ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT) SCHOOL

OF CHEMICAL AND BIOENGINEERING ENVIRONMENTAL

ENGIEERING POST GRADUATE PROGRAM

Treatment of Brewery Wastewater Using Sand and Carbon Fixed Bed

By: Ermias Demissie

Advisor: Ato Teshome Werku

July, 2016

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF CHEMICAL AND BIOENGINEERING

ENVIRONMENTAL ENGIEERING POST GRADUATE PROGRAM

Treatment of Brewery Wastewater Using Sand and Carbon Fixed Bed

By: Ermias Demissie Gezahegn

Approved by:

Prof. Watic Chin	…….	……
Chair person	Signature	Date
Teshome W.	…….	……
Advisor	Signature	Date
Dr.Bihanu A.	……..	…..……
Internal Examiner	Signature	Date
Dr. Amare G.	……..	……...
External Examiner	Signature	Date

ACKNOWLEDGEMENTS

First and foremost, I must thank God, the most gracious and the most merciful to whom my loyality will remain forever for his blessing and granting me this humble study.

I wish to thank Ato Teshome Werku for his invaluable supervision in every step of the way for the completion of this thesis. Sincere thanks are also extended to Mr. Teshale Tuguma, wastewater specialist at klinto branch of Heineken brewery, for his assist and contribution while I was conducting laboratory analysis there. I also convey my heartfelt appreciation to AAiT laboratory technicians, especially to Meseret Haile and Esegenet Worku to their assist and support. I also wish to acknowledge all the authors of various papers for their input.

This research work would not have been completed without the support of Heineken brewery by allowing me to use their resources without any limitation. This support is dully acknowledged and greatly appreciated.

Finally, all my gratitude, appreciation, and sincere love go to my family especially my parents, for their generous, unlimited love and support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS, ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
APHA	American public health association
ASTM	American society of testing material
AWWA	American water work association
COD	Chemical oxygen demand
CIP	Clean in place
EC	Electrical conductivity
EEPA	Ethiopian environmental protection authority
EDL	Electrical double layer
EC	Electrical conductivity
ES	Effective size
GAC	Granulated activated carbon
MoFE	Ministry of forestry and environment
NTU	Nephelometry turbidity unit
TN	Total nitrogen
TP	Total phosphorus
US EPA	United state Environmental protection authority
WHO	World Health Organization

ABSTRACT

Reclamation of process wastewater is a key to water resources conservation and sustainability. Since brewery is inherently associated with the use of considerable amount of water, this study was undertaken to investigate the appropriate treatment of wastewater generated by Heineken brewery for the possibility of reuse. For this work, samples of wastewater were collected and characterized. Series of experiments were conducted to determine the amount of alum to use by Jar test, the property of the sand using sieve analysis and finally treatment of the wastewater was carried out using fixed bed filtration column consisting of granular activated carbon and sand.

The characterization of the raw wastewater results obtained before application of the treatment for the biologically treated wastewater showed that 67.11NTU, 89.33 mg/l, 4.4 mg/l, 1.06 mg/l, 4.3mg/l and 1.92mS/cm for Turbidity, COD, TN, Ammonia, TP and EC respectively. Then Series of jar test experiments were conducted in which the efficiencies of ferric chloride and alum were compared with in a coagulation/flocculation process at discharge pH. Overall, alum was found to be a more preferable coagulant at a dosage of 40mg/l. After wards fixed bed filtration column was constructed from Granular activated carbon and Mojo sand. The sand was characterized by using sieve analysis and its uniformity coefficient, density and effective size is found to be 5.67, 1.66 g/ml, 0.15 – 0.85 mm respectively. Sample results of the analysis after using the fixed bed filtration showed that overall concentration of turbidity were reduced from 73 NTU to 25.92 NTU and COD from 98 mg/l to 32.02mg/l which didn't fit with the specified standards for industrial reuse, where as for the conventional filtration, it reduced to 2.22 NTU and 3mg/l which directly fits with the standards set by EPA, WHO and Heineken for industrial reuse. So a successive additional treatment of TN, Ammonia, TP and EC were done and resulted in reduction from 4.4 mg/l, 1.06 mg/l, 4.3mg/l and 1.92mS/cm to 0 mg/l, 0 mg/l, 0mg/l and 0.65mS/cm. These results showed that coagulation/flocculation and sedimentation stage improve the subsequent filtration process. These experimental results showed that the effluent from conventional treatment could be reused for boiler feed, cooling and process water.

1. INTRODUCTION

1.1. Background

In the food industry, the brewing sector holds a strategic economic position with the annual world beer production exceeding 1.34 billion hectoliters in 2002 (Fillaudeau et al, 2006). Beer is the fifth most consumed beverage in the world behind tea, carbonates, milk and coffee and it still continues to be a popular drink all over the world (Braeken, et al., 2004). This beverage is obtained through alcoholic fermentation, using selected yeast of genera Saccharomyces, malt cereals (mainly barley), and other sugar based raw material, to which hop, and adequate water is added. Brewers are very concerned that the techniques they use are the best in terms of product quality and cost effectiveness. During production, beer alternately goes through four chemical and biochemical reactions (mashing, boiling, fermentation and maturation) and three solid–liquid separations (wort separation, wort clarification and rough beer clarification) (Goldammer, 2008). Consequently water management and waste disposal have become a significant cost factors and an important aspect in the running of a brewery operation. Every brewery tries to keep waste disposal costs as low as possible whereas the legislation imposed for waste disposal by the authorities becomes more and more stringent.

Though this brewing industry is faced by a number of problems, now a day's their most critical concerns are water usage – its quality and scarcity - and the subsequent wastewater generated from its operations. The industry requires the use of large quantity of clean water in its beer production. The main water consuming areas of a typical brewery are brew house, cellars, packaging and general water use. Specifically, of the water consumed, about two-thirds are used in the process and the rest in the cleaning operations (Fillaudeau et al, 2006). As revealed in literature survey by Simate (Simate et al, 2012), it is estimated that about 3-10 liters of water is required to produce 1 liter of beer. As a result, a large quantity of wastewater is produced. Consequently, water and wastewater management in breweries remains a critical practical problem.

Currently the ever increasing need for clean, but scarce water in the brewing industry has continued to motivate the need to find alternative sources of water. One alternative that requires attention is wastewater reclamation and reuse. Wastewater reclamation and reuse has been an important option since industrialization accelerated pollution in water environment, making it a

limited resource for production activities. When properly treated and recycled, wastewater can be an alternative water source which can reduce the demand for fresh water. Recycled wastewater can also reduce stress on the environment as well. However, the removal of contaminants from wastewater completely remains a big challenge.

There have shown that a good number of brewery wastewater treatment methods are either in operation, being piloted or under evaluation. These treatment processes are selective depending on the purpose of water and the water quality required, and wastewater characteristics (Chung et al, 1997). Furthermore, each method has its advantages and disadvantages, and the removal of contaminants using these technologies can be complex.

Breweries in Ethiopia mostly use groundwater as a raw material as seen in Heineken, Meta and also in other breweries in the country for their Beer production because of its constant and good quality. This exert a tremendous pressure on the ground water resource of the country and plus the high quantity of wastewater they generate exert pollution load on the environment resulting in water pollution on nearby rivers and when released directly on the ground, the pollutant may percolate into the ground water resulting on ground water pollution. Brewery wastewater usually contains a high concentration of biodegradable and non biodegradable organic compounds Due to this; we must start looking for alternative water resources and ways of wastewater treatment to prevent pollution. In this context, sand and carbon fixed bed might be a solution to treat the wastewater so that it could be reused. It has already shown good results for the removal of organic and inorganic pollutants from surface water and wastewaters for the purpose of drinking water (Fillaudeau et al, 2006).

This paper investigates the possibilities of fixed bed filtration to treat the waste water in view of reusing in order to decrease the amount of fresh water needed and wastewater generated.

1.2. Statement of the problem

Water is a common element in the lives of all people and societies. Today, water continues to be essential for life sustenance (both human and animals), agricultural, economic and industrial activities that help society to develop. Less than a century ago, it was widely assumed that there were enough freshwater supplies in the world for everyone (Fillaudeau et al, 2006). Yet today, increased use of freshwater for industrial, agricultural, and domestic use has created acute water

shortages in some areas of the world, particularly in the developing countries which are facing periodic famine and draught (Fillaudeau et al, 2006).

The discharge of pollutants into freshwater resources due to human activities has contributed to the situation, since industrialization has accelerated conception of large quantity of freshwater and increases environmental water pollution. This makes the water resources a limited resource for water supply. One of such industries which are consuming large quantity of water and discharging large amount of wastewater is brewing industry (Braeken, et al., 2004). For example, Chinese breweries produce about 0.3 billion m^3 of wastewater annually, which is 1.5–2.0% of the total wastewater production in the country (Feng et al, 2008).

In Ethiopia, there are more than 7 big breweries which are characterized by consumption of large quantity of fresh water. This is becoming major problem interims of pollution (water pollution), economic standpoint (cost of treatment and rehabilitation of the damaged environment) and over utilization of fresh water resources because they are using the ground water intensively and generating large quantity of wastewater in doing so. This wastewater they generate contains numerous organic and inorganic chemical species.

1.3. Objective of the research

1.3.1. General objective

The major objective of this study is to treat brewery wastewater using sand and carbon fixed bed for reuse.

1.3.2. Specific objective

The specific objectives are;

- To characterize the brewery wastewater effluent.
- To study the presence of coagulation/flocculation and sedimentation steps to improve the subsequent fixed bed filtration process performance.
- To characterize the fixed bed treated water for application
- To compare the results of the analyses made for a brewery's wastewater with the specified standards.

1.4. Significance of the research

Wastewater reclamation and reuse has become an important option, since industrialization and urbanization have accelerated environmental water pollution, making it a limited resource for water supply. But when these wastewaters are properly treated, they can be an alternative water resource that can be beneficially for Brewery industry and also reduce the burden posed on fresh water resources.

The significance of this study with regard to Brewery industry includes:

- It will satisfy their fresh water demand.
- Reduce the burden on ground water resources. In doing so, reduce the burden on the environment interims reducing water pollution.

2. LITERATURE REVIEW

2.1. Overview of Brewing Process

The brewing industry employs a number of batch-type operations in processing raw materials to the final beer products. However, the two most important processes in beer production are the degradation of starch to sugar during mashing followed by the fermentation of these sugars to form alcohol and CO_2 (Goldammer, 2008). In its simplest form, the brewing process involves the following main steps as illustrated in Figure 2.1 below. Simplified descriptions of the stage by stage chemistry of the brewing process are summarized in the sub-sections below:-

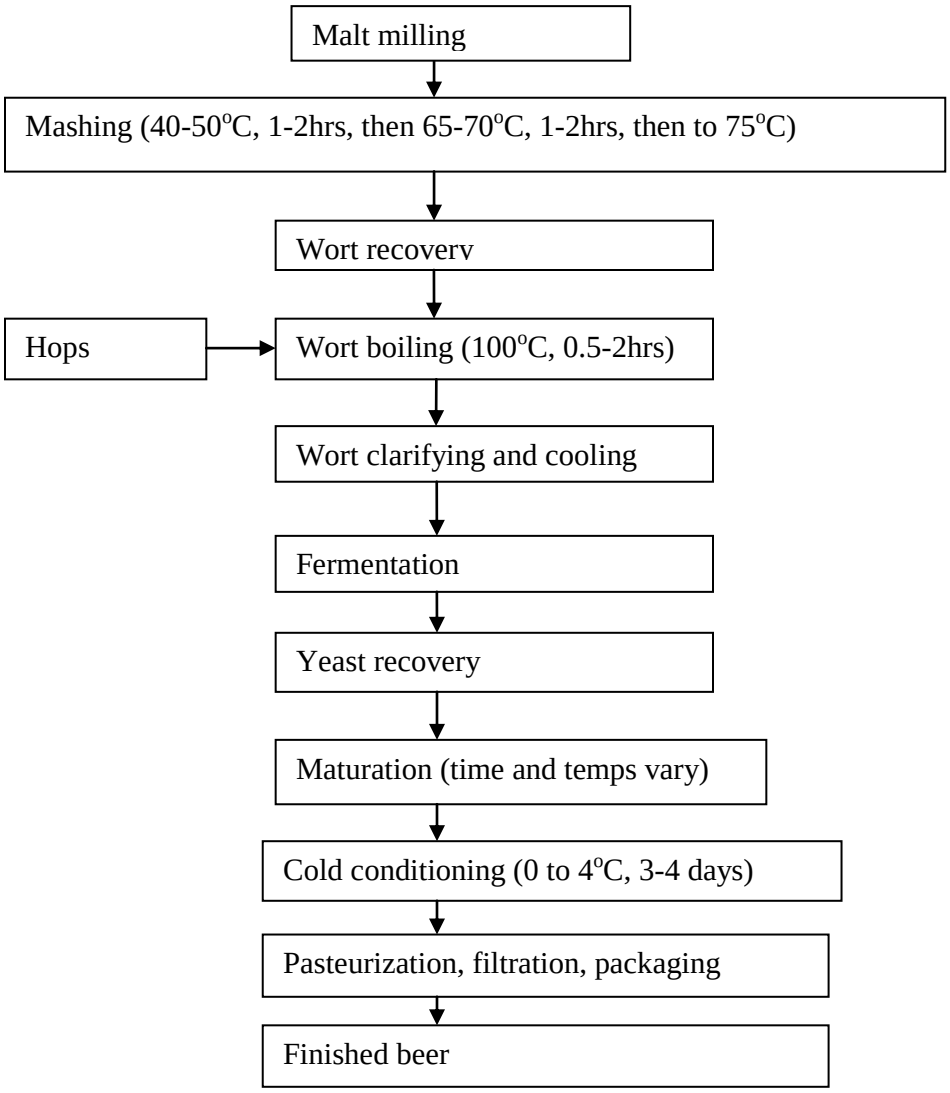


Figure 2.1 The brewing process (Goldammer, 2008).

Malting: The cereals from which beer is ultimately derived require first to be converted into a substrate which can be metabolized by yeast. This conversion is achieved by malting. To produce malted barley, barley grains are first steeped in 10-15°C aerated water and then germinated at 15-20°C for 3-7 days (Goldammer, 2008). Germination is then stopped by heating before much actual breakdown occurs and before significant seedling growth takes place. The main objective of malting is to produce an ample supply of enzymes that degrade starch, proteins, and other components of grain (Goldammer, 2008). The subsequent enzymatic changes provide fermentable sugars from starch and substances needed to support yeast growth (e.g., amino acids and fatty acids) from the other substrates. Malt also is a major contributor to the final color and body characteristics of the finished beer. For example, dark beers are made using darker, more favorable malt while less roasted malt is used to brew paler beers.

Mashing: The malted barley is first crushed to form very coarse flour (i.e., grist) in the grit mill (Phiarais and Arendt, 2008) so as to expose the starchy endosperm of the grain, thus making the carbohydrates more available (Goldammer, 2008). During the mashing step, most of the non-soluble, un-fermentable carbohydrates and proteins are hydrolyzed into soluble fermentable materials by the enzymes present in the malt (Goldammer, 2008). The breaking down of the macromolecular food reserves of the grain to small molecules is necessary because brewing yeasts cannot in general metabolize anything larger than a trisaccharide . To accomplish this, the ground malt is mixed with water and placed into a mash tun. To enhance α-amylase action during the initial mashing period, the temperature of the mixture is maintained between 40 and 50°C. After a period of time, the temperature of the mix is increased to 65-70°C to enhance β-amylase activity. Within a few hours, the process is complete, and the temperature is increased to at least 75°C to inactivate the enzymes.

After the naturally occurring and any added enzymes are inactivated, the solids settle out, leaving the wort. The soluble extract in the wort is separated from the insoluble ‘spent grains’ (grain husk) in the laughter tun. Furthermore water is sprayed from the top of the tank onto the mash to increase extract. The insoluble ‘spent grains’ are either discarded or sold as animal feed.

Wort processing, hop addition and kettle boiling; After the wort has been separated from the insoluble ‘spent grains’, the wort is transferred into a heating tank, called the brew kettle, in which hops are added to the wort before the mixture is boiled for 1-2 hrs (Goldammer, 2008).

This halts enzyme action, sterilizes the wort, coagulates some proteins and imparts distinctive flavors and aromas to the wort from the hops (Goldammer, 2008). After boiling, the wort is then separated from the spent hops and precipitated particles in the whirlpool, cooled rapidly and aerated, and placed into a fermentation vessel. Cooling and aeration of the wort produce an ideal medium for yeast fermentation (Phiarais and Arendt, 2008). The spent hops may be used as fertilizer.

Fermentation: The wort is fermented, first, by inoculating it with brewers' yeast. The inoculation step is also called other names, such as pitching and seeding (Goldammer, 2008). The strain of yeast used depends on what type of beer is desired. Lagers are produced using bottom-fermenting yeasts in the range of 6-15°C and takes 2-7 days, where the yeasts tend to flocculate and settle to the bottom of the fermentation tank (Goldammer, 2008). On the other hand, ales are produced using top-fermenting yeasts at temperatures of 6-15°C for 5-7 days, where yeasts tend to form small clumps of cells that are carried to the top of the fermenting liquid and adsorbed to bubbles of carbon dioxide (Goldammer, 2008). These yeasts have traditionally been referred to as Saccharomyces pastorianus and Saccharomyces cerevisiae for bottom-fermenting and top-fermenting, respectively (Goldammer, 2008). During fermentation, the yeast converts the carbohydrates present to produce alcohol, carbon dioxide, and contribute some additional flavor and aroma constituents (Goldammer, 2008).

