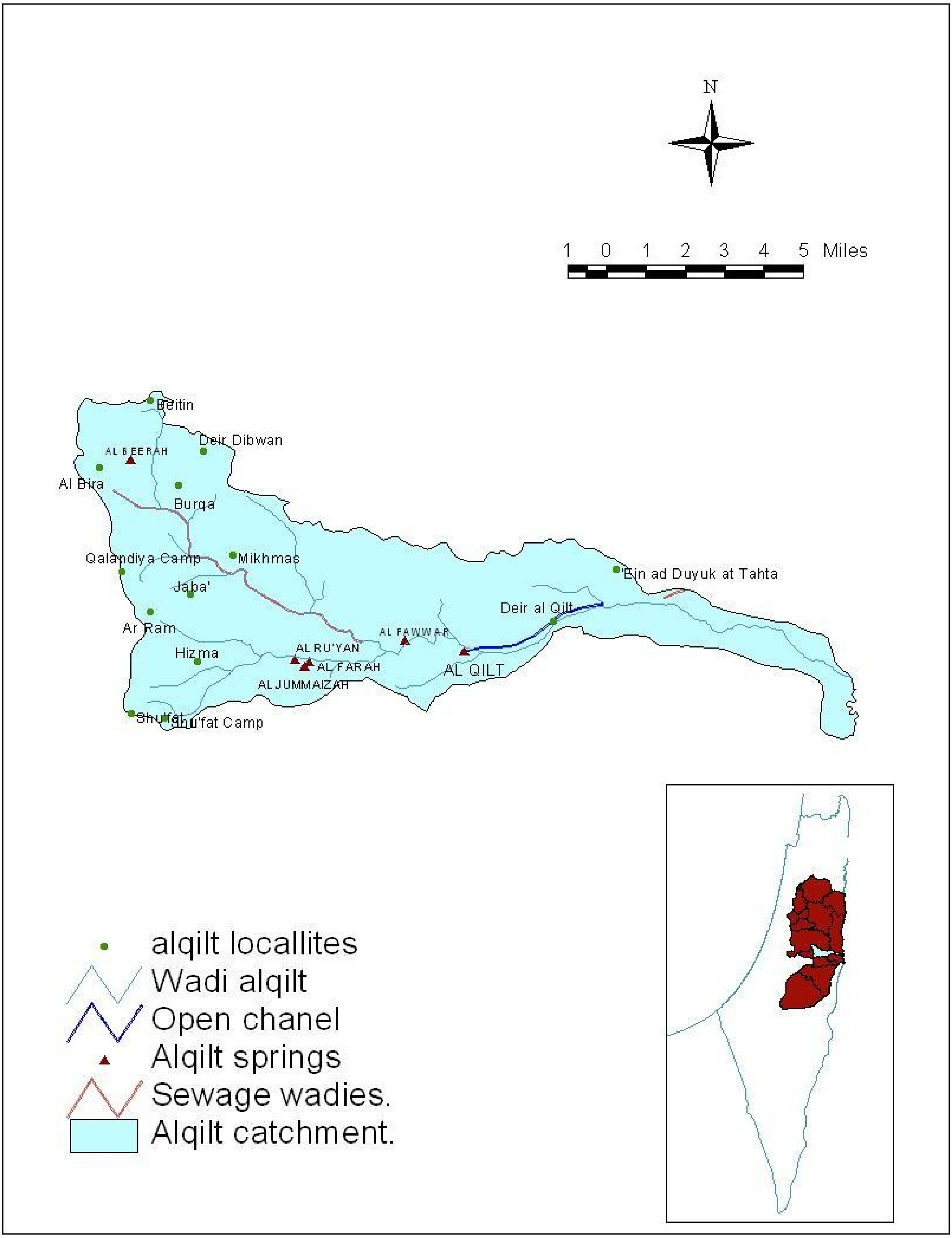


Figure 1.1: Palestinian localities in Al Qilt catchment areas.

Pre-treatment of surface water for reduction of turbidity or solid-matter concentration is required. Several treatment processes are used for solid removal like sedimentation, coagulation flocculation, up flow roughing filters. Sedimentation will remove the settleable and part of the suspended solids. Smaller Particles will hardly be separated and that make SSF not work properly. In such situation, sedimentation is enhanced by addition of chemicals. Pre-treatment using roughing filters are simple and more efficient low tech/cost solutions (Wegelin, 1996).

Up-flow roughing filters can be used to reduce the turbidity levels in raw water to ease later treatment problems. The filters hight, number, type and size of media, number of layers needed, filtration rate, flow rate, etc all these were considered in this study.

Roughing filters are often built in tanks with a number in series (each tank being a stage) or in parallel, using progressively less coarse media in each tank. Raw water quality will determine how many stages, i.e. how many roughing filter tanks will be required. The more stages used (usually no more than three) the greater the cleaning effect on the water. If the water is fairly clean, a single stage filter, or one with three different sized media layers in one tank may suffice (Collins, 1994). However pilot plant studies run on a model scale will give the best results for design of the system and these trials should also take into account seasonal variations in water quality.

1.2 Objectives

Water supply to the camp decreases during the rainy season especially from December to March because water coming from the open canal becomes polluted and turbid. The WTP becomes out of operation when the source of water has poor quality (turbidity more than 20 NTU). Consequently, there is no more water for treatment, and then no water supply for domestic use. This requires pretreatment stage to reduce the turbidity which is the main aim of this study, and to increase the efficiency of the WTP and then to ensure continuous operation of the plant to increase water supply to the camp.

This technology must satisfy the economical factor and not require a high personnel skill for operation, because of that up flow roughing filters might be the best choice.

The main objectives of this study are :

- To define the optimum dose of $FeCl_3$ coagulant for different raw water turbidities using the jar test.
- To find suitable design parameters for the pretreatment up-flow roughing filters using pilot scale tests like filtration rate, and assess the efficincy of filters in removal turbidity on diffirent filtration rate.
- To study the effect of Coagulant on turbidity elamination on roughing filtration process after being mixed with raw water (polluted water from canal) and to investigate the suitable dose needed for this process
- To asses the effect of roughing filter on Total and Fecal coliform removal and type of canal pollution.

CHAPTER 2

LITERETURE REVIEW

2.1 Coagulation

2.1.1 General

Water to be supplied for public use must be potable i.e., satisfactory for drinking purposes from the standpoint of its chemical, physical and biological characteristics. Drinking water should be obtained from a source free from pollution. The raw water normally available from surface water sources is, however, not directly suitable for drinking purposes.

The objective of water treatment is to produce safe and potable drinking water. Land erosion, dissolution of minerals, decay of vegetative matter, domestic human wastes, and animals wastes are the major sources of surface water pollution. These materials in water may comprise suspended, dissolved organic or inorganic matter and numerous of biological forms (Wegelin, 1996).

Chemical precipitation or coagulation and flocculation with various salts of aluminum, iron, lime and other inorganic or organic chemicals are widely used processes to treat water for the removal of colloidal particles (turbidity) and microbes. Although alum and iron salts are the most widely used chemical coagulants for community drinking water treatment, other coagulants have been and are being used (Letterman and O'Melia, 1999).

Chemical coagulation-flocculation enhances the removal of colloidal particles by destabilizing them, chemically precipitating them and accumulating the precipitated material into larger "floc" particles that can be removed by gravity settling or filtering. Flocculation causes aggregation into even larger floc particles that enhances removal by gravity settling or filtration (Letterman and O'Melia, 1999).

Optimum coagulation to achieve maximum reductions of turbidity and microbes requires careful control of coagulant dose, pH and consideration of the quality of the water being treated, as well as appropriate mixing conditions for optimum flocculation. Lack of attention to these details can result in poor coagulation flocculation and inefficient removal of particles and microbes (Wegelin, 1996).

Under optimum conditions, coagulation-flocculation and sedimentation with alum and iron can achieve microbial reductions of >90 to >99% for all classes of waterborne pathogens (Sproul, 1974, Leong, 1982, Payment and Armon, 1989). However, poor microbial reductions occur (<90%) when coagulation-flocculation or precipitation conditions are sub-optimal (Ongerth, 1990).

2.1.2 Purpose of Coagulation

Untreated surface waters contain clay, minerals, bacteria, inert solids, microbiological organisms, oxidized metals, organic color producing particles, and other suspended materials. Some of the microbiological organisms can include Guardia cysts, pathogenic bacteria, and viruses. Oxidized metals include iron and manganese. All of these materials can inhibit disinfection, cause problems in the distribution system, and leave the water cloudy rather than clear. The purpose of coagulation is to remove these particles (Wegelin, 1996).

Turbidity particles can range in size from molecular to 50 microns. Particles which are greater than one micron in diameter are considered silt, and settle out due to their relatively large size and density without the need to coagulate in a matter of seconds or minutes. Colloidal material ranges in size from 0.001 to one micron in diameter. These materials require days to months for complete settling (Boller, 1991).

The rate of settling of these colloidal particles must be increased in the water treatment process. This is accomplished in the coagulation process when tiny particles agglomerate into larger, denser particles which will settle more quickly (Letterman and O’Melia, 1999).

2.1.3 Coagulation Process

Coagulation is accomplished by the addition of ions having the opposite charge to that of the colloidal particles. Since the colloidal particles are almost always negatively charged, the ions which are added should be cations or positively charged. The coagulating power of an ion is dependent on its valence or magnitude of charge. A bivalent ion (+2 charges) is 30 to 60 times more effective than a monovalent ion (+l charge). A trivalent ion (+3 charges) is 700 to 1000 times more effective than a monovalent ion (Gregory and Carlson, 2003).

Typically, two major types of coagulants are added to water. These are aluminum salts and iron salts. The most common aluminum salt is aluminum sulfate(alum). When aluminum sulfate is added to water, the aluminum ions enter into a series of complicated reactions. The aluminum ions become hydrated, meaning that water molecules attach themselves to the aluminum ions. In addition, anions present in the water, such as hydroxide and sulfate ions can attach to the aluminum ions. These reactions result in large, positively charged molecules having aluminum ions at their center. These particles may have charges as high as +4. Following these reactions, a second type of reaction occurs, called Olation. This reaction involves the bridging of two or more of these large molecules to form even larger, positively charged ions. A typical molecule can contain eight aluminum ions, twenty hydroxide ions, and will have a +4 charge. Iron salts behave in a similar manner when added to water (Gregory and Carlson, 2003).

Once these large polymeric aluminum or iron compounds are formed, the magnitude of their high positive charge allows these species to rapidly move toward the colloid, where they are adsorbed onto the negatively charged surface of the turbidity particle. The coagulant compounds can penetrate the bound water layer because of their high positive charge. This rapid adsorption results in the compression of the electrical double layer, and results in the colloid becoming coated with the coagulant compounds. The net result of this process is that the electrical charges on the particle are reduced. The suspension is now considered to be destabilized, and the particles can be brought together through, among other forces, Brownian movement, and will be held together by the Van der Waals forces. As the coagulation reactions and destabilization are occurring, the Zeta Potential at the surface of the colloid is also found to be reducing (Gregory and Carlson, 2003).

2.1.4 Zeta Potential

To visualize the environment surrounding a charged colloidal particle and demonstrate how the repulsive force, as well as, the ionic concentration varies with distance; a double layer model is normally used. At the surface of the negative colloidal particle a layer of positive ions will form. This layer of positive ions is known as the Stern layer. More positive ions will be attracted by the negative colloid but they are partially repelled by the positive Stern layer. Conversely to the distribution of positive ions is the distribution of negative ions, i.e. very few at the colloid surface and increasing with distance until equilibrium is reached. The region in which the positive ions are decreasing and the negative ions are increasing, hereby reaching the bulk equilibrium concentration, is called the diffuse layer. The potential at the junction of the Stern layer and the diffuse layer is known as the Zeta potential. Zeta potential is a tool used for coagulation control because changes in Zeta potential indicate changes in the repulsive force between colloids. The Stern layer and the charged diffuse layer are referred to as the double layer (Figure 2.1). The thickness of the double layer depends upon the concentration of the ions in solution. A higher level of ions means more positive ions are available to neutralize the negative charge of the colloidal particle, and in turn a thinner double layer leading to an increased probability of intimate contact or collision between collide particles and hence coagulation or colloidal particle growth. On the other hand, a decrease in the ionic concentration reduces the number of positive ions resulting in a thicker double layer leading to increased dispersion (Gregory and Carlson, 2003).

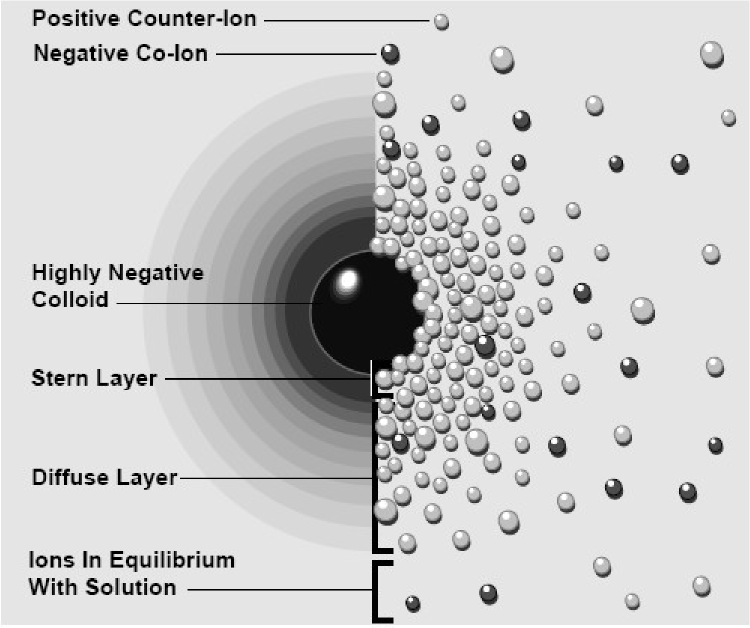


Figure 2.1: The electrical double layer (Zeta-Meter, 1993)

2.1.5 Factors Influencing Coagulation

pH

The pH range in which a coagulation process occurs may be the single most important factor in proper coagulation. The vast majority of coagulation problems are related to improper pH levels. Whenever possible, coagulation should be conducted in the optimum pH zone. When this is not done, lower coagulation efficiency results, generally resulting in a waste of chemicals and a lowered water quality. Each of the inorganic salt coagulants has its own characteristic optimum pH range. In many plants, it is necessary to adjust the pH level in the coagulation process. In most cases this involves the addition of lime, caustic soda, or soda ash to maintain a minimum pH level. In some cases, however, acids may be necessary to lower the pH level to an optimum range (Budd *et al.*, 2004).

salts

Since no natural waters are completely pure, each will have various levels of cations and anions such as calcium, sodium, magnesium, iron, manganese, sulfate, chloride, phosphate, and others. Some of these ions may affect the efficiency of the coagulation process. Generally, mono and divalent cations such as sodium, calcium, and magnesium have little or no effect on the coagulation process. Trivalent cations do not have an adverse effect on the process in most instances. In fact, significant concentrations of naturally occurring iron in a water supply has resulted in the ability to feed lower than normal dosages of inorganic salt coagulants.

