CHEMICAL DOSING OPTIMIZATION IN PRIMARY TREATMENT UNITS RECEIVING WASTEWATER FROM DENIM WASHING PLANT

A Thesis submitted by

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Engineering and Technology (BUET), Dhaka in partial fulfillment of the requirements
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DEDICATED

TO

MY BELOVED

PARENTS

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In extreme humbleness the author bows his head before Supreme Personality of Godhead Shree Krishna who created mankind in a most splendid manner and bestowed upon him a distinguished honor in the form of knowledge.

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ABSTRACT

The ready-made garment (RMG) sector has become one of the largest manufacturing sectors in Bangladesh. Among various RMG industries, denim-washing factories are water intensive and utilize a wide variety of chemicals and dyes. In this study an assessment of chemical dosing optimization in the primary treatment unit for a denim garment washing plant has been done for various water quality parameters.After finding the optimum dosing for different chemicals a sensitivity analysis has been conducted to find the effective combined dosing both for removal efficiency of selected water quality parameters and economic point of view. For this, chemical dosing optimization has been done for alum, ferrous sulfate and polymer with controlled pH condition.This is because pH controlling increases the removal efficiency. A comparison between the optimum dosing and half of the optimum dosing has been conducted to find the sensitivity for removing selected water quality parameters. It was observed that, even after reduction of chemical dosing by 50%, removal efficiencies for color, turbidity, TSS, COD, and BOD_5 did not seem to decrease significantly. Based on the observations from the above mentioned analysis,combined dosing of different concentartions for alum, ferrous sulfate and polymer were carried out to find the removal efficiencies. It was found that combination of chemicals provided better removal efficiencies than individual chemical dosing. Polymer and alum dosing provided better removal efficiencies for different water quality parameters. Dosing with combination of chemicals, having polymer and alum also provided better removal results. Ferrous sulfate provided least removal efficiencies for most of the water quality parameters when compared to other individual chemicals. Combinations having ferrous sulfate in them also provided relatively less removal of various water quality parameters. A cost analysis for that different combined dosing was also carried out to determine the possible effective dosings. The cost analysis will facilitate respective ETP management of denim washing factories with selection of combined dosing of chemicals, which is function of the overall design of ETP (i.e. primary, secondary and tertiary units) and willingness to pay for primary treatment stage.

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ABBREVIATIONS AND ACRONYMS

RMG	Ready made garments
COD	Chemical oxyzen demand
BOD	Biochemical oxyzen demand
ECA	Environment conservation act
ECR	Environment conservation rules
ETP	Effluent treatment plant
LDC	Least developing country
TS	Total solids
TDS	Total dissolved solid
TSS	Total suspended solids
BGMEA	Bangladesh garment manufacturers and exporters association
NTU	Nephelometric turbidity units
JTU	Jackson turbidity units
MLSS	Mixed liquor suspended solids
EDTA	Ethylenediaminetetraacetic acid
DO	Dissolved oxyzen
CBOD	Carbonaceous biochemical oxygen demand
EC	Electrical conductivity

Chapter 1 : Introduction

1.1 General

The ready-made garment (RMG) sector has become one of the largest manufacturing sectors in Bangladesh with over 5000 registered apparel manufacturing units. RMG sector accounts 82.62 percent of Bangladesh‟s total export, which was approximately USD $24.49 Billion in 2013-2014 (Kiron M. I., 2015). The growth in this sector, and other small and medium scale enterprises, undoubtedly has a positive effect on national economic development but there are also negative implications. Among various industrial organizations, the textile industry is water intensive and utilizes a wide variety of chemicals and dyes (Eckenfelder, 2003). The textile wastewater contains unused or partially used organic compounds, strong color, high chemical oxygen demand (COD) and biochemical oxygen demand (BOD).The polluted effluent discharged from this sector into sewage or neighboring water receiving bodies is a cause of major environmental and health concern (Tchobanoglous *et al*., 2003; Ahmed *et al*. 2006). Under the Bangladesh Environment Conservation Act (ECA 1995) and Environmental Conservation Rules (ECR 1997) textile dyeing industries are categorized as "Red industries", and must treat and monitor the wastewater quality conforming to national discharge quality standards (Sharif and Hannan, 1999; Huq, 2003). However, in many cases, this wastewater is disposed untreated to the nearby rivers or wetlands (Zobayer *et al*. 2013; Ahmed *et al*. 2012).

For the treatment of this wastewater the effluent treatment plants (ETPs) are typically designed to conservative design guidelines and are operated based on historic practices. Generally, experience has shown that such facilities often have considerable additional capacity that can be realized through optimization. Improvements in effluent quality and reductions in operating costs can also be realized. Furthermore, improvements in performance and reductions in operating costs can often be achieved through optimization approaches. By applying this optimization approaches, the capacity of the existing infrastructure can be maximized, the performance of the works enhanced, and the operating and maintenance costs reduced.

An ETP optimization approach is iterative, and clear objectives should be established before each iteration. Depending on the objectives established, the outcome of ETP optimization may include any or all of the following:

- An increase in the capacity of the existing works without the major capital costs associated with a plant expansion;
- An improvement in process without the major capital costs associated with a plant upgrade; and
- A reduction in operating costs through more efficient use of power, chemicals, or labor.

1.2 Rationale of the Study

Hundreds of Textile industries in Bangladesh produce wastewater as a bi-product of their production mainly due to dyeing and washing of garments. The effluent contains several organic pollutants and color producing substances, which cause severe environmental hazards on both aquatic life and human health. These pollutants can be reduced down to the permissible limit with the help of an effluent treatment plant (ETP). Most of the industries having ETP are not operating their plant regularly due to excessive operational and maintenance cost as they are not designed properly.

Concept of zero polluting industry is not relevant for Bangladesh. In Bangladesh the Ready Made Garments (RMG) sector employs close to 3.5 million workers, a further 10 million people depend on their livelihood because of the RMG industry. But in running this sector environmental concern is not a great concern and the implementation as well as awareness about the environmental law is very poor. Moreover the industry operators and owners are reluctant to maintain an effluent treatment plant for cost concern. As the options for treating textile wastewater are very expensive, industry owners of a Least Developing Country (LDC) like Bangladesh are often reluctant to allocate their budget for effluent treatment. The industries are always busy to bypass the law and discharging these wastes into surface water course without proper treatment.

In Bangladesh, ETPs have been designed by international design firms without considering the local facts (Ahmed *et al.* 2011). These are simply designed on the basis of some generalized data and involve use of technologies and chemicals which are cost prohibitive. For example, the physico-chemical methods with coagulation-flocculation can treat effectively the color and COD but it exhausts a large amount of flocculent reagent and can generate a large amount of sludge (Kim *et al*, 2003). So, there is a scope to observe efficiency of different chemicals in the primary treatment of wastewater from washing plants and optimize the dosing for effective performance and less sludge generation. Selection of suitable and cost effective dosing can considerably reduce operation and maintenance cost of the treatment process.

1.3 Objectives of the study

The specific objectives of the present research are as follows:

- Characterization of wastewater collected from Denim Garments Washing plant.
- Determination of optimum dosing of chemicals (Ferrous sulfate, Alum and Polymer) for the removal of turbidity and color.

- Evaluate removal efficiency of selected water quality parameters (EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD5) at varying dosing of individual and combination of chemicals.
- To assess the effectiveness of different chemicals with respect to treatment efficiency and and analyzing the result from economic point of view.

1.4 Organization of the thesis

The thesis contains five chapters-

Chapter one is introduction which describes the general overview, rational of the study and the objectives of the thesis work.

Chapter two covers a brief and selective review of the relevant literature which provides primary treatment of wastewater, chemicals used in primary treatment unit, and practices in Bangladesh.

Chapter three is for methodologies which includes the details about the various water quality parameters, optimum dosing determination for individual chemicals,Sensitivity analysis for different dosings of individual chemicals.It also discusses about the combined chemical dosing experiments.

Chapter four provides the results and discussions which contains the characterization of process wastewater from denim garments washing plant, determination of optimum dosing for different chemicals, sensitivity analysis for different dosings of individual chemicals.It also discusses details about the removal efficiency of the various water quality parameters for combined dosings of chemicals. A cost analysis has also been provided in this chapter.

Chapter five includes the conclusions of the research work and recommendations for future studies.

Chapter 2 : Literature Review

2.1 Introduction

The ready-made garment sector has become one of the largest manufacturing sectors in Bangladesh .Unfortunately, linked to great economic benefits given by the textile sector to several countries, severe environmental problems have been created due to discharge or inadequate disposal of textile wastes. The most important contaminants released by the textile industry are dyes, which enter the environment mainly via discharge of wastewaters (Cervantes, 2009).

Likely sources of textile process wastewater include wet processes such as scouring, dyeing, finishing, printing and coating of textile products. Dyeing processes are one of the largest sources of wastewater. The primary source of wastewater from dyeing operations is spent dye bath and wash water. Finishing processes which contains both rinsing and washing generally produce wastewater containing natural and synthetic polymers. Chemical handling and high pH are the primary pollution concerns associated with the bleaching process (EPA, 2004).

It is broadcasted that more than 60 % of the world dyestuff production is consumed by textiles industries. Designated as water soluble, it was estimated that 10 – 20 % of the dye was lost during the dyeing process and released as effluent. “The reagents used in textile industry are very diverse in chemical composition. The non-biodegradability of textile wastewater is due to the high content of dyestuffs, surfactants, and other additives, which are generally organic compounds of complex 7 structure” (Gharbani *et al*. 2008). Textile mill effluents are known to have extremes of pH (either alkaline or acidic) and temperature, high BOD, high COD and high concentrations of suspended solids (SS). Textile mill effluents are also characterized by high levels of color caused by residual dyes that were not fixed to fibers in the dyeing process. Dye molecules are highly structured polymers that are toxic to organisms (Sevimli and Kinaci, 2002).

In dyeing, the washing stage is necessary to complete the dyeing process itself or to eliminate the dyestuff which has not been fixed; during the printing stage, washing performs a finishing action. Washing is the operation carried out most frequently during a complete textile finishing cycle. It is almost always connected to key treatments and aimed at removing from the fabric insoluble matters, matters already in solution or an emulsion of other impurities. Washing is carried out after desizing, boiling and other bleaching and mercerizing processes. When using vat dyes or disperses dyes, the washing process aims at removing insoluble pigment substances from the fiber surface by means of wetting or dissolving agents.

2.2 Textile Wastewaters

There are several different steps in the production of textiles and these processes generate highly contaminated liquid streams. The quantity and composition of these wastewaters depend on many different factors, including the processed fabric and the type of process. Type of machinery, chemicals applied and other characteristics of the processes also determine the amount and composition of the generated wastewater. In the textile sector, although processes should be considered separately, treatment of each process may not be considered individually. Combined selected streams can lead to a better treatable wastewater. A stream could be separated from the rest to facilitate the recovery of water or chemicals, or to prevent dilution of a compound difficult to remove.

“Some processes in a textile mill hardly generate wastewater, such as yarn manufacture, weaving (some machines use water), and singeing (just some lightly polluted cooling water). The amount of wastewater produced in a process like sizing is small but very concentrated. On the other hand, processes like scouring, bleaching, and dyeing generate large amounts of wastewater, varying much in composition” (Cervantes, 2009). Mixed textile wastewater generally contains high levels of COD and color, and usually has a high pH (Dos Santos *et al*. 2007).

2.3 Treatment of Textile Wastewater

Treatment facilities incorporate numerous processes which in combination achieve the desired water quality objectives. These processes involve the separation, removal, and disposal of pollutants present in the wastewater. These treatment methods and their efficiencies are reviewed in following sections.

2.3.1 Preliminary and Primary Wastewater Treatment Processes

General

Preliminary treatment of wastewater generally includes those processes that remove debris and coarse biodegradable material from the waste stream and/or stabilize the wastewater by equalization or chemical addition. Primary treatment generally refers to a sedimentation process ahead of the main system or secondary treatment. In domestic wastewater treatment, preliminary and primary processes will remove approximately 25 percent of the organic load and virtually all of the nonorganic solids. In industrial waste treatment, preliminary or primary treatment may include flow equalization, pH adjustment or chemical addition that is extremely important to the overall treatment process. This section of the manual will discuss the various types of preliminary and primary treatment processes available.

Preliminary treatment

An important part of any wastewater treatment plant is the equipment and facilities used to remove items such as rags, grit, sticks, other debris, and foreign objects. These interfere with the operation of the facility and often cause severe problems. Methods of removing these materials prior to primary and subsequent treatment are part of a pretreatment or preliminary treatment.

Screening and comminution

Screening and comminution are preliminary treatment processes utilized to protect mechanical equipment in the treatment works, to aid downstream treatment processes by intercepting unacceptable solids, and to alter the physical form of solids so they are acceptable for treatment.

Figure 2.1 Screening in textile industry

Equalization

Equalization should be employed for many industrial discharges. it reduces fluctuations of the influent to levels compatible with subsequent biological or physical-chemical processes. A properly designed facility dampens the wide swings of flow, pH, BOD, and other parameters to levels such that downstream systems operate more efficiently and economically, and can be constructed at a reduced capital investment. Proper equalization will also minimize system upsets and more consistently provide a better quality effluent. A graphical example of how an equalization facility can stabilize a wastewater having significant cyclic pH variations is illustrated in figure 2.1.

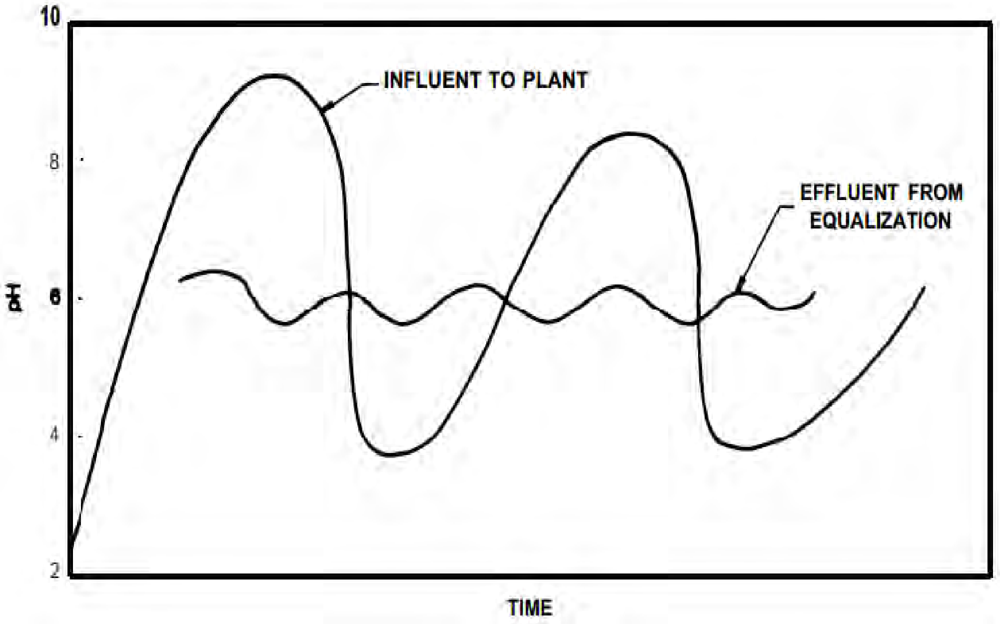

Figure 2.2 Wastewater having significant cyclic pH variations

pH control

Similarly to equalization, the use of pH control as a preliminary treatment step is usually limited to treatment of industrial process wastes. It is necessary to regulate pH since treatment processes can be harmed by excessively acidic or basic wastes. Regulation of this parameter may be necessary to meet effluent levels specified for secondary treatment. Control of the pH at elevated levels is usually required to precipitate certain heavy metals and/or alleviate an odor producing potential.