Maturation and conditioning: At the end of fermentation, the 'green beer' is separated from the sediment and transferred to wooden (e.g., oak) or glass-lined steel tanks. In traditional brewing, maturation of the beer occurs during storage at 0-2°C for several weeks (Goldammer, 2008). This step allows the beer to develop its final flavor, color, and body characteristics. Many brewers include a short conditioning period after fermentation. Conditioning can be done at temperatures of approximately -1°C for at least 3 days (Goldammer, 2008). Consequently, clarification occurs to some extent as the yeasts, unstable proteins, and other suspended solids precipitate.

Finishing: Finally, the beer is packaged in cans, bottles, barrels, and kegs, usually after it has been sterile-filtrated or pasteurized to increase the shelf life of beer, particularly canned or bottled beer (Goldammer, 2008).

2.2. Characterization of Wastewater

The main constituent of brewery wastewater arises from dissolved carbohydrates, alcohol from beer wastes, from cooling and washing operation, spent maize, malt, and yeast. (Braeken, et al., 2004). The effluents from brewery were typically characterized with: turbidity, foul smelling and high concentration in EC, pH, biodegradable and non biodegradable matter content which was measured by COD, organic nitrogen and ammonia.

The brewery wastewater effluent characterization showed pH Value 10.0, COD 1375 mg/l, ,Turbidity 750NTU,TP 4.8 mg/l, TN 116 mg/L, Ammonium (mg/l) 13.3, (van Benthum et al, 1997). Fang also found that the composition of the raw wastewater was as follows: COD 1300–2300 mg/l, TN 30–37 mg/l, pH Value 10.0 Ammonium, 15–28 mg/l an TP: 3.2–4.3 mg/l. (Fang et al, 1990).

pH: The pH of water affects the solubility of many toxic and nutritive chemicals; therefore, the availability of these substances to industrial equipments was affected. As acidity increases, most metals become more water soluble and more toxic. Ammonia, however, becomes more toxic with only a slight increase in pH. Elevated nutrient levels were some of the causes to acidity or alkalinity which cause excessive slim formation that lift pH values. If extremely high or extremely low pH values occur, it would result in the death of all aquatic life on nearby rivers and corrosion on copper based alloy boilers (Simate et al, 2012).

Electrical conductivity: The electrical conductivity is the ability of a substance to conduct electricity. The conductivity of water is a more-or-less linear function of the concentration of dissolved ions (AWWA, 2000). Conductivity itself is not a human or aquatic health concern, but because it is easily measured, it can serve as an indicator of other water quality problems (i.e. it is used to give an indication of the amount of inorganic materials in the wastewater including; calcium, sodium and others which are main causes for scale formation). Therefore, conductivity measurements can be used as a quick way to locate potential water quality problems. Conductivity is measured in terms of conductivity per unit length (mill Siemens/cm).

Turbidity: Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended materials in water. Because absorption and scattering are influenced by both size and surface characteristics of the suspended material, turbidity serve as quantitative measurement of suspended solids (Peavy et al., 1985). Most turbidity in water comes from the erosion of

colloidal material such as clay, silt, rock fragments, and metal oxides from the soil. Soaps, detergents, and emulsifying agents produce stable colloids that result in turbidity. Microorganisms may also contribute to turbidity.

COD: COD is a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong oxidant. The COD is considered an appropriate index for showing the amount of organic and inorganic in water (Mansourpanah, 2006).It mainly represents the biodegradable and non biodegradable organic components, although inorganic compounds may be significant in certain cases. However, in general, brewery effluents are easily biodegradable with BOD/COD ratio in the range 0.6–0.7 (Cronin et al, 1998). The organic components in the brewery effluent (expressed as COD) consist of sugars, soluble starch, ethanol, volatile fatty acids, etc.

Nutrients: Nutrients such as phosphorous and nitrogen form compounds which result in scale formation, stimulate microbial growth, slim formation and corrosion (Mary 2005). In brewery wastewater, nitrogen exists in the forms of ammonia, nitrite, nitrate and organic nitrogen. In breweries, sources of nitrogen are spent maize, malt, and yeast and operations they undergone (Braeken, et al., 2004).The main source of ammonia is CO_2 room which use it as a refrigerant. So discharge of these nitrogen compounds in to the receiving environment would lead to several environmental and health risks. In the brewery industry there presence results in Bacterial growth, slime/scale formation, foaming in boilers. Nitrogen compounds, therefore, need to be removed from the wastewater.

Phosphorus occurs naturally in low concentrations and is essential for all forms of life. Phosphorus indicates nutrient status, organic enrichment and the consequent health of the environment (Mary, 2005). Increased levels in brewery wastewater mostly results from discharge from CIP (e.g., caustic soda, phosphoric acid, nitric acid, sulphonic acid etc.) used. According to Mary (2005), when concentrations are too high, problems such as algal blooms in nearby rivers, stimulates microbial growth rivers, foul smelling, excessive weed growth in nearby rivers and the loss of species diversity can occur.

2.3. Wastewater Treatment Plant operation of Heineken brewery

Fine screen

Fine screen is installed after influent pumps, used for removal of fine particles to prevent accumulation of solids in tanks. The mesh size of fine screen is 0.8 - 1.0 mm. Fine screen is installed on top of pre-clarifiers; the trapped residual will fall into containers. Then wastewater flows to calamity tank.

Calamity tank

Abnormal wastewater will be pumped to calamity tank by the actions of pneumatic valves; also calamity tank could be used as a holding tank, for temporarily storing normal wastewater being out of specification.

Calamity pumps are controlled by level meter and level float. Level float protects calamity pumps and submersible mixers from drying running. Calamity pumps are equipped with a frequency converter, in the outlet pipe of calamity pumps; a flow meter is installed, frequency converter control calamity pumps running frequency according to flow setting. An inline pH meter is installed in calamity tank. To make sure calamity tank have the buffer ability, calamity tank level needs to be controlled always the low level.

Pre-clarifiers

Most of suspended solids will be removed in pre-clarifiers, the sludge in pre-clarifiers should be discharged in time, 2 de-sludge pumps are installed for discharging sludge to aerobic sludge tank. Pre-clarifiers effluent flows to equalization tank by gravity.

Equalization/acidification tank

Designed retention time of equalization tank is 10 hours, the retention time is required for balancing of flow, pH, temperature and organic load. Complex organic material will be hydrolyzed into sugars, amino acids, and fatty acids (acidification process).UASB bypass pipe is installed, in case of UASB is in bad situation, equalization tank wastewater can be pumped to aerobic tank directly.

Chemical storage and dosing

Caustic and acid are used for adjust UASB feeding line pH; also can be dosed to equalization/acidification tank. $FeCl_3$ is mainly used for removing phosphor, also can be dosed to

UASB feeding line when in commissioning phase. Dosing pumps are controlled by frequency converter according to UASB feeding line pH meter .Caustic can also be dosed to equalization/acidification tank by manual operation.

UASB tank

The Up flow Anaerobic Sludge Blanket Reactor (UASB) is anaerobic reactor containing anaerobic bacteria's (Cronin et al, 1998). The biogas, sludge, and water will be separated by 3-phase separators, at the bottom of UASB, water distributors are installed. The effluent will flow over into the anaerobic effluent tank, while a part will be pumped to UASB by anaerobic recycle pumps. In UASB feeding line, 2 inline pH meter are installed, used to control acid dosing pumps and caustic dosing pumps static mixer is installed in UASB feeding line, used for dosed chemicals mixing with water.

Aerobic tank

The effluent of UASB flows, via anaerobic effluent tank. Aerobic effluent tank is an improved type of sequential batch reactor, it is a batch reactor but with continuous feeding. Aerobic effluent tank tanks pass the following cycle steps:

1. Aeration (120 minutes);
2. Settling (30 minutes);
3. Skimming (90 minutes);
4. Idle (typical 2 minutes).After wards the effluent were discharged into the nearby river.

2.4. Treatment methods of wastewater

This section discusses retreatment of brewery wastewater, and will look at various methods that used to safely treat brewery wastewater for reuse.. In addition, some challenges associated with these methods will be discussed. It should be noted and emphasized here in that the treatment of brewery wastewater effluent is relatively complex activity; particularly with the need to meet governmental regulations, environmental friendliness and reuse qualities.

Aerobic and anaerobic treatment has been applied for the treatment of brewery wastewater and recently, anaerobic systems have become an attractive option, among other advantages, because of their high COD content removal (up to 98% of the COD and nutrients are removed) and low

operating and chemical cost (Cronin et al, 1998). Though these biological methods have found widespread application for the treatment of the characteristically high organic content of the brewery wastewater, further treatment is required for water reuse.

Electrochemical methods and microbial fuel cells methods have great potential to be used to treat brewery wastewater for reuse and needs to be further investigated with respect to different challenges and opportunities involved. For example, beer brewery wastewater might be a good source for electricity generation in MFCs due to its nature of high carbohydrates and low ammonium–nitrogen concentration. Therefore, it is expected that the brewery industry will also benefit from these discoveries. However, this method require well trained man power, large operating and design cost.. It is further recommended to carry out some studies to establish estimated capital costs of these promising processes since this process are tried on pilot scale with respect to brew industry.

On the other hand, the application of membrane filtration (e.g., NF and RO) to drinking water treatment and wastewater reuse is well established and has undergone accelerated development in the past decade with the improvement in membrane quality (Braeken et al, 2004). A very important trend in the development of membrane filtration for water treatment is the integration of different pretreatment strategies to improve their performance. The RO in particular, has been shown to be an effective process for the treatment of brewery wastewater for reuse(100% removal) but it is expensive technology to implement and require well trained man power to operate it (Mansourpanah, 2006).

Table below shows a summary of some of the studies conducted on brewery wastewater, showing the COD reductions. It must be noted, however, that these studies had different experimental designs.

Table 2.1; Summary of brewery wastewater treatment processes efficiency.

Process	Initial COD (mg/l)	Final COD (mg/l)	COD reduction (%)	Reference
UASB	1947–3079	Not given	73–91	(Cronin et al, 1998)
Electrochemical method	2470	64	97	(Barrera et al, 2009)
Microbial fuel cells	1710	105	94	(Feng et al, 2008)
Nanofiltration	3692	143	96	(Braeken et al, 2004)
Reverse osmosis	850	0	100	(Mansourpanah, 2006)

Integration of processes and technologies: It can be been seen in the above Table that none of the methods (apart from RO) can be used individually in brewery wastewater treatment applications with high degree of energy efficiency. Coupling these processes together as two or three stage processes would be more appropriate. Subsequently, different process combinations are proposed and discussed which are obtained from literature.

The demand for renewable energy in our society is ever increasing (Barrera et al, 2009). Therefore, the MFCs are recommended to be the first pretreatment stage of every integrated process particularly with filtration techniques. MFCs have operational and functional advantages over the technologies currently used for generating energy from organic matter (Barrera et al, 2009). First, the direct conversion of substrate energy to electricity enables high conversion efficiency. Second, MFCs operate efficiently at ambient temperature. Third, an MFC does not require gas treatment because the off-gasses of MFCs are enriched in carbon dioxide and normally have no useful energy content. Fourth, MFCs have potential for widespread application in locations lacking electrical infrastructures and can also operate with diverse fuels to satisfy energy requirements. The high COD removal efficiency could also reduce the load in other coupled stages. The uses of other techniques as first stages in an integrated process do not offer any foreseeable benefits.

Electrochemical methods can be well suited to be coupled in the latter stages of the integrated process. Sanitizing agents (often called disinfectants) which are present in brewery wastewater contain chlorine compounds. These compounds produce chlorine during electrolysis and, thereafter, chlorine generates hypochlorous acid which oxidizes organic compounds. Chlorine is one of the most widely used disinfectants. It is very applicable and very effective for the deactivation of pathogenic microorganisms. Therefore, electrochemical methods if coupled in the latter stages can serve as an organic oxidation and disinfecting stage. But this method requires well trained man power, high operating and fixed cost and not practically employed in large scale. Due to this reason it is not widely implemented.

Carbon adsorbents especially Activated carbons have shown remarkable adsorption power. Activated carbons with ultra filtration will result in substantial removal of organics. However, the addition of Activated carbons would rapidly increase the Trans membrane pressure due to the formation of Activated carbons cake on the membrane surface. Due to this and membrane technologies are expensive to operate and install its becoming difficult to use it.

So due to the complexity of operation, requirement of highly trained man power, higher fixed and operational cost associated with the above operations, this paper chooses carbon adsorbent and sand fixed bed in treatment of brewery waste water for reuse. Because it can be incorporated easily into the existing plant, economically less fixed cost than the above technologies, due to its long existence there won't be lack of trained man power and removal of residual turbidity and removal of pathogens. But most importantly its lower fixed cost will give it the outmost advantage over others in regenerating water from the brewery wastewater.

In this work, the filter will be constructed as a dual media by using carbon adsorbent and silica sand. In different countries this method has been applied for drinking water treatment by using anthracite carbon and sand to remove organic and inorganic pollutants and has shown a promising result. The process is also optimized by incorporating coagulation, flocculation and sedimentation stages before the wastewater enters into the filter media and these results in greater quality of the end water. But since brewery waste water contains higher COD and turbidity than surface and river water, this research will use activated carbon.

In the next section, the focus will be on the mechanisms of coagulation, flocculation and filtration process which are going to be employed in this research work. Over the years, these

methods have remained the widely used methods for solid-liquid separation in water and wastewater treatment.

2.4. The combined treatment process

2.4.1. Coagulation and flocculation processes

Coagulation and flocculation processes are an important part of water and wastewater treatment, and are considered as consisting of three sequential steps, i.e., coagulant formation, colloid/particle destabilization, and inter-particle collisions and aggregation (Emerick et al., 1997). Coagulant formation and particle destabilization occur in rapid mixing tanks whilst inter-particle collisions occur in slow mixing flocculation (Droste, 1997).Coagulation or destabilization of a colloidal suspension results in joining of minute particles. On the other hand, flocculation results in formation of larger structures that settle fast and that are more resistant to break-up into smaller particles in turbulent and high-shear zones. Subsequently, the larger particles are removed by solids removal processes.

In the sub-sections that follow, each of these mechanisms is discussed separately, but the solution to any specific coagulation-flocculation problem will almost always involve the simultaneous use of more than one of these.

Double or ionic layer compression: Particles in aqueous solutions usually carry a charge on their surface, which lead to stabilization of the suspension (Crittenden & Harza, 2005). Irrespective of the origin of the surface charge, it must be associated with an appropriate number of oppositely charged ions (counter-ions) in solution, so that overall the system has no net charge (Fitzpatrick and Gregory, 2003). Here, the double layer model (Figure 2.1 below) is used to visualize the ionic environment in the vicinity of a charged colloid and explain how electrical repulsive forces occur.

In explaining the double layer model, it is important to first consider the effect of the colloid on the counter-ions (Zeta-Meter Inc, 1993).

(1) Initially, attraction from the negative colloid causes some of the positive ions to form a firmly attached layer around the surface of the colloid. This layer of counter-ions is known as the Stern layer.

(2) Any additional positive ions will still be attracted by the negative colloid, but would also be repelled by the positive Stern layer as well as by other nearby positive ions that are also trying to approach the colloid. The positive ions diffuse away or are driven away from the surface, resulting in a diffuse layer of counter-ions. This diffuse layer of positive ions has a high concentration near the colloid but gradually decreases with distance until it reaches equilibrium with the normal counter-ion concentration in solution.

(3) The formation of the electrical double layer (EDL) occurs via attraction of oppositely charged counter ions by the primary surface charge and then a diffusion of the counter ions away from the surface. In other words, the attached counter-ions in the Stern layer and the charged atmosphere in the diffuse layer are referred to as the double layer.

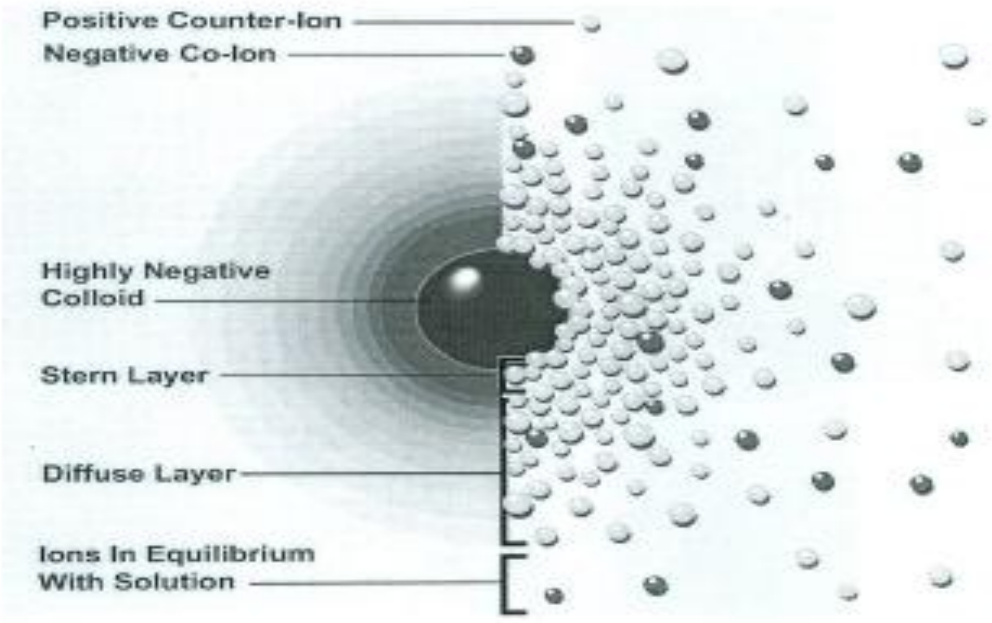


Figure 2.2. Two ways to visualize the double layer (Zeta-Meter Inc, 1993).
The left view shows the change in charge density around the colloid. The right shows the distribution of positive and negative ions around the charged colloid.