Some anions can have a more pronounced effect. Generally, monovalent anions such as chloride have little effect on the coagulation process. As the concentration of the divalent anion sulfate in a water supply increases, the optimum pH range of the inorganic salt coagulants tends to broaden, generally toward the lower pH levels. (Pernitsky and Edzwald, 2006).

Mixing

Poor or inadequate mixing results in an uneven dispersion of the coagulant. Unfortunately, many older plants were designed with mixing facilities which generally do not accomplish mixing in the most efficient manner. As a result, it becomes necessary to use higher than necessary dosages of coagulant to achieve an optimum level of efficiency in the process. The effects of low turbidity and cold water temperatures can tend to aggravate the lack of adequate mixing facilities in some plants (Chichuan *et al.*, 2002).

Nature of turbidity

Fine, colloidal material may be present in the supply, which may cause some difficulty in the coagulation process. Generally, higher turbidity levels require higher coagulant dosages. However, seldom is the relationship between turbidity level and coagulant dosage linear. Usually, the additional coagulant required is relatively small when turbidities are much higher than normal due to higher collision probabilities of the colloids during high turbidities. Conversely, low turbidity waters can be very difficult to coagulate due to the difficulty in inducing collision between the colloids. In this instance, floc formation is poor, and much of the turbidity is carried directly to the filters. Organic colloids may be present in a water supply due to pollution, and these colloids can be difficult to remove in the coagulation process. In this situation, higher coagulant dosages are generally required (Pernitsky and Edzwald, 2006).

Water temperature

Cold water temperatures can cause two factors which add to the difficulty of the coagulation process. As water temperatures approach freezing, almost all chemical reactions occur more slowly. It can be more difficult therefore to evenly disperse the coagulants into the water. As a result, the coagulant process becomes less efficient, and higher coagulant dosages are generally used to compensate for these effects. In addition, floc settling characteristics become poor due to the higher density of the water during near freezing temperatures (Pernitsky and Edzwald, 2006).

Coagulant type

The choice of the proper coagulant for the given conditions is of critical importance in maintaining an efficient coagulation scheme under widely varying conditions. The chemicals most commonly used in the coagulation process are aluminum sulfate (Alum), ferric chloride, ferric sulfate, and cationic polymers (Budd *et al.*, 2004).

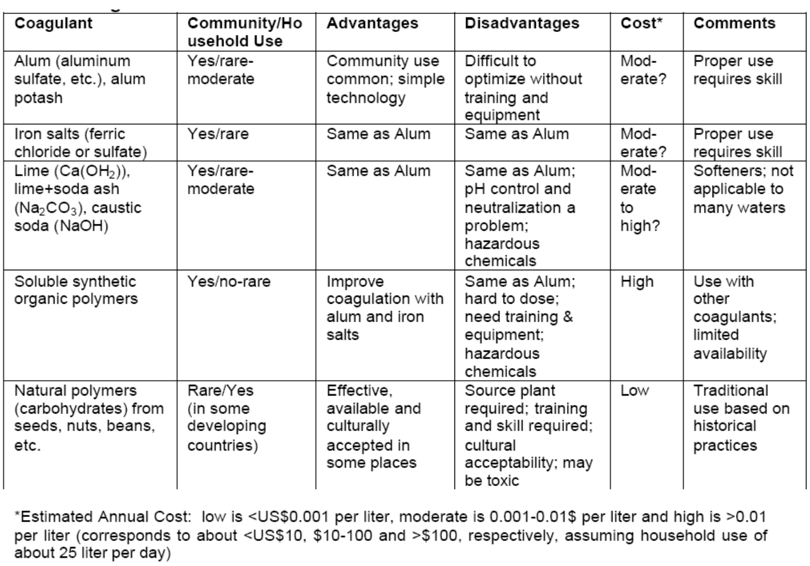
2.1.6 Metal Coagulants

Aluminum Sulfate and ferric chloride the most commonly used coagulant aluminum Sulfate is also known as alum, filter alum, and alumina sulfate. Alum is the most widely used coagulant. Alum is available in dry form as a powder or in lump form. It can also be purchased and fed as a liquid. Alum has no exact formula due to the varying water molecules of hydration which may be attached to the aluminum sulfate molecule. Once in water, alum can react with hydroxides, carbonates, bicarbonates, and other anions as discussed previously to form large, positively charged molecules carbon dioxide and sulfate are generally byproducts of these reactions. During the reactions, alum acts as an acid to reduce the pH and alkalinity of the water supply. It is important that sufficient alkalinity be present in the water supply for the various reactions to occur (Sobsey, 2002).

Alum can be effective in the pH range of 5.5 to 7.8, but seems to work best in most water supplies in a pH range of 6.8 to 7.5. Below a pH range of 5.5, alkalinity in the water supply is generally insufficient. The aluminum ions become soluble rather than insoluble and do not participate in the hydration and olation reactions necessary to make the alum effective as a coagulant. In these instances the plant may experience higher than normal filtered water turbidities, and much of the aluminum will pass through the filters. When the pH level of the water is above 7.8 after the addition of the alum, the aluminum ions again become soluble, and the efficiency of coagulation is decreased. Under these conditions, aluminum ions again penetrate the filters, and post filtration alum coagulation can occur in the clear well and in the distribution system in some cases (Sobsey, 2002).

Traditionally, ferric chloride has not been used widely as a coagulant, but this trend is not continuing. Ferric chloride is becoming more extensively used as a coagulant due partially to the fact that the material can be purchased as a liquid. Ferric chloride may also be purchased as an anhydrous solid. Liquid ferric chloride is highly corrosive, and must be isolated from all corrodible metals. Like ferric sulfate, ferric chloride exhibits a wide pH range for coagulation, and the ferric ion does not easily become soluble. As a result, many plants are replacing alum with ferric chloride to eliminate the penetration of aluminum ions through the plant filters. Ferric chloride also reacts as an acid in water to reduce alkalinity. Table 2.1 show chemical coagulants for water treatment and their advantages, disadvantage and costs (Sobsey, 2002).

Table 2.1 Chemical coagulants for water treatment and their advantages, disadvantage and costs (Sobsey, 2002).



Coagulant	Community/Household Use	Advantages	Disadvantages	Cost*	Comments
Alum (aluminum sulfate, etc.), alum potash	Yes/rare-moderate	Community use common; simple technology	Difficult to optimize without training and equipment	Mod-erate?	Proper use requires skill
Iron salts (ferric chloride or sulfate)	Yes/rare	Same as Alum	Same as Alum	Mod-erate?	Proper use requires skill
Lime ($Ca(OH_2)$), lime+soda ash (Na_2CO_3), caustic soda (NaOH)	Yes/rare-moderate	Same as Alum	Same as Alum; pH control and neutralization a problem; hazardous chemicals	Mod-erate to high?	Softeners; not applicable to many waters
Soluble synthetic organic polymers	Yes/no-rare	Improve coagulation with alum and iron salts	Same as Alum; hard to dose; need training & equipment; hazardous chemicals	High	Use with other coagulants; limited availability
Natural polymers (carbohydrates) from seeds, nuts, beans, etc.	Rare/Yes (in some developing countries)	Effective, available and culturally accepted in some places	Source plant required; training and skill required; cultural acceptability; may be toxic	Low	Traditional use based on historical practices

*Estimated Annual Cost: low is <US$0.001 per liter, moderate is 0.001-0.01$ per liter and high is >0.01 per liter (corresponds to about <US$10, $10-100 and >$100, respectively, assuming household use of about 25 liter per day)

2.2 Flocculation

Flocculation is widely employed in the purification of drinking water as well as sewage treatment, storm water treatment and treatment of other industrial wastewater streams. Flocculation refers to a process where a solute comes out of solution in the form of floc or "flakes." The term is also used to refer to the process by which fine particulates are caused to clump together into floc. The floc may then float to the top of the liquid, settle to the bottom of the liquid or can be readily filtered from the liquid (Zeta-Meter, 1993).

The terms flocculation and coagulation are sometimes used interchangeably. However, it is more accurate to use the term coagulant for a chemical that contributes to molecular aggregation, rather than particular aggregation. Usually dissolved substances are aggregated into microscopic particles by a coagulant and then these particles may be flocculated into a macroscopic floc with a flocculent. In general, coagulants will have higher net charge and a lower molecular weight than flocculants.

Flocculation refers to the successful collisions that occur when the destabilized particles are driven toward each other by the hydraulic shear forces in the rapid mix and flocculation basins. Agglomerates of a few colloids then quickly bridge together to form microflocs which in turn gather into visible floc masses (Zeta-Meter, 1993).

2.2.1 Bridging

Bridging occurs when a coagulant forms threads or fibers which attach to several colloids, capturing and binding them together (Figure 2.2). Inorganic primary coagulants and organic polyelectrolyte's both have the capability of bridging. Higher molecular weights mean longer molecules and more effective bridging. Bridging is often used in conjunction with charge neutralization to grow fast settling and/or shear resistant flocs. For instance, alum or a low molecular weight cationic polymer is first added under rapid mixing conditions to lower the charge and allow microflocs to form. Then a slight amount of high molecular weight polymer, often an anionic, can be added to bridge between the microflocs. The fact that the bridging polymer is negatively charged is not significant because the small colloids have already been captured as microflocs. (Zeta-Meter, 1993)

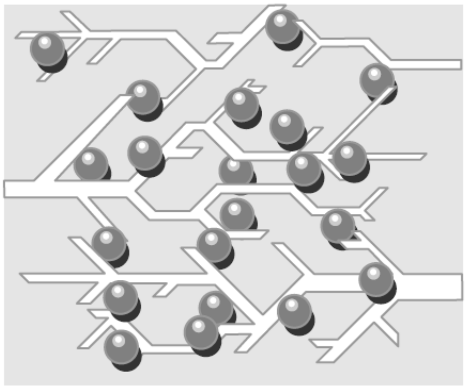


Figure 2.2: Bridging that each polymer chain attaches to many colloids (Zeta-Meter, 1993).

2.2.2 Flocculation Process

Flocculation is a time-dependent, slow process that directly affects clarification efficiency by providing multiple opportunities for particles suspended in water to collide through gentle and prolonged agitation. The process takes place in a basin equipped with a mixer that provides gentle agitation. This agitation must be thorough enough to encourage inter-particle contact but gentle enough to prevent disintegration of existing flocculated particles. Effective flocculation is important for the successful operation of the sedimentation process (Zeta-Meter, 1993).

Once the negative charges of the suspended solids are neutralized, flocculation begins. Charge reduction increases the occurrence of particle-particle collisions, promoting particle agglomeration. Portions of the polymer molecules not absorbed protrude for some distance into the solution and are available to react with adjacent particles, promoting flocculation. Bridging of neutralized particles can also occur when two or more turbidity particles with a polymer chain attached come together. It is important to remember that during this step, when particles are colliding and forming larger aggregates, mixing energy should be great enough to cause particle collisions but not so great as to break up these aggregates as they are formed. (Zeta-Meter, 1993)

In some cases flocculation aids are employed to promote faster and better flocculation. These flocculation aids are normally high molecular weight anionic polymers. Flocculation aids are normally necessary for primary coagulants and water sources that form very small particles upon coagulation (Zeta-Meter, 1993). A good example of this is water that is low in turbidity but high in color (colloidal suspension).

2.3 Roughing Filtration

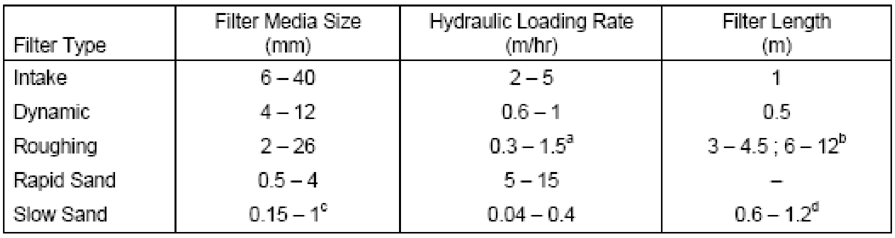
Previous studies have demonstrated the importance of physico-chemical Filtration (primarily the transport of suspended particles to filter media by sedimentation) for particle removal in roughing filtration.

This section summarizes the current understanding in roughing filtration, including a description of 1) roughing filtration in comparison to other granular filtration methods, 2) the primary mechanisms by which suspended solids are removed in roughing filtration and the key parameters governing particle removal, and 3) the two approaches used to model particle removal in roughing filtration. Findings from recent studies in roughing filtration are also provided.

2.3.1 Classification of granular filtration methods

The size of filter media, the hydraulic loading rate, and the length of the filter bed in the direction of flow are key design parameters in granular filters (Wegelin, 1987, Collins, 1994). Table 2.2 presents the typical design features of a roughing filter as well as those of other common granular filtration methods.

Table 2.2: Classification of granular filters (Collins, 1991; Wegelin, 1996).



Filter Type	Filter Media Size (mm)	Hydraulic Loading Rate (m/hr)	Filter Length (m)
Intake	6 – 40	2 – 5	1
Dynamic	4 – 12	0.6 – 1	0.5
Roughing	2 – 26	0.3 – 1.5[a]	3 – 4.5 ; 6 – 12[b]
Rapid Sand	0.5 – 4	5 – 15	–
Slow Sand	0.15 – 1[c]	0.04 – 0.4	0.6 – 1.2[d]

a rates above 1.0 are typically associated with horizontal roughing filters (HRFs)
b shorter filter lengths are associated with vertical roughing filters, longer depths with HRFs
c size typically between 0.35 - 0.15 mm
d does not include under drain gravel support, typically between 0.3 - 0.5 m in length

2.3.2 **Roughing filter configurations**

Roughing filters are generally either:-

1) A large compartment filled with successive layers of filter media decreasing in size in the direction of flow.

2) Multiple compartments connected in series, each filled with one media size. Water flow through the filter can be either horizontal or vertical.

Figure 2 shows three examples of roughing filters, including a horizontal roughing filter (HRF), a down flow roughing filter in series (DRFS), and an up flow roughing filter in series (URFS).