Flotation

In preliminary treatment, flotation is sometimes used for wastes which have heavy loads of grease and finely divided suspended solids. These are mainly systems having large industrial discharges and may apply to military installations with significant oil and grease quantities from manufacturing or laundry operations.

Primary treatment

It is designed to remove gross, suspended and floating solids from raw wastewater. It includes screening to trap solid objects and sedimentation by gravity to remove suspended solids. This level is sometimes referred to as “mechanical treatment”, although chemicals are often used to accelerate the sedimentation process. Primary treatment is usually the first stage of wastewater treatment. Many advanced wastewater treatment plants in industrialized countries have started with primary treatment, and have then added other treatment stages as wastewater load has grown, as the need for treatment has increased, and as resources have become available.

Plain sedimentation

Wastewater, after preliminary treatment, undergoes sedimentation by gravity in a basin or tank sized to produce near quiescent conditions. In this facility, settleable solids, and most suspended solids settle to the bottom of the basin. Mechanical collectors should be provided to continuously sweep the sludge to a sump where it is removed for further treatment and disposal. Skimming equipment should be provided to remove those floatable substances such as scum, oils, and greases which accumulate at the liquid surface. These skimmings are combined with sludge for disposal. Removals from domestic wastewaters undergoing plain sedimentation will range from about 30 to 40 percent for BOD and in the range of 40 to 70 percent for suspended solids. With optimum design conditions for sedimentation, BOD and suspended solids removal efficiency is dependent upon wastewater characteristics and the proportion of organics present in the solids. Advantages of increased solids separation in primary sedimentation facilities are:

- A decrease in organic loading to secondary treatment process units.
- A decrease in the quantity of secondary sludge produced.
- An increase in the quantity of primary sludge produced which can be thickened and dewatered more readily than secondary sludge.

Sedimentation with chemical coagulation and flocculation

Sedimentation using chemical coagulation has been implied mainly to pretreatment of industrial or process wastewaters. The colloidal sized particles in water and wastewater are generally hard to remove since they are very small (about 0.01 to 1 μm) and generally possess negative charges preventing from coming together to form large particles that could be more readily be settled out. The primary aim of coagulation and flocculation is to remove the suspended particles from water and if possible any dissolved particles that may be undesirable in the final water or effluent. Basically, the matter present in water can be divided into two categories – dissolved solids and suspended, or colloidal, particles. Before coagulation and flocculation can be properly described, it is necessary to have some understanding of how these two types of matter impact on water treatment.

Coagulation

The colloidal sized particles in water and wastewater are generally hard to remove since they are very small (about 0.01 to 1 μm) and generally possess negative charges preventing from coming together to form large particles that could be more readily be settled out. The removal of these particles requires charge neutralization and then particles are encouraged to collide with each other to form large particles and settle. Coagulation is the process of destabilizing colloidal particles via charge neutralization so that particle growth can occur as a result of particle collisions.

Coagulation can be also explained by electrical double layer model. Figure 2.3 is a representation of the static electric field surrounding the particle. Since the solid particle is negatively charged, it attracts the positively charged ions surrounding it. Some of the ions are so strongly attracted to the particle that they are virtually attached to the particle and travel with it forming a "shear plane" (slippage plane). These ions are held there through electrostatic and Van der Waals forces of attraction. Around this inner layer, an outer layer named as "diffused layer" consisting mostly of positive ions are attached less strongly to the particle. The electrical double-layer consists of a "stern layer" (compact layer) and a "diffused layer". The charge on the particle as it moves through the fluid is the negative charge, diminished by the positive ions in the inner layer. The latter, i.e. electrical potential at the shear surface depending on the distance through which the charge is effective is called the zeta potential.

In addition to the repulsive charges of the particles, all particles carry an attractive electrostatic charge, van der Waals force, which is a function of themolecular structure of the particle. The combination of these forces results in a net repulsive charge, an energy barrier, or "energy hill," that prevents the particles from coming together. The objective of coagulation is to reduce this energy barrier to zero so that the particles no longer repel each other. Adding trivalent cations to the water is one way to reduce the energy barrier. These ions are electrostatically attracted to the negatively charged particle and, because they are more positively charged, they displace the monovalent cations. The netnegative charge, and thus the net repulsive force, is thereby reduced. Under this condition, the particles do not repel each other and, on colliding, stick together. A stable colloidal suspension can be destabilized in this way, and the larger particles will not remain suspended. Aluminum sulfate is the usual source oftrivalent cations in water treatment.

Aluminum sulfate has an advantage in addition to its high positive charge: some fraction of the aluminum ions may form aluminum oxide and hydroxide by the reaction;

Al^{+3}+ $3OH^-$ = $Al(OH)_3$……………………………………………………………………….(2.1)

These complexes are sticky and heavy and will greatly assist in the clarification of the water in the settling tank if the unstable colloidal particles can be made to come in contact with the floc. This process is enhanced through an operation known as flocculation. As a second step after coagulation, flocculation introduces velocity gradients into the water so that the particles in a fast-moving stream can catch up and collide with slow-moving particles. After flocculation, particles are large enough to settle down and thereby can be removed from the water in the final step, i.e. settling (Weiner and Matthews, 2003; Tchobanoglous *et al*. 2003).

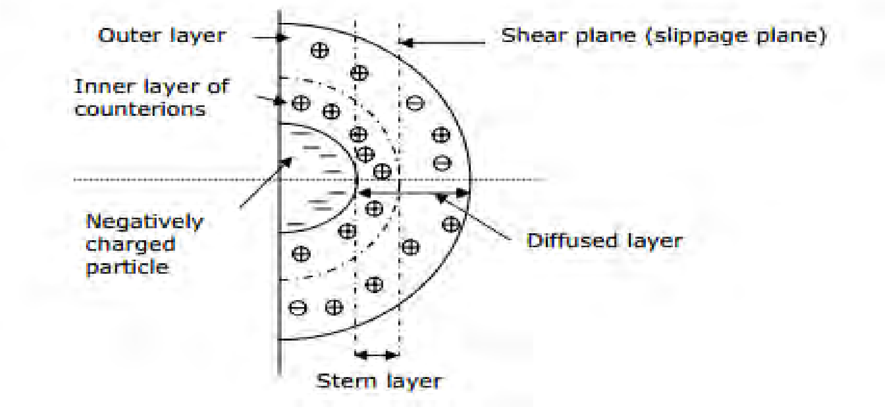

Figure 2.3 Coagulation mechanism

The nature of an industrial wastewater is often such that conventional physical treatment methods will not provide an adequate level of treatment. Particularly, ordinary settling or flotation processes will not remove colloidal particles and metal ions. In these instances, natural stabilizing forces (such as electrostatic repulsion and physical separation) predominate over the natural aggregating forces and mechanisms, namely, van der Waals forces and brownian motion, which tend to cause particle contact. Therefore, to adequately treat such particles in industrial wastewaters, coagulation is an important technology in which rapid mixing of coagulants with fluid ensures the chemical dispersion throughout the wastewater and flocculation provides particle contact at a slow mix letting particle agglomeration and settling allows large particle separation from liquid (Jeris *et al*. 2002).

Flocculation

Flocculation forms the second stage of the coagulation and flocculation process and is referred to as the conditioning stage. It is this stage in which the particles which are already in contact with molecules of coagulant start to grow. Flocculation occurs after coagulation has destabilized the suspended colloidal particles in water. Micro flocs then start to form and flocculation occurs through the collision of particles and micro flocs to form micro flocs. This is an essential process in phase separation (separation of water and particles, since the formation of micro flocs leads to particles that become too heavy to remain in suspension and will settle out (Van Durren, 1997). It has been shown that the movement which allows particle collisions to occur is critical and that without it, particles will remain in suspension indefinitely, despite the addition of an effective coagulant (Stamberger, 1962). Therefore flocculation is an important part of water and wastewater treatment and plants are generally designed with a view to achieving good flocculation.

Chemical Treatment Processes

Chemical treatment may be used at any stage in the treatment process as and when required (preferably before biological treatment as it removes toxic chemicals which may kill the microbes). In the treatment of textile wastewaters, chemical treatment methods are known to be much more effective than others in breaking down the straight, unsaturated bonds in the dye molecules (Ciardelli *et al*. 2001).

Chemical oxidation typically involves the use of an oxidizing agent such as ozone(O_3), hydrogen peroxide(H_2O_2), Fenton‟s reagent, permanganate (MnO_4) etc. to change the chemical composition of a compound or a group of compounds, e.g. dyes (Tchobanoglous *et al*. 2003).

2.3.2 Secondary treatment

This process involves decomposition of suspended and dissolved organic matter in waste water using microbes. The mainly used biological treatment processes are activated sludge process or the biological filtration methods.

Biological Treatment

Biological treatment can be applied to textile wastewaters as aerobic, anaerobic and combined aerobic-anaerobic. In most cases, activated sludge systems (aerobic treatment) are applied. In all activated sludge systems, easily biodegradable compounds are mineralized whereas heavily biodegradable compounds need certain conditions, such as low food-to-mass-ratios (F/M) (<0.15 kg BOD5/kg MLSS.d), adaptation (which is there if the concerned compounds are discharged very regularly) and temperature higher than 15^0C (normally the case for textile wastewater) (Lacasse and Baumann, 2004).

Ineffectiveness of aerobic biological treatment in reducing color caused by heavily biodegradable organics causes aesthetic problems in the receiving waters and encourages researchers to investigate alternatives. Dyes themselves are generally resistant to oxidative biodegradation, and a difficulty occurs in acclimation the organisms to this substrate (Reife and Freeman, 1996).

“Depending on the dyeing process; many chemicals like metals, salts, surfactants, organic processing assistants, sulfide and formaldehyde may be added to improve dye adsorption onto the fibers" (Dos Santos *et al*. 2007). These chemicals are mainly in toxic nature and decrease the efficiency of biological treatment in color removal regarding textile wastewater.

Due to the insufficiency of biological treatment in the removal of the dyes from textile and dyestuff manufacturing, this process requires the involvement of other physical, chemical, and physicochemical operations" (Rai, 2005; Banat *et al*. 2005)."Physical and chemical treatment techniques are effective for color removal but use more energy and chemicals than biological processes.

2.3.3 Tertiary treatment

It is the next wastewater treatment process after secondary treatment. This step removes persistent contaminants that secondary treatment is not able to remove. Tertiary treatment is the final cleaning process that improves wastewater quality before it is reused, recycled or discharged to the environment. Tertiary treatment is used for effluent polishing (BOD, TSS), nutrient removal (N, P), toxin removal (pesticides, VOCs, metals) etc.

Tertiary treatment can also be extensions of conventional secondary biological treatment to further stabilize oxygen-demanding substances in the wastewater, or to remove nitrogen and phosphorus. It can also involve physical-chemical separation techniques such as activated carbon adsorption, flocculation/precipitation, membranes filtration, ion exchange, de-chlorination and reverse osmosis (Doble and Kumar, 2005).

Advanced treatment processes which generally constitute of or are part of the tertiary treatment may also sometimes be used in the primary or secondary treatment or used in place of secondary treatment. Some of the common tertiary treatment processes are-

- Granular Media Filtration
- Membrane Filtration

- Activated carbon
- Ultraviolet (UV) Disinfection

2.4 Chemicals used in Primary Treatment

Coagulation or flocculation processes were conducted for the treatment of industrial wastewater to achieve maximum removal of COD, Color, Turbidity and TSS. Aluminum sulfate (alum), ferrous sulfate, ferric chloride,ferric chloro-sulfate, polymer etc. were commonly used as coagulants.Amongst them ferrous sulfate, alum and polymers are discussed in the following aricle:

2.4.1 Ferrous Salts

Ferrous sulphate and ferrous chloride are seldom used in water treatment as they need to be used in conjunction with lime or chlorine to precipitate the iron hydroxide in ferric form. There is however no theoretical reason why it should not be used provided the chemical is cost competitive on the basis of iron content and it does not contain other heavy metals in appreciable quantities. Whilst ferric salt solutions are characterized by their typical red-brown color, these ferrous salts are both green in solution.

Table 2.1 Typical specifications for commercially available ferrous chloride and ferrous sulphate (Leopold and Freese, 2009).

Dose(mg/l)	Ferrous chloride	Ferrous sulfate
Solution strength	18-28%	28-30%
Ferrous ion content	8-13% m/m	8-13% m/m
Specific Gravity (20^{0}C)	1.25	1.15
Free acid	Maximum 3%	Maximum 0.25%
pH	<2	1.5-3

Ferrous Salts in Wastewater Treatment

Ferrous salts can be used as an alternative to ferric salts for phosphate removal. Based on the chemistry and the fact that ferrous salts are soluble in water, ferrous iron would not be expected to precipitate phosphate. However, ferrous salts have been found to be quite efficient in the removal of phosphate, although they are usually used in conjunction with lime and not on their own for this application (Metcalf and Eddy, 1999). The process involves two reactions, namely the oxidation of ferrous iron to ferric iron and the precipitation of ferric phosphate. Interestingly, the ferrous iron itself does not act as a coagulant and so the competing reactions that detract from the efficiency of ferric salts do not seem to play a role in the use of ferrous salts for phosphate removal.

2.4.2 Aluminium Sulphate

Aluminum sulphate has been used for several centuries in water treatment and is probably the most well-known and commonly used coagulant. It is acidic in nature. The chemical is prepared by reacting bauxite, aluminum trihydrate or certain clays with sulphuric acid.

Aluminium sulphate is often known as alum. The name „alum" is not an accurate description because chemically alum is actually a much more complex salt of aluminium, hydrated aluminum potassium sulphate ($KAl(SO_4)_2.12H_2O$). Although the term „alum" is used for aluminium sulphate, aluminium sulphate is not one of the alums. Alums are compounds with the general formula $AB(SO_4)_2.12H_2O$ and some of them do not contain any aluminium at all (e.g. chrome alum, $K_2Cr(SO4)_2 \cdot 12H_2O$). Other forms of alum also exist and are manufactured as complex salts with ammonia or iron, for example.

Application of Aluminium sulphate in Wastewater Treatment

Aluminium sulphate is perhaps the most well-known of all water treatment chemicals and it was one of the first chemicals to be used for coagulating and flocculating water. Aluminium sulphate is widely used in the treatment of potable water and behaves in a similar way to ferric salts in that the primary behaviour is sweep flocculation following the formation of hydroxides such as $Al(OH)_3$.

Aluminium hydroxides have a limited span of pH over which they are insoluble and it is therefore important that the operating pH be carefully controlled to maintain it in the range of 5.8-8.5 (Freese *et al.* 1998) which is in agreement with the findings of (Randtke, 1998). Because aluminium hydroxide redissolves at high pH (i.e. pH values over 8.5), it is important that there is sufficient alkalinity in the water during flocculation to ensure complete formation and settling of the insoluble hydroxide. It is not uncommon for hydroxide to be carried over to the point of lime addition resulting in redissolution of the aluminium hydroxide. The dissolved (or residual) aluminium sulphate then passes through the filters and later reprecipitates in the reservoir or distribution system. A deep layer of aluminium hydroxide precipitate is often found at the bottom of reservoirs where aluminium sulphate is used for treatment of the water. It is therefore important to ensure good pH control throughout the process when using aluminium sulphate. The other situation in which aluminium sulphate is often the product of choice is for the removal of color. This is generally applied in drinking water applications although aluminium sulphate does find use in the treatment of coloured effluents such as those emanating from the textile industry. In both cases, the efficiency relies on reducing the pH to a value that allows for optimal color removal. However, it has been found that if the pH dropped below 4, solubilisation of aluminium occurred and removal of iron and manganese was impaired(Freese *et al.* 1998).