When two charged particles approach each other their diffuse layers overlap and this leads to repulsion or attraction depending on the signs of charge (Gregory, 2006) If there is significant repulsion between particles, then they will not be able to come into close contact and aggregation will be prevented (Gregory, 2006). Such particles are said to be colloidally stable, in the sense that they remain dispersed over long times. Therefore, in order to promote coagulation, it is

necessary to reduce electrical repulsion between particles (Gregory, 2006). This is achieved by the reduction of the thickness of the double layer or what is termed double layer compression. Double layer compression is achieved by adding large quantities of indifferent electrolyte (charged ions with no specific attraction for colloid primary surface) to the system (Zeta-Meter Inc, 1993), thus increasing the ionic strength of solution. High concentration of positive ions in the solution results in correspondingly high concentrations of the counter-ion in the diffuse layer. Therefore, the volume of the diffuse layer necessary to maintain electro neutrality is lowered and consequently the thickness of the diffuse layer is reduced (Gregory, 2006). If this layer is sufficiently compressed by high ionic concentration, then the van der Waals force will be predominant across the entire area of influence, so that no energy barriers will exist and the net force will be attractive (Peavy et al, 1985). In other words, high ionic strength induces the collapse of the double layer and hence lowers the Stern potential, resulting in particles being close to each other for the van der Waals force to dominate.

In summary, adding indifferent electrolyte increases the ionic strength of solution which has the effect of compressing the electrical double layer. As the counter-ions are pushed closer to the surface the repulsion forces becomes easier to negate by van der Waals forces.

It is important, however, to note that salting out just compresses the colloid's sphere of influence and does not necessarily reduce its charge (Zeta-Meter Inc, 1993). In general, double layer compression is not a practical coagulation technique for water treatment, but it can have application in industrial wastewater treatment if waste streams with divalent or trivalent counter-ions happen to be available (Zeta-Meter Inc, 1993).

Adsorption and charge neutralization: Charge neutralization involves adsorption of a positively charged coagulant on the surface of the colloid (Zeta-Meter Inc, 1993). This charged surface coating neutralizes the negative charge of the colloid, resulting in a near zero net charge (Zeta-Meter Inc, 1993). For example, the ionization of alum in water produces aluminium cations (Al^{3+}) which reacts immediately with water to form a variety of aquometallic ions and hydrogen as shown in equations below: (Crittenden & Harza, 2005)

$$Al^{+3} + H_2O \longrightarrow AlOH^{2+} + H^{+} \quad (2.3)$$

$$Al^{+3} + 2H_2O \longrightarrow Al(OH_2)^{+} + 2H^{+} \quad (2.4)$$

$$7Al^{+3} + 17H_2O \longrightarrow Al_7(OH_2)_{17}^{+} + 17H^{+} \quad (2.5)$$

$$Al^{+3} + 3H_2O \longrightarrow Al(OH_2)_3 + 3H^{+} \quad (2.6)$$

The aqua metallic ions thus formed become part of the ionic cloud surrounding the colloid and, because they have great affinity for surfaces, are adsorbed on the surface of the colloid where they neutralize the surface charge. Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that the contact amongst colloidal particles occurs freely. This is a different mechanism from a double layer compression.

Enmeshment in a precipitate: If certain metal salts (e.g., aluminum or iron) are added to water in sufficient amounts, rapid formation of precipitates will occur. The colloidal particles themselves can serve as nuclei for the formation of the precipitate or the colloidal particles can be enmeshed in these precipitates as they settle. The removal of colloids in this manner is termed as 'sweep coagulation' since colloidal particles are 'swept out' of water by a precipitate (Gregory, 2006). Sweep flocculation generally gives considerably improved particle removal than when particles are just destabilized by charge neutralization; partly because of the increased solids concentration which greatly improve the rate of aggregation (Gregory, 2006).

Adsorption and inter-particle bridging: Inorganic coagulants and organic polyelectrolyte's both have the capability of bridging (Zeta-Meter Inc, 1993). The bridging mechanism occurs when a coagulant forms threads or fibers which attach to several colloids, capturing and binding them together. Attachment may result from the columbic attraction if the coagulant and particle are of opposite charges or from ion exchange, hydrogen bonding and van der Waals forces if they are of similar charges (Aronino et al, 2009). For example, to be effective in destabilization, a polymer molecule must contain chemical groups which can interact with sites on the surface of the colloidal particle. When the polymer molecule comes into contact with the colloidal particle, some of these groups adsorb at the particle surface, leaving the remainder of the molecule extending out into the solution (Gregory, 2006). If a second molecule with some vacant adsorption sites contacts these extended segments, attachment can occur, thus forming a particle-polymer-particle complex in which the polymer serves as a bridge. If a second particle with vacant adsorption sites is not available, the extended segments of the polymer may eventually adsorb on other sites on the original particle, so that the polymer is no longer capable of serving as a bridge (Gregory, 2006).

Bridging is often used in conjunction with charge neutralization to grow fast settling and/ or shear resistant flocs (Zeta-Meter Inc, 1993). For example, alum or a low molecular weight cationic polymer is first added under rapid mixing conditions to lower the charge and allow microflocs to form. Then a slight amount of high molecular weight polymer, often an anionic, can be added to bridge between the microflocs. The fact that the bridging polymer is negatively charged is not significant because the small colloids have already been captured as microflocs (Zeta-Meter Inc, 1993).

2.4.2. Types of coagulants

The materials used as coagulating and flocculating agents can be classified broadly into two categories, i.e., inorganic coagulants and polymeric coagulants (Simate et al, 2012). The polymeric materials are further classified into natural and synthetic; the synthetic materials may be cationic, anionic or nonionic. Furthermore, a new class of polymeric flocculants have also been developed which are synthesized from natural and synthetic polymers. The table below lists the most commonly used coagulants.

Table 2.1.Common chemical coagulants used in the treatment of wastewater (Simate et al, 2012)

Common name	Chemical formula	Comments
Hydrated Aluminum sulfate	$Al_2(SO_4)_3.14H_2O$	Most common coagulant. Often used with cationic polymers
Ferric sulfate	$Fe_2(SO_4)_3$	Often used with lime softening
Ferrous sulfate	$FeSO_4.7H_2O$	Less pH depended than alum
Sodium aluminate	$Na_2Al_2O_4$	Used with alum to improve coagulation
Sodium silicate	$Na_2O.(SO_4)_x$	x can range from 0.5-4.0; ingredient of activated silica coagulant aids
Aluminum polymers	_	Include poly aluminum chloride and poly aluminum sulfate

2.4.3. Filtration process

Filtration in this work refers to fixed bed filtration. The purpose of filtration is the separation of suspended solids, dissolved solids, organic and inorganic pollutants from wastewater, by interposing a medium, such as sand and GAC, through which the water can pass. Flocs and other impurities are retained in the medium; while the water passes through. Separation of substances from water can be achieved by numerous mechanisms within the filters, depending on the media type and operation conditions. Particles larger than the filter bed pores will remain on the bed, a mechanism often referred to as straining. If filter grains are small, filter bed pores are small – leading to frequent clogging when the influent has a high particle concentration. The clogging then spreads over the whole filter bed height. As seen in Figure 2.3 below, suspended and colloidal particles have different ways of being transported to the filter media. (Achak, 2009).

The particle will typically follow the pathway of the flowing water through the filter. The pore structure of the filter bed will however make the water pathway complex and irregular. If the pathway gets curved, heavy particles are subjected to attach to the medium due to inertia. When the water flow approaches a filter grain, particles can become intercepted. Heavier particles are often attached to the filter through sedimentation, whereas particles of smaller mass can be captured due to diffusion. In parts of the filter turbulent flow can occur, and particles might get transported to the media grains (Crittenden & Harza, 2005).Consequently, suspended and colloidal particles may be attached to the filter grains when exposed to each other. Van der Waals forces give an attracting effect between grain and particle. Electrostatic forces can lead to both attraction and repulsion, depending on the particle charge. As suspended colloidal particles normally have a negative charge (Crittenden & Harza, 2005), particles are destabilized by coagulation.

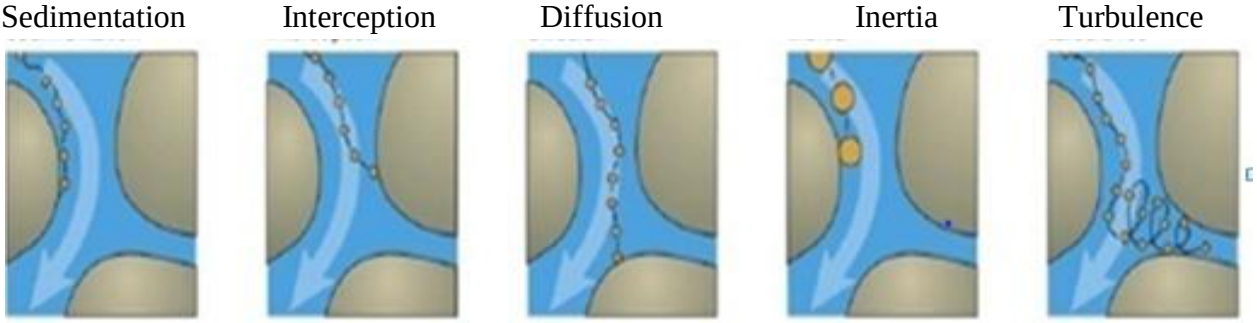


Figure 2.3 Ways of particle transportation with in a filter media (Achak, 2009)

2.4.4. Filter Media

There are a variety of fixed bed media products available. There are different standard ways of expressing the main properties of filter media. The "effective size" (ES) represents the size of a sieve opening which permits 10 percent of media particles (by weight) to pass. "Uniformity coefficient" indicates the sieve opening that will just pass 60 percent (by weight) of a representative sample of the media, divided by effective size (ASTM, 1993). The density describes the media weight per volume (ASTM, 1993). In this section, two main categories of filter media are described: Sand and GAC.

Silica sand is the most common filter medium which is frequently used in drinking water treatment. Sand filters is the original way of filtering in water treatment (Crittenden & Harza, 2005), and is based solely on the formation of a biologically active layer on the filter bed top and throughout the whole filter depth.

Activated carbon is a highly porous material made from carbon rich materials like wood, lignite or coal (Farizoglu et al, 2003). The carbon is "activated" by re-agglomeration. Essentially, this prepares the carbon to withstand abrasion of repeated backwashing, hydraulic transport and reactivation for reuse. It also makes the carbon like a molecular sponge – ensuring that pores of different sizes are present, ready to adsorb contaminants of different molecular weights (Droste, 1997). Here adsorption occurs in the inner spaces of a porous media. Backwashing alone will not remove the molecules absorbed into the pores. The point at which the GAC has used all its absorption capacity, the media can be regenerated – a process which is typically handled by the manufacturer. In Heineken brewery it will be regenerated every 6 months(Heineken brewery utility manual).

2.5. Industrial requirements for Reuse

Industrial wastewater reuse is a proven and required technology that has been used for many years in the world. It is a renewable supply of water that will prevent water resources of shrinking, help living things to survive and keep water tables from dropping. To get these vital advantages, governments or legal authorities form and publish guidelines or regulations. In this context, guidelines belong to EPA of United state of America and World Health Organization for the reuse of wastewater was discussed below.

I. United States Environmental Protection Agency (EPA) Guidelines

The 1992 Guidelines for Water Reuse examines opportunities for substituting water from potable water supplies where potable water quality was not required. It presents and summarizes recommended water reuse guidelines, along with supporting information, as guidance for the benefit of the water and wastewater utilities and regulatory agencies, particularly in the U.S (US EPA, 1992).

Quality requirements for industrial boiler-feed make-up water were dependent on the pressure at which boilers are operated, as shown in Table 2.2. Generally, the higher the pressure, the higher quality of water required.

Table 2.2 Recommended industrial boiler-feed water quality criteria (US EPA, 1992)

Parameter	Low Pressure (<150 psig)	Intermediate Pressure (150-700 psig)	High Pressure (>700 psig)
COD(mg/l)	≤5	≤5	≤1
Turbidity(NTU)	≤10	≤5	≤0.5
Conductivity($mScm^{-1}$)	≤1	≤1	≤1
Ammonia(mg/l)	0.1	0.1	0.1
TP(mg/l)	0.1	0.1	0.1
pH	7-10	7-10	8.2-9

The most frequent water quality problems in cooling water systems were corrosion, biological growth, and scaling. These problems arise from contaminants in fresh water as well as in reclaimed water. Table 2.3 provides recommended specifications values for cooling water supplies.

Table 2.3 Cooling water recommended specifications (US EPA, 1992)

Parameter	Recommended Limit Value
COD(mg/l)	≤20
Conductivity($mScm^{-1}$)	≤4
Ammonia(mg/l)	≤5.0
TP(mg/l)	≤1
Turbidity(NTU)	≤15
pH	6.9-9.0

The suitability of reclaimed water for use in industrial processes depends on the particular use. In investigations on the feasibility of industrial reuse with reclaimed water, the potential users must be contacted to determine specific requirements for process water. Table 2.5 provides recommended specifications values for process water by EPA together with WHO. But below on table 2.4 major Industrial water reuse quality problems are illustrated.

Table 2.4 Summary of water quality issues of importance for industrial water reuse (US EPA, 1992)

Parameter	Potential Problem
Residual COD	Bacterial growth, slime/scale formation, foaming in boilers
Ammonia	Interferes with formation of free chlorine residual, causes stress corrosion in copper-based alloys, stimulates microbial growth
Phosphorus	Scale formation, stimulates microbial growth
Turbidity	Deposition, “seed” for microbial Growth
Conductivity	Scale formation, foaming in boilers

So from this it is obvious that these contaminants should be removed before they are being used for any operation. The problems they cause could result in environmental pollution, equipment damage and health problems if used as process water.

II. World Health Organization (WHO) Guidelines

The WHO Guidelines are an integrated prescriptive and preventive management framework for increasing the public health benefits of wastewater reuse. The guidelines were built around the health part and the implementation part of the life cycle. Thus, the protection of health is dependent on both elements. The guidelines therefore strive to maximize overall public health benefits and the beneficial use of scarce resources (WHO, 2006). In case of using the treated wastewater as process water, treatment should be done until very clean and fresh water quality is gained (Braeken, et al., 2004). So before use, comparisons should be done with that of the drinking water qualities which were set by both organizations.

Table 2.5 WHO and EPA drinking water standards (WHO, 2006), (US EPA, 1992).

Parameter	WHO	EPA
COD(mg/l)	≤5	≤10
Turbidity(NTU)	≤5	5 – 10
pH	6.5-8.8	6.5-8.5
TN(mg/l)	≤0.1	≤1
Ammonia(mg/l)	≤0.1	≤1
TP(mg/l)	≤0.1	≤1

It must be noted, however, that recycling of regenerated water as brewing water is considered inappropriate and would require that drinking water standards are complied with (Fillaudeau et al, 2006).

III. Heineken requirements

The raw water which is used for boiler feed and process purpose doesn't contain any free or soluble oil, grease, toxic or radioactive substances. The water use criteria for Heineken states that the COD <5mg/l, Turbidity < 3NTU, Conductivity < 1 ms/cm and no nitrogen and phospurus or nutrient shouldn't be present for the boiler feed, cooling and brewing water.(Heineken brewery utility manual). The ground water quality was found to be COD < 2 mg/l, Turbidity < 1NTU, Conductivity < 0.05 ms/cm and no nitrogen and phospurus compounds after being pumped from the ground.(Heineken brewery utility manual).

.

3. MATHERIALS AND METHOD

3.1. Materials and Chemicals

The brewery wastewater used in this study was provided by the Heineken Breweries Ltd after it undergoes treatment process. It was obtained from the discharge point of the wastewater using plastic containers of size 10 liters in a period of 3 months from January to march of 2016 for 12 times at CIP operation periods where wastewater pollutant concentration is high. Then the collected wastewater was taken to Heineken wastewater and AAiT laboratories to carry out subsequent laboratory test works. The parameters that were measured include COD, turbidity, TN, EC, pH, and ammonia level. The materials and chemicals used in this research are listed below.

Table 3.1.Test instruments and chemicals with their specifications

Item	Equipment name	Specification
1	Electronic balance	CPA224S
2	Spectrophotometer	HACH and DR2700and Machery-Nagel
3	COD reactor	DRB200 and HI839800
4	Jar test	IC 142 D
5	Nephelo terbidometre	-
6	Reagents of P, N, and COD	-
7	Portable and fixed pH meter	-
8	Conductivity meter	Armfield
9	Plastic Containers and flasks	-
10	Ferric chloride and hydrated aluminium sulphate	-
11	Ro-Tap machine	-
12	Filtration column	H170D

3.2. Analytical Techniques

This section describes the analytical techniques that were used in characterizing raw water and treated water quality.

