Treatment of Wastewater from Slaughterhouses by Electrocoagulation:Case Study of Gachororo Slaughterhouse, Kiambu County, Kenya

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Abstract
Wastewater from slaughterhouses is highly contaminated with high concentrations of organic and colloidal materials such as proteins, cellulose, and fats, as well as suspended solids. Discharge of this water in the rivers brings about changes which affect the water quality and the microflora, and increases long term biological oxygen demand (BOD) as well as water treatment problems. The conventional methods used to treat this water are characterized by many disadvantages including; production of high levels of sludge, high energy consumption required for aeration, sensitivity to high organic loading rate and long hydraulic retention times. This makes it necessary to explore other alternative treatment methods such as electro-coagulation. This study therefore sought to explore wastewater remediation using electro-coagulation method. The purpose was to establish a method of treating water cheaply and more effectively in an environmental friendly manner. Samples of both raw slaughterhouse effluent and treated water samples were taken and subjected to standard procedures to determine the levels of pH, Chemical Oxygen Demand, Turbidity, Total Suspended Solids, and Biological Oxygen Demand. The results reveal that electro-coagulation method is able to reduce all these parameters in wastewater to levels that are acceptable by regulating boards such as Government of Kenya Standards for treated wastewater and effluent discharge into the environment. Electrocoagulation was able to reduce BOD, COD, TSS and turbidity to 20.78mg/l, 16.33mg/l, 2.33mg/l and 2 NTU from 1278mg/l, 1475mg/l, 405mg/l and 978 NTU respectively at voltage of 25V and surface area of 40 cm^2 with aluminum electrodes and 90 cm^2 when iron electrodes were used. Electro-coagulation is therefore an effective method for treating wastewater from slaughterhouses.
Keywords: Electrocoagulation, slaughterhouse wastewater, Biological Oxygen Demand, Chemical Oxygen Demand, alkalinity, turbidity, conductivity, pH, total soluble solids, Electrodes.

1. Introduction

The demand for new and better technologies for treating wastewater continues to grow as the world's population grows and sources of freshwater get polluted. Developing countries continue to struggle with waterborne diseases due to lack of funding as well as appropriate knowledge and technology regarding water purification (Dean & Hunter, 2012). The limited water sources are also used by industries which have been forced to use lower quality raw water as a higher proportion of the limited fresh water available is required for human consumption (Butler *et al.,* 2011; Belkacem *et al*., 2008). Technologies for treating wastewater in municipal as well industrial applications have to be improved and further developed so as to reduce pollution of the water bodies that receive the wastewater.

The availability of water, its cost and the treatment of wastewater are a growing area of concern. Hence great care should be taken in conserving it especially in Kenya which is regarded to be one of the countries with very little water (Ngigi & Macharia, 2006). Slaughterhouses are amongst the animal agricultural industries that produce wastewater with high concentrations of soluble and insoluble organics. Waste water and effluents from slaughterhouses are high in biodegradable organics such as proteins, carbohydrates; nitrogen and the cleaning and washing reagents. These organics have proved to be water pollutants (Eryuruk *et al.,* 2011; Budiyono & Johari 2010; Cuetos *et al*., 2008; Asselin *et al.,* 2008; Bayramoglu *et al.,* 2007).

Electrocoagulation is based on dissolution of the electrode material used as an anode. This "sacrificial anode" produces metal ions which act as coagulant agents in the aqueous solution in situ (Emamjomeh & Sivakumar, 2009). At its simplest, an electro-coagulation system consists of an anode and a cathode made of metal plates, both sub- merged in the aqueous solution being treated (Kuokkanen *et al.,* 2013). The electrodes are usually made of aluminum, iron, or stainless steel because these metals are cheap, readily available, proven effective, and non-toxic. Thus they have been adopted as the main electrode materials used in EC systems (Akbal & Camci, 2010). The anodes corrode to release active coagulants into solution. These hydroxides/polyhydroxides/polyhydroxy-metallic compounds have a strong affinity for dissolved, suspended or any ions that might be dissolved in the water to cause coagulation which then removes impurities from the water.