2.4.3 Polymer

Polymers--long-chained, high-molecular-weight, organic chemicals--are becoming more widely used, especially as coagulant aids together with the regular inorganic coagulants (Van Durren, 1997). Anionic (negatively charged) polymers are often used with metal coagulants. Low-to-medium weight, positively charged (cationic) polymers may be used alone or in combination with the aluminum and iron type coagulants to attract the suspended solids and neutralize their surface charge. The manufacturer can produce a wide range of products that meet a variety of source-water conditions by controlling the amount and type of charge and relative molecular weight of the polymer.Polymer is of two types-

- Anoinic polymer
- Catonic polymer

Anionic Polymer

Anionic polymer is produced by co-polymerizing acrylic acid, or the sodium salt of the acid, with acrylamide monomer. The ratio of the two ingredients will determine the extent of the anionic charge (usually measured as a percentage). Figure 2.4 shows the structure of a typical anionic polyacrylamide.

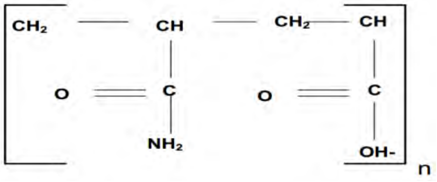

Figure 2.4 Anionic Polymer molecule

Cationic Polymer

Cationic polymer is produced by the co-polymerization of a quaternary ammonium salt (a cationic monomer) with acrylamide monomer. There are many cationic monomers available and many of them subject to proprietary knowledge as manufacturers seek to develop new differentiated products.The structure of a typical cationic polyacrylamide is shown in Figure 2.5.

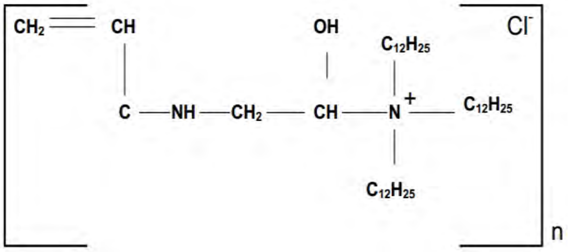

Figure 2.5 Cationic Polymer molecule

Application of Polymer in Wastewater Treatment

Polymers are widely used as flocculants although the most extensive uses are to be found in mining applications rather than in conventional water treatment. They are effective over a wider pH range than inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated, rapidly settling floc. The floc formed from use of a properly selected polymer will be more resistant to shear, resulting in less carryover and a cleaner effluent.

The most commonly used polymers in water treatment are the anionic polymers. Generally, polymers are used in conjunction with other chemicals, since polymers used on their own are not capable of floc formation. However, when used in conjunction with a coagulant such as aluminium sulphate, ferric chloride or a polymeric coagulant, they enhance floc formation resulting in larger, stronger flocs. In such applications, the polymers are added to the water treatment process after the addition of the primary coagulant, typically in a low energy, conditioning environment such as the centre well of a clarifier.

2.5 Practices in Bangladesh

Textile wastewater possess a high COD concentration, large amount of suspended solids, broadly fluctuating pH, strong color, high temperature and low biodegradability caused by varying contaminants within water environment (Chen *et al*. 2003). In the recent times many attempts have been made to treat textile wastewater using conventional wastewater treatment methods such as chemical coagulation, electrochemical oxidation, filtration and biological treatment. Several methods have been developed to treat textile wastewater, but most of them cannot be used individually because they do not adequately treat the wastewater (Nelson and Avijit, 1991). Individual processes have many problems, for example, in the chemical coagulation process a large amount of sludge can be generated and the treatment capability is low, and electrochemical oxidation may produce pollutants, which increases the treatment cost. Regarding biological treatment, treatment of such wastewater is rather difficult because post-treatment by biological processes and specific bioreactors is required (Ahn *et al*. 1999). The use of combined processes has been suggested recently to overcome the disadvantages of individual unit processes (Ali *et al*. 2004).

However, in Bangladesh, no study has been conducted for the primary treatment units regarding the optimum dosing for the effective performance of washing plant which may eventually reduce the generation of sludge. A study of this nature under a local condition in Bangladesh is considered to be of prime importance for effectively treating the wastewater from the primary treatment unit.

Chapter 3 : Methodology

3.1 Introduction

The following chapter details the materials and methods used during this thesis work. The chapter deals with the washing plant characterization, chemicals used, optimum dosing determination, experimental matrix for assessing effectiveness of different chemicals, relative assessment of cost and dosing performance. Although effluent characteristics differ greatly even within the same process, some general values for major processes in a denim washing plant has been determined in the present study. Mixed textile wastewater generally contains high levels of COD and color, and usually has a high pH.

3.2 Evaluation of Water Quality Parameters

The textile industry generally has difficulty in meeting wastewater discharge limits, particularly with regard to dissolved solids, pH, BOD, COD, Color, Turbidity of effluent. The main wastewater quality parameters concerned in this study are Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and color, turbidity, alkalinity and hardness.

3.2.1 pH

Calibration of the pH meter has been done using standard pH solutions. The calibration procedure would depend on the pH range of interest. 100 ml of the test sample was taken in a beaker. The sample should not be agitated to prevent exchange of gases between the sample and the atmosphere. Then pH meter was inserted into the sample. After allowing some time for attainment of equilibrium pH meter was turned on and reading was taken for pH.

3.2.2 Color

50-mL of filtered test sample and 50 ml distilled water was taken in two different beakers. Distilled water sample was taken as blank. Spectrophotometer being set to determine the color concentration of the sample. Then putting the blank sample inside the spectrophotometer cell and setting the reading "zero", the blank sample was taken out and the test sample was entered into the spectrophotometer .After a while, the display showed the color concentration of the sample.

3.2.3 Turbidity

Turbidimeter was standardized using formazin standards.Then filling the clean sample cell with the water sample and being placed it in the sample cell holder. The sample cell was covered with the light shield. Finally turning on the switch turbidity value was determined directly from the screen.

3.2.4 Alkalinity

100 mL of the sample was taken into one beaker and the same amount of distilled water into another beaker. pH of the sample was measured. Then 3 drops of phenolphthalein indicator to each was added (step 3). If the sample becomes pink, go to step- 3. Otherwise, go to step- 4. 0.02N H_2SO_4 acid was added from a burette until the pink color just disappears (step 4). The volume of acid (mL) of the acid used was recorded. Then 3 drops of methyl orange indicator to each beaker was added. If the sample turned yellow, 0.02N H_2SO_4 was added until the first change in color was noted. The end point is a slight orange tinge. The volume of acid (mL) of the acid used was recorded finally.

3.2.5 Hardness

50 mL sample in a 150 mL beaker was taken. Add one nil of standard buffer solution (supplied by HACH)was used to raise the pH of water sample to about 10.01(Note: If 100 mL sample is taken, add 2 mL buffer). One packet of Eriochrome Black T dye (supplied by HACH) indicator to

the beaker was added. The sample would turn wine-red (if hardness is present). Then 'Cartridge containing standard EDTA solution to the titrator device (supplied by HACH) was fitted. Flow control knob of the device was turned on until the solution starts to come out of the tube fitted to the cartridge. Initial reading of the counter was taken. After that immerse the tube fitted to the cartridge into the water sample and start titrating (under constant stirring) by turning the flow control knob of the auto-titrator. Continue until the wine-red color of the sample changes to blue. Finally take the final reading.

3.2.6 TDS

Measurement of Total Solids (TS)

Take a clear dry 150 mL capacity glass beaker (which was kept at 103°C in oven for 1 hour) and put appropriate identification mark on it. Take the weigh the empty beaker. Thoroughly mix the sample. Measure 100 mL of the sample using the measuring cylinder and pour in to the beaker. Place the beaker in an oven maintained at 103°C for 24 hours. After 24 hours, cool the beaker and weigh. Find out the weight of solids in the beaker by subtracting the weight of the clean beaker.

Dissolved Solids (TDS)

Clear dry 150 mL capacity glass beaker (which was kept at 103°C in oven for 1 hour) was taken and put appropriate identification mark on it. Empty beaker was weighed then. Then taking a 100 mL of sample and filtering it through a double layered filter paper, the filtrate in a beaker was collected. TDS can be measured from this value.

3.2.7 Biochemical Oxygen Demand (BOD_5)

For determination of DO

Two BOD bottles with sample (or diluted sample) was completely filled. Initial Dissolved Oxyzen (DO) in one bottle immediately after filling with sample (or diluted sample) was determined. And the other bottle was kept in dark at 20°C and after particular days (usually 5-days) DO (DO_f) in the sample (or diluted sample) was measured. Dissolved oxygen (DO) was determined according to the following procedure: 1 mL of manganous sulfate solution to the BOD bottle by means of pipette was added by dipping in end of the pipette just below the surface of the water.Then 1 mL of alkaline potassium iodide solution to the BOD bottle in a similar manner was added. After that stopper was inserted and the solution was mixed by inverting the bottle several times. Then allowing the "precipitates" to settle halfway the solution was mixed again and "precipitates" again allowed to settle halfway. 1 mL of concentrated sulfuric acid was added and immediately the stopper was inserted and being mixed as before. After that the solution was allowed to stand at least for 5 minutes. Withdrawing 100 mL of solution into an Erlenmeyer flask and immediately adding 0.025N sodium thiosulfate drop by drop from a burette was added until the yellow color almost disappeared. Then about 1 mL of starch solution was added and being continued the addition of the thiosulfate solution until the blue color just been disappeared.The amount of thiosulfate solution used (disregard any return of the blue color) was recorded finally.

3.2.8 Chemical Oxygen Demand (COD)

2 ml sample was taken into the COD vial.The COD vial may be high range or low range depending on the quality of wastewater. Then sample was heated for 2 hours by following the „Closed Reflux-Colorimetric method". After that the COD vial has been cooled down for 30 minutes. After that by the help of spectrophotometer COD is being determined.

3.3 Boundary condition considered for present research

Effluent treatment plants (ETPs) in different washing industries may have a wide range of design and layout, which depend on wastewater characteristics, land area availability, treatment objective etc. In general industries operating with an ETP, have two to three major segments in overall treatment approach. These segments are:

(a) Primary Treatment: Mostly removes solids (both settleable and dispersed in solution)

(b) Secondary Treatment: Mostly removes organic fraction of waste from solution

(c) Tertiary Treatment: Further treatment/ removal of contaminant from wastewater.

The scope/focus area of the present study is within the primary treatment unit of an ETP in denim washing plant. Primary treatment units involve physical and chemical processes to separate solids from the influent wastewater stream. Chemical treatment involve dosing of coagulants to form larger flocs of colloidal particles and remove them from solution due to increased size and weight through sedimentation process.

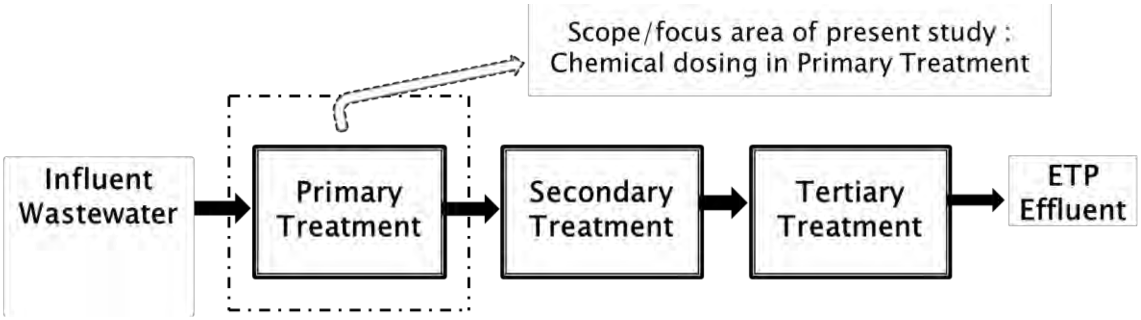

Figure 3.1 Generic layout of effluent treatment plant (ETP) in denim washing industries of Bangladesh showing focus area of the present study.

Chemical treatment, which is a cost intensive treatment approach, thus can remove a substantial wasteload in influent wastewater. Optimization of chemical dosing can reduce cost of operation and sludge production in primary treatment unit. Hence the present study focused into chemical dosing optimization in primary treatment stage of ETPs in denim washing industries.

3.4 Optimum dosing determination for individual chemicals

Wastewater sample was collected from a denim washing plant and transported to the laboratory as quickly as possible. Water quality parameters, such as pH, EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD_5, PO_4, SO_4, NH_3-N of raw wastewater was measured using relevant standard methods.

Figure 3.2 Typical raw wastewater sample from denim washing plant

Then turbidity and color removal efficiency of individual chemicals (Ferrous sulfate, Alum, and Polymer) by conventional coagulation and flocculation process at varying doses were assessed and optimum dosing was determined.

(a) (b) (c)

Figure 3.3 (a)Ferrous sulfate solution;(b) Alum solution; (c) Polymer solution

For this, wastewater was stirred in a 1L beaker with rapid mixing (45 rpm) for 1 minute to allow complete mixing followed by a slow mixing (25 rpm) for 15 minutes which is then kept for 30 minutes to settle down. These initial experiments were carried out with and without pH control of raw wastewater. In experiments with pH control, the pH value was maintained between 7.0 ~ 7.5.

Figure 3.4 Dosing of individual chemicals into the raw wastewater

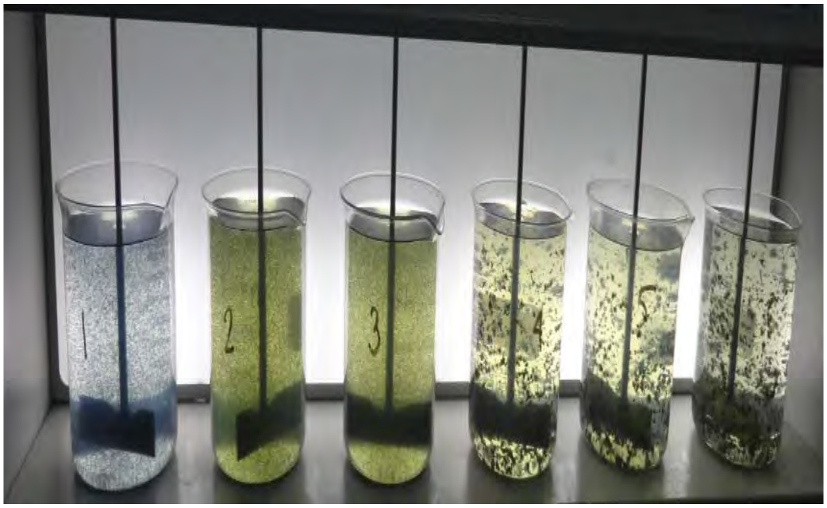

Figure 3.5 Typical coagulation and flocculation process

Figure 3.6 Typical scenario of the wastewater after settling down for 30 minutes

3.5 Sensitivity analysis for different dosings of individual chemicals

After determination of optimum chemical dosing for individual chemicals, the effect of reduced levels of dosing on different water quality parameters were assessed. In order to assess the sensitivity of water quality parameters (like Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD_5) on a different chemical dosing two different chemical dosings were selected in the present study. The chemical dosings selected for different chemicals were: (a) Optimum chemical dosing with respect to maximum turbidity removal, and (b) Half of the optimum chemical dosing with respect to maximum turbidity removal. These experiments were also carried out in controlled pH (between 7.0 ~ 7.5) condition. The results, showing reduction of various water quality parameters, were used to assess sensitivity of removal of a particular parameter to optimum chemical dosing.