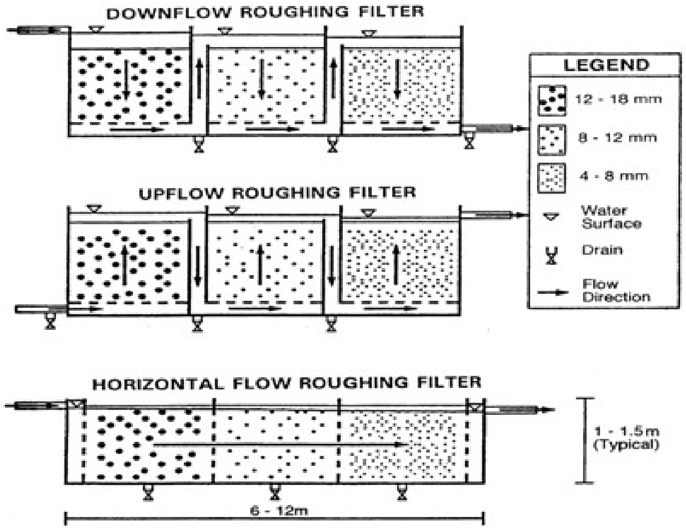


Figure 2.3: Roughing filters (Collins, 1994).

2.3.3 Roughing filter design parameters

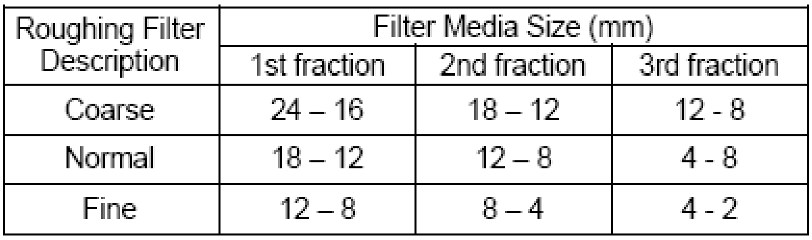
2.3.3.1 Filter media size

Media types commonly used in roughing filtration are quartz sands and gravels but can be replaced by any clean, insoluble, and mechanically resistant material (Graham, 1988). Previous work by Wegelin (1987) showed that the effect of surface porosity and roughness of filter media on particle removal efficiency in roughing filtration was insignificant compared to the size and shape of macro-pores in the filter. Rockledge and Ketchum (2002) studied the removal efficiencies in calcite limestone, basaltic river rock, and limestone-amended basalt horizontal roughing filters and found only marginally improved efficiency (7%) for calcite amended basalt filters over unaltered filters. Improved removal efficiencies are generally correlated to smaller media sizes (Wegelin, 1987; Collins, 1994).

The use of multiple grades of filter media in a roughing filter promotes the penetration of particles throughout the filter bed and takes advantage of the large storage capacities offered by larger media and high removal efficiencies offered by small media. The size of filter media decreases successively in the direction of water flow,

and ideally the uniformity of filter media fractions is maximized to increase filter pore space (storage capacity) and aid in filter cleaning (Boller, 1993).
Common grades of media used in roughing filters are provided by Wegelin (1996) and shown in Table 2.2.

Table 2.3: Typical media grades used in roughing filtration (Wegelin, 1996).



Roughing Filter Description	Filter Media Size (mm)		
	1st fraction	2nd fraction	3rd fraction
Coarse	24 – 16	18 – 12	12 - 8
Normal	18 – 12	12 – 8	4 - 8
Fine	12 – 8	8 – 4	4 - 2

2.3.3.2 Hydraulic loading rate

Because sedimentation represent a key filtration mechanism in roughing filtration (Wegelin, 1987), operation of roughing filters under laminar flow conditions is essential to maximize removal efficiencies. Flow conditions are described by the Reynold's number, which can be calculated through a porous medium by the following equation (Wegelin, 1996):

Re = (vdc) / ν

Where, v = hydraulic loading rate (m/s)
dc = collector (media) diameter (m)
ν = kinematic viscosity = 1.004 x 10-6 m2/s at 20°C

Laminar flow, characterized by consistent fluid motion, occurs at small Reynolds numbers (Re <10). Turbulent flow, characterized by random forces producing eddies and vortices, occurs at large Reynold's numbers (Re >100). A transition zone occurs where the Reynold's number is between 10 and 100. Figure 2.4 shows the different combinations of hydraulics loading rate and collector diameter (at 20°C) that result in a Reynold's number equal to 10.

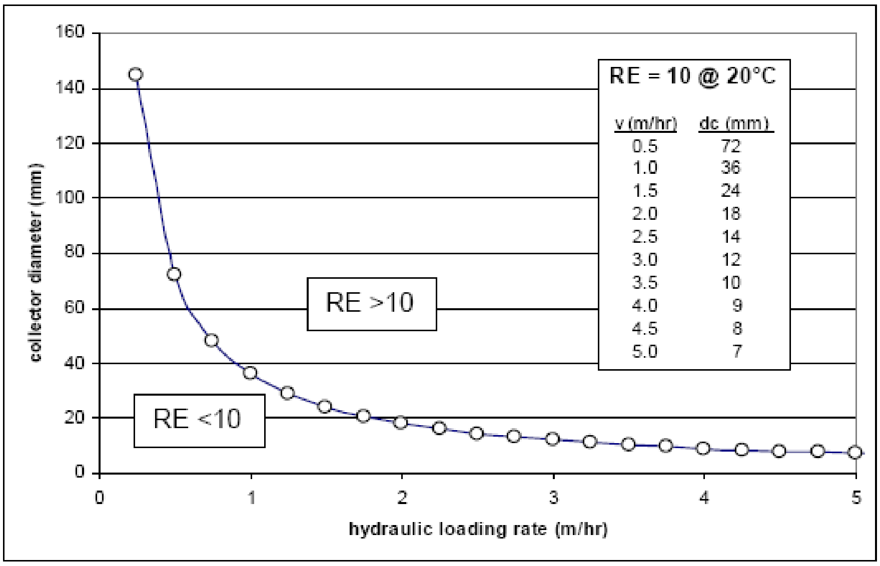


Figure 2.4: Relationship between Reynolds number and different combination hydraulic loading rate and collector (media) diameter (Wegelin, 1987; Collins, 1996).

Previous studies have shown that improved removal efficiencies are correlated to slower hydraulic loading rates when flow in laminar (Wegelin, 1987; Collins, 1996).

2.3.3.3 Filter length

Improved cumulative removal efficiencies are typically correlated to longer filter lengths (Wegelin, 1987; Collins, 1994). However, incremental removal efficiencies tend to decrease with increasing filter length due to the preferential removal of larger particles early in the filter (Wegelin, 1996). The rate of decline is dependent on filter design variables and the size and nature of particles in suspension. The use of different media sizes may allow for treatment targets to be met by a shorter filter with multiple media sizes compared with long filter packed with one media size, as illustrated in Figure 2.3.

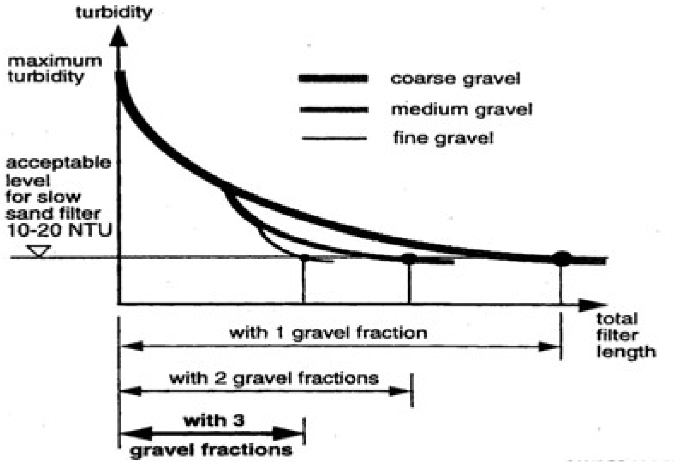


Figure 2.5: Significance of filter length (and media size) in roughing filtration (Wegelin, 1996).

2.3.4 Roughing filter operation and maintenance

The treatment performance of a roughing filter over time can be divided into two phases (Collins, 1994). The first phase represents a period when the particle removal efficiency remains relatively constant (steady-state) with increasing solids deposition, whereas the second phase represents a period of decreasing removal efficiency due to increasing particle deposition in, and penetration through, the filter.

Particle removal efficiency and particle penetration play a key role in determining filter run lengths. During a filter run, particles in a horizontal roughing filter (HRF) drift deeper in the direction of flow and also downward by gravity (Wegelin, 1996). Unlike in a HRF, particle drift in VRFs occurs only in the direction of water flow allowing for deeper penetration of particles in the filter and generally shorter filter run lengths (Collins, 1994).

The end of a filter run is typically determined when the quality of filter effluent deteriorates due to increasing solids deposit until minimum water treatment targets are exceeded. Drainage facilities located at the base of roughing filter compartments allow for rapid down flow drainage, a common maintenance procedure used to remove solids accumulated in the filter at the end of a filter run cycle (Galvis *et al.*, 1996).

Increases in filter resistance or head loss are typically small (<5cm) in roughing filtration due to the relatively coarse filter media used and low hydraulic loading rates applied (Wegelin, 1996). A condition, whereby actual head loss exceeds the available head loss prior to decreases in removal efficiency (i.e. the filter storage capacity is not exhausted before filter cleaning is required) signals the need to re-evaluate the filter design.

2.3.5 Important of suspension characteristics in roughing filtration

2.3.5.1. Size and density distribution of solid matter

Knowledge of the sizes and densities of solids in suspension is critical to predicting particle removal efficiencies in roughing filtration (Boller, 1991). Figure 2.6 shows the range of solid matter commonly found in natural surface waters.

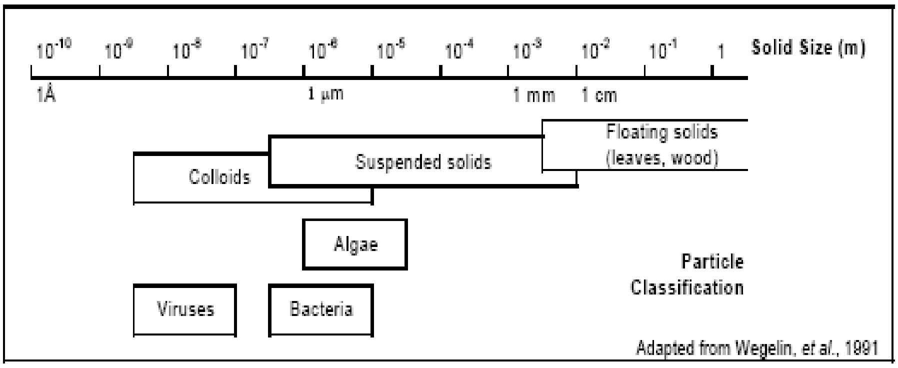


Figure 2.6: Range of solid matter commonly found in natural surface waters (Boller, 1991).

Prior to roughing filtration, large floating solids are typically removed by screening methods, and solids greater than about 20 µm can be separated from solution effectively using sedimentation methods. Remaining solids in suspension (suspended mineral and organic solids, algae, bacteria, viruses, and colloids) are thus the most commonly removed solids in roughing filtration (Wegelin, 1991).

2.3.5.2 Influence of water chemistry on solid surface-chemical properties

The chemistry of the water in which particles are suspended effects particle removal efficiency in roughing filtration, particularly for particles <10 µm (Boller, 1991). Particles in solution will develop a charge due to 1) the adsorption of ions from solution, 2) dissolution of ions from the solid lattice into solution, and/or 3) ionization of surface groups (Hunter, 1981). A particle’s charged surface attracts ions in solution of opposite charge and creates a charge (or potential) distribution into the bulk solution, the sign and magnitude of which is commonly measured as electrophoresis mobility or zeta potential of the particle. The distribution of charge on the solid surface is called the electrical double layer. When two particles approach, their electrical double layers cause the particles to repel one another. However, if the repulsion can be overcome, then particles will be attracted by van der Waals attractive forces, resulting in particle flocculation and increased particle settling rates (Hunter, 1981).

Increasing solution ionic strength increases particle flocculation rates and particle removal efficiency in granular filtration (Yao, *et al*. 1971). In freshwater, particles (e.g. clay minerals and organic matter) develop a negative surface charge potential due to the lack of sufficient cations in solution to satisfy negatively charged surfaces (Olphen, 1963; Boller, 1991). The same condition applies to the surfaces of filter media in treatment systems (Fitzpatrick and Spielman, 1973). The association of particles with dissolved organic matter (e.g. humic and fulvic acids) further increase the negative surface charge density of particles (Narkis and Rebhun, 1975). Polyvalent cations and flocculants are commonly used to neutralize negative surface charges, promote flocculation and improve filter removal efficiencies.

2.3.6 Particle removal mechanisms in roughing filters

Particles suspended in solution may be removed in roughing filters by one of three Mechanisms (Figure 2.7). These include:

- Surface (or cake) filtration,
- straining filtration, and
- Physico-chemical filtration

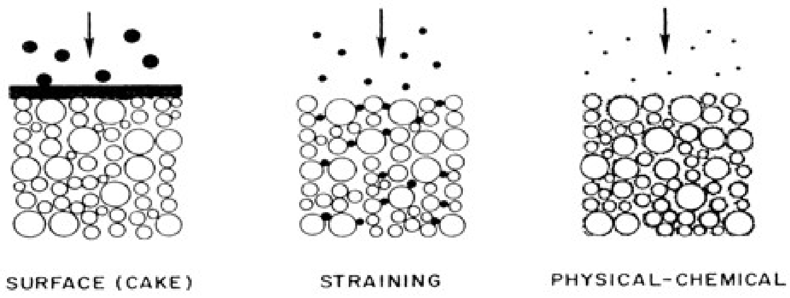


Figure 2.7: Primary particle removal mechanisms in granular filtration (Collins, 1994).

2.3.6.1 Physico-chemical filtration

For particles much smaller than the size of filter media (the common case in roughing filtration), particle removal is dependent on the successful transport and attachment of a particle to a media (or collector) surface.

Transport Process

The three dominant mechanisms governing transport of particles to a single collector (Diffusion, interception and sedimentation) are depicted in (Figure 2.8).