COD analysis

The procedure was that first Turn on the Reactor and Preheat to 150 °C. Then homogenize 100 ml of sample for 30 seconds in a blender. Carefully pipet 2.0 ml of sample into the vial Cap and clean the outside of the vial. Hold the vial by the cap over a sink. Invert gently several times to mix. The sample vials will become very hot during mixing. Then Place the vial in the preheated Reactor for two hours. Turn the reactor off. Wait about 20 minutes for the vial to cool to 120 °C or less. Invert the vial several times while still hot. Place the vial into a rack to cool to room temperature. Install the Light Shield in Cell Compartment. Select the ultra-low range, low range, or high range test. Install the Light Shield in Cell Compartment. Insert the blank into the 16-mm cell holder. (Heineken brewery laboratory manual)

Total Phosphorus – analysis

TP was an analyzed using the DRB200 Reactor and HACH Spectrophotometer in Heineken brewery wastewater laboratory

The procedure that's followed includes:

- Select the test. Install the Light Shield in Cell Compartment. Use a Pipette to add 5.0 ml of sample to a Reactive Phosphorus Test 'N Tube Dilution Vial. Cap and mix. Insert the vial into the 16-mm round cell holder. Press Zero. The display then shows 0.00 mg/l TP**.**
- Using a funnel, add the contents of one PhosVer 3 Phosphate Powder Pillow to the vial. Immediately cap the vial tightly and shake for at least 20 seconds. The powder will not dissolve completely. A two-minute reaction period will begin. Read samples between two and eight minutes after adding the PhosVer 3 reagent.
- Wipe the outside of the vial with a damp towel, followed by a dry one, to remove fingerprints or other marks. When the timer expires, insert the vial into the 16 mm round cell holder. Results were TP. (Heineken brewery laboratory manual).

Ammonia – analysis

Measurement of ammonia concentration in waters were be done by the Nessler method – based on the yellow to brown color produced by the chemical reaction between the Nessler reagent and ammonia. The Nessler's reagent is an aqueous solution consisting of HgI_2, KI and NaOH. The color is absorbed over a wide range of wavelengths (λ= 400-500 nm). After adding the Nessler's reagent to the sample, the sample was mixed by shaking and waited for 30 minutes before colorimetric measurement in spectrophotometer takes place.(Heineken brewery laboratory manual).

Total nitrogen analysis

TN was an analyzed using the DRB200 Reactor and HACH Spectrophotometer.

Analysis procedure;

- Turn on the DRB200 Reactor and heat to105 °C. Using a funnel, add the contents of one Total Nitrogen Per sulfate Reagent Powder Pillow to each of two Total Nitrogen Hydroxide Digestion Reagent vials. Wipe off any reagent that may get on the lid or the tube threads.
- Prepared Sample: Add 2 ml of sample to one vial.
- Blank Preparation: Add 2 ml of the deionizer water included in the kit to a second vial.
  Note: Use only water that is free of all nitrogen-containing pieces as a substitute for the provided de ionized water.
- Cap both vials. Shake vigorously for at least 30 seconds to mix. Insert the vials in the reactor. Heat for exactly 30 minutes. Using finger cots, immediately remove the hot vials from the reactor. Cool the vials to room Temperature**.** Install the Light Shield in Cell Compartment.
- Remove the caps from the digested vials and add the contents of one Total Nitrogen (TN) Reagent a Powder Pillow to each vial. Cap the tubes and shake for 15 seconds. Then three-minute reaction period will begin.
- After the timer expires, remove the caps from the vials and add one TN Reagent B Powder Pillow to each vial. Then Cap the tubes and shake for 15 seconds. The reagent will not completely dissolve. This will not affect accuracy. The solution will begin to turn yellow.

- Press timer ok. A two-minute reaction period will begin. Then after the timer expires, remove the caps from two TN Reagent C vials and add 2mL of digested, treated sample to one vial. Add 2mL of digested, treated reagent blank to the second TN Reagent C vial.
- Cap the vials and invert ten times to mix. Use slow, deliberate inversions for complete recovery. The tubes will be warm to the touch. Then Press timer ok. A five-minute reaction period will begin. The yellow color will intensify. Wipe the reagent blank and insert it into the 16-mm round cell holder.
- Press zero. The display will show:0.0 mg/L .Wipe the reagent vial and insert it into the 16-mm round cell holder and Press read. Results are in mg/L TN. (Heineken brewery laboratory manual).

pH – analysis

pH value of water was determined by the relative concentrations of H^+ ion and OH^- ion. pH analysis was carried out using pH meter. Put the sensor of pH meter into sample, open pH meter, and wait for some time when the reading was stable, read the result. (Heineken brewery laboratory manual)

Turbidity analysis

Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended materials in water (EPA, 1993). Turbidity was measured using a turbidity meter. It is measured photo metrically by determining the percentage of light of a given intensity that is either absorbed or scattered. In the absorption mode, a photometer measures the light intensity on the side of the vial opposite the light source, while in the scattering mode a photometer measures the light intensity at a 90° angle from the light source. In this study the Hatch turbid meter was used following the scattering principle with NTU as unit of measure (US EPA, 1993).

Conductivity analysis

Conductivity is a measure of electrical conductance of water or the mineral content of water. It gives a qualitative measure of the total dissolved solids in water. It is important to measure conductivity of water in order to know the likelihood of the water becoming corrosive (US EPA, 1992). Conductivity was measured in milli Siemens per centimeter (mS/cm) using Conductivity meter.

3.2. Jar test

The coagulation and flocculation potential of ferric chloride and alum were evaluated using the standard jar tests at discharge pH to determine their dosage for maximum pollutant removal. The procedure followed is as given below.

According to the APHA, the standard method for conducting Jar test for brewery wastewater consists of a three-phase mixing process of rapid mix, gentle mix, and no mix. The rapid mix phase consists of 1 minute of stirring at a speed of 100 rpm. The mixing speed was then reduced over the next 30 seconds to 40 rpm, and left to mix at this speed for exactly 20 minutes during the slow mix phase. In the no mix phase, the samples settled for 20 additional minutes, after which turbidity, pH, and COD measurements were taken to quantify changes induced by coagulation and settling (APHA, 1995). In each jar, 500ml of wastewater was placed and the above operations were performed. Here the pH of the wastewater was in neutral condition (always discharged at neutral pH) and the other factors were specified by APHA standard (eg. mixing speed and time, settling time were specified in the standard), the only variable factor was dosage and its effect was considered at three different levels (dosages) namely at 20mg/l, 40mg/l and 60mg/l. These dosages were selected because this coagulants were effective at lower dosage as stated in different literatures while used in wastewater and surface water treatment using conventional treatments and determination of effectiveness of coagulants (Achak, 2009) (Simate et al, 2012). Then settling studies were performed using 10 liter volumes of water. After the rapid mix, gentle mix and settling phases, turbidity measurements were taken every 15 minutes for up to two hours.

3.3. Sieve Analysis

The standard procedure for conducting a sieve analysis of a filter medium was detailed in ASTM Standard Test C136-9 (ASTM, 1993).Since the activated carbon was obtained from Heineken factory, its properties were already known and there was no need to carry out sieve analysis to it. Whereas for the sand, the analysis was carried out since its natural sand (Mojo sand) and its principal properties were not identified.

Sieving was carried out on 1000-g sample of Mojo sand, on 8-in sieves, and using a Ro-Tap sieving machine, it required three sieving periods of 5 minute with 2 minute gap in between. The Ro-Tap machine imparts both a rotary shaking and a vertical hammering motion to the nest of

sieves. Then the size distribution graph was drawn and the properties were determined as discussed in the following topics.

Figure 3.1 Ro-Tap machine

3.3.1. Grain Size Distribution

Grain size has an important effect on filtration efficiency for a fixed bed medium. It is determined by sieve analysis using ASTM Standard Test C136-92 (ASTM, 1993).Log-probability plot of the sieve analysis were drown to show the size gradation of the media constituents from which most properties determined. It was drown by calculating the % cumulative passed (weight basis) through each sieve. The following equations were used while drawing the Log-probability graph (ASTM, 1993);

$$CPR = \frac{CMR}{M} * 100 \quad (3.1)$$

$$CPP = 100 - CPR \quad (3.2)$$

Where; CMR is cumulative mass retained

CPR is cumulative percent retained

M is total dry sample mass

CPP is cumulative percent passing

The size gradation of a filter medium was described by the effective size (ES) and the uniformity coefficient (UC).The ES was the size for which 10 percent of the grains were smaller by weight. It is read from the sieve analysis curve at the 10 percent passing point on the curve, and is often abbreviated by d_{10} .The UC was a measure of the size range of the media. It is the ratio of the 60% and 10% passing points which were observed from the sieve analysis curve (ASTM, 1993).

Values of d_{10} and d_{60} were read from an actual sieve analysis curve. The UC was calculated using the following formula; (ASTM, 1993)

$$\text{UC} = \frac{d60}{d10} \quad (3.3)$$

$$\text{d useable} = 2(\text{d60} - \text{d10}) \quad (3.4)$$

Where; d_{10} is 10 percent passing point on the curve

d_{60} is 60 percent passing point on the curve and

$d_{useable}$ is usable portion of the sand.

3.3.2. Grain Density

Grain density is determined from the following ASTM Standard Test C128-93 (ASTM, 1993).This ASTM test uses a displacement technique to determine the density of sand. The procedure was an oven-dry sample were weighted and inserted into known volume of distilled water and then the density was calculated using the formula: (ASTM, 1993)

$$\rho s = \frac{Ms}{Vw} \quad (3.5)$$

Where; Ms is mass of the sample,

Vw is the volume of the water displaced by the sand.

3.4. Fixed bed media arrangement

This section discusses the setup of the fixed bed media filter. The AAiT laboratory fixed bed column was made using a transparent PVC pipe with an internal diameter of 6cm and a total height of 12 cm.

The media was arranged as follows: The lighter (lower density) and courser (higher ES) activated carbon was placed on denser and finer sand and sintered plastic beads under-drain supported the media from the bottom. The depth of the GAC bed was of the order of 6cm with sufficient sand to give a combined depth of 12 cm.

Figure 3.2 Arrangement of the fixed bed.

After the construction, fixed bed filtration was carried out. But before that, the loading rate was determined. As can be seen from different literatures head loss development was observed earlier for higher initial flow rates: higher initial flow rates develop head lose more quickly than smaller initial flow rates (Crittenden & Harza, 2005). Furthermore, head losses increased proportionally with the square of the flow rate as was also observed by Farizoglu and his team (Farizoglu et al, 2003) in their studies. This was because of the progressive reduction in the filter effective surface area as the particulates were deposited onto the filter surface or lodged into the spaces between grains (filter pores).Because of this, sand and carbon fixed bed was operated at the smallest loading rate which was 1 l/h using AAiT laboratory fixed bed column. The filter run time is an indicator of the efficiency of the fixed bed. So the removals of the contaminants were checked every 15minute for 2 hours. Before the sand was loaded into the column, it was washed with distilled water to remove any contaminants and dried overnight in an oven.

3.5. Experimental design

After the jar test and sieve analysis, typical operations of the experiments consisted of the followings: The raw wastewater at the discharge point of the biological treatment was taken to coagulant tank. Addition of a coagulant to coagulant tank will take place. In the coagulant tank, the wastewater mixed with the coagulant by mechanical agitation with a stirrer. Thereafter, the water undergoes flocculation by reducing the stirring speed and allowed to settle in by stopping the stirring completely. The sample from the flocculation and settling unit then goes to the fixed filter bed (mixture of GAC and sand).where as for sand and carbon fixed bed operation alone this all process were left of and the wastewater was introduced in directly.

Table 3.2 is a summary of the design of the experiments carried out in this study indicates test conditions, materials and/or samples tested, and the number of replicates in each experimental test in this study.

Table 3.2 Experimental design

Test type	Test conditions	Material/Samples tested	Replicates
Characterization of the wastewater	pH, COD,TN,TP, conductivity, Ammonium, turbidity	brewery wastewater	3
Jar test	pH, COD, Turbidity	brewery wastewater, ferric chloride and alum	3
Sedimentation	Settling time	Brewery wastewater, alum	3
Sieve analysis	ES,UC, Pusable, Density of the sand	Natural sand	3
Sand and GAC Fixed bed	COD, Turbidity	Brewery wastewater, alum	3
Conventional filtration	COD, Turbidity,	Brewery wastewater, alum, reagents	3

3.6. Data Analysis

Statistical analysis was performed with the help of Microsoft Excel program .Descriptive data analyses using graphs were made using Microsoft Excel program. Results obtained by experiment were compared with the specified industrial discharge limit values. The time series analysis for the significance of the data collected in equal time increment with different response parameters regarding the wastewater treatment during experiment was analyzed statistically using one way ANOVA. Removal efficiencies of treatment system were calculated based on the following formula.

$$\% \text{ Removal Efficiency} = \frac{Cinf - Ceff}{Cinf} \quad (3.4)$$

Where; *Cinf* is initial parameter concentration

Ceff is final parameter concentration.

4. RESULT AND DISCUSSION

4.1. Characterization of the brewery wastewater

In order to evaluate the physico-chemical parameters of the brewery wastewater quality before application of wastewater treatment, samples were collected at the discharge point of the wastewater treatment and analyzed for different pollutant parameters. The results of these pollutant concentration levels with their range before application of the sand and GAC fixed bed were presented together with permissible limits of industrial effluent set by EEPA (currently called MoFE) standards in Table 4.1. For the discussion on table 4.1, reference should also be made to the experimental data in appendix A.

The characterization result showed that the pH level range was 7 to 8. It was influenced by the amount and type of chemicals used in cleaning and sanitizing operations (e.g, caustic soda, phosphoric acid, sulphonic acid). The Nitrogen and phosphorus levels range from 4-5 mg/l and 3-4mg/l and their concentration mainly dependent on the handling of raw material and the amount of yeast present in the effluent .Whereas the ammonia level range from 0.6 – 1.6. The electrical conductivity was also in a range of 1.5 – 2 Scm^{-1} as can be seen from table 4.1 which rose due to the existence of total dissolved solids and salt. Generally the result of these analyses indicated that the concentration of COD, TN, TP and ammonia were found to be in the range of their respective permissible values set by MoFE of Ethiopia to be discharged into the environment but not in a range to be reused for industrial purposes.

Table 4.1 characterization of brewery wastewater

Parameters	Average	Range	Standard deviation	MoFE
pH	7.70	7 – 8	0.48	6.0-9.0
COD(mg/l)	89.33	75 – 110	6.97	≤ 250
Turbidity(NTU)	67.11	55 – 78	3.68	------
Total nitrogen (mg/l)	4.4	4 – 5	0.26	≤ 40
Total ammonia(mg/l)	1.06	0.6 – 1.6	0.15	≤ 20
Total phosphorus(mg/l)	4.3	3 – 4	0.66	≤ 20
Conductivity($mScm^{-1}$)	1.92	1.5 – 2	0.12	-----

4.2. Coagulants dosage determination

4.2.1. Determination of ferric chloride dosage

The ferric chloride dosage was determined following the APHA standard procedures as discussed in the previous chapter.

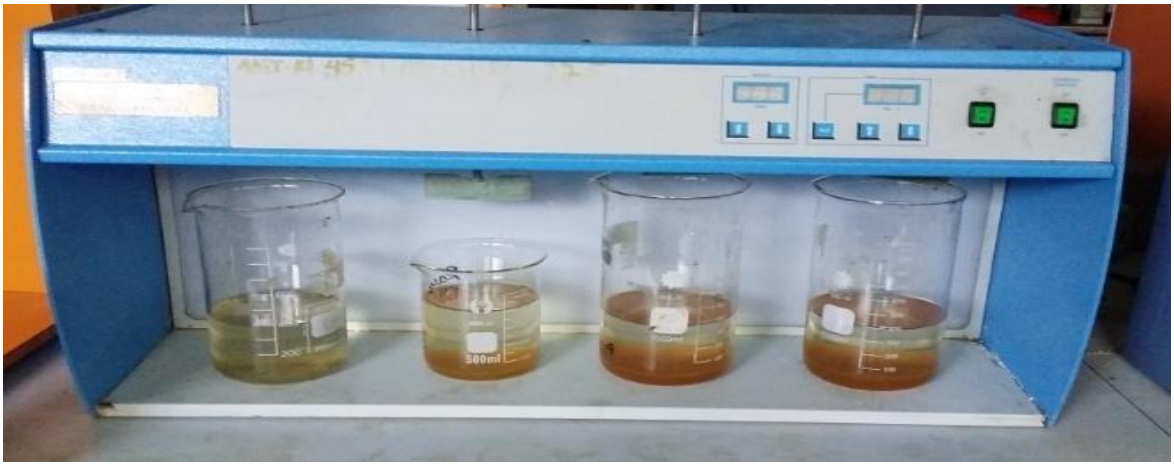


Figure 4.1 Jar test to determine ferric chloride dosage

For the discussion on Figure 4.2, 4.3 and 4.4; reference should also be made to the experimental data in Appendix B1. The results in the tables were runs conducted under similar experimental conditions.

As can been seen from figure 4.2, ferric COD removal efficiency were high at 20mg/l and then it decreased with the concentration of the ferric chloride increased. This was mainly due to the formation of ferric salt .Whereas the turbidity removal efficiency increased as the concentration increases and maximum removal were achieved at 40mg/l and remained almost constant then after. Finally the pH decreased with increase in concentration of ferric even entered into acidic condition. This was mainly due to the formation of HCl after the dissociation of ferric chloride.

In general ferric chloride concentration for the treatment of brewery waste water was found to be 20mg/l because, the COD removal was higher and the pH was in desired level (almost neutral) even though the turbidity removal was lower than the subsequent dosages at discharge pH of the wastewater.