3.6 Combined chemical dosing experiments

Removal efficiencies of various water quality parameters (Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD_5) were assessed for different combination dosings of different chemicals along with cost of chemicals involved. These experiments were carried out with controlling the pH of the raw wastewater. pH of the sample was controlled close to neutral range (i.e. 7.0) by the addition of small aliquots of NaOH/HCl solution. The combinations of different chemicals used in the present study are given below;

(1) Alum (0.5 times of optimum dosing w.r.t. turbidity removal) + Polymer (0.5 times of optimum dosing w.r.t. turbidity removal)

(2) Alum (0.5 times of optimum dosing w.r.t. turbidity removal) + Ferrous Sulphate (0.5 times of optimum dosing w.r.t. turbidity removal)

(3) Polymer (0.5 times of optimum dosing w.r.t. turbidity removal) + Ferrous Sulphate (0.5 times of optimum dosing w.r.t. turbidity removal)

(4) Alum (0.5 times of optimum dosing w.r.t. turbidity removal) + Polymer (0.5 times of optimum dosing w.r.t. turbidity removal) + Ferrous Sulphate (0.5 times of optimum dosing w.r.t. turbidity removal)

In order to asses the water quality parameters along with the removal efficiency the solution was stirred in a 1L beaker with rapid mixing (45 rpm) for 1 minute to allow complete mixing followed by a slow mixing (25 rpm) for 15 minutes which is then kept for 30 minutes to settle down. Results from these experiments were compared with the results of individual chemical dosing experiments (with half of the optimum chemical dosing with respect to maximum turbidity removal) as explained in the previous section. Both these results were analyzed to assess effectiveness of different chemicals and combination of chemicals for the treatment of denim washing plant wastewater both in terms of water quality and economic point of view.

Chapter 4 : Results and Discussions

4.1 Introduction

This chapter contains the optimum dose determination for different chemicals, sensitivity analysis for varying doses below optimum level (i.e. percentage reduction in efficiency and cost) and finally the analysis of the effect of combined dosings of chemicals with respect to removal efficiency and economic point of view.

4.2 Characterization of process wastewater produced from the denim washing plant.

In the present study periodic water samples were collected from a denim washing plant "S. F. Washing Ltd.", located in Kanchpur, Narayanganj, and analyzed in the Environmental Engineering Laboratory at CE, BUET following the procedure given in Standard Methods. The parameters analyzed were pH, EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD_5, PO_4, SO_4, NH_3-N which have been given in Table 4.1.

Table 4.1 Characterization of process wastewater produced from denim washing plant

Water quality parameter	Parametric value	Water quality parameter	Parametric value
pH	5.3-6.7	NH_3-N (mg/l)	2.6-3.0
DO (mg/l)	0.46-0.50	Alkalinity (mg/l as $CaCO_3$)	200-280
EC (μ S/cm)	596-668	Hardness (mg/l as $CaCO_3$)	120-126
Color (Pt-Co Unit)	44-108	TS (mg/l)	580-624
Turbidity (NTU)	50-69	TDS (mg/l)	480-540
PO_4 (mg/l)	1.8-2.1	COD (mg/l)	200-430
SO_4 (mg/l)	110-130	BOD_5 (mg/l)	144-240

4.3 Optimum dose determination for different chemicals

To determine the optimum dosing of the chemicals (i.e. polymer, alum and ferrous sulphate) for different parameters (EC, color and turbidity) an U-shape curve (the value of specific parameters vs. the dosing of individual chemicals) has been developed in the normal graph paper. This experiment has been conducted for both the case of uncontrolled and controlled pH. pH ,turbidity, color, and EC of the raw water sample was determined first. Then fill 1000 mL beakers (depends on the number dosage applied) of each with 500 mL raw water. After that, individual chemicals (with different concentrations) were being mixed to each beaker. Then with the help of conventional coagulation-flocculation process as described in the article 3.4 experiment has been conducted. Finally, the flocs were allowed to settle down for about 30 minutes. Then after collecting the supernatant from each beaker required parameter was being measured. The following section discusses about the details.

4.3.1 Optimum dose determination for polymer

Optimum dose for turbidity

To determine the optimum dose of turbidity for polymer the following five doses have been applied as shown in Table 4.2.To observe the effectiveness for removing turbidity the experiment has been conducted by both the condition i.e. uncontrolled and controlled pH. As initial pH of the raw sample was found to be below 7.0 therefore pH needed to be raised. This raising of pH was done by adding NaOH solution into the sample. Figure 4.1 provides a graphical representation of the Experimental data for the determination of optimum dose of turbidity for polymer.

Table 4.2 Experimental data for the determination of optimum dose of turbidity for polymer

Dose(mg/l)	Turbidity(before pH control)	Turbidity(after pH control)
0.1	9.5	13
0.3	9.2	9.2
0.7	9.4	7.9
0.9	9.6	8.4
1.1	9.7	9.4

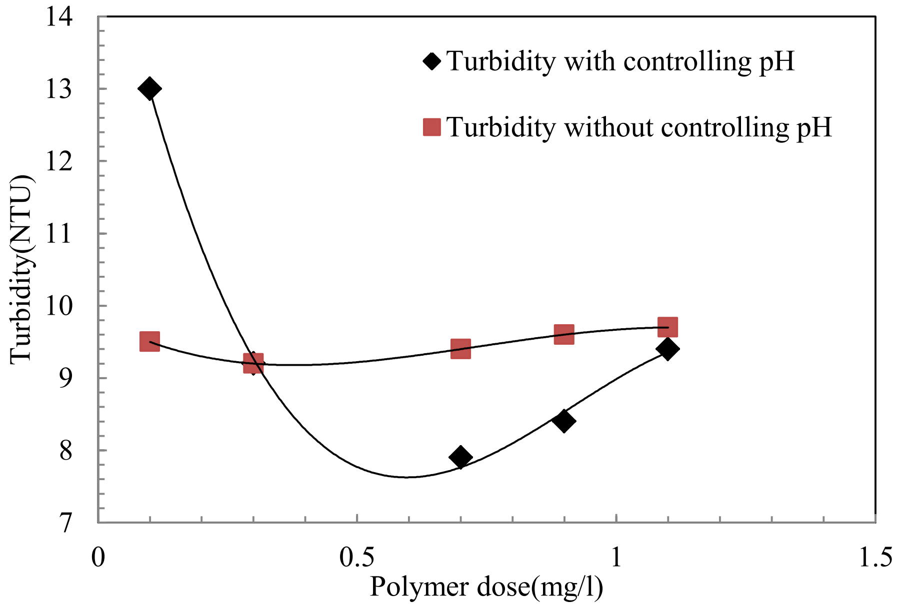

Figure 4.1 Turbidity vs. polymer dosing curve

From the Fig 4.1 the following conclusions can be made-

- Optimum dosing of polymer is around 0.5 mg/l when pH is controlled. For uncontrolled pH, the optimum dosing is almost same as controlled condition.
- It can be also seen that the removal efficiency is far better for controlled pH than when it is uncontrolled. This can be attributed to the charge neutralization of colloidal particle surfaces in the neutral pH range (~7.0), which enables quicker and larger floc formation between the particles due to Van der Waal"s force of attraction.

Optimum dose for color

Simillar procedure as described in for turbidity, the optimum dose for color(Pt-Co Unit) was determined by applying the doses shown in Table 4.3. This experiment was also conducted twice times. Before pH controlling and after pH controlling the observed results for the determination of optimum dose were shown in Table 4.3. Figure 4.2 provides a graphical representation of the Experimental data for the determination of optimum dose of color for polymer.

Table 4.3 Experimental data for the determination of optimum dose of color for polymer

Dose(mg/l)	Color(before pH control)	Color(after pH control)
0.1	45	49
0.3	33	45
0.7	44	44
0.9	40	45
1.1	39	45

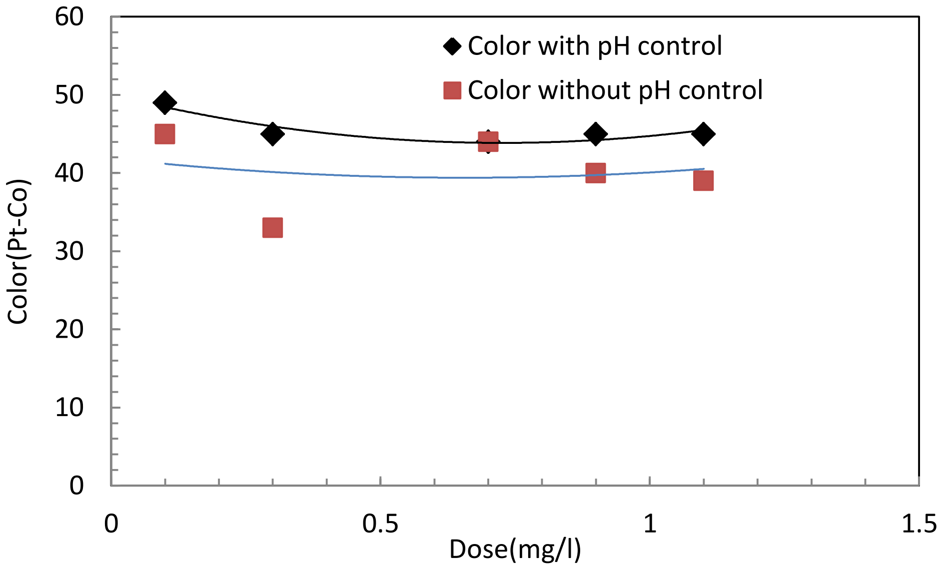

Figure 4.2 Color vs. polymer dosing curve

From the Fig 4.2 the following conclusions can be made-

- Optimum dosing of color for polymer is around 0.5 mg/l for both conditions.

- There is not a significant difference for removing color for both pH controlled and uncontrolled situation.

Effect for EC (Electrical Conductivity)for polymer dosing

The change in electrical conductivity for both the condition (controlled and uncontrolled pH) was assessed which are shown in Table 4.4. Figure 4.3 provides a graphical representation of the experimental data for the value of EC for polymer.

Table 4.4 Experimental data of the electrical conductivity for polymer

Dose(mg/l)	EC(before pH control)	EC(after pH control)
0.1	820	838
0.3	819	837
0.7	811	836
0.9	808	835
1.1	805	824

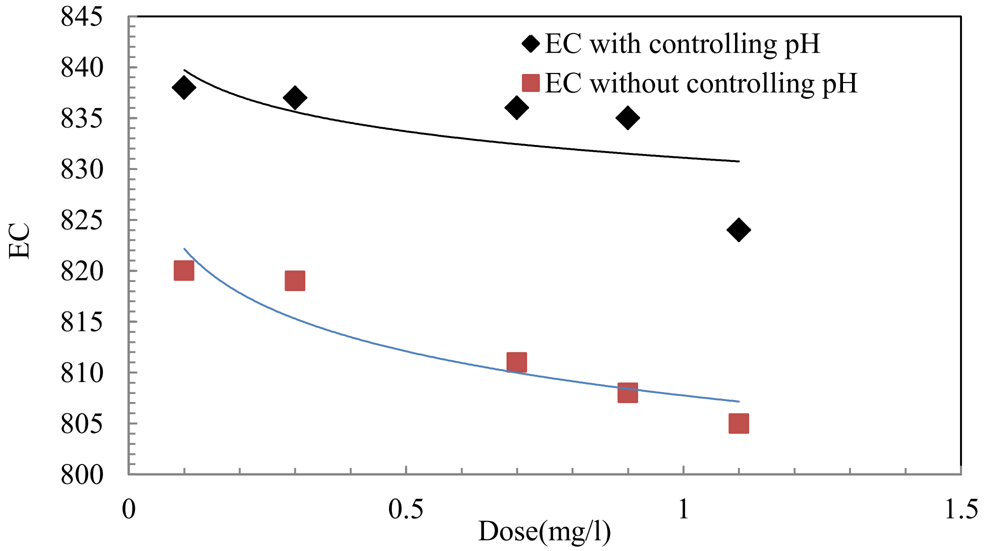

Figure 4.3 Electrical Conductivity vs. polymer dosing curve

From the Fig 4.3 the following conclusions can be made-

- As more NaOH/HCl is added therefore the concentrations of Na^+ or Cl^- ion increases. So EC value becomes higher when pH is controlled in the experiment.
- Adding of polymer into the solution showed a slight decrease in solution. This may be due to the neutral charged nature of the polymer which did not increase the ion concentration in solution.

4.3.2 Optimum dose determination for Alum

Optimum dose for turbidity

To determine the optimum dose of turbidity for alum the following six doses have been applied as shown in Table 4.5.To observe the effectiveness for removing turbidity the experiment has been conducted by both the condition i.e. uncontrolled and controlled pH. As initial pH of the raw sample was found to be below 7.0 therefore pH needed to be raised. As it has been studied before that the coagulant alum is very effective for pH in the range around 7.5.This raising of pH was done by adding NaOH solution into the solution. Figure 4.4 provides a graphical representation of the Experimental data for the determination of optimum dose of turbidity for alum.

Table 4.5 Experimental data for the determination of optimum dose of turbidity for alum

Dose(mg/l)	Turbidity(before pH control)	Turbidity(after pH control)
40	59.8	54.4
70	55.9	44
100	45.4	33
130	42.6	32.7
150	38.7	27.7
180	41.7	30

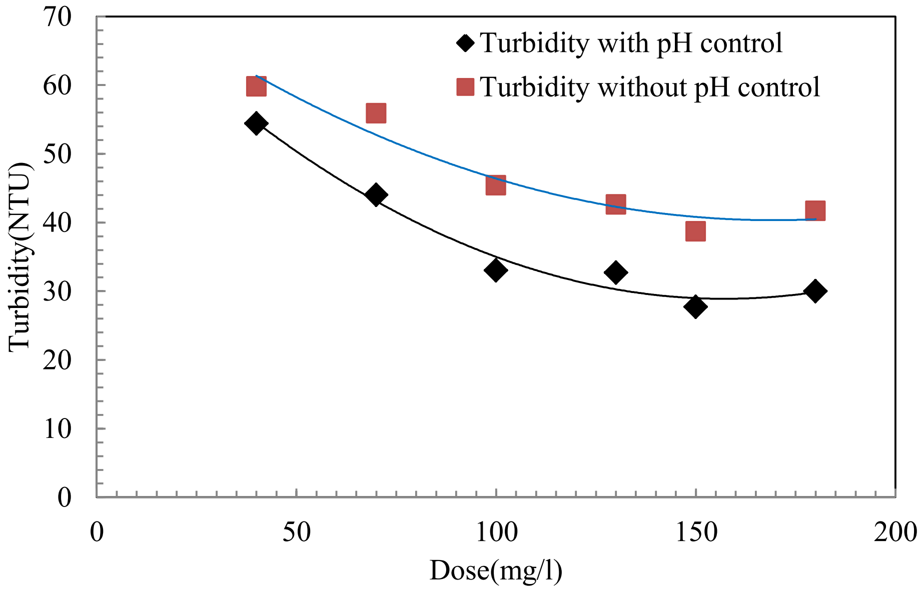

Figure 4.4 Turbidity vs. alum dosing curve

From the Fig 4.4 the following conclusions can be made-

- Optimum dosing of alum is around 120 mg/l when pH is controlled. For uncontrolled pH, the optimum dosing is around 150 mg/l.
- It can be also seen that the removal efficiency is better for controlled pH than when it is uncontrolled. This can be attributed to the charge neutralization of colloidal particle surfaces in the neutral pH range (~7.0), which enables quicker and larger floc formation between the particles due to Van der Waal"s force of attraction.