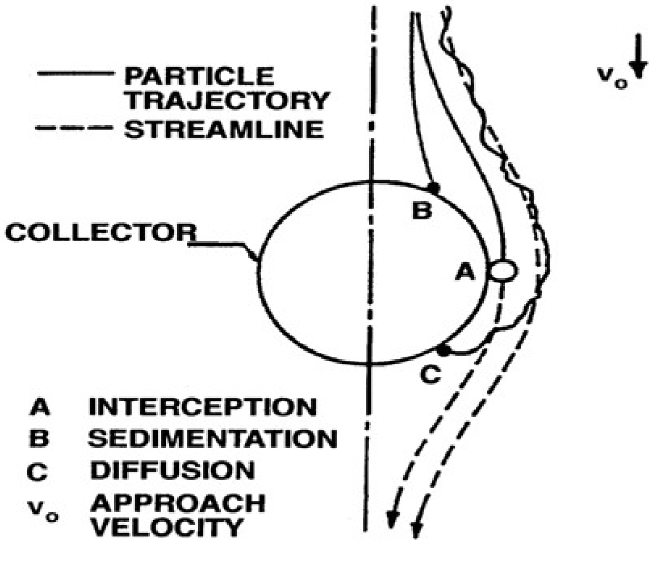


Figure 2.8: Mechanisms of particle transport to a single collector surface (Collins, 1994).

2.3.6.2 Surface and straining filtration

Surface (or cake) filtration results from the screening of particles at the surface of a porous media, resulting in the closing off of pore openings. Cake filtration is most likely to occur when the ratio of the collector diameter (dc) to particle diameter (dp) is less than 10 (McDowell-Boyer *et al.*, 1986). Straining filtration occurs when particles penetrate into porous media but are later lodged in the filter due to their large size. Straining filtration is likely to occur for the range of $10 \leq dc/dp \leq 20$ (McDowell-Boyer *et al.*, 1986).

Surface and straining filtration are not likely to play a dominant role in roughing filtration for the following reasons:

- Large particles (>20 μm) are usually removed prior to roughing filtration by methods, such as sedimentation (Wegelin, 1987) assuming particle densities allow large particles to settle faster.
- Proper roughing filter design promotes the removal of larger particles earlier in the filter in the presence of larger media allowing progressively smaller particles to penetrate deeper into the filter, where they come into contact with smaller sized media.
- Filter cake development in horizontal roughing filters and vertical up flow roughing filters are limited by particle drift and secondary particle detachment, respectively.

For all configurations, periodic filter maintenance limits filter cake development. Surface filtration may become more significant in the latter stages of a filter run as particles retained in the filter act as strainers for smaller particles. A filter cake of up to 7mm of kaolinite clay was observed at the completion of filter runs in DRF experiments with 2.68 mm diameter media (Collins, 1994). However, these experiments were conducted using very high particle concentrations (1,000 mg/L), which increased the potential for surface and straining filtration (Collins, 2005).

2.3.6.3 Iron removal

Iron is generally removed from ground water by the process of areation or chemical oxidation followed by rapid sand filtration. Different mechanisms (physicochemical and biological) may contribute to iron removal in filters but dominant mechanism depends on the physical and chemical characteristics of the water and process conditions applied.

The World Health Organisation (WHO) recommends that the iron concentration in drinking water should be less than 0.3 mg/l (WHO 1996).

Alterature review revealed that biological iron removal is not suitable when pH and oxygen concentrations are high and/or NH_{4+}, H_2S and Zn are present(Saroj K Sharma, Branislav Petrusevski, 2005).

Two mechanisms in the commonly applied oxidation precipitation filtration method can be identified

1- Oxidation-floc formation (floc filtration), in which iron (II) is first oxidised to iron(III) by oxygen or chemical oxidant, which upon hydrolysis and agglomeration forms iron hydroxide flocs. These flocs are subsequently removed in rapid sand filters.
2- Adsorption-oxidation (adsorption filtration), which involves the adsorption of iron(II) onto the surface of the filter media and its subsequent oxidation in the presence of oxygen or other oxidant to form a new iron oxide layer which enhances the adsorption and oxidation of iron(II) and facilitates the process.

2.3.7 Review of previous roughing filtration studies

There have been several studies on the application of up flow roughing filtration for both synthetic and natural waters using different filter configurations, media types and sizes, hydraulic loading rates, and filter lengths. Example design parameters and results are provided in below Table.

Removal efficiency (%) (NTU only otherwise noted)	**Media Type**	**Water Type**	**Influent Particle Concentration (NTU unless otherwise noted)**	**Test Duration**	**Hydraulic Loading Rate (m/hr)**	**Media (m**

60-75% average	Gravel	River water and kaolin-clay	average 10-20, up to 400 (<2 days); unknown NTU for clay challenge	568 days	0.6	40, 2
80% turbidity; 97% TSS	Gravel	Dynamic RF- treated Cauca River water	average 71-167, up to 420 NTU average 146-333, up to 881 mg/L TSS	25 weeks	0.7	19-13, 1
15%	Gravel	Reservoir water	384	N/A	0.53	1
13.2-20%			393-895		0.42	
30%			377		0.3	
41%	Angular, crushed granite	Synthetic (unknown)	100-200	40 days	0.75	25.4
						22x1
42%	Polystyrene (s-shaped)					11x8x7
<90%						11x8x
>90% for highly turbid water	Polystyrene (s-shaped) + Beads					11x8x7
average 45%; >60% for higher NTU						11x8x
average 45%; >60% for higher NTU						
54-83%	Quartz sand and gravel	Kaolinite clay	1,000 TSS	256-600 hrs	60	2.68, 4.8 11
75-97%	S/A (algae ripened)					

CHAPTER 3

MATERIALS AND METHODS

The experiments were conducted in two stages, first Jar tests, and secondly the pilot roughing plant set up and operation.

3.1 Jar test analysis

These tests were conducted in order to find the optimum conditions to coagulate and flocculate the raw turbid water using ferric chloride ($FeCl_3$) coagulant.

Jar test is a common laboratory apparatus used to determine the optimum operating conditions for pre treatment rughing filters, and to find the optimum coagulant dose used in roughing filters pilot test in order to predict the functioning of a large scale treatment operation. Jar test simulates the coagulation, flocculation and sedementation processes that encourage removal of suspended colloids and organic matter which can lead to turbidity problems. Raw water was taken from the open canal at Aqbat Jabber treatment plant during rainy season with highly turbidity ranges from 20 to more than 1000 NTU.

Jar test experiments were done at Birzeit laboratory and Aqbat Jabber water treatment plant. The apparatus consist of six paddles which stir the content of six 1 litter beakers (raw water content), one beaker may act as control while the operating conditions can vary (dose of coagulant., speed of mixing,…etc) among the remaining five beakers. An revolutions per minute(rpm) gage at the top center of the device allows for the uniform control of the mixing speed in all of the beakers (Figure 3.1).

In order to determine optimum dosage, several series of experiments carried out in this research from the turbid raw water open canal.

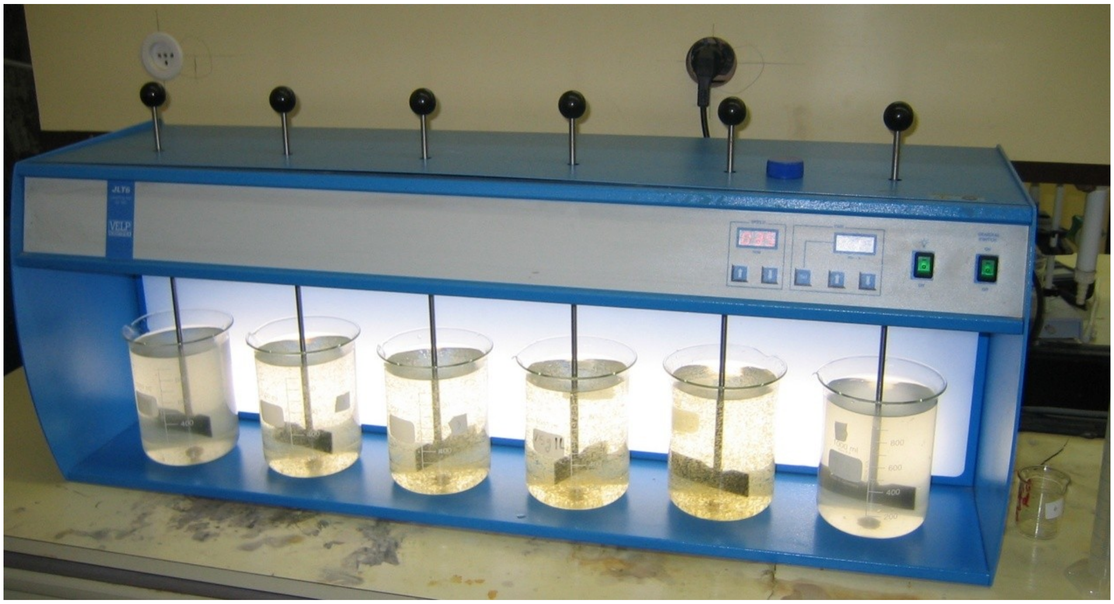


Figure 3.1: Photo of Laboratory Jar Test apparatus at Birzeit University

Jar test procedure was followed:-

1- Stock solution of coagulant was prepared by dissolving 10g of $FeCl_3$ coagulant in a 1 litter of demineralised water (each 1ml of stock solution = 10 mg/l $FeCl_3$ dose) and was stored in dark at room temperature. HCl was used for pH correction by adding few drops to demineralised water to for pH correction before adding $FeCl_3$coagulant.

2- Raw water from open canal was taken directly, pH and turbidity were measured.

3- Jar test apparatus six beakers filled with raw water.

4- One beaker was used as a control while different coagulant doses were added to the other beakers.

5- Different coagulant dose were added to the beakers (Appendix 1) at the same time while stir at 100 rpm speed for 1 min. The rapid mixing helps to disperse the coagulant throughout each beaker.

6- The stirring speed were reduced to 35 rpm and continue mixing for 15 min, this slower mixing speed helps promote floc formation that lead to large flocs (Figure 3.2).

7- The mixers were turned off and the beakers allowed settling for 30 min.

8- The final turbidity and pH were measured in each beaker.

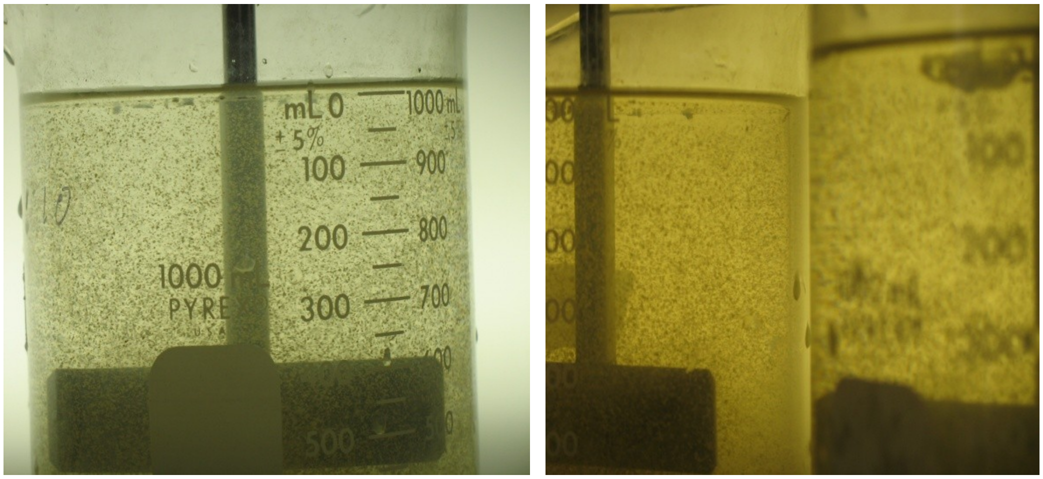


Figure 3.2: Large floc produced according jar test with slow mixing.

3.2 Roughing Pilot plant set up and operation

Roughing filtration runs were carried out at Aqbat Jaber WTP. Turbid raw water was entered the two filter columns A and B directly from the open canal. The turbidity in the canal was not constant. The experiments were carried out with varying process conditions as given in table 3.5. Turbidity was measured continuously to check the filters performance at the end of filter layers of each filter. Turbidity removal is a good indicator of the extended of suspended solids. The experimental filter run is ended when the effluent turbidity start deterioration.

A schematic diagram of the experimental set up used in this research is given in figure 3.3 and 3.4. The pilot plant consists of:

1- Raw water intake feeding system with two stages:
    a- Raw water with natural high turbidity from open canal directly at rainy season.
    b- Synthetic turbidity produced after turbidity lost in canal stored in large tank.
2- Up flow gravel filter columns
3- Coagulation system
4- Static mixers

5- Peri-staltic Pumps.

6- Rotameter for flow mesurment.

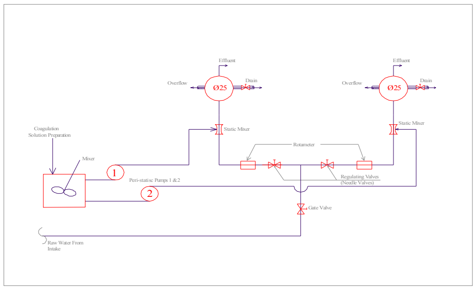


Figure 3.3: Layout of the Water Treatment Pilot plant

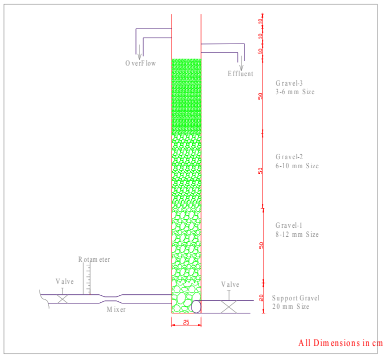


Figure 3.4: Cross section of the Roughing Filter Pilot plant.

3.2.1 Raw water intake

The raw water used for feeding the roughing filters was coming from the open canal that transports water from Wadi Al Qilt springs to the Water Treatment Plant at Aqbat Jabber. This water becomes highly turbid especially during rainy season (figure 3.5), because of rain water runoff. A plastic tubes was used to feed the two up flow roughing filters with this turbid water. Regulating valves and rotameters were added to control the water flow rates.