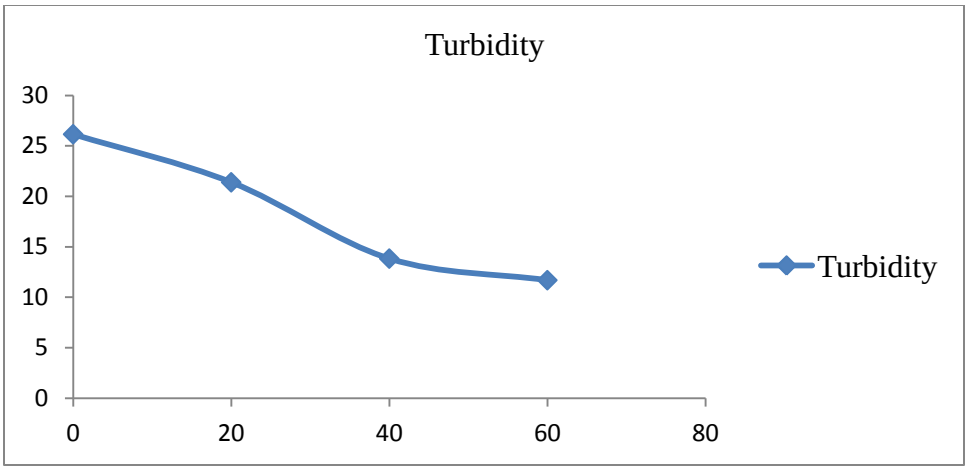


Figure 4.2 Ferric chloride effects on removal of COD

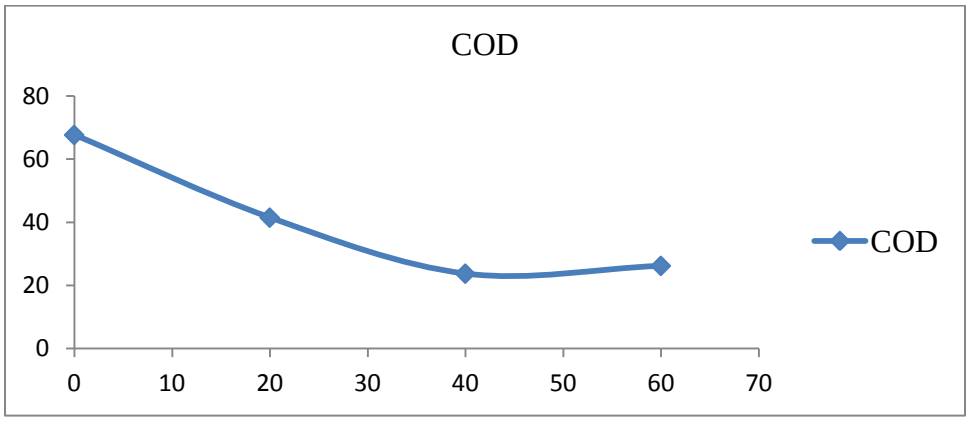


Figure 4.3 Ferric chloride effects on removal of turbidity

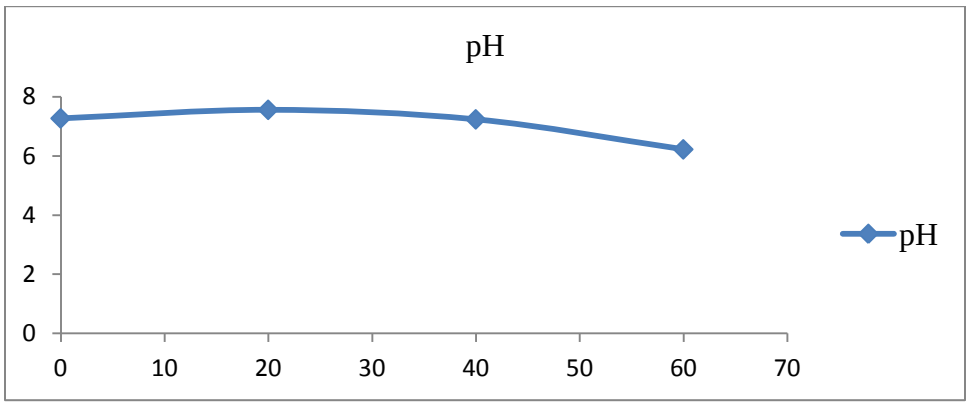


Figure 4.4 Ferric chloride effects on pH

4.2.2. Determination of hydrated aluminum sulfate dosage

The optimum dosages of hydrated aluminum sulfate were also determined using APHA standard procedures as discussed in the previous chapter.

For the discussion on figure 4.5 to 4.7 below reference should also be made to the experimental data in Appendix B2. The results in the tables were runs conducted under similar experimental conditions.

As can been seen from the figure 4.5,4.6 and 4.7 hydrated aluminum sulfate COD removal efficiency increased until 40mg/l and then remained almost constant after wards until it reached 60mg/l. With the concentration of the hydrated aluminum sulfate increased, the turbidity removal efficiency also increased. The maximum removal was achieved at 60mg/l. This was mainly due to the effect of coagulation, flocculation and sedimentation mechanisms which were explained in the literature part. Finally the pH decreased a bit or remained almost in a constant range (6.2 – 7.2) with increase in concentration of hydrated aluminum sulfate. Generally alum concentration for the treatment of brewery waste water was found to be 40mg/l because, the COD removal was higher, the pH was in desired level(almost neutral) even though the turbidity removal was lower than 60mg/l at discharge pH of the wastewater.

In summary, the results showed that 20 mg/l of ferric chloride was enough for removal of both turbidity and COD. In the case of hydrated aluminum sulfate, 40 mg/l of hydrated aluminum sulfate was found to be sufficient for the removal of both turbidity and COD.

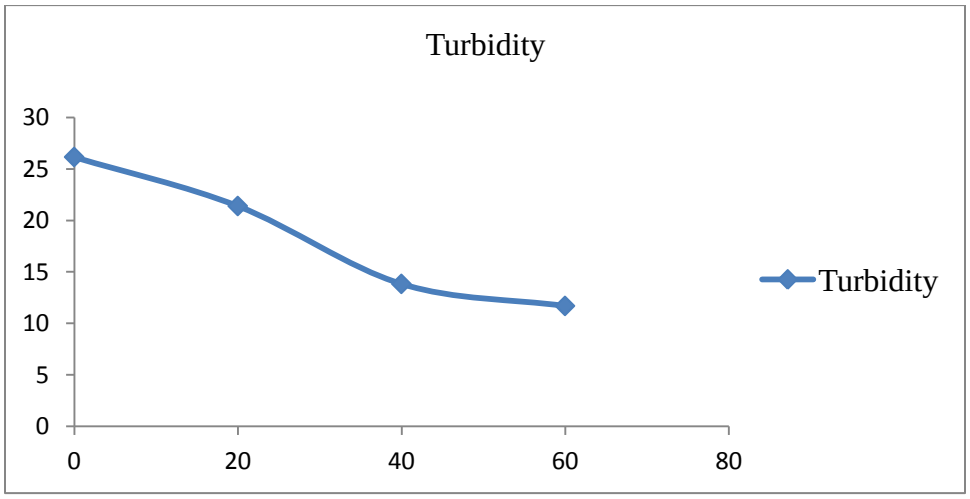


Figure 4.5 Hydrated aluminum sulfate effects on removal of turbidity

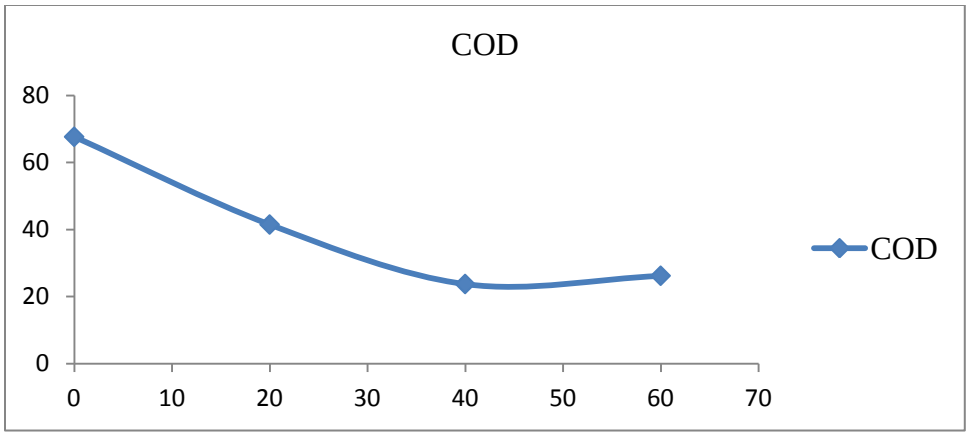


Figure 4.6 Hydrated aluminum sulfate effects on removal of COD

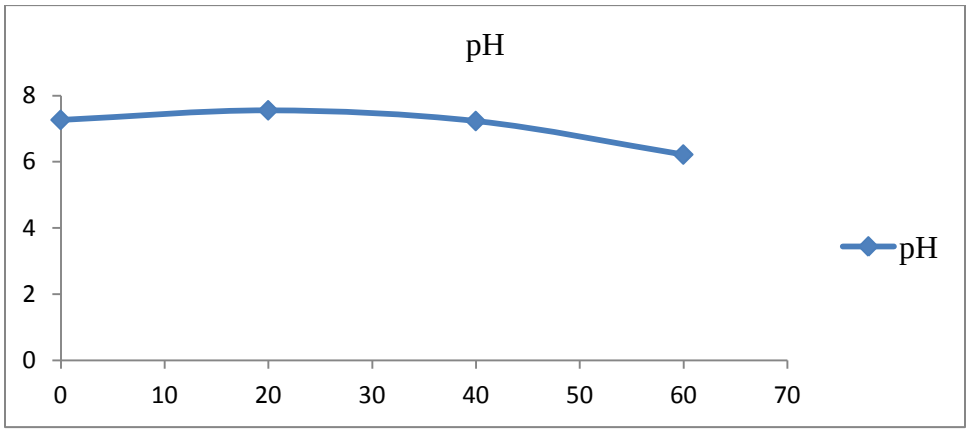


Figure 4.7 Hydrated aluminum sulfate effects on pH

4.2.3. Comparison of hydrated aluminum sulfate and ferric chloride

The suitability of using hydrated aluminum sulfate coagulants and flocculants in the treatment of brewery wastewater was compared with ferric chloride. Ferric chloride and hydrated aluminum sulfate were chosen among other inorganic coagulants because they are effectiveness over a wider pH range (4 – 10), easily accessible and the floc they form is heavier than others, thus improving settling characteristics (Simate et al, 2012).

Figures below shows a comparison of the effectiveness of hydrated aluminum sulfate and ferric chloride in removing turbidity and COD from brewery wastewater and pH condition they result in. The wastewater discharged into the environment by Heineken brewery was always in neutral condition due to discharge regulations set by appropriate authorities, to protect the environment and also it was always adjusted before it enters into biological treatment system in order not to harm the microorganisms in the biological treatment plant.

For the discussion on the Figures 4.8, 4.9 and 4.10 below reference should also be made to the experimental data in Appendix B1 and B2. The results in the tables were runs conducted under similar experimental conditions.

An overview of the figures 4.8, 4.9 and 4.10 above shows that both coagulants were able to remove turbidity and COD to a larger extent. This may be attributed to the fact that several flocculation mechanisms may have been simultaneously involved when they are used, i.e., (1) adsorption/ charge neutralization, and (2) sweep-floc coagulation (or enmeshment). Sweep-floc coagulation was significant and more likely to have predominated. In sweep-floc coagulation, metal hydroxide precipitates promote coagulation by increasing the antiparticle collision rate and enmeshing suspended particles (Peavy et al, 1985).

However, ferric chloride was found to display higher efficiency than hydrated aluminum sulfate for the coagulation/flocculation of colloidal matter in brewery wastewater due to its ability to form heavier flocs especially in turbidity removal at lower concentration. However, it showed in significant pH drop as the concentration increased. This was mainly due to hydrolysis reaction taking place which resulted in the formation of HCl (Crittenden & Harza, 2005).where as for hydrated aluminum sulfate, as the concentration increased; the pH dropped but was still in neutral range. The following reactions show main reasons for drop of pH in the coagulation /flocculation test for both coagulants. (Crittenden & Harza, 2005)

$$(Al(H_2O)_6)^{3+} \longrightarrow (Al(H_2O)_5OH)^{2+} + H \quad (4.1)$$

$$(Al(H_2O)_5OH)^{2+} \longrightarrow (Al(H_2O)_4(OH)_2)^{+} + H^{+} \quad (4.2)$$

$$(Al(H_2O)_4(OH)_2)^{+} \longrightarrow \downarrow (Al\,(H_2O)_3(OH)_3) + H^{+} \quad (4.3)$$

$$(Al(H_2O)_3(OH)_3) \longrightarrow (Al\,(H_2O)_2(OH)_4)^{-} + H^{+} \quad (4.4)$$

$$Fe^{3+} + 3H_2O \longrightarrow \downarrow Fe\,(OH)_3 + 3H^{+} \quad (4.5)$$

When the H^+ ions formed react with the sulfate, it resulted in acidic condition but it's not that much as that of the ferric chloride because its effect was countered by the soluble salt formed as seen in Equation 4.2, whereas for ferric the same type of reaction(hydrolysis reactions) took place as can be seen in Eq.4.5 ,followed by the reaction of the H^+ ions with the Cl^- which resulted in the formation of HCl which was the root cause for the lowering of pH of the solution.

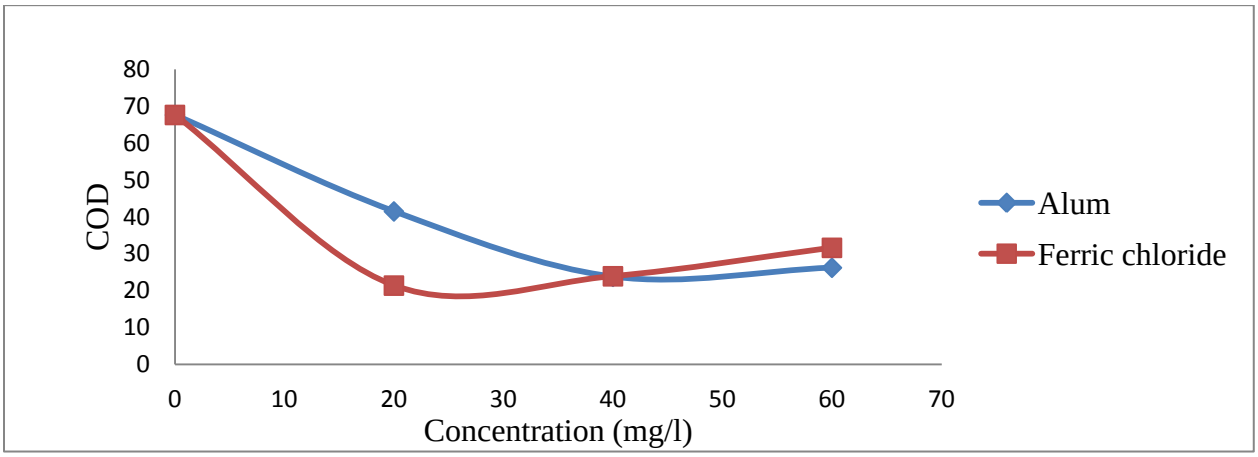


Figure 4.8 Comparison of Alum and ferric chloride on removal of COD

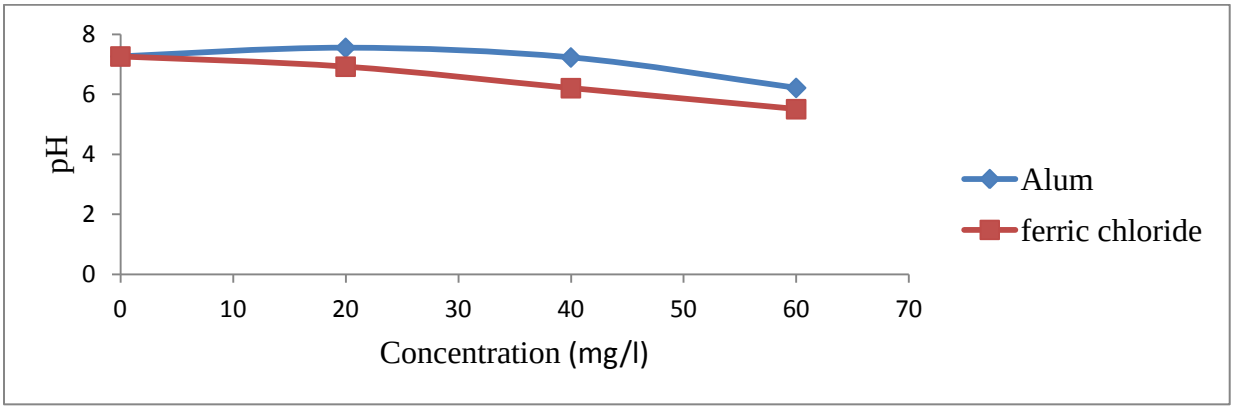


Figure 4.9 Comparison of Alum and ferric chloride effect on final pH

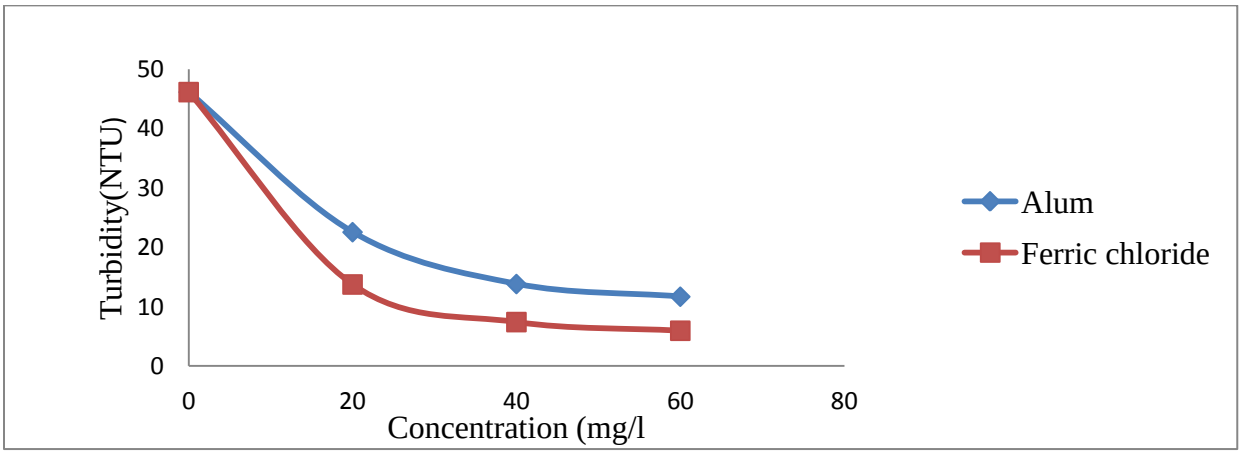


Figure 4.10 Comparison of Alum and ferric chloride on removal of turbidity

In general, this comparison shows Heineken brewery can use Alum as an alternative to ferric chloride and can be as effective as ferric chloride. Even though ferric chloride posses higher

COD and turbidity removal than hydrated aluminum sulfate, it was hydrated aluminum sulfate that was chosen as a coagulant for this operation because;

1) Hydrated aluminum sulfate is widely available and produces in Ethiopia, whereas ferric chloride is imported from abroad, as a result it is too costy.
2) The drop in pH due to the use of ferric chloride may finally result in need of additional treatment.