Optimum dose for color

Simillar procedure as described in for turbidity, the optimum dose for color(Pt-Co Unit) was determined by applying the doses shown in Table 4.6. This experiment was also conducted twice times. Before pH controlling and after pH controlling the observed results for the determination of optimum dose were shown in Table 4.6. Figure 4.5 provides a graphical representation of the Experimental data for the determination of optimum dose of color for alum..

Table 4.6 Experimental data for the determination of optimum dose of color for alum

Dose(mg/l)	Color(before pH control)	Color(after pH control)
40	251	242
70	306	202
100	214	189
130	191	188
150	200	183
180	202	170

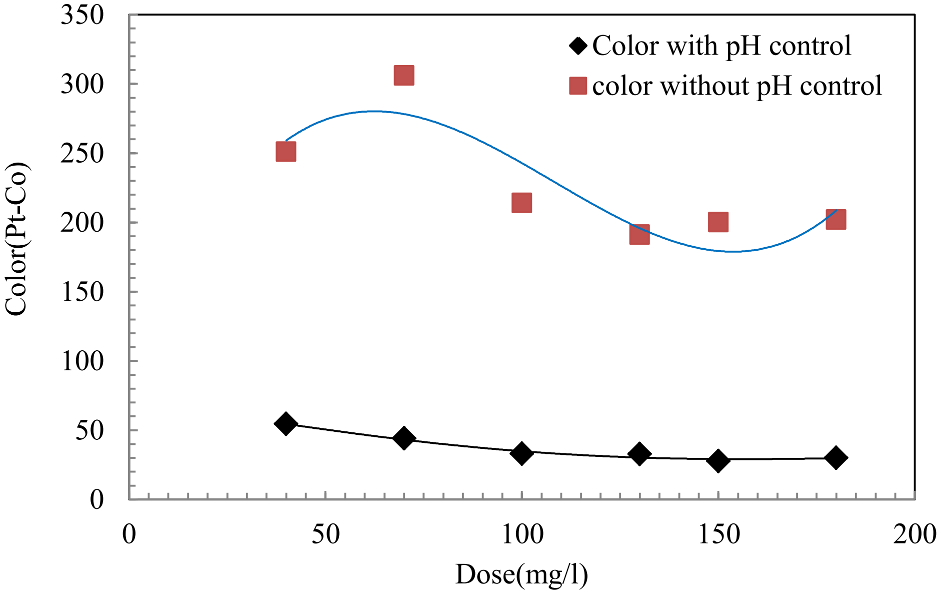

Figure 4.5 Color vs. alum dosing curve

From the Fig 4.5 the following conclusions can be made-

- Optimum dosing of alum is around 120 mg/l when pH is controlled. For uncontrolled pH, the optimum dosing is around 150 mg/l
- It can be also seen that the removal efficiency is much better for controlled pH than when it is uncontrolled.

Effect for EC (Electrical Conductivity)for alum dosing

The change in electrical conductivity (μ S/cm) for both the condition (controlled and uncontrolled pH) was evaluated which are shown in Table 4.7. Figure 4.6 provides a graphical representation of the experimental data for the value of EC for polymer.

Table 4.7 Experimental data of the electrical conductivity for alum

Dose(mg/l)	EC(before pH control)	EC(after pH control)
40	819	858
70	828	890
100	838	903
130	848	933
150	855	943
180	865	980

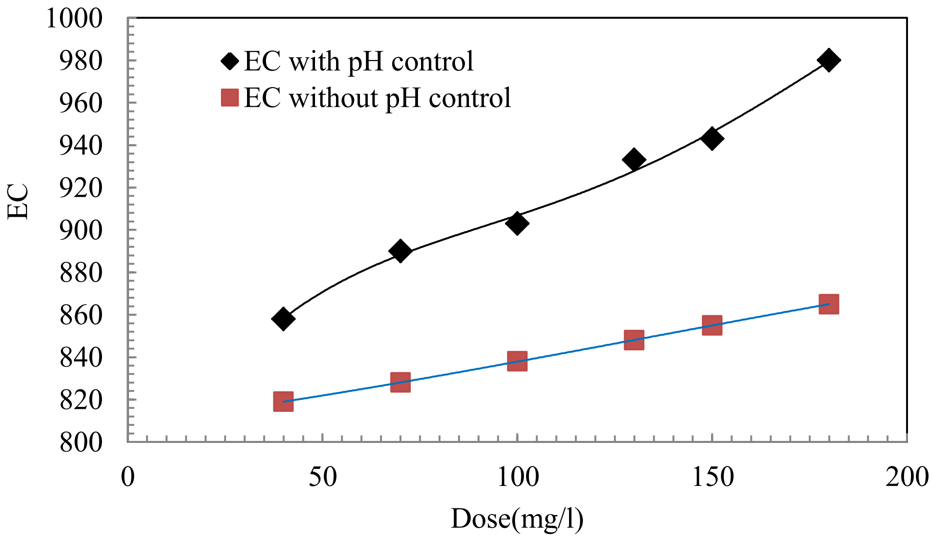

Figure 4.6 Electrical Conductivity vs. alum dosing curve

From the Fig 4.6 the following conclusions can be made-

- More alum addition means there is a increase of Al^{3+} ion in the solution. Hence the graph shows the increase of EC with the increasing dosing of alum.
- As more NaOH/HCl is added therefore the concentrations of Na^+ or Cl^- ion increases. So EC value becomes higher when pH is controlled in the experiment.
- The more Al^{3+}, $SO_4^{2-}$and Na^+ added into the solution more the value of electrical conductivity will rise.

4.3.3 Optimum dose determination for Ferrous Sulfate

Optimum dose for turbidity

To determine the optimum dose of turbidity for ferrous sulfate the following seven doses have been applied as shown in Table 4.8.To observe the effectiveness for removing turbidity the experiment has been conducted for both the condition i.e. uncontrolled and controlled pH. As initial pH of the raw sample was found to be below 7.0 therefore pH needed to be raised by the addition of NaOH solution. Figure 4.7 provides a graphical representation of the experimental data for the determination of optimum dose of turbidity for ferrous sulfate.

Table 4.8 Experimental data for the determination of optimum dose of turbidity for ferrous sulfate

Dose(mg/l)	Turbidity(before pH control)	Turbidity(after pH control)
5	70.3	-
10	72.7	62.8
20	63.3	59.9
50	71	56.5
80	81.1	51.8
110	86.3	47.9
140	91.2	51.1

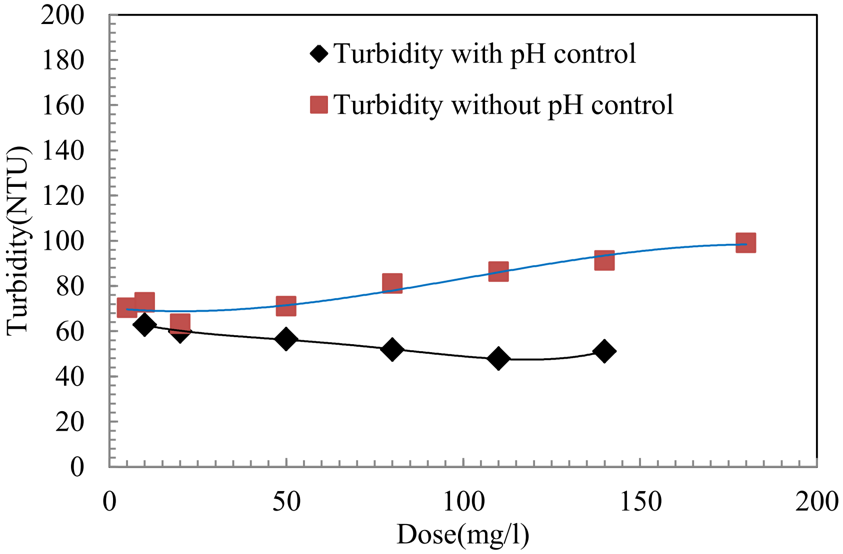

Figure 4.7 Turbidity vs. ferrous sulfate dosing curve

From the Fig 4.7 the following conclusions can be made-

- Optimum dosing of ferrous sulfate is around 120 mg/l when pH is controlled. For uncontrolled pH, the optimum dosing is around 50 mg/l
- However, removal efficiency is better for controlled pH. This can be attributed to the charge neutralization of colloidal particle surfaces in the neutral pH range (~7.0), which enables quicker and larger floc formation between the particles due to Van der Waal"s force of attraction.

Optimum dose for color

Simillar procedure as described in for turbidity, the optimum dose for color(Pt-Co Unit) was determined by applying the doses shown in Table 4.9 for controlling and without controlling pH. The observed results for the determination of optimum dose were shown in Table 4.9. Figure 4.8 provides a graphical representation of the experimental data for the determination of optimum dose of color for ferrous sulfate.

Table 4.9 Experimental data for the determination of optimum dose of color for ferrous sulfate

Dose(mg/l)	Color(before pH control)	Color(after pH control)
10	188	160
20	208	138
50	219	113
80	254	129
110	304	95
140	378	115

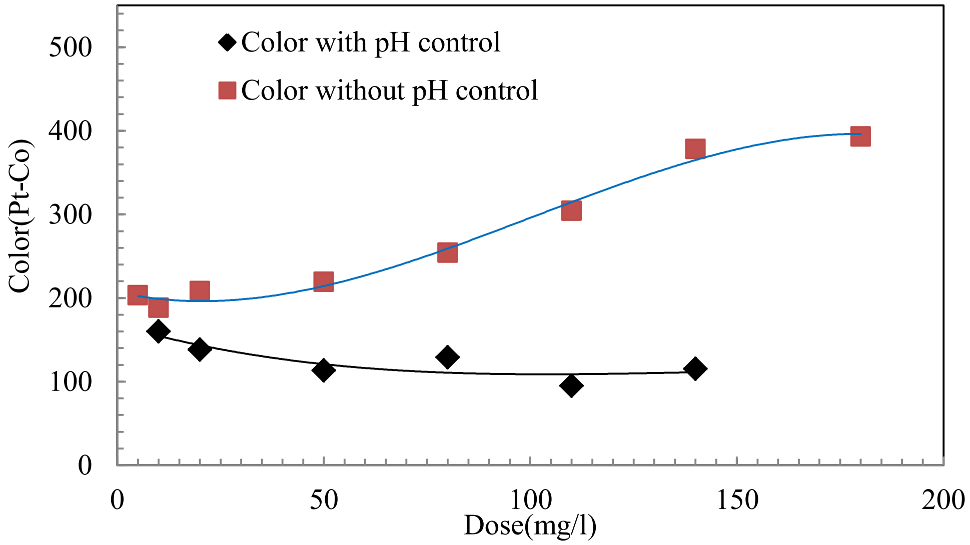

Figure 4.8 Color vs. ferrous sulfate dosing curve

From the Fig 4.8 the following conclusions can be made-

- Optimum dosing of ferrous sulfate is around 120 mg/l when pH is controlled. For uncontrolled pH, the optimum dosing is around 50 mg/l.
- It can be also seen that the removal efficiency is better for controlled pH as predicted.

Optimum dose for EC (Electrical Conductivity)for ferrous sulfate

The change in electrical conductivity (µ S/cm) for both the condition (controlled and uncontrolled pH) was evaluated which are shown in Table 4.10. Figure 4.9 provides a graphical representation of the experimental data for the value of EC for ferrous sulfate.

Table 4.10 Experimental data of the electrical conductivity for ferrous sulfate

Dose(mg/l)	EC(before pH control)	EC(after pH control)
10	858	850
20	890	854
50	903	865
80	933	880
110	943	920
140	980	927

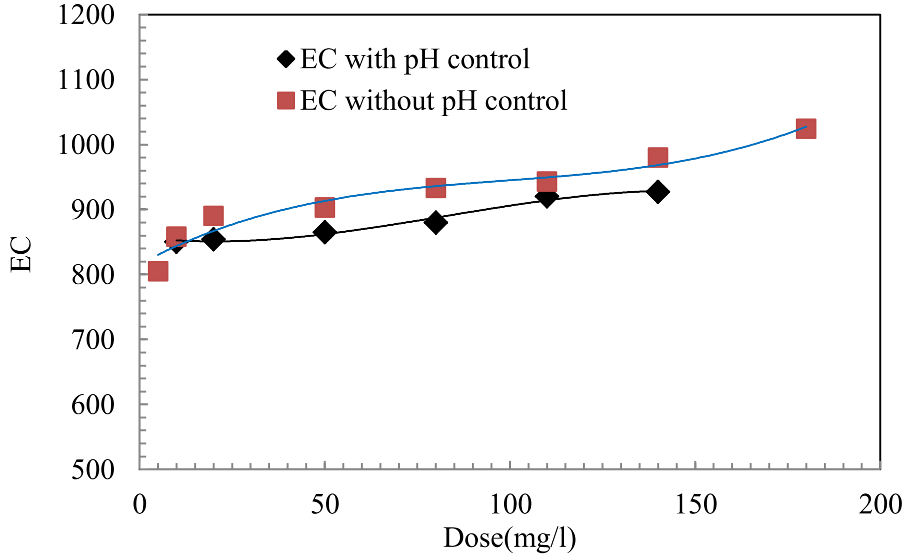

Figure 4.9 EC vs. ferrous sulfate dosing curve

From the Fig 4.6 the following conclusions can be made-

- There is no optimum point for EC in case of addition of ferrous sulfate. More ferrous sulfate addition means there is an increase of Fe^{2+} and SO_4^{2-} ion in the solution. Hence the graph shows the increase of EC with the increasing dosing of alum.

- As more NaOH/HCl is added therefore the concentrations of Na^+ or Cl^- ion increases. So EC value becomes higher when pH is controlled in the experiment.

4.4 Dose sensitivity analysis for polymer, alum and ferrous sulfate

Optimum dose selected based on removal of turbidity and color for different chemicals indicated better performance scenario with pH control. However, experimentally derived optimum dosing may not be feasible in primary treatment due to excessive cost involvement. Since most of the ETPs have additional secondary and/or tertiary treatment units, the practical levels of dosing, observed in different industries, for these chemicals in primary treatment are less than the optimum dosing. Hence a dose sensitivity analysis have been carried out in this study to assess the effectiveness of different chemicals on different water quality parameters. From the article as discussed in 4.3.1, 4.3.2 and 4.3.3, optimum dose for turbidity has been taken for consideration for sensitivity analysis. All the experiments were conducted in pH controlled condition. From the experiment it has been found that the optimum dosing for polymer, alum, and ferrous sulfate were 0.5 mg/l, 120 mg/l, and 120 mg/l, respectively in pH controlled condition.