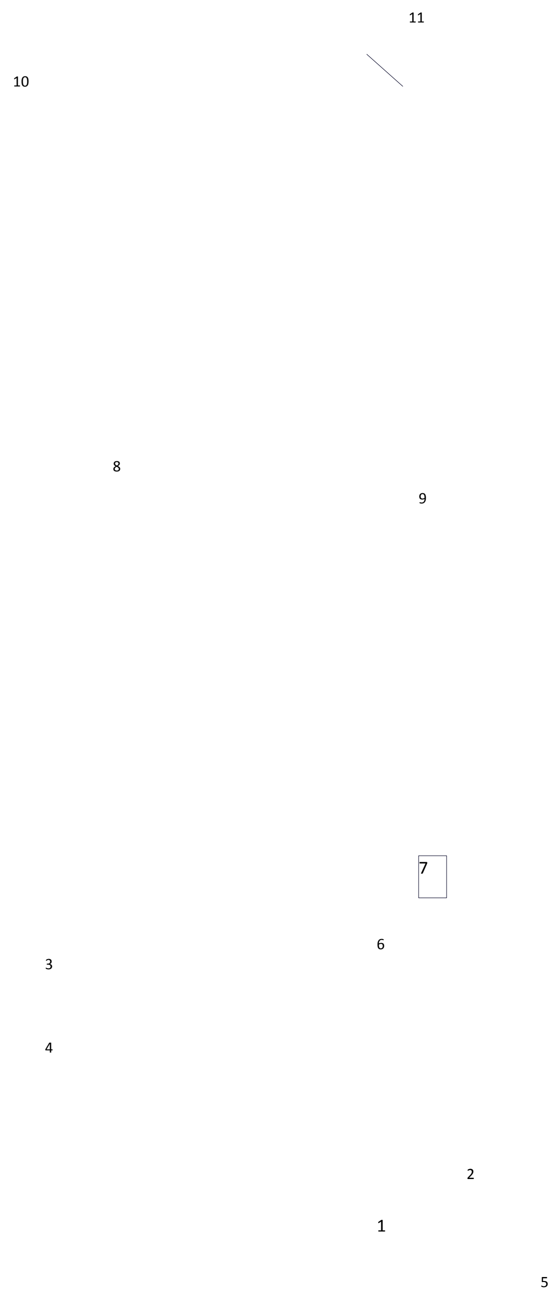
Synthetic turbid water were prepared and used when water turbidity was low in the canal, this water was collected in large 1500 L tank.

Figure 3.5: Highly turbid water transport in open canal at Aqbat Jaber.

3.2.2 Up flow gravel filter columns

Two units of gravel up flow filters were used. They are made by PVC tube with 0.25 m diameter and 2 m high. These units consist of raw water inlet, Effluent filtered water (figure 3.6), and overflow pipes, four layers of gravels media were filled in each column begin with 20 mm size at the bottom to reach 6 mm at the top. Figure 3.6 gives the results of the sieve analysis.

Four samples collection tubes piezometers were added at the end of each layer for each column to measure turbidity for performance examination of each filter layer.


11
10
8
9
7
6
3
4
2
1
5

1: Raw water inlet 2: Regulating valve 3: Raw water line 4: Coagulant line
5: Peri-static pump 6: Static mixer 7: Rotameter 8: Piezometer
9: Sample point 10: Effluent 11: Overflow

Figure 3.6: Roughing Pilot plant at Aqbat Jaber WTP

3.2.3 Coagulation system

Ferric Chloride ($FeCl_3$) was used as a coagulant, because it's cheap and available, many previous research work obtained to compare with this research results, it's a slightly difference in cost and action found in previous research if compared with alum coagulant.

The coagulant dosing system consists of the coagulant stock solution, peri-staltic pumps as a feeding system, and rapid mixing tools. A stock coagulant solution was prepared in 10 litter's plastic tank by dissolving 100 g of ferric chloride in 10 L demineralised water. A volumetric peristaltic pump was used to feed the required coagulant dosage to the up flow roughing filter via plastic tube after passing through a static mixer were rapid mixing with raw water was achieved.

3.2.4 Static mixer

A static mixer is a device for blending (mixing) two liquid materials. The device consists of mixer elements contained in a cylindrical (tube) or squared housing (Figure 3.7). The static mixer elements consist of a series of baffles that are made from stainless steel. The mixer type is Komax tube mixer manufactured in the USA. The mixer is of 17.5 cm length and 1 cm diameter.

The overall system design incorporates a method for delivering two streams of liquids into the static mixer (raw water and coagulant stock solution). As the streams move through the mixer, the non-moving elements continuously blend the materials. Complete mixing is dependent on many variables including mixer length, tube inner diameter, the number of elements and their design.

Figure 3.7: Static mixer

3.2.5 Peri-staltic pumps

Two peristaltic pumps with different Q max, 3.3 l/hr and 0.6 l/hr were used in this research. Pump flow for coagulation stock solution was calculated to know the amount of coagulant dose needed (appendix 7), one ml of stock solution stored in coagulant tank equal 10 mg $FeCl_3$ dose.

3.3 Measurements

3.3.1 Turbidity

Turbidity in raw water was measured at the beginning of each run and during filter run; turbidity meter type (HI 93703) was the instrument used. Four sampling point were provided in each filter at the end of each layer. Turbidity samples were measured from these points and from the final effluent.

3.3.2 Flow control

Two filtration rate obtained from previous research were kept constant, 0.5, and 1.5 m/hr. there was sufficent pressure as the raw water inlet from the canal was at high elevation. Rotameter were used in this research to measure the water flow rate. Two different flow rate obtained according to filtration rate and area of column by this equation:-

Flow rate = filtration rate * Area.

Area of the column = $(0.125)^2 * 3.14$
$=0.049\ m^2$

$0.5\ m/hr * 0.049\ m^2 = 24.5\ l/hr$

So for 0.5 m/hr filtration rate, 24.5 l/hr flow rate of water was obtained, and 73 l/hr were obtained for 1.5 m/hr, these two flow rates were kept constant and controlled using rotameter.

3.3.3 Head loss

Head loss measurement is important in filters operation to determine filter resistance to flow. According to filtration process head loss occur when the pores of filter closed from suspended particles accumulation causing flow rate decreased and loss of permeability. In this research filters were operated in constant flow rate (constant head) mode. The head loss was kept constant by maintaining a constant flow by adjusting the regulating valve opening over each experimental run.

3.3.4 pH measurements

Measurements of pH to the raw water from canal were carried out at Aqbat Jaber WTP using pH meter at the beginning of each filter run. Calibration is also done before using this meter.

3.3.5 Fe measurements

Total Fe measurement was conducted at Aqbat Jaber WTP using DR/890 HACH colorimeter from filter effluent and water canal influent. Samples were taken each 4 hours during a filter run.

3.4 Total and fecal coliform

Samples of raw water from open canal influent before roughing treatment were taken and analyzed for microbial pollution, total coliform (TC) and fecal coliform (FC), to determine the pollution sources such as waste water infiltration and uncontrolled disposal of waste. Microbiological tests were carried out at Ministry of Health Center Public Health laboratory by membrane filter techniqe .

3.5 Sieve analysis

Measurements of filter media size are the most important step in roughing filters setup to achieve a desired purification which is the main objectives of this research. Particles suspended in solution may be removed in roughing filters by attachment of media (gravel particles), so particle removal is dependent on the successful transport and attachment of a particle to a media (or collector) surface. Sieve analysis was done at Birzeit University laboratory.

3.6 Pilot experimental process conditions

Six filtration runs at different filtration rate were done, the pilot experimental process conditions are presented in table 3.5.

Table 3.5 *Pilot experimental process conditions.*

Run no	Filtration rate m/h	Coagulant dose mg/l Ferric chloride	pH	Temp.
1A	0.5	0	8.3	10.8
2A	0.5	0	8.4	16.1
2B	0.5	0	8.4	16.1
3A	1.5	0	8.1	10.2
3B	0.5	0	8.1	10.2
4A	1.5	0	8.4	26
4B	0.5	0	8.4	26
5A	0.5	40	8.1	25
5B	0.5	0	8.1	25
6A	0.5	30	8.2	23
6B	0.5	0	8.2	23

Note A= Filter column no. 1 B= Filter column no. 2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Presentation of results

Six roughing filtration runs at different filtration rates, and seventeen jar test experiments were carried out to achieve the objectives of this research.

The results of these filter runs are presented in detail in Appendix 2. The results of jar test experiments are summarized in table 4.1.

Results of jar tests are presented in detail in appendix 1. Results of sieve analysis are presented in appendix 6.

Results of filter turbidity removal vs. time are presented in figures 4.3A1, 4.4A2, 4.4B2, 4.5A3, 4.5B3, 4.6A4, 4.6B4, 4.7A5, 4.7B5, 4.8A6, 4.8B6 and annex 2 (tables of filters runs).

Results of Fe, fecal coliform and total coliform measurements for water canal and pilot filters effluent are presented in this chapter.

4.2 Jar test experiments

Jar test experiments were carried out at Aqbat Jaber WTP, turbid raw water used was from the open canal directly at rainy season, Tempreture and turbidity were mesured directly (water canal). Different turbidity was used and different doses of coagulant were also used to choose the optimum doses needed for filtration (Appendix 1). Table 4.1 show the summary of jar test results obtained.

Table 4.1: Summary of 16 Jar test optimum doses results suitable for different turbidity.

Turbidity canal	Optimum dose mg/l $FeCl_3$
30	0
35	0
37	<10
40	0
50	<10
65	<10
80	<10
140	0
235	<10
240	10-20
300	<10
530	10-20
800	10-20
1000	20-30
More than 1000	≥30

Table 4.1 shows the summary of jar test optimum doses that can be used in the pilot filter runs. Some experimental results show unexpectedly that turbidity between 37 and 39 need coagulant less than 10 mg/l and with turbidity between 40 to 45 no need for coagulant (Table 4.1). This may occur because of different type of water pollutant like soil particles size that sedimentation is a kind of process after mixing and solubility.

Most of jar experiments satisfy slow sand filter requirements without filtration and without need of coagulant Appendix 1, and Table 4.1. Optimum dose in these experiments chosen as one that brings down NTU to less than 20.

4.3 Pilot filter runs

4.3.1 System workability

In this run, which was the first filter run to gain hand on operating the system, no coagulant was added to the raw water prior to filtration.

The filter run were mode at a filtration rate of 0.5 m/hr. From figure 4.1A1 raw water turbidity was not constant and ranged from 25 to 75 NTU. The effluent turbidity obtained after this run was ranged from 0 to 3.8 with more than 95% removal efficiency at raw water turbidity as high as 75 NTU.

During the run, and in all pilot filters run, turbidity removal was varying at the end of each layer according of different filter gravel layers size Table . From tables' appendices 2, we can see that the turbidity removal is increased due to decreases in filter media size from the bottom to reach the less turbidity water at the top. So the use of multiple grades of filter media in a roughing filter promotes the penetration of particles throughout the filter bed and with large storage capacities achieved by large media and high removal efficiencies by small media.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.1A1 Effluent water Turbidity (EFT) from pilot filter column A with raw water canal turbidity (RWT) vs. filtration run time at the first pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.3.2 Similarity of tow filter columns

This run was done with the same process conditions as the first run (0.5 m/hr, 35-75 NTU turbidity influent from canal). This run was done to examin the similarity of the two pilot filter columns A and B.

Column A

From figure 4.2A2 raw water turbidity is not constant and range from 35 to 75 NTU, effluent turbidity obtained is below detection limit after representing an excellent removal efficiency closed to 100%.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.2A2 Effluent water Turbidity from pilot filter column A with raw water canal turbidity vs. filtration run time at the second pilot filter run with 0.5 m/h filtration rate without using coagulant.

Column B

From figure 4.3B2, effluent turbidity obtained is below detection limit after representing an excellent removal efficiency closed to 100%.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.3B2 Effluent water Turbidity from pilot filter column B with raw water canal turbidity vs. filtration run time at the second pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.3.3 Filtration rate

In this run, which was the third run no coagulant was added to the raw water prior to filtration. The roughing filters was operated at filtration rate of 1.5 m/hr for the first filter A, and 0.5 m/hr for the second filter B .

<u>Column A</u>

From figure 4.4A3 and Table 4.2 raw water turbidity is not constant and ranged from 25 to 87 NTU, the effluent turbidity obtained after this run ranged from 2.4 to 15 with 82% removal efficiency at higher raw water turbidity (87 NTU).

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 1.5 m/hr produces a good results.

Figure 4.4A3 Effluent water Turbidity from pilot filter column A with raw water canal turbidity vs. filtration run time at the third pilot filter run with 1.5 m/h filtration rate without using coagulant.

Table 4.2 Detailed measurements for pilot filter run in filtration rate test for filter column A.

Sample port	**parameter**	**Sampling time**													
		7:30 PM	**8:30 PM**	**10:00 PM**	**11:00 PM**	**12:00 AM**	**1:00 AM**	**2:00 AM**	**3:00 AM**	**6:00 AM**	**7:00 AM**	**8:00 AM**	**10:00 AM**	**2:00 PM**	**4:30 PM**
A	**Turbidity NTU**	**23**	**17.4**	**14.5**	**12**	**13.4**	**13.54**	**11.4**	**9.65**	**5.47**	**8.30**	**8.22**	**8.50**	**9.65**	**8.40**
B	**Turbidity NTU**	**22**	**13.6**	**12**	**10.7**	**13**	**12**	**10**	**7.60**	**6.9**	**8.10**	**7.70**	**7.20**	**8.00**	**8.00**
C	**Turbidity NTU**	**18.6**	**10.6**	**9.6**	**9.46**	**10.8**	**9.65**	**9.3**	**7.20**	**5.50**	**6.40**	**6.10**	**7.00**	**7.30**	**6.30**
D	**Turbidity NTU**	**16.6**	**9.13**	**8.78**	**8.16**	**9.26**	**8.58**	**7.5**	**5.90**	**3.89**	**2.70**	**5.40**	**6.50**	**7.00**	**7.60**
Final	**Turbidity NTU**	**15**	**8.76**	**8.40**	**8.10**	**9.20**	**8.30**	**7.3**	**5.85**	**4**	**2.40**	**4.70**	**6.40**	**6.60**	**7.60**

From the table above pilot filter composed of three filter fraction ranging in size from coarse (layer A) to fine gravel size (layer D). As in figure 3.4 chpter 3 a large amount of suspended solids are removed by the first filter

filter medium located next to the filter inlet, in table 4.2 we can see that the turbidity is decreased from 87 NTU appendix 3 to 23 NTU at the first gravel layer A, because of its large pore volume for accumulation and by the aid of gravity, the last filter fraction role as polishing function as it supposed to removed the last traces of the finest suspended solids found in the water, so removal efficincy increased at the bottom of filter.

Column B

From figure 4.5B3 and Table 4.3 raw water turbidity was not constant and ranged from 25 to 87 NTU, the effluent turbidity obtained after this run ranged from 2 to 9.8 with 87% removal efficiency at higher raw water turbidity (87 NTU).

Table 4.3 Detailed measurements for pilot filter run in filtration rate test for filter column B.