Electrocoagulation (EC) method is one of the electro-chemical processes used in tertiary treatment of water and has been has been suggested as an advanced alternative to chemical coagulation in pollutant removal from raw waters and wastewaters. The process has proven to be a very effective and reliable technology that provides a method of treating wastewater of various pollutants that is environmentally friendly (Chen, 2004; Bayramoglu *et al.,* 2004; Mollah et *al.,* 2004). Moreover, unlike the case of chemical treatment, the salt content of the liquid /electrolyte does not increase appreciably during the EC process (Budiyono & Johari, 2010). EC has been found to be very effective in removing inorganic and organic contaminants as well as pathogens from wastewaters. Research such as that conducted by Belkacem *et al.,* (2008); Saleem e*t al.,* (2011); and Butler *et al*., (2011) indicate that EC has several advantages including: simple equipment which is easy to operate and automate, small area occupied by the plant, short retention time, high sedimentation velocity, low sludge production, no chemicals required, and processes multiple contaminants. This technology, which is fairly new offers an alternative way of removing pollutants from wastewater, particularly that with high concentration of suspended solids such as slaughterhouse wastewaters.

Electro-coagulation been applied in treating water containing various contaminants including oil wastes, mine wastes, foodstuff waste, suspended particles, organic matter from landfill lecheates, dyes, synthetic detergent effluents, solutions containing heavy metals, deflourination of water, and chemical and mechanical polishing waste (Budiyono & Johari 2010; Bayramoglu *et al.,* 2007). Several types of wastewater such as textiles industrial effluent; domestic wastewater; lecheate, and chemically industrial fibre have successfully been treated using the EC technology (Budiyono & Johari 2010; Chen 2004). According to the findings of the study by Adhoum and Monser (2004) and Chen *et al.,* (2000), EC has also been found to be effective in treating wastewaters from various food industries such as restaurants and olive oil processing plants.

This study therefore seeks to determine the effectiveness of electrocoagulation as a method of treating wastewater from slaughterhouses. This is based on the observation that in Kenya, wastewater from slaughterhouses is often dumped untreated into streams, rivers or sometimes just left to flow through drainage systems. This has been attributed to the high costs associated with its treatment. Secondly, the techniques used in treating slaughterhouse wastewaters in Kenya are generally dominated by conventional methods such as aerobic processes (which are disadvantaged and limited by high sludge production and the fact that they consume high energy which is required for aeration (Masse & Masse, 2001)) and anaerobic biological treatment processes (which are reported as being sensitive to high organic loading rates and also impaired by accumulation of floating fats and suspended solids in the reactor which results in reduced methanogenic activity as well as biomas washout (Saddoud & Sayadi, 2007). Hence the need to explore electrocoagulation as a treatment alternative.

1.1 Electrocoagulation Theory and Process

Electrocoagulation (EC) is regarded as one of the most simple and efficient electrochemical methods for the purification of various types of water and wastewaters (Chen, 2004). This process involves electrolytic oxidation of a suitable anode made to generate the coagulant at an appropriate pH. It forms an insoluble metal hydroxide which then removes various pollutants from the wastewater (Chen 2004; Budiyono & Johari, 2010). The metal hydroxide ions/species neutralize the electrostatic charges present on the suspended solids and oil drops facilitating coagulation and the resulting separation from the aqueous phase (Chen 2004; Kanu *et al.,* 2006).

In EC using iron electrodes, the generation of iron hydroxides $Fe(OH)_n$ is followed by an electrophoretic concentration of colloids (usually negatively charged) in the region close to the anode (Kurt *et al.,* 2008). The produced ferrous ions hydrolyze to form polymeric hydroxide complexes and monomeric hydroxide ions that are dependent on the solution's pH. The polymeric hydroxides, which are highly charged cations, destabilize the negatively charged colloidal particles allowing aggregation and formation of flocs. Generation of the hydroxides also depends on how soluble the metal hydroxide is. When the iron amount in the water being treated exceeds the solubility of the metal hydroxide, the amorphous metal hydroxide precipitates is formed, which causes sweep-floc coagulation (Saleem *et al*., 2011).

Coagulation in the EC process is generated in situ by electrolytic oxidation of an anode made from appropriate material (Shafaei *et al.,* 2010). Charged ionic species are removed from wastewater during this process through its reaction with an ion having the opposite charge, or by reacting with floc metallic hydroxides produced within the effluent. EC treatment methods present an alternative to the use of polymers, polyelectrolyte and metal salts that are usually added in the water being treated to break stable emulsions and suspensions (Kongjao *et al.,* 2008). The EC treatment method generates polymetric metal hydroxides that are highly charged in the aqueous media. This neutralizes the electrostatic charges that exist on suspended solids and oil droplets to facilitate coagulation and the resulting separation from the aqueous phase. This triggers the precipitation of certain metals and salts. According to research, treatment performance of EC system is studied by observing optimization of electrical current and of electrode types, the two most important parameters for the EC method (Chen, 2004).

1.1.2 Main Reactions

In the EC system there are multiple electrochemical reactions occurring simultaneously at the anodes and cathodes.