A set of experiments have been conducted at two different dosing to determine the removal efficiency of the various parametric values including EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, COD, and BOD_5). The first applied dose was the optimum dose itself and the second one was half of the optimum dose. The following sections discuss details on the findings:

4.4.1 Sensitivity analysis for varying doses of alum

In order to assess sensitivity of alum dosing on different water quality parameters, coagulation and flocculation experiments were carried out using two concentrations of alum: 120 mg/l (i.e.

the optimum dosing w.r.t. turbidity removal), and 60 mg/l (i.e. half of the optimum dosing w.r.t. turbidity removal). Water quality parameters assessed after the dosing of alum were EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, COD, and BOD_5. Table 4.11 shows the values of different water quality parameters and the percentage decrease from initial values of parameters after two different alum dosing experiments. The initial values of the water quality parameters are also provided in the footnote of Table 4.11. Figure 4.10 provides a graphical representation of the sensitivity of alum dosing concentration to the decrease of different water quality parameters.

Table 4.11 Experimental data of different water quality parameters and the reomoval efficiency for optimum and below optimum dosing of alum

Water Quality Parameters	Value changed from initial value (% change)	
	Alum (60 mg/l)	Alum (120 mg/l)
EC (µ S/cm)	713 (-10%)	743 (-14%)
Color(Pt-Co Unit)	79 (42%)	68 (50%)
Turbidity (NTU)	26.9 (33%)	18.3 (54%)
Alkalinity(mg/l as $CaCO_3$)	260 (4%)	240 (11%)
Hardness(mg/l as $CaCO_3$)	132 (-10%)	112 (7%)
TSS(mg/l)	20 (80%)	10 (90%)
TDS(mg/l)	460 (4%)	470 (2%)
COD(mg/l)	77 (62%)	66 (67%)
BOD_5(mg/l)	48 (67%)	48 (67%)

Note: Initial turbidity = 40 NTU, color = 137 Pt-Co unit, EC = 649 µ S/cm, Alkalinity= 270 mg/l, hardness= 120 mg/l, TS= 580 mg/l, TDS= 480 mg/l, BOD_5= 144 mg/l, COD= 200 mg/l.

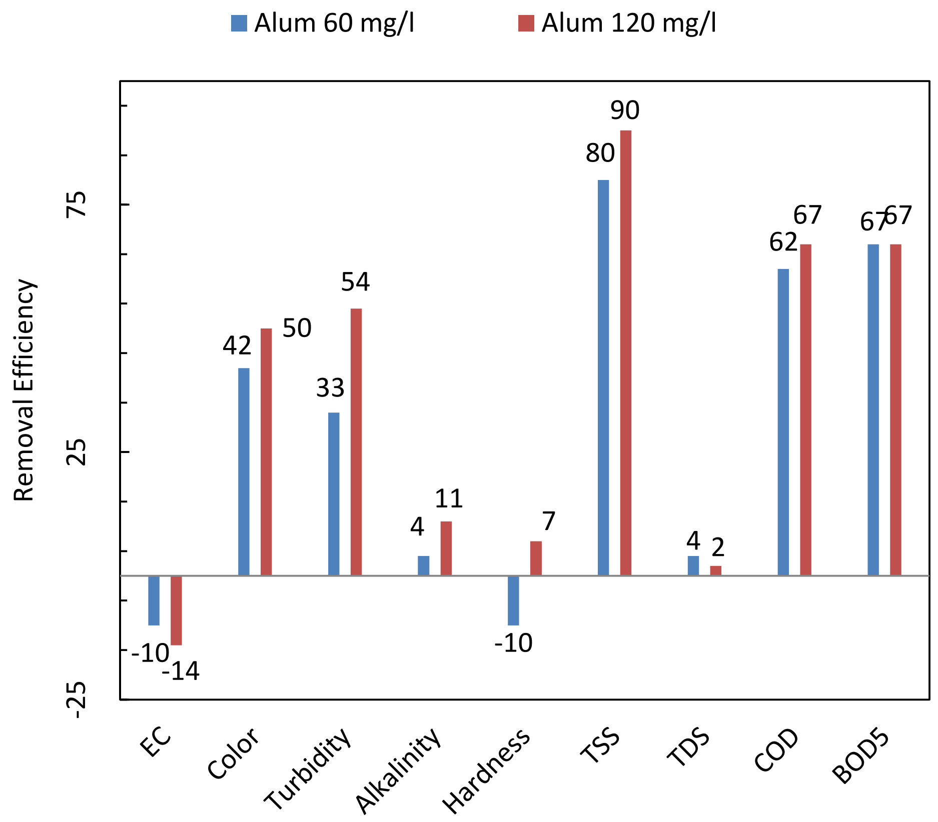

Figure 4.10 Removal efficiency vs. parameters for Alum

From the Fig.4.10 the following observations can be made-

- In case of BOD_5 removal there is literally no difference between the application of a dose of 60 mg/l (i.e.half of the optimum dose) and 120 mg/l (i.e.optimum dose).
- There is not a significant difference in removal efficiency for color, Alkalinity, TSS, and COD even though we increase the dose from 60 mg/l to 120 mg/l. It can be seen from the graph, 100% increase of alum dosing is capable of increasing removal efficiency of color, Alkalinity,TSS, and COD only upto 10% which is definitely a big concern from the economic point of view. To be more specific, for optimum dose i.e. twice the increase

from 60 mg/l the removal efficiency for color, alkalinity, TSS, and COD increases only by 8%, 7%, 10%, and 5%, respectively.

- Additionally, the removal efficiency decreases with the increasing of the doses for EC and TDS. 100% increase of dosing increases the Electrical Conductivity by 4%. For total dissolved solid, the condition is even more worse. For instance, 100% increase in dose is responsible for increasing the TDS by 100%. This is because with the edition of alum into the solution more Al^{3+} enters into the solution and hence EC rises. Also alum is a salt itself so there is an increase of total dissolved solids.
- However, increasing the dose from 60 mg/l to 120 mg/l the only noteworthy removal efficiency has been found for turbidity (100% increasing of dose increase the removal by 21%) and hardness (removal upto 17%) .

4.4.2 Sensitivity analysis for varying doses below optimum doses for Ferrous sulfate

The optimum dose for ferrous sulfate for turbidity removal was found to be 120 mg/l (from Fig.4.4). After that an experiment was conducted to see the variations of the different water quality parameters (EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, COD, and BOD_5) for the optimum dose along with the dose which is half of the optimum dose (i.e. 60 mg/l). All the water quality parameters experimental value along with their removal efficiency has been represented in the Table 4.12. Figure 4.11 provides a graphical representation of the sensitivity of ferrous sulfate dosing concentration to the decrease of different water quality parameters.

Table 4.12 Experimental data of different water quality parameters and the reomoval efficiency for optimum and below optimum dosing of ferrous sulfate

Water Quality Parameters	Value changed from initial value (% change)	
	Ferrous sulfate (60 mg/l)	Ferrous sulfate (120 mg/l)
EC (µ S/cm)	704 (-8%)	708 (-9%)
Color(Pt-Co Unit)	118 (14%)	145 (-6%)
Turbidity (NTU)	60.1 (-50%)	72 (-80%)
Alkalinity(mg/l as $CaCO_3$)	260 (4%)	254 (6%)
Hardness(mg/l as $CaCO_3$)	120 (0%)	120 (0%)
TSS(mg/l)	70 (-30%)	200 (-100%)
TDS(mg/l)	530 (-10%)	600 (-25%)
COD(mg/l)	72 (64%)	57 (72%)
BOD_5(mg/l)	56 (61%)	48 (67%)

Note: Initial turbidity = 40 NTU, color = 137 Pt-Co unit, EC = 649 µ S/cm, Alkalinity= 270 mg/l, hardness= 120 mg/l, TS= 580 mg/l, TDS= 480 mg/l, BOD_5= 144 mg/l, COD= 200 mg/l.

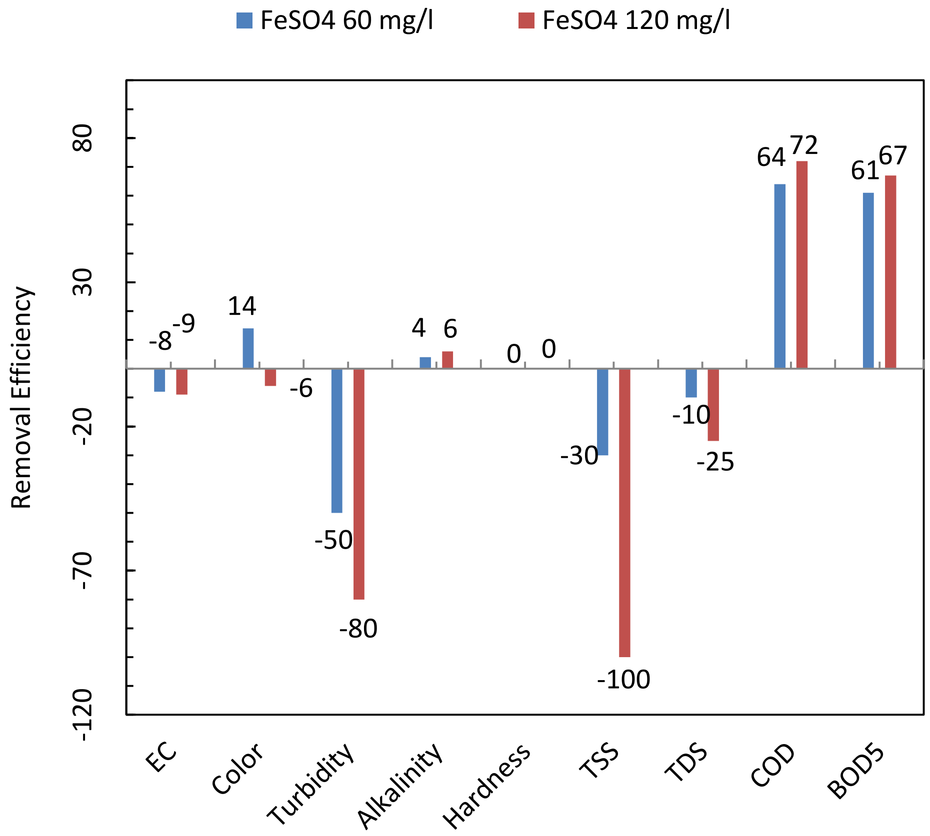

Figure 4.11 Removal efficiency vs. parameters for Ferros sulfate

From the Fig.4.11 the following observations can be made-

- Addition of ferrous sulfate increases turbidity in a great extent which can be upto 80%.It‟s very undesireable for the treatment of wastewater.
- The removal efficiency is higher for 60 mg/l dosing except for BOD_5, COD.Therefore, we can say that more ferrous sulfate is added to the solution, less removal efficiency has been found.
- In case of hardness removal there is literally no difference between the application of a dose of 60 mg/l (i.e.half of the optimum dose) and 120 mg/l (i.e.optimum dose).

- There is not a significant difference in removal efficiency for Alkalinity, COD and BOD_5 even though we increase the dose from 60 mg/l to 120 mg/l. It can be seen from the graph, 100% increase of ferrous sulfate dosing is capable of increasing removal efficiency of Alkalinity, COD and BOD_5 only upto 10% which is definitely a big concern from the economic point of view. To be more specifiq, for optimum dose i.e. twice the increase from 60 mg/l the removal efficiency for alkalinity increases only by 2%, COD increases by only 8%, whereas for BOD_5 it is only 6%.
- Additionally, the removal efficiency decreases with the increasing of the doses for EC, color, turbidity, TSS and TDS. 100% increase of dosings lowers the electrical conductivity removal by 1%. For the parameters- color, turbidity, TSS and TDS the condition is even more worse. For instance, 100% increase in dose is responsible for decreasing the removal efficiency of the color, turbidity, TSS and TDS by 20%, 30%, 70% and 15% respectively.This is because with the edition of ferrous sulfate into the solution more Fe^{2+} enters into the solution and hence EC rises. Also ferrous sulfate is a salt itself so there is an increase of total dissolved solids.

4.4.3 Sensitivity analysis for varying doses below optimum doses for Polymer

The optimum dose for polymer for turbidity removal was found to be 0.5 mg/l (from Fig.4.7). After that an experiment was conducted to see the variations of the different water quality parameters (EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, COD, and BOD_5) for the optimum dose along with the dose which is half of the optimum dose (i.e. 60 mg/l). All the water quality parameters experimental value along with their removal efficiency has been represented in the Table 4.13. Figure 4.12 provides a graphical representation of the sensitivity of polymer dosing concentration to the decrease of different water quality parameters.

Table 4.13 Experimental data of different water quality parameters and the reomoval efficiency for optimum and below optimum dosing of polymer

Water Quality Parameters	Value changed from initial value (% change)	
	Polymer (0.25 mg/l)	Polymer (0.5 mg/l)
EC (µ S/cm)	676 (-4%)	676 (-4%)
Color(Pt-Co Unit)	78 (43%)	73 (47%)
Turbidity (NTU)	33.8 (16%)	36.1 (10%)
Alkalinity(mg/l as $CaCO_3$)	280 (-4%)	268 (1%)
Hardness(mg/l as $CaCO_3$)	132 (-10%)	120 (0%)
TSS(mg/l)	40 (60%)	20 (80%)
TDS(mg/l)	460 (4%)	480 (0%)
COD(mg/l)	65 (68%)	70 (65%)
BOD_5(mg/l)	20 (86%)	32 (78%)

Note: Initial turbidity = 40 NTU, color = 137 Pt-Co unit, EC = 649 µ S/cm, Alkalinity= 270 mg/l, hardness= 120 mg/l, TS= 580 mg/l, TDS= 480 mg/l, BOD_5= 144 mg/l, COD= 200 mg/l.