Sample port	parameter	Sampling time													
		7:30 PM	8:30 PM	10:00 PM	11:0 PM	1	1:00 AM	2:00 AM	3:00 AM	6:00 AM	7:00 AM	8:00 AM	10:0 AM	2:0 PM	4:0 PM
A	Turbidity NTU	16.20	13	10.90	9.00	1	12.5	8.42	9.80	4.67	7.99	9.00	10.0	8.30	8.00
B	Turbidity NTU	13.00	10.20	7.00	8.20	1	9.95	7.48	7.00	4.60	5.90	6.10	8.10	8.00	7.70
C	Turbidity NTU	12.20	10.00	6.90	7.30	6	8.20	7.00	4.85	5.90	4.30	3.58	6.00	6.50	4.28
D	Turbidity NTU	9.95	9.49	3.52	6.19	5	5.76	5.00	2.80	2.10	2.80	3.10	4.00	4.70	2.70
Final	Turbidity NTU	9.83	9.00	3.60	6.10	5	5.67	5.00	3	3.10	2.30	3.20	4.00	4.40	2.00

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.5B3 Effluent water Turbidity from pilot filter column B with raw water canal turbidity vs. filtration run time at the third pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.3.4 Effect of long term filtration

In this run, no coagulant was added to the raw water prior to filtration. The filter run were made at filtration rate of 1.5 m/hr for the first filter A and 0.5 m/hr for the second filter B.

Column A

From figure 4.6A4 raw water turbidity is not constant and lower range from 0 to 4 NTU, the effluent turbidity obtained after this run was closed to zero with a removal efficiency closed to 100% at higher raw water turbidity (4 NTU).

The effluent quality in this run was meet the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 1.5 m/hr produces a good results.

Figure 4.6A4 Effluent water Turbidity from pilot filter column A with raw water canal turbidity vs. filtration run time at the fourth pilot filter run with 1.5 m/h filtration rate without using coagulant.

Column B

From figure 4.6B4 raw water turbidity is not constant and lower range from 0 to 4 NTU, the effluent turbidity obtained after this run was closed to zero with removal efficiency closed to 100%.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

RWT = Raw water turbidity from canal   EFT = Effluent filter turbidity

Figure 4.6B4 Effluent water Turbidity from pilot filter column B with raw water canal turbidity vs. filtration run time at the fourth pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.3.5 Effect of coagulant on filtration process

4.3.5.1 High water influent turbidity

In this run, 30 mg/l of $FeCl_3$ coagulant was added to the raw water prior to filtration in the first column A, no coagulant added to the second filter B, the two columns were operated at 0.5 m/hr.

Column A

From figure 4.7A5 raw water turbidity was high more than 950 NTU, the effluent turbidity obtained after this run was 0.63 and 26 at the first 8 hours with 99.9% and 97% removal efficiency but after 14 hours the effluent turbidity start deterioration and reached 112 with flow water resistance that mean the end of this run .

During the run, turbidity removal was varying at the end of each layer according of deferent filter gravel layers size appendix 2.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.7A5 Effluent water Turbidity from pilot filter column A with raw water canal turbidity vs. filtration run time at the fifth pilot filter run with 0.5 m/h filtration rate with 40 mg/l $Fecl_3$ coagulant.

Column B

From figure 4.7B5 raw water turbidity is very high 950 NTU, the effluent turbidity obtained after this run was 182, 169 and 159 with more than 82% removal efficiency

The effluent quality in this run did not meet the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr without coagulant produces unsatisfactory results.

Figure 4.7B5 Effluent water Turbidity from pilot filter column B with raw water canal turbidity vs. filtration run time at the fifth pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.3.5.2 Very High water influent turbidity

In this run, 40 mg/l of $Fecl_3$ coagulant was added to the raw water prior to filtration at the first column A, no coagulent addition at second filter column B. the two columns were operated at 0.5 m/hr.

Column A

From figure 4.8A6 raw water turbidity is very high more than 1000 NTU. The effluent turbidity obtained after this run was 3.5 and 12.6 at the first 6 hours with approximately 95% removal efficiency but after 10 hours the effluent turbidity started deterioration and reached 111 NTU with flow water resistance that mean the end of this run.

The effluent quality met the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr produces a good results.

Figure 4.8A6 Effluent water Turbidity from pilot filter column A with raw water canal turbidity vs. filtration run time at the sixth pilot filter run with 0.5 m/h filtration rate with 30 mg/l $Fecl_3$ coagulant.

Column B

From figure 4.8B6 raw water turbidity is very high more than 1000 NTU, the effluent turbidity obtained after this run was 188, 174 and 166 with more than 80% removal efficiency

The effluent quality in this run did not meet the influent requirement of SSF of at least 20 NTU, implying that under the given process conditions a filtration rate of 0.5 m/hr without coagulant produces unsatisfactory results.

Figure 4.8B6 Effluent water Turbidity from pilot filter column B with raw water canal turbidity vs. filtration run time at the sixth pilot filter run with 0.5 m/h filtration rate without using coagulant.

4.5 Total and fecal coliform results

Total and fecal coliform tests were carried out at Ministry of Health Center Public Health laboratory. Samples of raw water from open canal influent before roughing treatment were taken and tested the results show that the water canal is a highly polluted with TC and FC.

The results of all the tests done from the canal was TMTC and also from the filter effluent. The FC and TC of slow sand filter after chlorination was zero, so chlorination and slow sand filtration are the most important stages in water treatment after roughing filtration. Because of small retention time and high turbidity the small pilot roughing filters can not releases or decreases Total and Fecal coliform.

4.5 Fe results

The results of Fe measurements for water canal shows that Fe is zero, but the effluent water from the roughing filter show increases to reach more than 1.17 mg/l , 1.19 mg/l and 1.15 mg/l. The samples were taken every 2 hour during filter run, the coagulant dose was 40 mg/l $FeCl_3$ with turbidity more than 1000 NTU (Appendix 2, filter run 6B).

4.6 Discussion

4.6.1 General

The aim of this research was to find suitable design parameters for the pre-treatment of up flow roughing filters and asses the filter efficiency in decreasing high water canal turbidity to less than 20 NTU for enhancing slow sand filters operational performance, and to asses the influence of coagulant on filtration process.

As can be seen from the results in table 4.2 and figures 4.3A1 to 4.8B6, the filter proved efficiency by decreasing turbidity until more than 87 NTU to less than 20 NTU without using coagulant with 0.5 and 1.5 m/hr filtration rate, and removed turbidity for more than 1000 NTU by the aid of chemical coagulant with 0.5 m/hr filtration rate.

4.6.2 Removal efficiency

Treatment efficiency is dependent on raw water, characteristics, layout and operation of roughing filters.

1st – size, concentration, type of particles and suspension stability are the most important water quality parameters influencing suspended solids removal efficiency.

2nd – filter material size, filter length, applied filtration rate, cleaning frequency are the key factors determining filter efficiency. Hence, roughing filter with identical layout and operation may vary in filter performance with deferent raw water sources. Therefore, an exact indication of filter efficiencies is generally quite impossible (Wegelin, 1996).

In this research the filter performance has been tested with different filtration rates. The dependency of overall efficiency on turbidity removal, and filter run time and filtration rates can be seen in Table 4.4

Table 4.4 Filter turbidity removal efficiency in all filter runs

Run #	Filter run time hr	Filtration rate m/hr	Turbidity influent NTU	Turbidity effluent NTU	Turbidity removal %
1A	8	0.5	25-75	0 - 3.8	*97
2A	8	0.5	35-75	Near zero	Closed to100
2B	8	0.5	35-75	Near zero	Closed to100
3A	24	1.5	25-87	2.4 - 15	*82
3B	24	0.5	25-87	2 - 9.8	*87
4A	288	1.5	0-4	Near zero	Closed to100
4B	288	0.5	0-4	Near zero	Closed to100
5A	After 8 hrs	0.5	950	0.63 - 26	*97
5B	14	0.5	950	159 - 182	*82
6A	After 6 hrs	0.5	More than 1000	3.5 – 12.6	More than 95
6B	14	0.5	More than 1000	166 - 188	More than 80

* Efficiency calculated at higher influent and effluent turbidity.

* A: the first column, B: the second column

Mechanical, physical, biological and chemical processes all play role in up flow roughing filtration. Experience to date is limited and little is known about the mechanism responsible for removal of suspended and colloidal materials.

O'Melia and stumm reported that the removal process and removal efficiency in filtration depends on the combination of particle transport and attachment, the removal of particles depend more on the attachment mechanisms (O'Melia, 1967).

From the set of experiments excellent removal efficiency were observed along the period of filter runs ranges between 80% and closed to 100% in some parts of this runs. Slightly different observed in removal efficiency between 0.5 m/hr and 1.5 m/hr as seen in run 3A and 3B in table 4.4 and figures 4.5A3 and 4.5B3, the removal efficiency is better at 0.5 m/hr because this lower in filtration rate may increase the probability of particles being retained.

4.6.3 Effect of coagulant

Remove particulate impurities from water by beds of granular media becomes more effective for larger particles. In this process the removal efficiency is greatly dependent on particle size and can usually be enhanced by aggregation of particles by a coagulation/flocculation procedure in which particles are destabilized by a coagulant causing this aggregates. Removal of particles of a few µm or less is quite difficult by this process so it is necessary to increase their size in some way, the only practical methods is to cause particles to aggregate forming large unit (coagulation) to enhanced its removal. To be removed, a particle must not only come into contact with a media grain, but must also attach to it. Not all contacts between particles and media lead to attachment; attachment efficiency (α) is used to represent the fraction of successful contact. The value of α varies from one (all contact results in attachment) to zero (no contact results in attachment). Chemical coagulation pretreatment promotes attachment efficiency, with optimized coagulation conditions increasing the value of α. (O'Melia & Stumm, 1967).

From the table 4.4 and figures 4.7 A5 and 4.8 A6 we can see that the removal efficiency is increased with the aid of chemical coagulant compared with that without coagulant figures 4.7B5 and 4.8B6 at the same filtration rate. Large aggregate was seen in the 5A and 6A filter runs were passed throw Piezometer of filters (Figure 4.9), the aggregates produced after turbid water was mixed with coagulant these aggregates were helping in enhanced and increased removal of particles.

Adding a sedimentation tank before roughing filter is more feasible also to decrease the high water canal turbidity as we see in (appendix 1), water turbidity of blank according jar test were decreased every time esspesally for higher turbidity.

Figure 4.9 Large flocks passed throw Piezometer of filter.

4.6.4 Grain size

The filter material should have a large specific surface to enhance the sedimentation process taking place in the roughing filters, and high porosity to allow the accumulation of the separated solids (Wegelin, 1996).

Pilot filters were made at aqbat jaber composed of three filter fraction ranging in size from coarse to fine, a larger amount of suspended solids are removed by the first filter medium located next to the filter inlet (A sample port appendix 2) because of its large pore volume for accumulation, the last filter fraction role as polishing function as it supposed to removed the last traces of the finest suspended solids found in the water. Small and irregular grains play an important role in increasing removal efficiency by increasing the surface area per unit volume of filtering material and destabilized particles (Husman, 1986).

4.6.5 Filter cleaning

Filter efficiency is not constant but may increase at start of filter run and certainly decrease with filter run time increased that solid matter accumulates excessively in the filter, hence periodic removal of this accumulated matter is required to restore efficiency and possibly hydraulic filter performance.

When the turbidity in the water increased intensively like in run 5A, 5B, 6A, 6B (more than 1000 NTU) the filter run decreased because of a huge particles sedimentation that closed the pores leading to loss permeability and end the filter run with a short time (14 hours) in the 5A, 5B, 6A, 6B runs result in high turbid water effluent. The filters were cleaned hydraulically, the drainage valve opened quickly, shock drainage achieved by fast opening and closing valve.

4.6.6 Bacteriological and Fe water quality improvement

The pre treated water still needs further treatment for final removal or in activation of pathogens. From total and fecal coliform result we can see that the effluent pilot filter water is still bacteriological high because of low water retention time. Slow sand filtration and chlorination are the two most commonly applied treatment processes for Bacteriological water quality improvement.

The effluent of well designed and operated slow sand filter is virtually free from pathogenic microorganisms. Chlorination aims at destroying harmful microorganisms, such as pathogenic bacteria, viruses, and cysts present in water because chlorine is a strong oxidant. From the results done at MOH laboratories show that the water effluent after SSF and chlorination processes are free from total and fecal coliform, that mean low efficiency of pretreatment filters for releasing fecal and total coliform does not affected the final water quality for drinking at AJWTP. Also for

Fe concentrations that are high also slow sand filter can remove iron and decreased it to allowable concentrations for drinking.

CHAPTER 5

Conclusions and Recommendation

5.1 Conclusions

1. The roughing filters effluent quality met the influent requirement of SSF in this study of less than 20 NTU, implying that under the given process conditions a filtration rate of 1.5 m/hr and 0.5 m/hr produces a good results without addition of any chemical with turbidity range 20 to 100 NTU.

2. This study confirms that use of coagulant before roughing filtration yields better effluent quality for turbidity water canal more than 100 NTU from the results of filter runs at the same conditions and design parameters.

3. According to field study done, water turbidity at Aqbat Jaber WTP canal is not constant, its increased at rainy days as follows

- Turbidity first increased to more than 1000 NTU for few hours then its decrease to less than 300 and 200 NTU also for few hours and sometimes for one day that can enter filters with addition of coagulant pretreatment.
- The most dominant turbidity range from 20 to 90 for few days that can enter the filters without use of coagulant (appendix 3).
- Turbidity in summer is low (less than 5 NTU) and no need for pre treatment.

- Adding a sedimentation tank before roughing filter is more feasible to decrease the high water canal turbidity at rainy season produced by soil errosion.

4. Aqbat jaber water canal is highly polluted with FC and TC due to several pollution sources seen according field investigation (appendix 5) like AWWTP and waste water disposal from Israeli settlements and also, because its open canal that can polluted from different other sources pollutants.

5. From total and fecal coliform result the effluent pilot filter water is still bacteriological high because of low water retention time. From the results done at MOH laboratories show that the water effluent after SSF and chlorination processes are free from total and fecal coliform that mean low efficiency of pretreatment filters for releasing fecal and total coliform does not affected the final water quality for drinking at AJWTP.

5.2 Recommendation.

1. Further research studies are needed to prevent contamination of water canal from waste water disposal from different sources that affected Ein alfawwar and Alqilt springs (appendix 5).

2. Maintenance of open canal between Ein alfawwar and Ein Al-Qilt is important to achieve this prevention to avoid mixing with waste water, due to a good water quality and quantity of Ein alfawwar, and then connected with open transport canal feeding AJWTP.

3. Watershed management plan should be developed to reduce water pollution loads of un controlled waste disposal sites and winter runoff events.

4. Furthermore measurements for Fe after pre-treatment and after SSF before drinking are needed when coagulant use to measure the efficiency of SSF in removing Fe.