4.3 Determination of the effect of settling time on residual turbidity

Experiment 3 was conducted to determine the optimum settling time before the filtration operation. It showed high turbidity removal at 50 minutes. However, achievement of 5.47 NTU level occurred only within a narrow range and final turbidities could not be lowered much lower than 5.47 NTU level. Knowing that the jar test employs a 20 minutes settling time (APHA, 1995), effect of settling time was tested to observe the changes in the final turbidity before it goes into the filtration process. For the discussion on Figure 4.11, reference should also be made to the experimental data in appendix c.

As illustrated in the Figure 4.11 increase in the settling time resulted in the increase in the turbidity removal efficiency. 20 minute settling time created more the residual turbidity value than that created by 50 minute settling time for the same hydrated aluminum sulfate concentration. So as the settling time increases from 20 to 50 minute, the turbidity removal efficiency increased. However, it should be stated that settling times of 65, 80, 95 and 120 minutes caused the same values of residual turbidities, from which it could be concluded that additional minutes after 50 minute settling time didn't help the colloids to settle down.

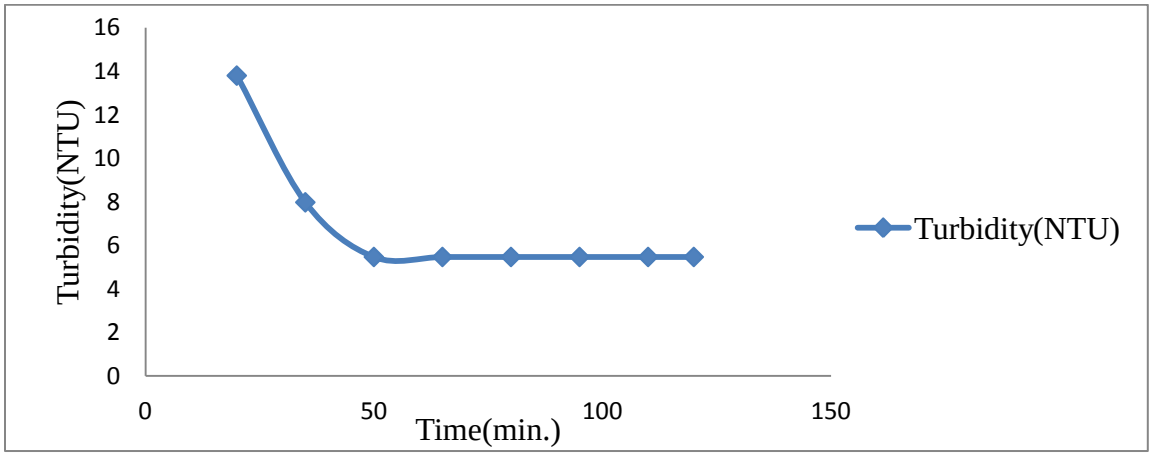


Figure 4.11 Effect of settling time on final turbidity

4.4 Determinations of properties of the fixed bed filtration medium

4.4.1 Determination of properties of Mojo sand

The sand used in this operation was obtained from local market which is widely used in our country. It is found in larger quantity in Mojo region and widely used for construction purpose only. The sieve opening for the sieve analysis range from 100µm - 2mm. The usable portion and other properties of the sand were determined from the graph 4.10 below which show size of the sieve opening verses cumulative percent passing (% weight basis) and by using the appropriate equations listed in the methodology. Since the activated carbon was obtained from Heineken brewery factory, its properties were already determined by its manufacturer and there was no need to carry out sieve analysis to it. For the discussion on Figure 4.12, reference should also be made to the experimental data in Appendix D.

Since it was natural (not processed) sand, it has too fine and too coarse portion and this portion has to be removed in order for its filtering ability to improve interims of uniformity. The portion of the sand that remained after removing these parts was the usable portion. All sand remaining between d_{10} and d_{60} was useable (this is 50% of sand) (ASTM, 1993). Filtration process could only use the part that corresponds to the usable part of specific sand (ASTM, 1993). From the above graph, the usable portion of the sand found between 150 - 850µm as can been seen in figure 4.12. The ES (d_{10}) was approximately 150 µm and d_{60} was 850 µm. Then from the usable portion, 4g of sand were taken and inserted into 20ml of distilled water in order to calculate the density using displacement method. The sand density was found to be 1.66 g/ml (see appendix F2). Table 4.2 below shows the characteristics of the sand from the above graph and the GAC which was going to be used in this research.

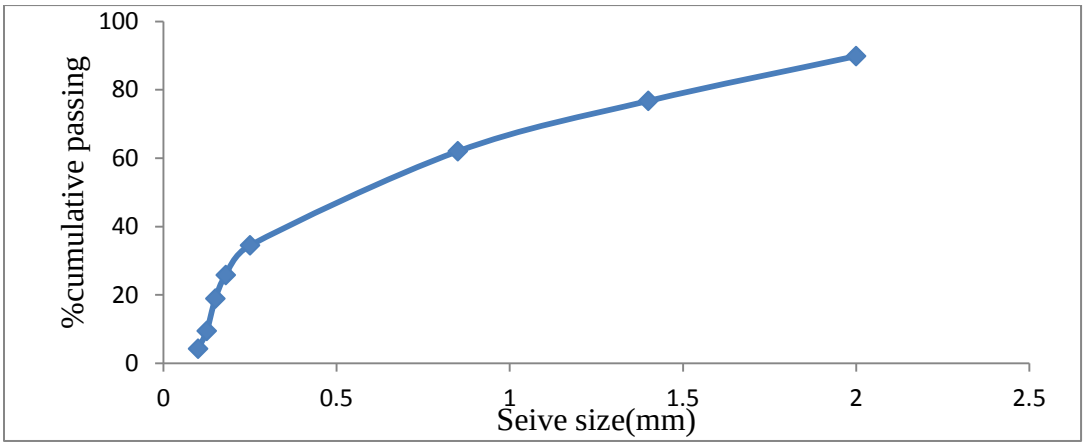


Figure 4.12 Size distribution of the Mojo sand

Table 4.2 Properties of the fixed bed media

Media	Diameter(mm)	ES(mm)	UC	density(g/ml)
Sand	0.15 – 0.850	0.17	5.67	1.66
GAC	1 -2	1.6	1.85	1.53

Note that the experiments were only conducted for the sand. So after the properties of the fixed bed determined, the bed was constructed as discussed in the methodology and the treatment was carried out.

4.5 Treatment of brewery wastewater using sand and GAC fixed bed

The performance of sand and GAC fixed bed filtration on removal of both Turbidity and COD were investigated. Turbidity and COD are important parameters in the water industry which are used in assessing the effectiveness of the filtration process and the quality of drinking water (Peavy et al, 1985).

Figure 4.11 showed the removal of turbidity and COD from brewery wastewater using fixed bed filtration. For the discussion on Figure 4.13 and 4.14, reference should also be made to the experimental data in appendix E1.

Figure 4.13 and 4.14 showed that there was low turbidity and COD removal at the beginning of the sand and GAC fixed bed filtration process. As the wastewater pass through the clean bed, its low capability at the start for capturing particles, caused the turbidity and COD to be around the initial value. This was because the maturation or ‘ripening’ period of the fixed bed filter was not reached. But after 15 minute the removal rate for both, as can be seen from the graph, increased and finally achieved final residual turbidity and COD of 23.92 NTU and 32.84mg/l respectively. This was mainly due to two main processes. Firstly, physical straining (size exclusion) by trapping the particulate matter in between the grains of filters media or settling on top due to its size. Secondly, adsorption, when particulates in the wastewater attach themselves to the fixed bed especially to GAC as they move dawn or to previously retained particles. It yields removal efficiencies of 44.94% and 47% for both turbidity and COD but the final residual turbidity and COD remained didn’t fit the specified industrial water use criteria’s which were set by EPA and WHO for boiler feed, cooling and process water.

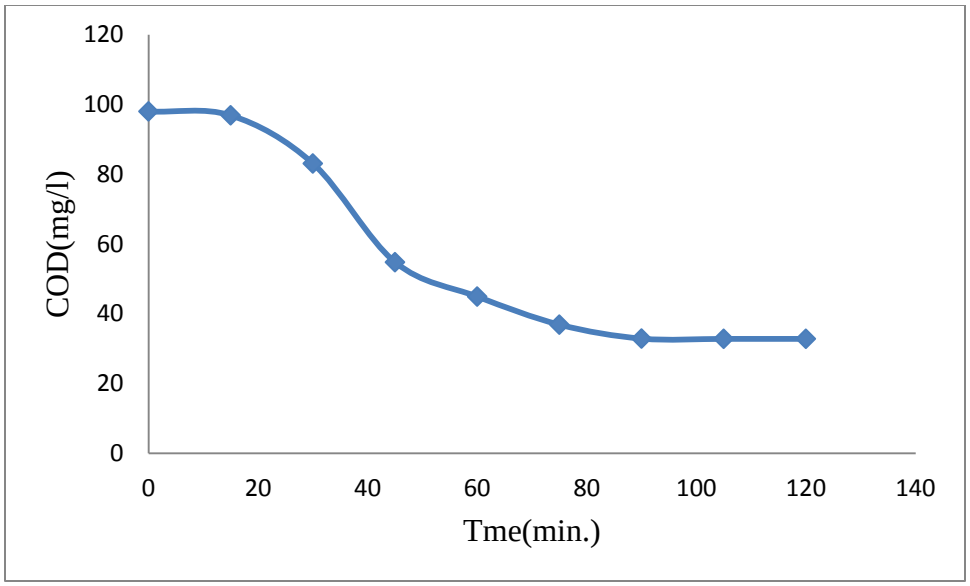


Figure 4.13 COD removal using sand and carbon fixed bed filtration.

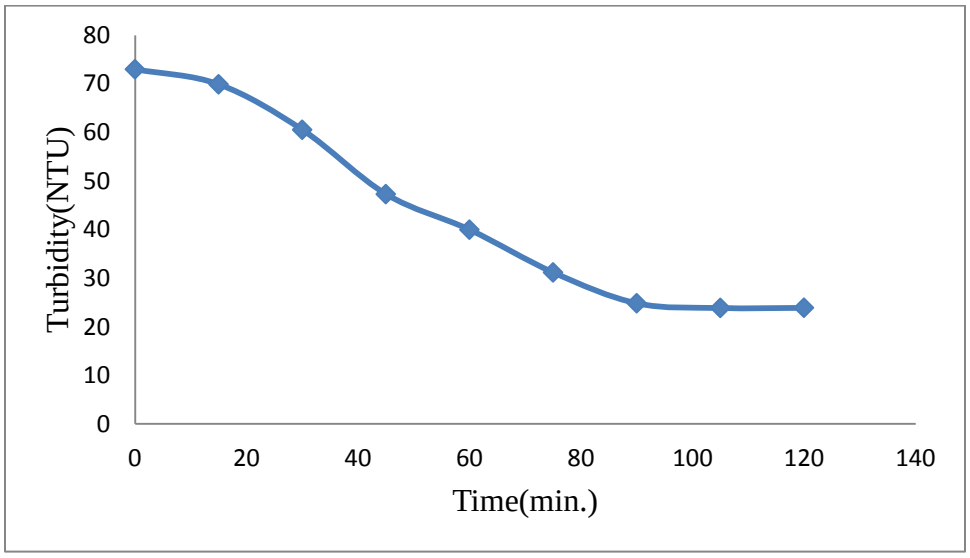


Figure 4.14 Turbidity removal using sand and carbon fixed bed filtration.

4.6 Treatment of brewery wastewater by conventional filtration

Conventional filtration is a common term used whenever coagulation/flocculation and sedimentation processes preceded filtration process in the treatment of surface water for the purpose of drinking water (Crittenden & Harza, 2005). Here the raw water was taken to coagulant tank. Addition of a 40mg/l of hydrated aluminum sulfate to coagulant tank took place. In the coagulant tank, the wastewater mixed with the coagulant by mechanical agitation with a stirrer at 100rpm for 1minute. Thereafter, the water undergoes flocculation by reducing the stirring speed to 40 rpm for the next 20 minutes and allowed to settle for 50 minutes by stopping

the stirring completely. The sample from the flocculation and settling unit then taken to the GAC and sand fixed bed to be filtered.

Figures 4.15 and 4.16 showed the removal of turbidity and COD from brewery wastewater by conventional filtration. For the discussion on Figures 4.15 and 4.16, reference should also be made to the experimental data in appendix E.2.

The COD and turbidity of the filtrate from the conventional filtration as a function of operation time was also plotted on figure 4.12. A similar trend of removal (see Figure 4.15 and 4.16) was also obtained for the conventional treatment but at a better rate as can be seen from figure 4.15 and 4.16. It yields a removal of 92 % for both COD and Turbidity.

The final residual Turbidity and COD remained were 2.12NTU and 2.81mg/l respectively. It fit the specified industrial water use criteria's which were set by EPA and WHO for boiler feed, cooling and process water. Therefore, coagulation/flocculation step followed by sedimentation enhanced the removal efficiency of colloidal particulates and other suspensions. As for the GAC and sand fixed bed filtration, both the coagulation/flocculation and sedimentation steps were missing, therefore, the removal of the small-size particulates of COD only happens in the filter-bed; hence least COD and turbidity removal efficiency were observed.

The role of coagulation/flocculation and sedimentation processes in the removal of turbidity and COD may be explained as follows. During coagulation and flocculation, insoluble particles, suspended particles and dissolved organic and inorganic matter interact to form larger and denser particles or flocs (orthokenetics). These larger and denser aggregates were then removed by allowing them to settle out of the water under the force of gravity in the subsequent sedimentation stage by allowing them to settle for 50 minute. Then the remaining pollutant from sedimentation undergoes fixed bed filtration as explained above. In addition to sand and carbon fixed bed filter itself, the destabilization of particulates by coagulation and flocculation also enables particles to be attached to the filter media more readily. Therefore, coagulation/flocculation and sedimentation step followed by sand and carbon fixed bed enhanced the removal of colloidal particulates and other suspensions.

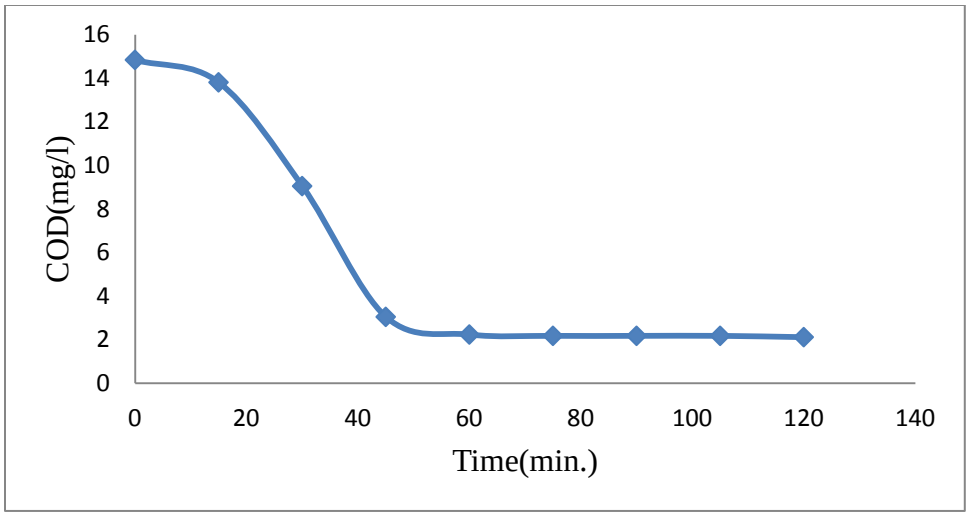


Figure 4.15 COD removal by conventional filtration.