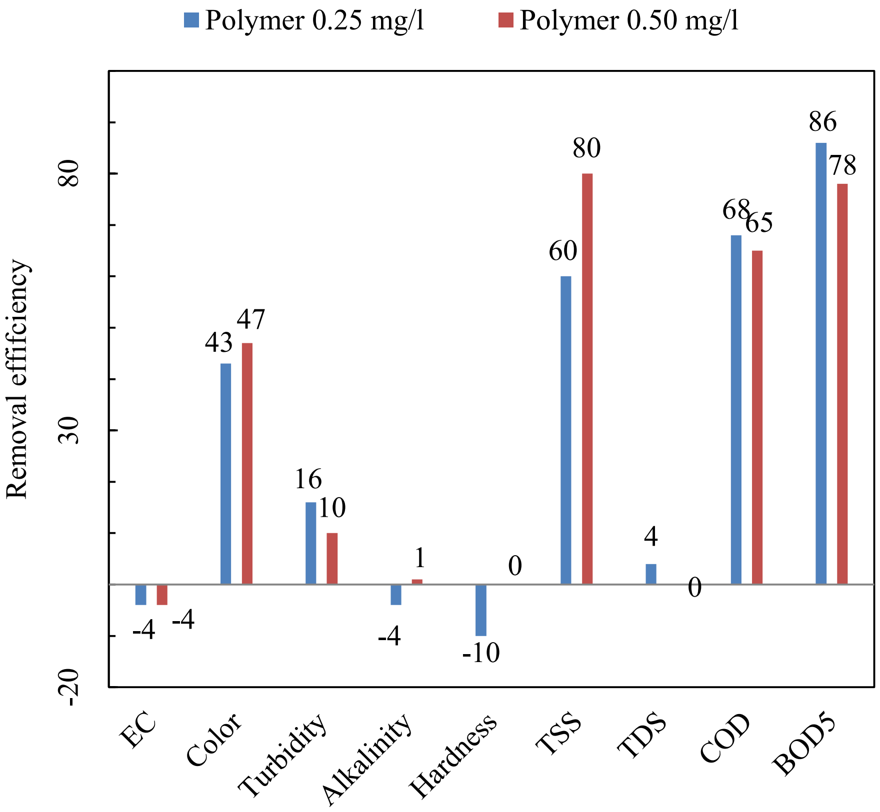

Figure 4.12 Removal efficiency vs. parameters for Polymer

From the Fig.4.12 the following observations can be made-

- For Turbidity, TDS, COD and BOD_5 removal it has been found that 0.25 mg/l is more effective than 0.50 mg/l polymer dosing.
- In case of EC removal there is literally no difference between the application of a dose of 0.25 mg/l (i.e.half of the optimum dose) and 0.50 mg/l (i.e.optimum dose).
- There is not a significant difference in removal efficiency for color, alkalinity and hardness even though we increase the dose from 0.25 mg/l to 0.5 mg/l. It can be seen from the graph, 100% increase of polymer dosing is capable of increasing removal efficiency of color, alkalinity and hardness only upto 10% which is definitely a big

concern from the economic point of view. To be more specific, for optimum dose i.e. twice the increase from 0.25 mg/l the removal efficiency for color increases from 43% to only 47% (i.e. 4% greater), alkalinity removal increases by only 5%. For the hardness the the removal efficiency increases upto 10%.

- Additionally, the removal efficiency decreases with the increasing of the doses for TDS. 100% increase of dosings lowers the TDS removal by 4%.
- However, increasing the dose from 0.25 mg/l to 0.50 mg/l the only noteworthy removal efficiency has been found for TSS removal (100% increasing of dose increase the removal by 20%).

4.5 Effect of combined dosings of chemicals

4.5.1 Sensitivity analysis and the removal efficiency of the parameters for the combined dosing of different concentration of chemicals

Experiment was conducted for various combination of chemicals in order to determine the removal efficiency of the water quality parameters as well as the characterstic values as shown in table 4.15. The selected combination of the chemicals has been listed in the table 4.14.

Table 4.14 The selected combination of the chemicals and their notations

Dose(mg/l)	Notations
Polymer (0.25 mg/l)+ Alum (60 mg/l)	A
Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)	B
Polymer (0.25 mg/l)+ Ferrous sulfate (60 mg/l)	C
Polymer (0.25 mg/l)+ Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)	D

*In the next article this notations will be used.

Table 4.15 Experimental data of different water quality parameters and the reomoval efficiency for different combination dosings of different chemicals

Dose(mg/l)	EC(µS/cm)	Color(Pt-Co unit)	Turbidity (NTU)	Alkalinity(mg/l)	Hardness(mg/l)	TSS(mg/l)	TDS(mg/l)	COD(mg/l)	BOD$_5$(mg/l)
Polymer 0.25 mg/l	676 (-4%)	78 (43%)	33.8 (16%)	280 (-4%)	132 (10%)	40 (60%)	460 (4%)	65 (68%)	20 (86%)
Alum 60 mg/l	713 (-10%)	79 (42%)	26.9 (33%)	260 (4%)	132 (10%)	20 (80%)	460 (4%)	77 (62%)	48 (67%)
Ferrous sulfate 60 mg/l	704 (-8%)	118 (14%)	60.1 (-50%)	260 (4%)	120 (0%)	70 (-30%)	530 (-10%)	72 (64%)	56 (61%)
A	808 (-24%)	36 (74%)	5.3 (87%)	292 (-8%)	122 (-2%)	15 (85%)	565 (-18%)	19 (91%)	14 (90%)
B	830 (-28%)	42 (69%)	10 (75%)	270 (0%)	122 (-2%)	20 (80%)	590 (-23%)	20 (90%)	18.7 (87%)
C	799 (-23%)	54.8 (60%)	15.2 (62%)	296 (-10%)	120 (0%)	30 (70%)	550 (-15%)	40 (80%)	31.7 (78%)
D	807 (-24%)	34 (75%)	12.3 (69%)	270 (0%)	112 (7%)	16 (84%)	575 (-20%)	22 (89%)	10 (93%)

Note: Initial turbidity = 40 NTU, color = 137 Pt-Co unit, EC = 649 µ S/cm, Alkalinity= 270 mg/l, hardness= 120 mg/l, TS= 580 mg/l, TDS= 480 mg/l, BOD$_5$= 144 mg/l, COD= 200 mg/l.

From the Table 4.15 the following observations can be made-

- Combination of chemicals provided better removal efficiencies than individual chemical dosing.

- Amongst all the combinations of chemicals (i.e. A, B, C, and D) as shown in table 4.15 the combination “A” has the highest removal efficiency for the parameters of turbidity, TSS, and COD and the removal efficiency for this parameters are 87%,85%, and 91% respectively. Combination “D” is also very effective for TSS, and COD removal and has the removal efficiency value 84% and 90% respectively.However, combination “D” shows only 69% removal efficiency for turbidity removal which is 18% less compared to the combination “A”.
- For color and BOD_5 removal combination “D” has the highest removal efficiency and the values are 75% and 93% correspondingly whereas the combination “A” shows almost similar efficiency (color removal 74 % and BOD_5 removal 90%) compared to the combinations “D”.
- Combinations “D” contributes more salt (20%) into the solution than combination “A” (18%).However, combination “D” is good at removing alkalinity and hardness compared to “A”.
- Combination “C” has the lowest removal efficiency for removing for color (60%), turbidity(62%),COD (80%) and BOD_5 (78%). However it produces less metal ion and hence has lower TDS (compared to the other combinations).
- Combination “B” has almost similar effects like “A” and “D” for removing TSS, COD ,and BOD_5 ,but not good at color(69%) and TSS (-23%) removal.
- However, all the combinations has more or less similar effect on EC.
- Table 4.15 also indicates that polymer and alum dosing of 0.5 times of optimum level provided better removal efficiencies for different water quality parameters, when compared to other individual chemicals.
- Ferrous sulphate provided least removal efficiencies for most of the water quality parameters when compared to other individual chemicals. Combinations having ferrous

sulphate in them also provided relatively less removal of various water quality parameters.

4.5.2 Cost analysis for the combined dosing of different concentration of chemicals

By observing the removal efficiency of various water quality parameters(EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, COD, and BOD_5) an attempt has been made to analyze the cost for different combinations. Table 4.16 represents the cost (in taka) per m^3 of wastewater for different chemical combinations. The capacity of S.F. Washing Plant is 100 m^3/hr . The monthly cost for individual and combined chemicals has also been shown in the Table 4.16.

Table 4.16 Cost comparison among all the experimental data including different combination dosings of different chemicals

Dose(mg/l)	Cost (BDT/m^3) of wastewater	Monthly Cost (BDT/m^3) of wastewater
Polymer (0.25 mg/l)	0.085	6,200
Alum (60 mg/l)	2.1	1,51,000
Ferrous sulfate (60 mg/l)	1.5	1,08,000
A	2.20	1,57,500
B	3.60	2,59,000
C	1.60	1,14,000
D	3.70	2,65,000

Polymer: Tk. 340 /Kg; Alum : Tk. 35 /Kg; Ferrous Sulfate : Tk. 25/Kg.

By analyzing all the removal efficiency parameters as discussed briefly in article 4.5.1 and 4.5.2 it has been found that-

- Combination “A” (i.e. polymer 0.25 mg/l+ alum 60 mg/l) is more cost effective. The cost for this combination is Tk. 2.20 per m^3 of wastewater which leads to a monthly cost of Tk. 1,57,500.
- Though it has been found that combination “D” (i.e. polymer 0.25 mg/l+ alum 60 mg/l+ ferrous sulfate 60 mg/l) has more efficiency for removing color,COD, alkalinity and hardness but the cost per m^3 of wastewater is Tk. 3.70 ,which leads to a monthly cost of Tk. 2,65,000. It is 70 % costlier than the combinations “A”. Here it appears that the combination “A” (i.e. polymer 0.25 mg/l+ alum 60 mg/l) is more effective from both removal and economic point of view.
- The proper selection of chemical in the primary treatment process will depend on the overall design of the ETP (combination of primary, secondary and tertiary treatment units). Improved performance of chemical treatment can be used to offset loads from subsequent treatment steps. However, the choice of chemical will depend on budget and influent water quality for secondary treatment units.

Chapter 5 : Conclusions and Recommendations

5.1 General

In this study an assessment of chemical dosing optimization in the primary treatment unit for a denim garment washing plant was done for various water quality parameters.After finding the optimum dosing for different chemicals a sensitivity analysis has been conducted to find the effective combined dosing both for removal efficiency of selected water quality parameters and economic point of view. For this,chemical dosing optimization has been done for alum, ferrous sulfate and polymer with the controlled pH condition.This is because pH controlling increases the removal efficiency. A comparison between the optimum dosing and half of the optimum dosing was conducted to find the sensitivity for removing selected water quality parameters. Based on the observations from the above mentioned analysis combined dosing of different concentartions for alum, ferrous sulfate and polymer were carried out to find the removal efficiency. A cost analysis for that different combined dosing was also carried out to determine the possible effective dosings.

5.2 Conclusions of the study

The results of the present research works are summarized below:

I. The removal efficiency for different water quality parameters is good for controlled pH than when pH is uncontrolled.

II. Turbidity and color removal efficiency of alum, polymer, and ferrous sulfate by conventional coagulation and flocculation process at varying doses were found 120 mg/l, 0.50 mg/l and 120 mg/l respectively.

III. After conducting experimental sensitivity analysis it has been found that water quality parameters (like color, turbidity, BOD_5, COD, and Alkalinity) were less sensitive for applied dosing of alum, polymer, and ferrous sulfate to half of its optimum value (i.e. 60 mg/l, 0.25 mg/l and 60 mg/l, respectively). This finding is critical for ETP operation as there is a great concern for excessive use of chemicals in the primary treatment process leading to large volume of sludge generation. Increasing of the dosings upto the optimum level have not shown the proportional increasing for removal efficiency for these water quality parameters.

IV. From the research it has been found that the combination of polymer (0.25 mg/l) and alum (60 mg/l) dosing is capable of removing color, turbidity, TSS, COD, and BOD_5 upto 74%, 87%, 85%, 91%, and 90% respectively.Whereas,combination of polymer (0.25 mg/l),alum (60 mg/l), and ferrous sulfate (60 mg/l) dosing is capable of removing color, turbidity, TSS, COD, and BOD_5 upto 75%, 69%, 84%, 89%, and 93%, respectively. For all other combinations the removal efficiency is lower.

V. From the cost point of view all the possible combinations were further analyzed and found that for polymer (0.25 mg/l) and alum (60 mg/l) dosing the cost is only Tk. 2.20 per m^3 of wastewater (which leads to monthly cost of around Tk. 1,57,500) whereas for the combination of polymer (0.25 mg/l) ,alum (60 mg/l), and ferrous sulfate (60 mg/l) the cost is Tk.3.70 per m^3 of wastewater(which leads to monthly cost of around Tk. 2,65,000) which is almost 70% higher.

VI. From the present study, the ETP designer can choose the required chemical dosing based on the budget and influent water quality for secondary treatment unit.This study therefore can also play a significant influence on design of the ETP (combination of primary, secondary and tertiary treatment units).

5.3 Recommendations for future study

As a continuation of the present work research works can be carried in the following areas in the future:

I. The present research has been carried out for three individual chemicals i.e. alum, polymer, and ferrous sulfate. Further experiment can be conducted with other chemicals like poly aluminium chloride (PAC), decoloring agent.

II. Optimization has been done for denim washing plant only in this research. But future analysis can be conducted for other industries such as for tannery industry, pharmaceuticals.

III. There is a scope to assess the effluent from the washing plant after the optimization is done in the primary treatment units. Before and after the optimization in primary treatment units a comparative study can be made to observe the removal efficiency of different water quality parameters for the effluent from the denim garments washing plant.

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Appendix A : Test results

A.1 Test result for characterization of of parameters for different combination of dosing of chemicals

Periodic water samples from a denim washing plant “S. F. Washing Ltd.”, located in Kanchpur, Narayanganj, and wrer analyzed in the Environmental Engineering Laboratory at CE, BUET following the procedure given in Standard Methods. The parameters analyzed were pH, EC, Color, Turbidity, Alkalinity, Hardness, TS, TDS, TSS, COD, BOD_5, PO_4, SO_4, NH_3-NH_4^+ .

Table A.1 Characterization of process wastewater produced from denim washing plant

Water quality parameter	Parametric value	Water quality parameter	Parametric value
pH	5.3-6.7	NH_3-N (mg/l)	2.6-3.0
DO (mg/l)	0.46-0.50	Alkalinity (mg/l as $CaCO_3$)	200-280
EC (µ S/cm)	596-668	Hardness (mg/l as $CaCO_3$)	120-126
Color (Pt-Co Unit)	44-108	TS (mg/l)	580-624
Turbidity (NTU)	50-69	TDS (mg/l)	480-540
PO_4 (mg/l)	1.8-2.1	COD (mg/l)	200-430
SO_4 (mg/l)	110-130	BOD_5 (mg/l)	144-240

A.2 Test result for characterization of of parameters for different combination of dosing of chemicals

The Table A.2 is the representation of various water quality parameters such as EC, Color,Turbidity,Alkalinity, Hardness, TSS, TDS, COD and BOD_5, Total Fe, and Total Al.

Table A.2 Water quality parameters for individual and combined chemical dosing of different concentration of alum, ferrous sulfate and polymer and their combinations.