These mechanisms can be divided into the main mechanisms that cause destabilisation of pollutants, and side reactions, such as hydrogen formation.

EC mechanism extremely depends on the chemistry of the aqueous medium, in particular its conductivity. The mechanism by which ions are generated by the EC process can be explained using iron and aluminum. These electrodes produce coagulants into water.

Iron produces iron hydroxide in an electrolyte system. In the case of iron or steel and aluminum anodes, two mechanisms for the production of the metal hydroxide have been proposed (Kurt *et al*., 2008; Saleem *et al*., 2011). Iron and aluminum cations dissolve from the anodes according to Equations 1 and 2.

$Fe\ (s) \rightarrow Fe^{n+}\ (aq) + ne^-$ …………………………………………………………. (1)

$Al\ (s) \rightarrow Al^{3+}\ (aq) + 3e^-$ ………………………………………………………...... (2)

In typical aqueous conditions and environment of the EC process, iron can dissolve in divalent Fe (II) and trivalent Fe (III) forms, whereas aluminum dissolves only in trivalent form Al (III). Fe (II) can further oxidise to Fe (III) (Eq.3) if oxidation-reduction potential (ORP) and pH conditions are suitable. Oxygen has to be present and pH has to be neutral or alkaline to achieve a reasonable reaction rate (Moreno *et al.,* 2009).

$4Fe^{2+}\ (aq) + O_2\ (g) + 10H_2O\ (l) \rightarrow 4Fe(OH)_3(s) + 8H^+\ (aq)$ .... (3)

The amount of metal cations dissolved during the reactions at the anode can be calculated according to Faraday's law (Eq. 4).

$m = ItM_w/zF$ ………………………………………………………………………. (4)

Where I is the current (measured in amperes), t refers to the operation time (in seconds (s)), M_w refers to the molecular weight of the substance (g/mol), F is Faraday's constant (given as 96485 C/mol), while z refers to the number of electrons involved in the reaction (2 for Fe^{2+} and 3 for Fe^{3+} and Al^{3+}) and m is the quantity (mass) of metal dissolved (g). Several studies have reported current yields higher than 100% for the dissolving of aluminum electrodes (Picard, Cathalifaud-Feuillade, Mazet & Vandensteendam, 2000). It seems that aluminum also dissolves from the cathodes. This occurs when pH on the surface of the cathode decreases as a result of the formation of HO^- as described in Eq. 5 or as a result of the consumption of hydronium ions/protons as demonstrated in (Eq. 6).

$2H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2OH^-\ (aq)$ .... (5)

$2H^+\ (aq) + 2\ e^- \rightarrow H_2\ (g)$ .... (6)

At higher pH, aluminum dissolves as aluminate (Eq. 7)

$2Al\ (s) + 6H_2O + 2HO^-\ (aq) \rightarrow 2[Al\ (OH)_4]^- + 3H_2\ (g)$ …………………………………. (7)

When aluminium ion, aluminate or iron ions are produced on the electrodes they experience hydrolysis or dehydrolysis reactions in the solution. Green rust is formed when iron electrodes are used. Green rust contains both Fe (II) and Fe (III) hydroxides and anions, such as Cl^-, CO_3^{2-} and SO_4^{2-}. Other metal cations, such as Cu (II) and Ni (II), can also substitute Fe (II) in green rust if they exist in the solution (Refait & Genin 1998). In an EC system, green rust and hydrogen are formed according to Eq. 8

$6Fe\ (I) + 12\ H_2O \rightarrow ½\ (12)\ H_2\ (g) + {}^{x}Fe\ (OH)_3.(6 - {}^{x})\ Fe(OH)_2(s)$ ….................................. (8)

In summary, when iron electrodes are used, the reactions occurring during the electrochemical treatment process are as follows:

Reactions in a cathode environment,

$2H_2O\ (l) \rightarrow +2e^-\ H_2\ (g) + 2OH^-\ (aq)$ .... (9)

$8H^+\ (aq) + 8e^- \rightarrow H_2(g)$ .... (10)

Reactions in an anode environment,

$2H_2O\ (l) \rightarrow O_2\ (g) + 4H^+\ (aq) + 4e^-$ .... (11)

$Fe(s) \rightarrow Fe_2\ (aq) + 2e^-$ .... (12)

Due to OH^- ion concentrations increasing near the cathode, the pH of the medium begins rising. Meanwhile, the anode melts and dissolves ferrous ions into solution as shown in the following equation;

$Fe_2\ (aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$ ………….. (13)

$2Fe^{2+}\ (aq) + 1/2\ O_2(g) + 5H_2O(l) \rightarrow 2Fe(OH)_3(s) + 4H^+(aq)$ ....(14)

Overall

$Fe(s) + 2H_2O\ (l) \rightarrow Fe\ (OH)_2 + H_2$ .... (15)

$Al^{3+} + 3H_2O \rightarrow Al\ (OH)_3 + 3H^+$ ……………………....…………………………….……(16)

1.2 Study Objective

The objective of this study was to characterize wastewater from slaughterhouses in Gachororo in terms of COD, BOD_5, total alkalinity, turbidity, and total soluble solids (TSS), and then assess the effectiveness of electrocoagulation in treating slaughterhouse wastewater of these contaminants.