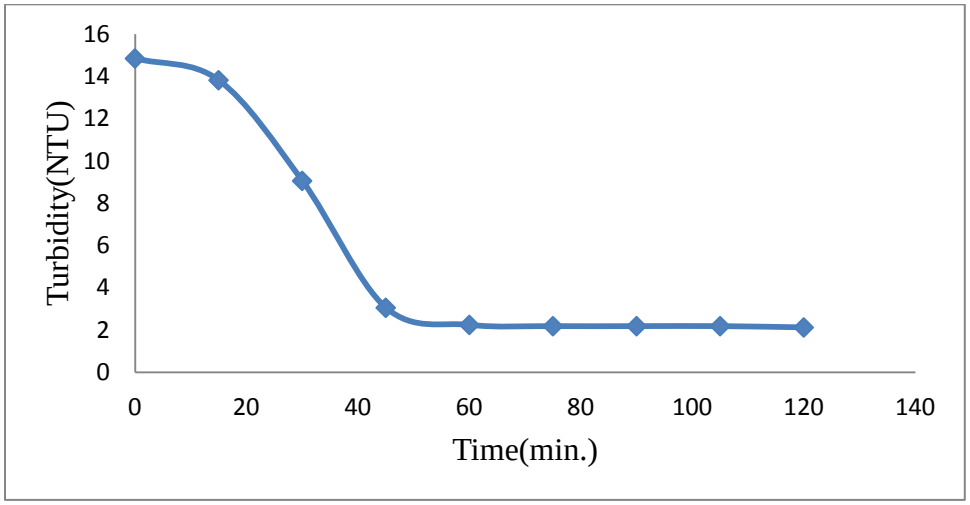


Figure 4.16 Turbidity removals by conventional filtration.

4.7 Additional characterizations of the conventionally treated wastewater

Since the average values of the filtrate from the conventional treatment (coagulation/flocculation and sedimentation step followed by sand and carbon fixed bed) satisfies the turbidity and COD limit specification, additional characterizations were conducted to make sure it satisfies other set criteria as well. For the discussion on Figures 4.17 and 4.18, reference should also be made to the experimental data in appendix F.1.

Datas in appendix F.1 above illustrate the removal of pollutants after coagulation/flocculation and sedimentation process preceded by the sand and carbon fixed bed. There has seemingly been little ammonium in the characterization of the wastewater, and the remaining were completely

removed (100% removal rates).Total nitrogen was not detected in any of the filtrates of the column. Its concentrations were generally found to be in the range from 4-5 mg/l in the wastewater and the remaining was completely removed after passing through the filter columns. Total phosphorus was also not detected in any of the effluent of the column. Total phosphorus concentrations were generally found to be in the range from 4-5 mg/L, effluent wastewater and the remaining was also completely removed after passing through the conventional filtration method. But the total EC was not completely removed. It reduced from 1.88 – 2.11mScm^{-1} range to below 1mScm^{-1}after passing through the conventional filtration method. There were still remaining of carbonate, phosphate and nitrate. The pH of the water after treatment still remained in neutral region. For detailed on total pH data, see appendix F.

The above results obtained in illustrate that there was a complete removal of TN, TP and NH_4 after conventional filtration treatment and the conductivity was also reduced as can be seen in figure 4.17.the pH is also in neutral range as can be seen from figure 4.18.for the rest since it is complete removal, the graph was not drawn. These were major criterion for reusing the wastewater because they determine the corrosively, biological activities and scale formation nature of the wastewater which was going to be used either for cooling, boiler feed or process purpose.

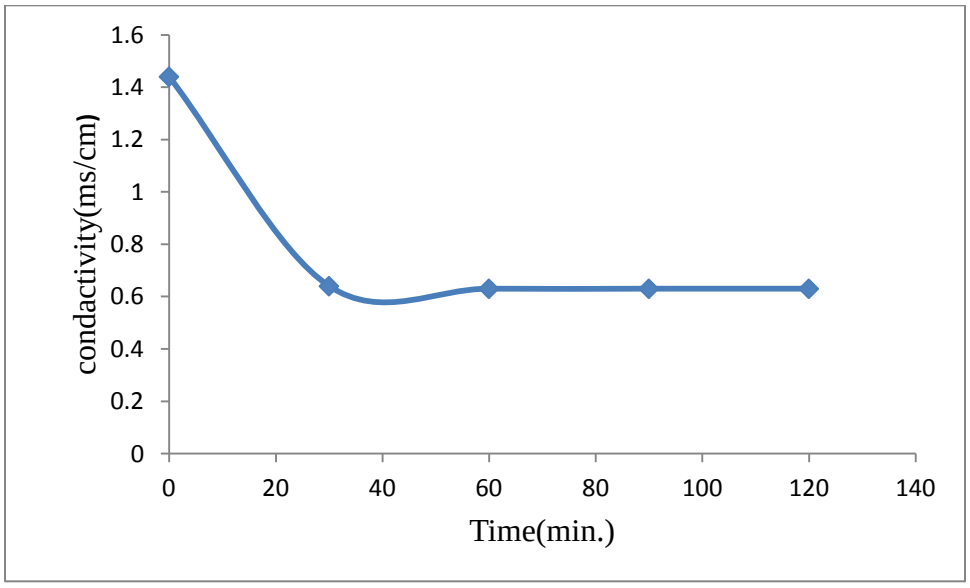


Figure 4.17 Conductivity removals by conventional filtration.

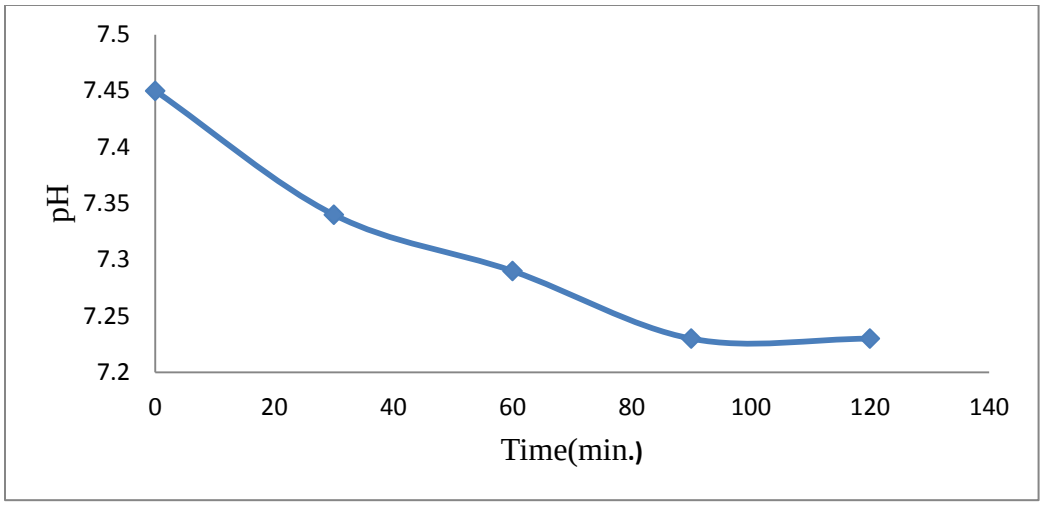


Figure 4.18 pH conditions after conventional filtration.

4.8 The Evaluation of the conventionally treated wastewater for Industrial reuse

Reclaimed water quality for industrial uses needs to be protective. Due to this, the effluent needs to be in the specified range. Generally, industrial reuse of the reclaimed water was classified into three categories as cooling water, boiler-feed water, and process water (US EPA, 1992). The compatibility of reuse options were discussed in the following topics, below.

4.8.1 Compatibility as Cooling Water

Cooling water recommended specifications which were specified by EPA of united state of America, Heineken standard and average effluent values of the conventionally treated wastewater were given in table 4.3. So, a comparison was done below for these results. It's seen that the values of turbidity, COD, conductivity, ammonium and TP parameters were well below the limits.

Table 4.3 Comparison on the compatibility of treated effluent wastewater with Cooling Water standard.

Parameter	US EPA	Heineken	Effluent
COD(mg/l)	≤20	≤5	≤3
Conductivity($mScm^{-1}$)	≤4	≤1	≤1$mScm^{-1}$
Ammonia(mg/l)	≤5	0	0
TP(mg/l)	≤1	0	0
Turbidity(NTU)	≤15	0	≤3
pH(mg/l)	6.9-9.0	7 – 8	7 – 8

So as could be seen from table 4.3, treatment by sand and carbon fixed bed resulted in good quality effluent which can serve as cooling water. The reduction in conductivity below 1 mS/cm tells, there will be low probability of scaling (removal of carbonate, phosphate and nitrate) and corrosion since total dissolved solids can promote corrosion by increasing the electrical conductivity of the water were reduced. Corrosion may also occur when acidic condition develops in the cooling water due to ammonia. The ammonia in water may convert into nitrates in cooling water result in lowering of pH (US EPA, 1992)**.** But this condition is controlled by 100% removing the remaining ammonia and nitrogen compounds.

The reclaimed water for cooling must not supply any nutrient or organic substances which promote the growth of slim forming organisms. The moist in the cooling water is conductive for biological growth. Microorganisms can significantly reduce the heat transfer efficiency, reduce water flow and in some cases generate corrosive by products (US EPA, 1992). The significant reduction of COD, turbidity and complete removal nutrients of during the treatment reduces the potential of the reclaimed water to sustain microorganisms.

4.8.2 Compatibility as Boiler-Feed Water

Boiler-Feed water recommended specifications which were specified by EPA of united state of America were given in table 2.2 in the literature review. Also filtrate values of the fixed bed treatment were given in Table 4.2 above. So, a comparison was done with the data in table 2.2 which shows boiler-Feed Water standards.

The higher pressure of the boilers needs higher quality of feeding water, according to the table 2.2. Thus, the filtrate from the conventional treatment was not good enough and it needs more additional treatment to reach the standard values for high pressure boilers. But for the intermediate and low pressure boilers, all values were in the permitted range as can been seen from table 2.2 lists of standards. In general the reclaimed water conductivity level must be close to zero. The removal of insoluble salts of calcium, sodium, aluminum and total dissolved solids are required since these are principal causes of scale formation and corrosion as explained above. The removal of reduction of COD, turbidity and removal of all nutrients also ensured the reclaimed boiler feed water couldn’t support any biological growth after sand and carbon fixed bed treatment. But he result was not sufficient enough to be used as high pressure boiler feed

water since it requires higher quality water. Since Heineken has only high pressure boilers, it is not safe to be used for its boilers.

4.8.3 Compatibility as Process Water

The appropriateness of reclaimed water for industrial processes changes up to the usage. For example, the brewery process requires water of almost distilled water quality. On the other hand cooling process requires relatively low quality water. In case of using the treated wastewater as process water, treatment should be done until very clean and fresh water quality is gained but still it is not recommended and inappropriate to reuse wastewater for either drinking or for brewing process (Braeken, et al., 2004). Table 4.4 shows the quality of the filtrate in relation to the drinking water standards.

Table 4.4 Comparison of drinking water standards with the conventional filtration effluent

Parameter	WHO	EPA	Heineken	Effluent
COD(mg/l)	≤5	≤10	≤3	≤3
Turbidity(NTU)	≤5	5 – 10	≤1	≤3
pH	6.5-8.8	6.5-8.5	0	7 – 8
TN(mg/l)	≤0.1	≤1	0	0
Ammonia(mg/l)	≤0.1	≤1	0	0
TP(mg/l)	≤0.1	≤1	7 – 8	0

In summary, The Quality standards for boiler feed water (low and intermediate pressure boilers); cooling water and process water were met as can be seen from WHO and EPA standards which were listed above. Since Heineken brewery boilers are high pressure boilers, it is not safe to use the treated effluent for Heineken brewery.

Generally this research showed that treatment of the brewery wastewater using sand and carbon fixed bed will not only make the environment safer but also make the brewing industry more productive interims of saving and properly utilizing the fresh water resources. For example Heineken brewery on average discharges 1900m^3 of wastewater daily. This wastewater which is discharge into nearby river annually exceeds 590,000m^3.So if this research became functional, it will provide an opportunity to reuse this much amount of wastewater for either of the above purposes and reduce the enormous burden on the ground water resources of klinto Area in Addis Ababa.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this work, Treatment of brewery wastewater using natural sand and granular activated carbon fixed bed filtration was carried out and the following conclusions are drawn:

The wastewater being discharged from Heineken Brewery contains organic and inorganic pollutants such as ammonia, nitrogen, phosphorus compounds and larger amount of COD. Due to this, it is not suitable for further reuse.

Ferric chloride and hydrated aluminum sulfate resulted in better turbidity and COD removal for brewery wastewater. Even though ferric chloride was more effective at lower dosage than hydrated aluminum sulfate while conducting jar test, hydrated aluminum sulfate was chosen due to its easy availability in our country and result in neutral pH at the end of the operation.

Treatment of brewery wastewater using sand and GAC fixed bed filtration results in significant reduction of COD and turbidity but the filtrate quality doesn't meet EPA and WHO reuse requirements. But when the fixed bed is preceded by Coagulation/flocculation and sedimentation, a better quality effluent was obtained which can be used as boiler feed, cooling and process water.

5.2. Recommendation

- ✓ Factories like Heineken should start to give more attention for coagulants which are produce in the country than importing more expensive ones from abroad. As can be seen from this research, substituting ferric chloride with alum has give almost nearly similar result.
- ✓ Detail characterization should be carried out in Mojo sand and priority should be given in improving their filtering capacity. If possible it should also be tried in other wastewaters to check its effectiveness.
- ✓ The development and implementation of treatment technologies for reusing industrial wastewater may inquire additional costs. Hence studies for waste benefit analyses need to be conducted.

REFERENCE

Achak, M., Mandi, L., Ouazzani, N. (2009). Removal of organic pollutants and nutrients from olive mill wastewater by a sand filter. Journal of Environmental Management 90, 2771-2779.

American Water Works Association (AWWA),(2000). Water Treatment Plant Design. McGraw-Hill, New York..

Aronino, R., Dlugy, C., Arkhangelsky, E., Shandolov, S., Oron, G., Brenner, A., Gitis, V., (2009). Removal of viruses from surface water and secondary effluents by sand filtration. Water Research 43, 87-96.

APHA, (1995), Standard Methods for the Examination of Water and Wastewater, 20th edition, American Public Health Association/Water Environment Federation, Washington DC.

Au, k. & Lechevallier, m. (2004). Removal processes. Water treatment and pathogen control: process efficiency in achieving safe drinking water. WHO.

Braeken, B. Van der Bruggen, C. Vandecasteele, (2004) .Regeneration of brewery wastewater using nanofiltration, Water Research 38 (13) 3075–3082.

Crittenden, J. & harza, M. W. (2005). Water Treatment: Principles and Design, Wiley, 922 - 956.

Chuang, C. J., Li, K. Y., (1997). Effect of coagulant dosage and grain size on the performance of direct filtration. Separation and Purification Technology 12, 2290-2419.

Chan, Y.J., Chong, M.F., Law, C.L., Hassell, D.G., (2009). A review on anaerobic–aerobic treatment of industrial and municipal wastewater, Chemical Engineering Journal 155, 1–2.

Droste, R. L. (1997). Theory and Practice of Water and Wastewater Treatment, Wiley.

EEPA, (2003). Provisional Standards for Industrial Pollution Control in Ethiopia. Prepared under the ecologically sustainable industrial development (ESID) project – US/ETH/99/068/Ethiopia, EPA/UNIDO, Addis Ababa.

Emerick, R. W., Test, R. M., Tchobanoglous, G., Darby, J., (1997). Shallow intermittent sand filtration performance evaluation. Small Flows Journal 3 (1), 12-22.

US EPA ,(1993). Determination of Turbidity by Nephelometry, Revision 2.0, Method 180.1. Environmental Monitoring Systems Laboratory . Cincinnati, OH.

US EPA,(1992). Guidelines for water reuse. Center of Research and development. EPA/625/R-92/004. Washington , DC.

Farizoglu, B., Nuhoglu, A., Yildiz, E., Keskinler, B., (2003). The performance of pumice as a filter bed material under rapid filtration conditions. Filtration and Separation 40 (3), 41-47.

Feng, Y.,Wang, X. ,Logan, B.E.,Lee, H., (2008) .Brewery wastewater treatment using aircathode microbial fuel cells, Applied Microbiology and Biotechnology 78 , 873–880.

Fillaudeau, L., Blanpain-Avet, P., Daufin, G., (2006).Water, wastewater and waste management in brewing industries. Journal of Cleaner Production 14, 463-471.

Fitzpatrick and Gregory. (2003). The Handbook of Water and Wastewater Microbiology, Third Edition. London: Elsevier.

Forstmeier M, Goers B, Wozny G., (2002). Treatment of rinsing waters in a liquid detergent production plant. Desalination; 149(1–3):175–210.

Goldammer, T., (2008). The Brewers' Handbook, 2nd edition. Apex Publishers, Clifton.

Gregory. (2006). Particles in Water: Properties and Processes. IWA Publishing. London: CRC press.

Heineken utility manual (2012), Water Treatment Plant, Kilinto Addis Ababa, Ethiopia

Mary, S., (2005). Nitrogen Reducing Technologies for Onsite Wastewater Treatment Systems, Report to the Puget Sound Action Team, Washington State Department of Health, Olympia,WA.