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APPENDICES

Appendix 1: Detailed measurements of jar tests experiments done at Aqbat Jaber

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.5	129	0	**1 Blank**
7.98	34	10	**2**
7.80	10.4	20	**3**
7.72	9	30	**4**
7.59	5.3	40	**5**
7.43	**0.0**	**50**	**6**

Date: 30-1-2008

Coagulant: ferric chloride

Turbidity: 230-240

PH: 8.6

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
7.91	9.29	10	**1**
7.88	2.57	20	**2**
7.63	0.95	30	**3**
7.47	0.44	40	**4**
7.31	0.0	50	**5**
7.18	**0.0**	**60**	**6**

Date: 31-1-2008

Coagulant: ferric chloride

Turbidity: 65-70

PH: 8.7

Temperature: 10.2Co

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
7.73	104	10	**1**
7.45	76	20	**2**
7.40	56	30	**3**
7.39	22.7	40	**4**
7.36	7.12	50	**5**
7.30	**5.31**	**60**	**6**

Date: 31-1-2008

Coagulant: ferric chloride

Turbidity: 395-400

PH: 7.84

Temperature: 10.6Cº

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.3	27	0	**1 Blank**
7.92	6	10	**2**
7.81	1.56	20	**3**
7.69	0.0	30	**4**
7.46	0.0	40	**5**
7.34	**0.0**	**50**	**6**

Date: 31-1-2008

Coagulant: ferric chloride

Turbidity: 37-39

PH: 8.3

Temperature: 10.1Cº

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.3	7.18	10	**1**
7.92	1.79	20	**2**
7.81	0.87	30	**3**
7.69	0.14	40	**4**
7.46	0.0	50	**5**
7.34	**0.0**	**60**	**6**

Appendix 1: (continued)

Date: 04-2-2008

Coagulant: ferric chloride

Turbidity: 210-235

PH: 8.68

Temperature: 11.1Cº

[APPENDICES]

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.54	17	0	**1 Blank**
8.28	1.2	10	**2**
7.81	0.65	20	**3**
7.68	0	30	**4**
7.52	0	40	**5**
7.40	**0**	**50**	**6**

Date: 04-2-2008

Coagulant: ferric chloride

Turbidity: 138-140

PH: 8.6

Temperature: 9.6C^o

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.4	9	0	**1 Blank**
8.2	4.49	10	**2**
7.98	3.7	20	**3**
7.8	1.5	30	**4**
7.49	0.0	40	**5**
7.43	**0.0**	**50**	**6**

Date: 05-2-2008

Coagulant: ferric chloride

Turbidity: 30-35

PH: 8.2

Temperature: 18.1C^o

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.4	13	0	**1 Blank**
8.24	3.98	10	**2**
7.87	2.1	20	**3**
7.65	1.93	30	**4**
7.49	0.0	40	**5**
7.43	**0.0**	**50**	**6**

Date: 05-2-2008

Coagulant: ferric chloride

Turbidity: 40-45

PH: 8.5

Temperature: 18.1C°

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	6	0	**1 Blank**
8.0	2.9	10	**2**
7.81	0.73	20	**3**
7.77	0.0	30	**4**
7.49	0.0	40	**5**
7.43	**0.0**	**50**	**6**

Appendix 1: (continued)

Date: 08-2-2008

Coagulant: ferric chloride

Turbidity: 30

PH: 8.3

Temperature: 10.1C°

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	175	0	**1 Blank**
7.85	21	10	**2**
7.6	8.29	20	**3**
7.43	7.7	30	**4**
7.19	1.4	40	**5**
7.0	**0.0**	**50**	**6**

Date: 12-2-2008

Coagulant: ferric chloride

Turbidity: 500-530

PH: 8.0

Temperature: 10.2 C°

* Sample were prepared by dilution from 1000NTU sample(the sample were take in 31-1-2008) in water from canal.

[APPENDICES]

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	215	0	**1 Blank**
7.99	19	10	**2**
7.7	11.4	20	**3**
7.25	6.1	30	**4**
7.3	2.5	40	**5**
7.0	**1.4**	**50**	**6**

Date: 13-2-2008

Coagulant: ferric chloride

Turbidity: 750-800

PH: 8.4

Temperature: 13.2 C°

* sample were prepared by dilution from 1000NTU sample(the sample were take in 31-1-2008) in water from canal.

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.3	33	0	**1 Blank**
8.14	8.21	10	**2**
7.90	4.11	20	**3**
7.63	3.23	30	**4**
7.42	1.28	40	**5**
7.23	**0.0**	**50**	**6**

Date: 15-2-2008

Coagulant: ferric chloride

Turbidity: 80-85

PH: 8.4

Temperature: 10.2 C°

Appendix 1: (continued)

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	19	0	**1 Blank**
8.0	2.2	10	**2**
7.80	0.89	20	**3**
7.79	0.0	30	**4**

7.65	0.0	40	**5**
7.59	**0.0**	**50**	**6**

Date: 16-2-2008

Coagulant: ferric chloride

Turbidity: 50

PH: 8.1

Temperature: 10.2 C°

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	7.2	0	**1 Blank**
7.92	0.80	10	**2**
7.80	0.0	20	**3**
7.71	0.0	30	**4**
7.50	0.0	40	**5**
7.44	**0.0**	**50**	**6**

Date: 16-2-2008

Coagulant: ferric chloride

Turbidity: 30

PH: 8.2

Temperature: 10.1C°

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.1	442	0	**1 Blank**
7.85	28.9	10	**2**
7.67	19.9	20	**3**
7.53	7.14	30	**4**
7.41	3.63	40	**5**
7.28	**1.33**	**50**	**6**

Date: 19-2-2008

Coagulant: ferric chloride

Turbidity: 1000 NTU

PH: 8.2

Temperature: 11.7C°

[APPENDICES]

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.24	143	0	**1 Blank**
7.89	7.85	10	**2**
7.71	3.25	20	**3**
7.59	0.58	30	**4**
7.44	0	40	**5**
7.26	**0**	**50**	**6**

Date: 19-2-2008

Coagulant: ferric chloride

Turbidity: 300 NTU

PH: 8.3

Temperature: 11.7C°

Appendix 1: (continued)

PH	Turbidity NTU	Coagulant Dose mg/l	Beaker #
8.29	461	0	**1 Blank**
7.96	61	10	**2**
7.77	36.9	20	**3**
7.53	14.5	30	**4**
7.13	9.3	40	**5**
7.87	**6.8**	**50**	**6**

Date: 25-2-2008

Coagulant: ferric chloride

Turbidity: more than 1000 NTU

PH: 8.4

Temperature: 11.7C°

Appendix 2: Detailed measurements for all pilot filters runs done at aqbat jaber.

Sample port	Parameter	Sampling time					
		7:15 pm	8:05 pm	8:40 pm	9:15 pm	10:20 pm	11:30 pm
A	Turbidity NTU	11.53	13.4	9.4	9	6.7	6.8
B	Turbidity NTU	4.10	6.27	4.3	3.6	2	0.1
C	Turbidity NTU	0.80	4.3	2.43	1.4	0	0
D	Turbidity NTU	3.90	3	2.2	0.7	0	0

Final	**Turbidity NTU**	**3.89**	**3.69**	**2.3**	**1.1**	**0**	**0**

Filter Run 1A

Date of experiment: 4-2-2008

Starting time: 4:00 pm

Filter medium depth (H): 170m

Column diameter (D): 25cm

Raw water turbidity: not constant 25-75

Filtration rate: 0.5m/hr

Water temperature: 10.8°C

PH: 8.3

Allowable effluent turbidity: 20 NTU

Coagulant dose: 0.0

**A, B, C, D (layers of filter from the bottom (A) to top (D)).*

Sample port	**Parameter**	**Sampling time**		
		3:15 pm	5:30 pm	**7:30 pm**
A	*Turbidity NTU*	12	15	**11**
B	*Turbidity NTU*	7	5	**5**
C	*Turbidity NTU*	2.7	2	**1.2**
D	*Turbidity NTU*	0	0	**0**
Final	**Turbidity NTU**	**0**	**0**	**0**

Filter Run 2A

Date of experiment: 5-2-2008

Starting time: 12:00 pm

Filter medium depth (H): 170m

Column diameter (D): 25cm

Raw water turbidity: not constant 35-75

Filtration rate: 0.5m/hr

Water temperature: 16.1C^0

PH: 8.4

Allowable effluent turbidity: 20 NTU

Coagulant dose: 0.0

Appendix 2: (continued)

Sample port	**Parameter**	**Sampling time**		
		3:15 pm	**5:30 pm**	**7:30 pm**
A	*Turbidity NTU*	20	10.4	**6.5**
B	*Turbidity NTU*	10	3.5	**1.5**
C	*Turbidity NTU*	5.4	1.3	**0.7**
D	*Turbidity NTU*	0	0	**0**
Final	**Turbidity NTU**	**0**	**0**	**0**

Filter Run 2B

Date of experiment: 5-2-2008

Starting time: 12:00 pm

Filter medium depth (H): 170m

Column diameter (D): 25cm

Raw water turbidity: not constant 35-75

Filtration rate: 0.5m/hr

Water temperature: 16.1C^0

PH: 8.4

Allowable effluent turbidity: 20 NTU

Coagulant dose: 0.0

Filter Run 3A

Date of experiment: 15-2-2008 Filtration rate: 1.5m/hr

Starting time: 4:30pm Water temperature: 10.2C^0

Filter medium depth (H): 170m PH: 8.1

Column diameter (D): 25cm Allowable effluent turbidity: less than 20 NTU

Raw water turbidity: not constant 25-87 NTU Coagulant dose: 0.0

Sample port	parameter	Sampling time													
		7:30 PM	8:30 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	6:00 AM	7:00 AM	8:00 AM	10:00 AM	2:00 PM	4:30 PM
A	Turbidity NTU	23	17.4	14.5	12	13.4	13.54	11.4	9.65	5.47	8.30	8.22	8.50	9.65	8.40
B	Turbidity NTU	22	13.6	12	10.7	13	12	10	7.60	6.9	8.10	7.70	7.20	8.00	8.00
C	Turbidity NTU	18.6	10.6	9.6	9.46	10.8	9.65	9.3	7.20	5.50	6.40	6.10	7.00	7.30	6.30
D	Turbidity NTU	16.6	9.13	8.78	8.16	9.26	8.58	7.5	5.90	3.89	2.70	5.40	6.50	7.00	7.60
Final	Turbidity NTU	15	8.76	8.40	8.10	9.20	8.30	7.3	5.85	4	2.40	4.70	6.40	6.60	7.60

Appendix 2: (continued)

Filter Run 3B

Date of experiment: 15-2-2008 Filtration rate: 0.5m/hr

Starting time: 4:30pm Water temperature: 10.2C^0

Filter medium depth (H): 170m PH: 8.1

Column diameter (D): 25cm Allowable effluent turbidity: less than 20 NTU

Raw water turbidity: not constant 25-87 NTU Coagulant dose: 0.0

Sample port	parameter	Sampling time													
		7:30 PM	8:30 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	6:00 AM	7:00 AM	8:00 A	10:00 AM	2:00 PM	4:30 PM

[APPENDICES]

											M			
A	Turbidity NTU	16.20	13	10.90	9.00	15.26	12.95	8.42	9.80	4.67	7.99	9.00	10.50	8.30	8.00
B	Turbidity NTU	13.00	10.20	7.00	8.20	11.60	9.95	7.48	7.00	4.60	5.90	6.10	8.10	8.00	7.70
C	Turbidity NTU	12.20	10.00	6.90	7.30	6.70	8.20	7.00	4.85	5.90	4.30	3.58	6.00	6.50	4.28
D	Turbidity NTU	9.95	9.49	3.52	6.19	5.92	5.76	5.00	2.80	2.10	2.80	3.10	4.00	4.70	2.70
Final	Turbidity NTU	9.83	9.00	3.60	6.10	5.89	5.67	5.00	3	3.10	2.30	3.20	4.00	4.40	2.00

Filter Run 4A

Date of experiment: 14-5-2008 Filtration rate: 1.5m/hr

Starting time: 3:00pm Water temperature: 26.0C^{0}

Filter medium depth (H): 170m PH: 8.4

Column diameter (D): 25cm Allowable effluent turbidity: less than 20 NTU

Raw water turbidity: not constant 0.0 – 4.0 NTU Coagulant dose: 0.0

Sample port	parameter	Sampling time												
		14/5/2008		15/5/2008				16/5/2008				17/5/2008		
		6:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM
A	Turbidity NTU	0.09	0.0	0.0	0.94	0.0	0.20	0.2	0.15	0.6	0.42	0.0	1.18	2.40
B	Turbidity NTU	0.0	0.0	0.0	0.61	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.34	1.0
C	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
D	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 2: (continued)

Sample port	parameter	Sampling time												
		18/5/2008			19/5/2008			20/5/2008				21/5/2008		
		7:00 AM	3:00 PM	11:00 AM	7:00 AM	3:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM
A	Turbidity NTU	0.0	2.27	0.0	0.55	0.0	0.47	0.0	0.05	0.4	0.16	0.22	0.60	0.15
B	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample port	parameter	Sampling time												
		22/5/2008			23/5/2008			24/5/2008				25/5/2008		
		7:00 AM	3:00 PM	11:00 AM	7:00 AM	3:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM	11:00 PM	7:00 AM	3:00 PM	6:00 PM
A	Turbidity NTU	0.0	0.17	0.0	0.0	0.46	0.0	0.0	0.15	0.0	0.0	0.25	0.95	0.0
B	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Final	Turbidity NTU	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Sample port	parameter	Sampling time	
		26/5/2008	
		7:00 AM	3:00 PM
A	Turbidity NTU	0.21	0.50
B	Turbidity NTU	0.14	0.0
C	Turbidity NTU	0.0	0.0
D	Turbidity NTU	0.0	0.0
Final	Turbidity NTU	0.0	0.0

Appendix 2: (continued)

Filter Run 4B

[APPENDICES]