2. Methodology, Experiments and Data Collection

The wastewater used in this study was taken from a slaughterhouse plant located at Gachororo, Juja in Kiambu County, Kenya. The wastewater was sampled two times from the pipe that leads it from the slaughterhouse to the waste tank. The water was then mixed to form the study sample. Samples were collected on two different days each week for a period of four months. The water was immediately stored in a cold box after its temperature was recorded to avoid any changes or biodegradation prior to analysis. It was then transported to the laboratory while still in the ice box and stored in the refrigerator at 4°C.

2.1 Materials

The study used both iron and aluminum as electrode materials in determining the effectiveness of the EC process. Iron and aluminum metals of 1mm thickness were cut into pieces measuring 1cm by 10cm and then connected using a non-reactive and non-conducting material to achieve different surface area as illustrated in Figure 2.1.

2.2 Experimental Set Up

The experiment set up involved a batch reactor consisting of aluminum and iron plates (electrodes) of different surface area which were then connected to a source of power. Three litres of wastewater was used for each run. Sample of wastewater is illustrated in figure 1 while the set up is presented in figures 2 and 3. The electrodes arrangement can be horizontal or vertical. However, this study focused on horizontal arrangement of electrodes and compared performance between aluminum and iron plates. Each horizontal plate measured 1 cm by 10cm with a space of 1cm between the different plates. The study used up to 10 plates (100 cm^2) with iron as electrode material and four plates (40 cm^2) for aluminum.

The data presented was collected after 2 hours at voltage of 25V and current of 0.4A. These were determined after a series of preliminary trials with variations in voltage as well as time.

Figures 4 and 5 illustrate the treatment process with formation of coagulants on top of clean treated water.