Peavy, H. S., Rowe, D. R., Tchobanoglous, G., (1985). Environmental Engineering. McGraw-Hill, Inc., New York.

Shue, k.,Schuler, P. F., Ghosh, M. M., Gopalan, P., (1991). Slow sand and diatomaceous earth filtration of cysts and other particulates. Water Research 25 (8), 995-1005.

Simate, G. S., Iyuke, S. E., Ndlovu, S., Heydenrych, M.,(2012). The heterogeneous coagulation and flocculation of brewery wastewater using carbon nanotubes. Water Research 46 (4), 1185-1197.

Van der Merwe, Friend. (2002). Water management at a malted barley brewery. Water SA 28 (3) , 313-318.

Wen, Y. Wu, L. Zhao, Q. Sun, F. Kong, (2010). Electricity generation and brewery wastewater treatment from sequential anode - cathode microbial fuel cell. Journal of Zhejiang university Science B11(2) , 87 - 93.

World Health Organization (2006). WHO guidelines for the safe use of wastewater, excreta and greywater vol.2 wastewater use in agriculture. France: World Health Organization.

Williams, G. J., Sheikh, B., Holden, R. B., Kouretas, T. J., Nelson, K. L., (2007). The impact of increased loading rate on granular media, rapid depth filtration of wastewater. Water Research 41, 4535-4545.

van Benthum, W.A.J., van Loosdrecht, M.D.M., Heijnen, J.J.,(1997).Control of heterotrophic layer formation on nitrifying biofilms in a biofilm airlift suspension reactor. Biotechnol. Bioeng. 53 (4), 397–405.

Zeta-Meter Inc. (1993). Coagulation and flocculation-guide . Virginia: Zeta-Meter Inc.

APPENDIX

Appendix A. Characterization of the brewery wastewater

Parameters	Run 1	Run 2	Run 3	Standard deviation
pH	7.69	7.22	8.2	0.48
COD(mg/l)	85	77	106	6.97
Turbidity(NTU)	65.45	57.87	78.01	3.68
Total nitrogen (mg/l)	4.3	3.7	4.7	0.26
Total ammonia (mg/l)	1.2	0.9	1.1	0.15
Total phosphorus(mg/l)	4.77	3.58	4.55	0.66
Conductivity($mScm^{-1}$)	1.88	2.11	1.92	0.12

Appendix B. Jar test results

Appendix B.1Effect of $FeCl_3$ dosage on turbidity and COD removal using Jar test

Initial Conditions: initial turbidity: 66 NTU ;initial COD:85 mg/L;10litres of wastewater; flash mixing speed of 100 rpm for 1 minutes; slow mixing speed of 40 rpm for 20 minutes and sedimentation for 20 minute.

Turbidity

Sample	$FeCl_3$ (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	46.02	46.45	46	46.15	0.25
Jar 2	20	13.9	13.65	13.72	13.75	0.12
Jar 3	40	7.45	7.39	7.43	7.42	0.03
Jar 4	60	5.97	5.01	5.92	5.96	0.54

COD

Sample	$FeCl_3$ (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	67.63	67.85	67.43	67.66	0.21
Jar 2	20	22.42	20.36	21.39	21.39	0.87
Jar 3	40	24.55	23.76	23.46	23.92	0.56
Jar 4	60	31.25	32.65	31.00	31.63	0.62

pH

Sample	$FeCl_3$ (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	7.56	7.61	7.62	7.59	0.03
Jar 2	20	7	6.88	6.89	6.92	0.06
Jar 3	40	6.22	6.22	6.18	6.20	0.03
Jar 4	60	5.58	5.46	5.48	5.50	0.06

Appendix B.2 Effect of hydrated aluminum sulfate dosage on turbidity and COD removal using jar test

Initial Conditions: initial turbidity: 66 NTU ; initial pH:7.6;initial COD:85 mg/L; 10litres of wastewater; flash mixing speed of 100 rpm for 1 minutes; slow mixing speed of 40 rpm for 15minue and sedimentation for 20 minute.

Turbidity

Sample	Alum (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	46.02	46.45	46	46.15	0,25
Jar 2	20	23.00	21.68	23.01	22.56	0.78
Jar 3	40	13.98	13.78	13.73	13.83	0.13
Jar 4	60	11.83	12.03	11.21	11.69	0,42

COD

Sample	Alum (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	67.63	67.85	67.43	67.66	0.21
Jar 2	20	38.2	43.33	43.32	41.50	0.95
Jar 3	40	23.44	23.66	24.21	23.77	0.39
Jar 4	60	24.80	27 .01	27.5	26.23	0.67

pH

Sample	Alum (mg/l)	Run 1	Run 2	Run 3	Mean	Standard deviation
Jar 1	0	7.56	7.61	7.62	7.59	0.03
Jar 2	20	7.4	7.65	7.61	7.55	0.13
Jar 3	40	7.2	7.23	7.26	7.23	0.03
Jar 4	60	6.19	6.23	6.23	6.21	0.02

Appendix C. Turbidity (NTU) at Intervals into Settling Phase

Initial Conditions: initial conditions were 10litres of wastewater; initial pH:7.6; alum 40mg/l and turbidity of 66 NTU, flash mixing speed of 100 rpm for 1 minutes; slow mixing speed of 40 rpm for 20 minutes.

Time (min)	Run 1	Run 2	Run 3	Mean	Standard deviation
20	13.8	13.78	14.08	13.80	0.16
35	7.98	7.98	7.98	7.98	0
50	5.47	5. 47	5.47	5.47	0
65	5.47	5.47	5.47	5.47	0
80	5.47	5.47	5. 47	5.47	0
95	5.47	5.47	5.47	5.47	0
110	5.01	5.47	5.47	5.47	0.26
120	5.47	5.47	5.47	5.47	0

Appendix D. sieve analysis

Appendix D.1

Initial Conditions: 1000g of natural sand used

Sieve size (mm)	Cumulative Mass retained(g)	Cumulative % Retained	% passing
2mm	135.54	13.55	86.45
1.4mm	92.90	9.29	77.16
0.85mm	169.66	17.00	60.16
0.25mm	365.92	36.59	23.57
0.18mm	55.00	5.5	18.07
0.15mm	33.80	3.38	14.69
0.125mm	66.68	6.67	8.02
0.1mm	38.26	3.82	4.19
	9.30	2.93	
Total	967.44		

Appendix D.2

Initial Conditions: 1000g of natural sand used

Sieve size (mm)	Cumulative Mass retained(g)	Cumulative % Retained	% passing
2mm	67.70	6.77	93.23
1.4mm	169.01	16.90	76.33
0.85mm	126.45	12.64	63.68
0.25mm	182.96	18.26	45.38
0.18mm	118.96	11.80	33.48
0.15mm	104.03	10.40	23.07
0.125mm	108.46	10.80	10.84
0.1mm	66.02	6.60	4.23
	13.46	1.35	
Total	956.46		

Appendix D.3

Initial Conditions: 1000g of natural sand used

Sieve size (mm)	Cumulative Mass retained(g)	Cumulative % Retained	% passing
2mm	124.81	12.48	87.52
1.4mm	142.90	14.3	73.23
0.85mm	114.60	11.46	61.76
0.25mm	283.11	28.31	33.45
0.18mm	50.00	5.00	28.45
0.15mm	121.34	12.13	16.32
0.125mm	80.21	8.02	8.30
0.1mm	18.50	1.85	6.45
	16.25		
Total	951.72		

Appendix D.4

Sieve size (mm)	% passing 1	% passing 2	% passing 3	Mean
2mm	86.45	93.23	86.45	86.45
1.4mm	77.16	76.33	76.33	73.23
0.85mm	60.162	63.68	60.16	60.162
0.25mm	23.57	45.38	23.57	23.57
0.18mm	18.07	33.48	18.07	18.07
0.15mm	14.69	23.07	14.69	14.69
0.125mm	8.02	10.84	8.02	8.02
0.1mm	4.19	4.23	4.19	4.19

Appendix E. Fixed bed filtration

Appendix E.1 Sand and GAC fixed bed filtration

Initial Conditions: turbidity: 73 NTU; pH: 7.65; COD: 98mg/L; running time 2 hrs.

Time	COD 1	COD 2	COD 3	Mean	Standard deviation
0	98.00	98.00	98.00	98.00	0
15	99.15	94.84	96.67	96.88	0.89
30	83.13	80.46	85.62	83.07	0.92
45	54.61	55.70	54.06	54.79	0.66
60	44.01	44.79	43.04	43.94	0.65
75	44.03	44.63	43.04	43.90	0.61
90	44.06	44.63	43.04	43.91	0.61
105	33.00	32.53	33.00	32.84	0.27
120	32.06	32.00	32.04	32.03	0.03

Time	Turbidity 1	Turbidity 2	Turbidity3	Mean	Standard deviation
0	73.00	73.00	73.00	73.00	0
15	58.68	58.83	56.21	57.90	0.88
30	61.00	59.59	61.04	60.54	0.51
45	47.89	47.02	47.00	47.30	0.43
60	39.69	39.65	40.63	39.99	0.31
75	37.33	35.25	36.01	36.19	0.74
90	31.32	35.25	35.00	33.85	0.98
105	29.00	28.69	29.00	28.89	0.17
120	28.45	29.36	28.97	28.92	0.45

Appendix E.2; Conventional filtration

Initial Conditions: turbidity: 78 NTU; pH: 7.65; COD: 92 mg/L: running time 2 hrs

Time	COD1	COD 2	COD 3	Mean	Standard deviation
0	18.92	16.9	16.9	17.57	0.36
15	16.69	16.55	16.65	16.63	0.07
30	13.91	13.78	3.78	13.82	0.11
45	6.00	6.88	6.88	6.58	0.5
60	2.99	2.83	2.83	2.88	0.09
75	2.77	2.83	2.83	2.81	0.03
90	2.77	2.83	2.83	2.81	0.03
105	2.77	2.83	2.83	2.81	0.03
120	2.99	2.54	2.9	2.81	0.23

Time	Turbidity1	Turbidity 2	Turbidity3	Mean	Standard deviation
0	14.05	14.166	13.99	14.06	0.08
15	13.25	14.24	14.04	13.84	0.2
30	10.02	9.81	9.64	9.82	0.1
45	3.36	3.79	3.66	3.60	0.09
60	2.32	2.2	2.2	2.24	0.02
75	2.22	2.17	2.17	2.18	0.05
90	2.22	2.17	2.17	2.18	0.05
105	2.22	2.17	2.17	2.18	0.01
120	2.24	2.2	2.19	2.21	0.01

Appendix F. Additional Characterization and Calculations

Appendix F.1 Additional Characterization after Conventional filtration

Total nitrogen (mg/l)

Time	Run1	Run2
0	0	0
30	0	0
60	0	0
90	0	0
120	0	0

Total ammonia (mg/l)

Time	Run1	Run2
0	0	0
30	0	0
60	0	0
90	0	0
120	0	0

Total phosphorus (mg/l)

Time	Run1	Run2
0	0	0
30	0	0
60	0	0
90	0	0
120	0	0

Electrical Conductivity ($mScm^{-1}$)

Time	Run1	Run2
0	0.65	0.65
30	0.63	0.65
60	0.62	0.65
90	0.65	0.65
120	0.65	0.65

pH

Time	Run1	Run2
0	7.44	7.45
30	7.29	7. 26
60	7.29	7. 26
90	7.25	7. 26
120	7.23	7. 26

Appendix F.2 Calculations

For the determination of the sand property

From figure 4.10, we can read d_{10} =ES = 0.15 and d_{60} = 0.85mm and the sand which was found between them serve as a fixed bed media (usable portion of the sand).Then the uniformity coefficient was calculated as follow;

UC = $\frac{d60}{d10}$ =5.67

From the usable portion of the sand, 4g were taken and placed in 30ml of distilled water and the following results were obtained. (Note that the volume was the one displaced by the sand).

ρ_S = $^{4g}/_{2.2ml}$ = 1.8g/ml……by using displacement method

ρ_S = $^{4g}/_{2.53ml}$ = 1.58g/ml……by using displacement method

ρ_S = $^{4g}/_{2.8ml}$ =1.42g/ml……by using displacement method

ρ_S = 1.6g/ml……..average of the above three

Appendix G. Statistical analysis using ANOVA for the experimental results

I.$FeCl_3$ dosage on turbidity and COD removal using Jar test

Response: Turbidity

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	776.41	3	258.80	2766.21	< 0.0001	significant
A	*776.41*	*3*	*258.8*	*2766.21*	*< 0.0001*	
Pure Error	0.75	8	0.094			
Cor Total	777.16	11				

The Model F-value of 2766.21 implies the effect of the treatment on turbidity removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: COD

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	4339.95	3	1446.65	1966.29	< 0.0001	significant
A	*4339.95*	*3*	*1446.65*	*1966.29*	*< 0.0001*	
Pure Error	5.89	8	0.74			
Cor Total4	345.84	11				

The Model F-value of 1966.29 implies the effect of the treatment on COD removal is significant.There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are

not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: pH

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	7.53	3	2.516	35.72	< 0.0001	significant
A	*7.53*	*3*	*2.51*	*635.72*	*< 0.0001*	
Pure Error	0.032	8	3.950E-003			
Cor Total	7.56	11				

The Model F-value of 635.72 implies the effect of the treatment on pH is significant.There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

II. Alum dosage on turbidity and COD removal using Jar test

Response: Turbidity

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	429.84	3	143.28	677.66	< 0.0001	significant
A	*429.84*	*3*	*143.28*	*677.66*	*< 0.0001*	
Pure Error	1.69	8	0.21			
Cor Total	431.53	11				

The Model F-value of 677.66 implies the effect of the treatment on turbidity removal is significant.There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are

not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: COD

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	3641.11	3	1213.70	440.32	< 0.0001	significant
A	*3641.11*	*3*	*1213.70*	*440.32*	*< 0.0001*	
Pure Error	22.05	8	2.76			
Cor Total	3663.16	11				

The Model F-value of 440.32 implies implies the effect of the treatment on COD removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: pH

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	3.72	3	1.24	241.89	< 0.0001	significant
A	*3.72*	*3*	*1.24*	*241.89*	*< 0.0001*	
Pure Error	0.041	8	5.125E-003			
Cor Total	3.76	11				

The Model F-value of 241.89 implies the effect of the treatment on pH is significant.There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(dosage) are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are

many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

III. Turbidity (NTU) at Intervals into Settling Phase

Response: Turbidity

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
ModeL	84.09	7	26.30	3004.07	< 0.0001	significant
A	*184.09*	*7*	*26.30*	*3004.07*	*< 0.0001*	
Pure Error	0.14	16	8.754E-003			
Cor Total	1	84.23	23			

The Model F-value of 3004.07 implies the effect of the treatment on turbidity removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A(settling time) are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model

IV. Fixed bed filtration

Response: COD

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	16940.37	8	2117.55	1344.65	< 0.0001	significant
A	*16940.37*	*8*	*2117.55*	*1344.65*	*< 0.0001*	
Pure Error	28.35	18	1.57			
Cor Total	16968.72	26				

The Model F-value of 1344.65 implies the effect of the treatment on COD removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values

of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: Turbidity

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	5824.90	8	728.11	682.44	< 0.0001	significant
A	*5824.90*	*8*	*728.11*	*682.44*	*< 0.0001*	
Pure Error	19.20	18	1.07			
Cor Total	5844.10	26				

The Model F-value of 682.44 implies the effect of the treatment on turbidity removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

V. Conventional filtration

Response: COD

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	907.10	8	113.39	144.95	< 0.0001	significant
A	*907.10*	*8*	*113.39*	*144.95*	*< 0.0001*	
Pure Error	14.08	18	0.78			
Cor Total	921.18	26				

The Model F-value of 144.95 implies the effect of the treatment on COD removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.05 indicate model terms are significant.In this case A are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Response: Turbidity

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

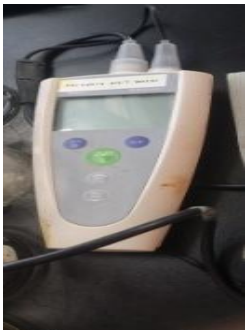
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	609.49	8	76.19	136.95	< 0.0001	significant
A	*609.49*	*8*	*76.19*	*136.95*	*< 0.0001*	
Pure Erro	10.01	18	0.56			
Cor Total	619.50	26				

The Model F-value of 136.95 implies the effect of the treatment on turbidity removal is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.Values of "Prob > F" less than 0.05 indicate model terms are significant.In this case A are significant model terms.Values greater than 0.1000 indicate the model terms are not significant.If there are many insignificant model terms (not counting those required to support hierarchy),model reduction may improve your model.

Appendix H. Diagrams of equipments

COD reactor

Electronic balance



pH meter

wastewater

HACH Spectrophotometer

Nephelo terbidometre

Ro-Tap machine

ferric chloride

Aluminum sulfate 18 hydrated

sand and sieving dishes with size Size 100µm - 2mm

AAiT fixed bed filtration column

DECLARATION

I declare that this thesis entitled "Treatment of Brewery Wastewater Using Sand and Carbon Fixed Bed**"** is my own, original work done under the supervision of Ato Teshome Worku at Addis Ababa Institute of Technology in 2015/16 academic year for partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering and that I have not previously submitted it entirely or in part for obtaining any qualification at any other university and all references used in this work have been properly sited and accredited.

Ermias Demissie …… ……..

Signature Date