Date of experiment: 14-5-2008

Filtration rate: 0.5m/hr

Starting time: 3:00pm

Water temperature: 26.0C^0

Filter medium depth (H): 170m

PH: 8.4

Column diameter (D): 25cm

Allowable effluent turbidity: less than 20 NTU

Raw water turbidity: not constant 0.0 – 4.0 NTU

Coagulant dose: 0.0

Sample port	**parameter**	Sampling time												
		14/5/2008		**15/5/2008**				**16/5/2008**				**17/5/2008**		
		6:00 PM	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**
A	**Turbidity NTU**	**0.0**	**0.00**	**00.0**	**0.40**	**0.0**	**0.10**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
B	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
C	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
D	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Final	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Sample port	**parameter**	Sampling time														
		18/5/2008			**19/5/2008**			**20/5/2008**				**21/5/2008**			
		7:00 AM	**3:00 PM**	**11:00 AM**	**7:00 AM**	**3:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**
A	**Turbidity NTU**	**0.0**	**0.47**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.15**	**0.0**
B	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
C	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
D	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Final	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Sample port	**parameter**	Sampling time													
		22/5/2008			**23/5/2008**			**24/5/2008**				**25/5/2008**			
		7:00 AM	**3:00 PM**	**11:00 AM**	**7:00 AM**	**3:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**	**7:00 AM**	**3:00 PM**	**6:00 PM**	**11:00 PM**
A	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**
B	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
C	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
D	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Final	**Turbidity NTU**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Sample port	**parameter**	Sampling time	
		26/5/2008	
		7:00 AM	**3:00 PM**
A	**Turbidity NTU**	**0.0**	**0.0**
B	**Turbidity NTU**	**0.0**	**0.0**
C	**Turbidity NTU**	**0.0**	**0.0**
D	**Turbidity NTU**	**0.0**	**0.0**
Final	**Turbidity NTU**	**0.0**	**0.0**

Appendix 2: (continued)

Filter Run 5A

Sample port	Parameter	Sampling time		
		4:00 AM	8:00 AM	**1:00 AM**
A	Turbidity NTU	568	565	**481**
B	Turbidity NTU	95	344	**495**
C	Turbidity NTU	30.5	231	**153**
D	Turbidity NTU	0.8	26	**112**
Final	**Turbidity NTU**	**0.63**	**26**	**112**

Date of experiment: 13-8-2008

Starting time: 11:00 PM

Filter medium depth (H): 170

Column diameter (D): 25 cm

Raw water turbidity: 950 NTU

Filtration rate: 0.5 m/hr

Water temperature: 25 C^0

PH: 8.1

Initial head loss: 0

Allowable effluent turbidity: 20 NTU

Coagulant dose: 30 mg/l $Fecl_3$

Sample port	**Parameter**	**Sampling time**		
		4:00 AM	8:00 AM	**1:00 PM**
A	Turbidity NTU	667	554	**473**
B	Turbidity NTU	426	357	**382**
C	Turbidity NTU	334	252	**270**
D	Turbidity NTU	183	169	**159**
Final	**Turbidity NTU**	**182**	**169**	**159**

Filter Run 5B

Date of experiment: 13-8-2008

Starting time: 11:00 PM

Filter medium depth (H): 170

Column diameter (D): 25 cm

Raw water turbidity: 950 NTU

Filtration rate: 0.5 m/hr

Water temperature: 25 C^0

pH: 8.1

Initial head loss: 0

Allowable effluent turbidity: 20 NTU

Coagulant dose: 0

Appendix 2: (continued)

Sample port	**Parameter**	**Sampling time**

		1:30 AM	5:30 AM	**9:30 AM**
A	Turbidity NTU	614	648	**515**
B	Turbidity NTU	363	392	**388**
C	Turbidity NTU	131	211	**267**
D	Turbidity NTU	3.7	12.7	**113**
Final	**Turbidity NTU**	**3.5**	**12.6**	**111**

Filter Run 6A

Date of experiment: 14-8-2008

Starting time: 11:00 PM

Filter medium depth (H): 170

Column diameter (D): 25 cm

Raw water turbidity: more than 1000 NTU

Filtration rate: 0.5 m/hr

Water temperature: 23 C^0

PH: 8.2

Initial head loss: 0

Allowable effluent turbidity: 20 NTU

Coagulant dose: 40 mg/l $Fecl_3$

Sample port	**Parameter**	**Sampling time**		
		1:30 AM	5:30 AM	**9:30 AM**
A	Turbidity NTU	677	655	**612**
B	Turbidity NTU	435	421	**396**
C	Turbidity NTU	354	332	**289**
D	Turbidity NTU	188	174	**166**
Final	**Turbidity NTU**	**188**	**174**	**166**

Filter Run 6B

Date of experiment: 14-8-2008

Starting time: 11:00 PM

Filter medium depth (H): 170

Column diameter (D): 25 cm

Raw water turbidity: more than

1000 NTU

Filtration rate: 0.5 m/hr

Water temperature: 23 C^0

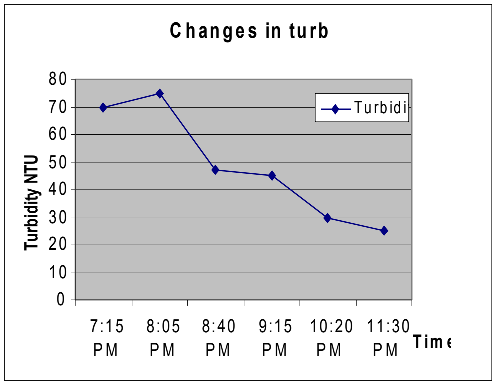
PH: 8.2

Initial head loss: 0

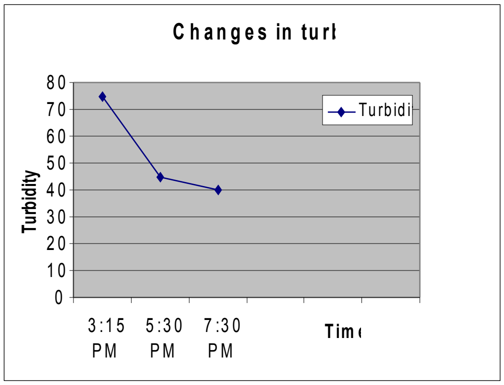
Allowable effluent turbidity: 20 NTU

Coagulant dose: 0

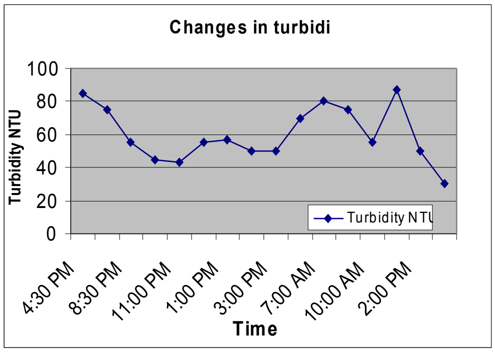
Appendix 3: Turbidity measurements from water canal (influent) for all pilots filter runs done at aqbat jaber.



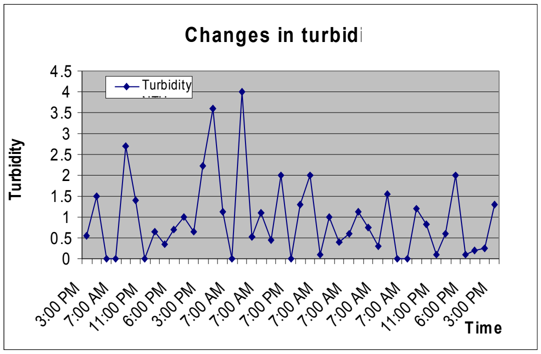
Change in turbidity for experiment 1A



Change in turbidity for experiment 2A 2B



Change in turbidity for experiment 3A 3B



Change in turbidity for experiment 4A 4B

Appendix 4: Wadi Al-Qilt study area figures taken along study periods.

Transportation canal 13 Km along wadi Al - Qilt area that transported water from Al- Qilt spring

Appendix 4: (continued)

Appendix 5: Turbidity measurement in water canal according 2007/2008 at rainy season.

Date	Turbidity (NTU)
1.9.2007	0.85
2.9.2007	0.76
3.9.2007	1.45
4.9.2007	33.31
5.9.2007	36.31
6.9.2007	2.5

8.9.2007	2.38
9.9.2007	4.15
10.9.2007	2.45
11.9.2007	2.1
12.9.2007	2.45
13.9.2007	2.93
15.9.2007	2.18
16.9.2007	2.38
17.9.2007	4.13
18.9.2007	3.51
19.9.2007	1.98
20.9.2007	5.19
21.9.2007	5.61
23.9.2007	1
24.9.2007	1.05
25.9.2007	4.16
26.9.2007	2.85
27.9.2007	2.6
29.9.2007	8.4
30.9.2007	2.13

Turbidity in September

Appendix 5 : (continued)

Date	Turbidity (NTU)
1.10.2007	3.99
2.10.2007	2.72
3.10.2007	1.05
4.10.2007	1
6.10.2007	2.08
7.10.2007	2.14
8.10.2007	0.8
9.10.2007	2.4
10.10.2007	2.02
11.10.2007	1.9
13.10.2007	4
14.10.2007	0.3
15.10.2007	0.3
18.10.2007	2.1
20.10.2007	4.43
21.10.2007	4.43
22.10.2007	2
23.10.2007	2.71
24.10.2007	1.43
25.10.2007	2.6
27.10.2007	2.48
28.10.2007	5.4
29.10.2007	2
30.10.2007	3
31.10.2007	2.24

Turbidity in October

Appendix 5 : (continued)

Date	Turbidity (NTU)
1.11.2007	2
3.11.2007	2.45
4.11.2007	12.16
5.11.2007	11.43
6.11.2007	5.34
7.11.2007	5.62
8.11.2007	2.93
10.11.2007	18.86
11.11.2007	8.63
12.11.20	2.95

07	
13.11.2007	2.73
14.11.2007	5.82
15.11.2007	1
17.11.2007	2.6
18.11.2007	2.83
19.11.2007	1.9
20.11.2007	1.85
21.11.2007	5.36
26.11.2007	4.2
27.11.2007	2.5
28.11.2007	1.43
29.11.2007	4.33

Turbidity in November

Appendix 5 : (continued)

Date	Turbidity (NTU)
1.12.2007	1.52
2.12.2007	1
3.12.2007	2.51
4.12.2007	2.93
5.12.2007	3.02
10.12.2007	2.43
11.12.2007	2.4
12.12.2007	2.63
13.12.2007	2.47
15.12.2007	2.73
16.12.2007	3.12
17.12.2007	2.9
18.12.2007	1.89
20.12.2007	2.9
22.12.2007	4.12
23.12.2007	3.65
24.12.2007	2.09

25.12.2007	2.13
26.12.2007	0.53
27.12.2007	2.8
29.12.2007	1.95
30.12.2007	1.53
31.12.2007	1.6

Turbidity in December

Appendix 5 : (continued)

Date	Turbidity (NTU)
1.1.2008	1.5
2.1.2008	3
3.1.2008	2.7
5.1.2008	2.09
6.1.2008	2
7.1.2008	1.96
8.1.2008	1.5
9.1.2008	0.78
10.1.2008	2.12
12.1.2008	1.79
13.1.2008	1.83
14.1.2008	1.65
15.1.200	1.1

8	
16.1.2008	1.84
17.1.2008	0.45
19.1.2008	0.91
20.1.2008	0.95
21.1.2008	0.27
22.1.2008	0.2
23.1.2008	0.15
24.1.2008	0.18
26.1.2008	0.09
27.1.2008	0.78
28.1.2008	0.12
29.1.2008	0.41
30.1.2008	741
31.1.2008	760

Turbidity in January

Date	Turbidity (NTU)
2.2.2008	80
3.2.2008	72.5
4.2.2008	41.125
5.2.2008	47.8
6.2.2008	37.2

7.2.2008	41.58
8.2.2008	23.53
9.2.2008	2.203
10.2.2008	18.5
11.2.2008	9.09
12.2.2008	5.8
13.2.2008	19.36
14.2.2008	14.38
15.2.2008	72
16.2.2008	55.17
17.2.2008	21.5
18.2.2008	24.16
19.2.2008	29.7
20.2.2008	95.5
21.2.2008	80.25

Appendix 5 : (continued)

Turbidity in February

Appendix 6: Sieve analysis results done at Birzeit university lab.

Appendix 7 : Pumps stock solution flow Calculation

For 10 mg/l $FeCl_3$ dose, 1ml of stock is needed in 1 litter of raw water, so we have 24.5 litter/hr raw water flows because of that we need 24.5 ml $FeCl_3$ stock solution or 0.025 l/hr.

The equation is

ml stock solution * flow/1000 = pump flow litter per hour.

Q max of pump = 0.6 litter per hour so when the flow of stock solution is 0.025 l/hr as in (table 3.1) the percentage of flow need by this pump is 0.025/0.6*100 = 4.2 %.

The equation is

Pump flow/0.6 * 100

Table 3.1 used to turn on the pump for choosing coagulant dose according to turbidity entered the columns. The selection of coagulant dose is depending on the jar test result optimum dose.

Table 3.1: Pump flow of stock coagulant For Filtration rate 0.5 m/h, raw water flow 24.5 l/hr, Q max of pump 0.6 l/hr.

% of pump from Q max	Flow of pump l/hr	Stock solution ml	Dose mg/l
4.2	0.0245	1	10
8.16	0.049	2	20
12.3	0.074	3	30
16.3	0.098	4	40
20.3	0.122	5	50
24.5	0.147	6	60
28.7	0.172	7	70
32.7	0.196	8	80

* Q max: The maximum capacity of the pump

Pump flow for the second pump that has Q max 3.3 l/hr was also calculated, Table 3.2 show the pump flow at the same 24.5 l/hr flow of raw water.

Table 3.2: Pump flow of stock coagulant for filtration rate 0.5 m/h, raw water flow 24.5 l/hr, Q max of pump 3.3 l/hr.

% of pump from Q max	Flow of pump l/hr	Stock solution ml	Dose mg/l
0.74	0.0245	1	10
1.48	0.049	2	20
2.24	0.074	3	30
2.97	0.098	4	40
3.70	0.122	5	50
4.45	0.147	6	60
5.2	0.172	7	70
5.9	0.196	8	80

Pump flow for the two pumps that has a 73 l/hr raw water flow was also calculated, (Table 3.3 and 3.4).

Table 3.3: Pump flow of stock coagulant for filtration rate 1.5 m/h, raw water flow 73 l/hr, Q max of pump 0.6 l/hr.

% of pump from Q max	Flow of pump l/hr	Stock solution ml	Dose mg/l
12.16	0.073	1	10

24.33	0.146	2	20
36.5	0.219	3	30
48.66	0.292	4	40
60.83	0.365	5	50
73	0.438	6	60
85.1	0.511	7	70
97.3	0.584	8	80

Table 3.4: Pump flow of stock coagulant for filtration rate 1.5 m/h, raw water flow 73 l/hr, Q max of pump 3.3 l/hr.

% of pump from Q max	Flow of pump l/hr	Stock solution ml	Dose mg/l
2.21	0.073	1	10
4.42	0.146	2	20
6.63	0.219	3	30
8.84	0.292	4	40
11	0.365	5	50
13.3	0.438	6	60
15.5	0.511	7	70
17.7	0.584	8	80

According to calculations and tables above the coagulant stock solution flow were controlled, the low capacity pump was used with low raw water flow in order to getting a precise dosing.