Dose(mg/l)	EC(µ S/cm)	Color(Pt-Co unit)	Turbidity (NTU)	Alkalinity(mg/l)	Hardness(mg/l)	TSS(mg/l)	TDS(mg/l)	COD(mg/l)	BOD_5(mg/l)
Polymer 0.25 mg/l	676	78	33.8	280	132	40	460	65	20
Alum 60 mg/l	713	79	26.9	260	132	20	460	77	48
Ferrous sulfate 60 mg/l	704	118	60.1	260	120	70	530	72	56
Polymer 0.25 mg/l+ Alum 60 mg/l	808	36	5.3	292	122	15	565	19	14
Alum 60 mg/l+ Ferrous sulfate 60 mg/l	830	42	10	270	122	20	590	20	18.7
Polymer 0.25 mg/l+ Ferrous sulfate 60 mg/l	799	54.8	15.2	296	120	30	550	40	31.7
Polymer 0.25 mg/l+ Alum 60 mg/l+ Ferrous sulfate 60 mg/l	807	34	12.3	270	112	16	575	22	10

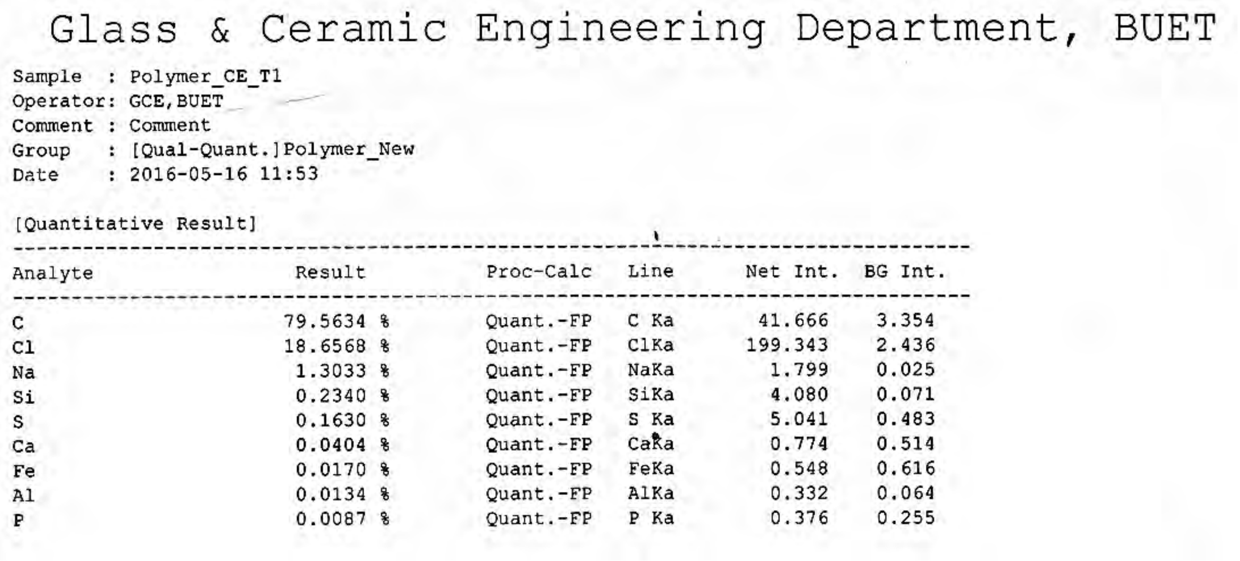
Continuation of **Table A.2**

Dose(mg/l)	Total Fe (mg/l)	Total Al (mg/l)
Polymer (0.25 mg/l)	Not done	Not done
Alum (60 mg/l)	Not done	0.168
Ferrous sulfate (60 mg/l)	10	Not done
Polymer (0.25 mg/l)+ Alum (60 mg/l)	Not done	0.170
Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)	10.1	0.165
Polymer (0.25 mg/l)+ Ferrous sulfate (60 mg/l)	10.1	Not done
Polymer (0.25 mg/l0+ Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)	10.15	0.172

A.3 XRF analysis for polymer

To get an idea about the elementary compounds about the polymer XRF test was done in the laboratory of Glass and Ceramic Engineering Department, BUET. The table A.2 shows the quantitative result of the polymer.

Table A.3 XRF analysis for polymer



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Glass & Ceramic Engineering Department, BUET

Sample  : Polymer_CE_T1
Operator: GCE,BUET
Comment : Comment
Group   : [Qual-Quant.]Polymer_New
Date    : 2016-05-16 11:53

[Quantitative Result]
---------------------------------------------------------------------------------
Analyte                 Result          Proc-Calc   Line      Net Int.  BG Int.
---------------------------------------------------------------------------------
C                      79.5634 %        Quant.-FP   C Ka        41.666    3.354
Cl                     18.6568 %        Quant.-FP   ClKa       199.343    2.436
Na                      1.3033 %        Quant.-FP   NaKa         1.799    0.025
Si                      0.2340 %        Quant.-FP   SiKa         4.080    0.071
S                       0.1630 %        Quant.-FP   S Ka         5.041    0.483
Ca                      0.0404 %        Quant.-FP   CaKa         0.774    0.514
Fe                      0.0170 %        Quant.-FP   FeKa         0.548    0.616
Al                      0.0134 %        Quant.-FP   AlKa         0.332    0.064
P                       0.0087 %        Quant.-FP   P Ka         0.376    0.255
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A.4 Combined chemical effect for different dosing

Data and graph of sensitivity and cost analysis for the combined dosing of Polymer 0.25 mg/l + Alum 60 mg/l

Table A.4 Removal efficiency of different water quality parameters for combined chemical dosing of different concentration of Polymer (0.25 mg/l)+ Alum (60 mg/l)

Water Quality Parameters	Polymer (0.25 mg/l) + Alum (60 mg/l)	Cost (BDT/m^3) of wastewater
EC (µ S/cm)	-24	2.20
Color(Pt-Co Unit)	74	
Turbidity (NTU)	87	
Alkalinity(mg/l as $CaCO_3$)	-8	
Hardness(mg/l as $CaCO_3$)	-2	
TSS(mg/l)	85	
TDS(mg/l)	-18	
COD(mg/l)	91	
BOD_5(mg/l)	90	

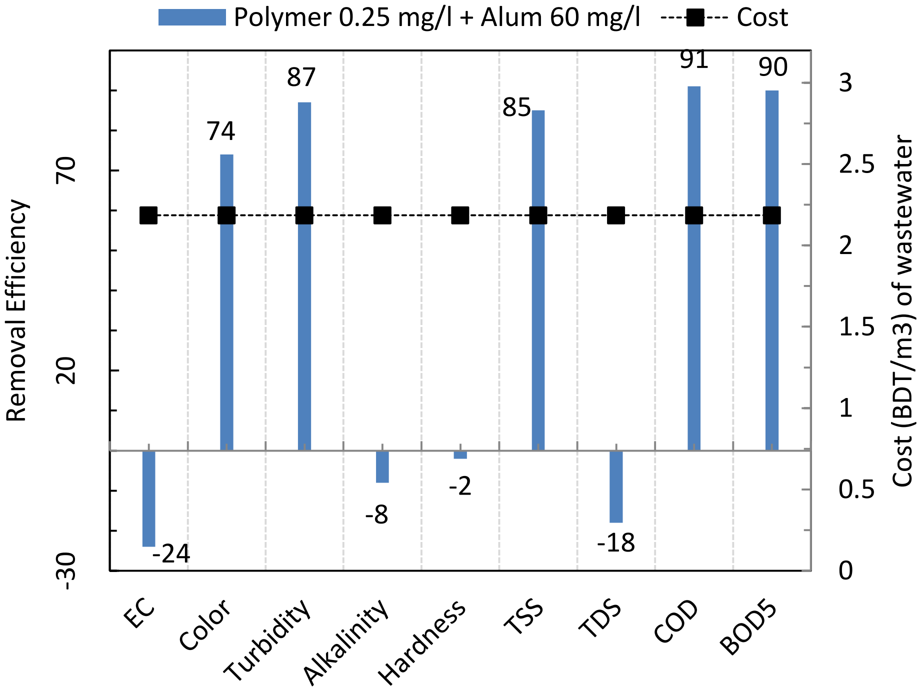


Fig A.1 Removal efficiency vs. parameters for combined dosing including cost

Data and graph of sensitivity and cost analysis for the combined dosing of Alum 60 mg/l +Ferrous sulfate 60 mg/l

Table A.5 Removal efficiency of different water quality parameters for combined chemical dosing of different concentration of Ferrous sulfate (0.25 mg/l) + Alum (60 mg/l)

Water Quality Parameters	Ferrous sulfate (60 mg/l)+ Alum (60 mg/l)	Cost (BDT/m^3) of wastewater
EC (µ S/cm)	-28	3.60
Color(Pt-Co Unit)	69	
Turbidity (NTU)	85	
Alkalinity(mg/l as $CaCO_3$)	0	
Hardness(mg/l as $CaCO_3$)	-2	
TSS(mg/l)	90	
TDS(mg/l)	-23	
COD(mg/l)	95	
BOD_5(mg/l)	94	

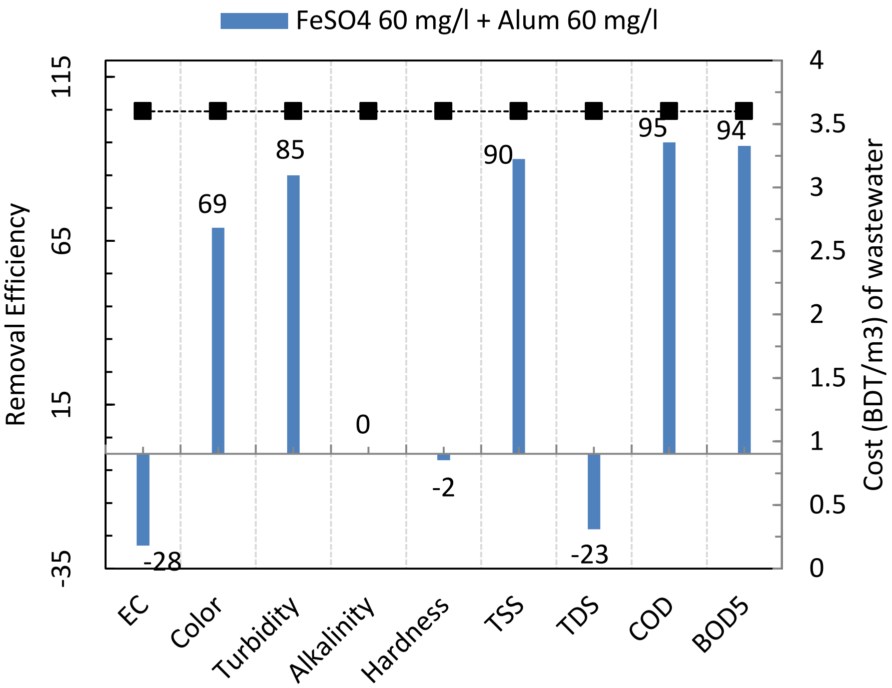
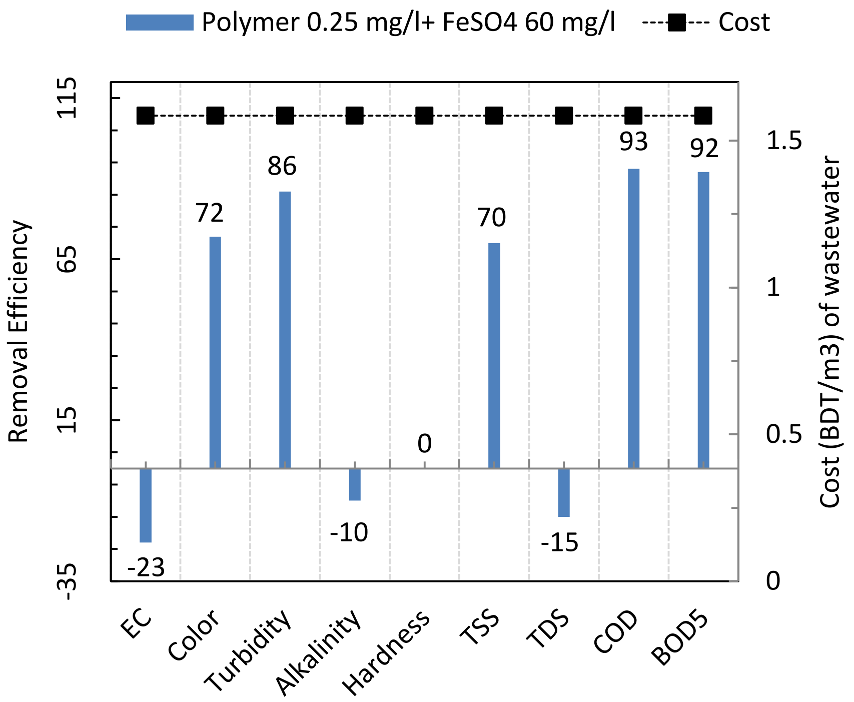


Fig A.2 Removal efficiency vs. parameters for combined dosing including cost

Data and graph of sensitivity and cost analysis for the combined dosing of Polymer (0.25 mg/l)+ FeSO4 (60 mg/l)

Table A.6 Removal efficiency of different water quality parameters for combined chemical dosing of different concentration of Polymer (0.25 mg/l)+ Ferrous sulfate (60 mg/l)

Water Quality Parameters	Polymer (0.25 mg/l)+ Ferrous sulfate (60 mg/l)	Cost (BDT/m^3) of wastewater
EC (µ S/cm)	-23	1.60
Color(Pt-Co Unit)	72	
Turbidity (NTU)	86	
Alkalinity(mg/l as CaCO$_3$)	-10	
Hardness(mg/l as CaCO$_3$)	0	
TSS(mg/l)	70	
TDS(mg/l)	-15	
COD(mg/l)	93	
BOD$_5$(mg/l)	92	



FigA.3 Removal efficiency vs. parameters for combined dosing including cost

Sensitivity and cost analysis for the combined dosing of Polymer 0.25 mg/l+ Alum (60 mg/l)+ FeSO4 60 mg/l

Table A.7 Removal efficiency of different water quality parameters for combined chemical dosing of different concentration of Polymer (0.25 mg/l)+ Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)

Water Quality Parameters	Polymer (0.25 mg/l)+ Alum (60 mg/l)+ Ferrous sulfate (60 mg/l)	Cost (BDT/m^3) of wastewater
EC (µ S/cm)	-24	3.70
Color(Pt-Co Unit)	75	
Turbidity (NTU)	69	
Alkalinity(mg/l as $CaCO_3$)	0	
Hardness(mg/l as $CaCO_3$)	7	
TSS(mg/l)	90	
TDS(mg/l)	-17	
COD(mg/l)	89	
BOD_5(mg/l)	93	

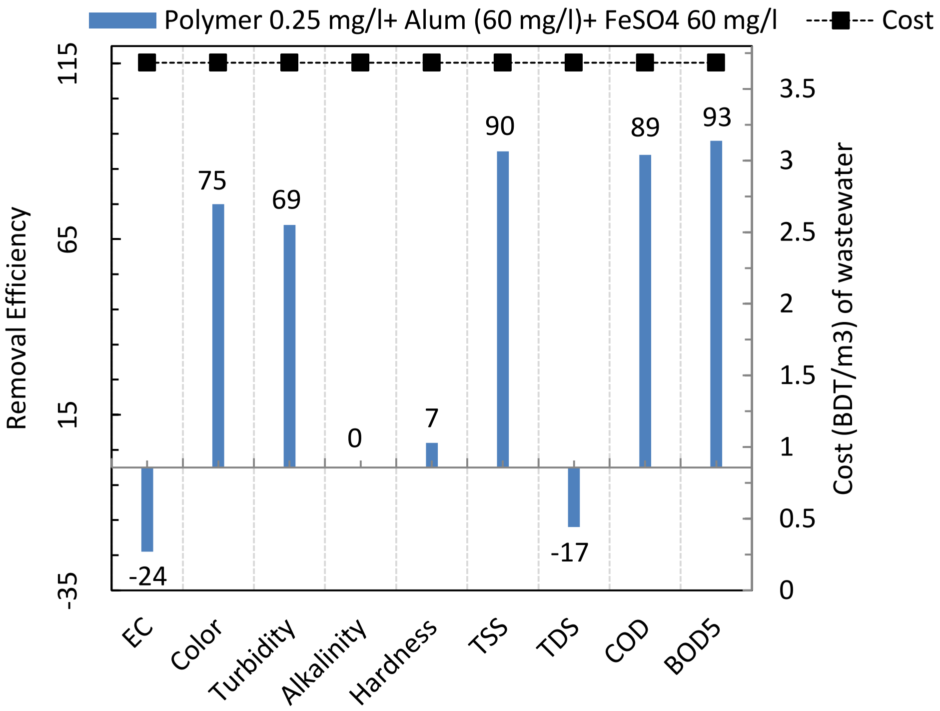


Fig A.4 Removal efficiency vs. parameters for combined dosing including cost