Figure 1: Raw wastewater

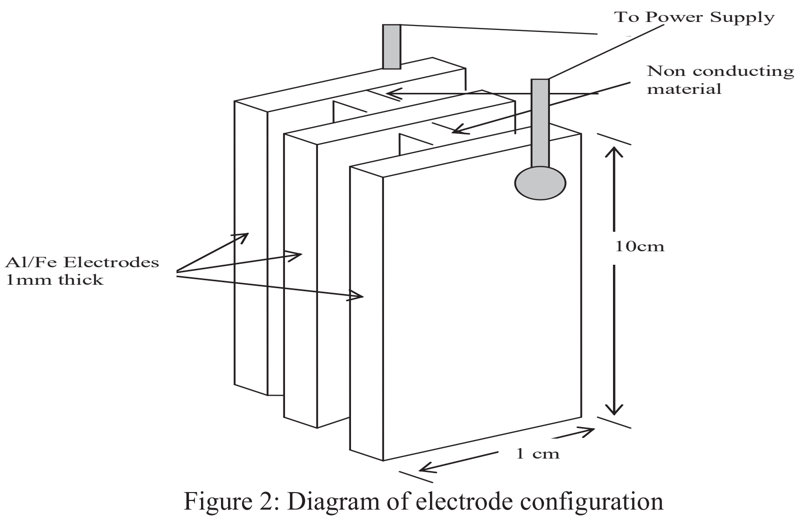

Figure 2: Diagram of electrode configuration

Figure 3: Experimental set-up

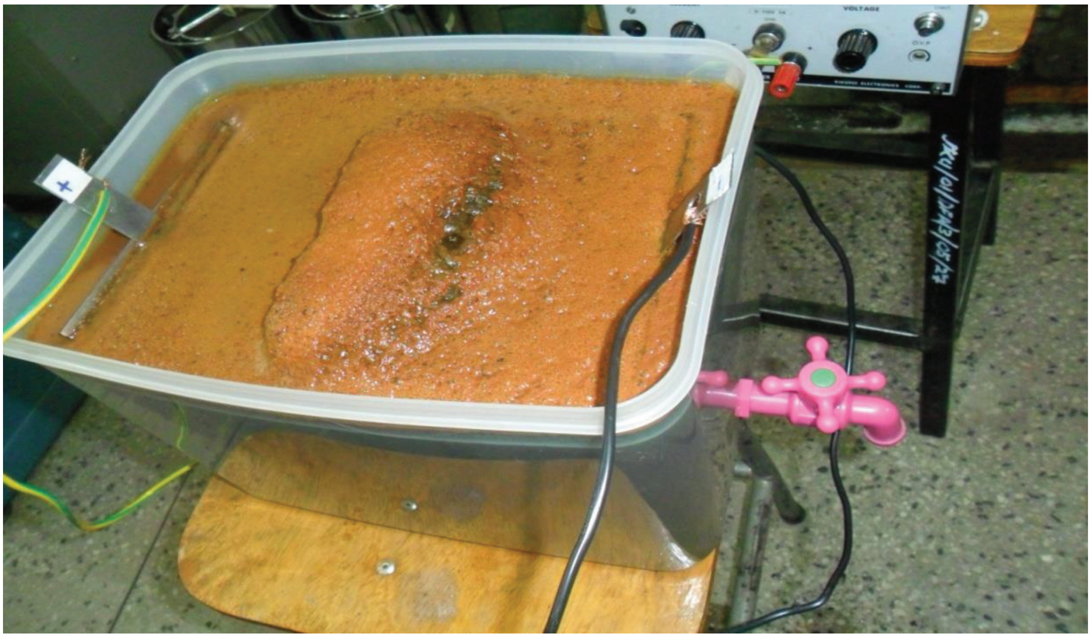

Figure 4: Ongoing Treatment for Iron Plates (with formation of Coagulants)

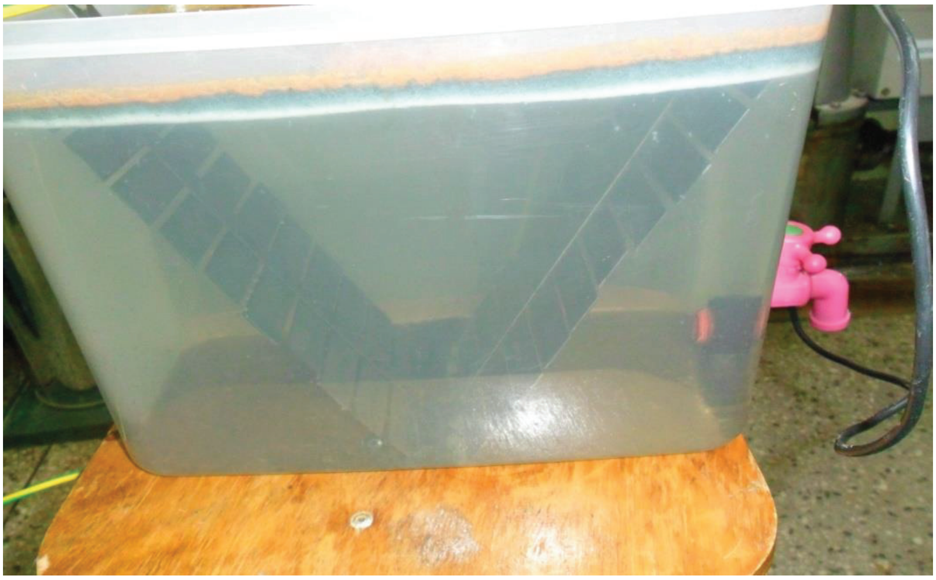

Figure 5: Complete Process with clean water below the coagulants

2.3 Experiments

In order to establish how effective the EC process is, the following water quality parameters were measured before and after treatment: pH, Conductivity, Dissolved oxygen, BOD, alkalinity, COD, turbidity, and TSS.

2.3.1 Dissolved Oxygen (DO)

DO was measured and used in determination of BOD using the standard method described in APHA (1998) manual. Dissolved oxygen was calculated using the formula:

$$DO = \frac{a \times V_1}{V_2} \times \frac{1000}{(V_1 - 2)} \times 0.2 \ldots\ldots\ldots\ldots .1$$

Where;

DO = dissolved oxygen in mg/l
A = volume of titrant used
V_1 = Volume of BOD bottles
V_2 = Volume of sample partly taken from BOD bottle for titration
0.2 = oxygen equivalent of 0.025M sodium thiosulfate solution

2.3.2 Biological Oxygen Demand

This was determined using standard method that uses DO as explained in the APHA (1998) manual.
BOD (mg/l) was then calculated using the following formulae;

$$BOD = \frac{D_1 - D_2}{P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .2$$

Where,

D_1 = DO of the diluted sample immediately after preparation (mg/l)
D_2 = DO of the diluted sample after 5 days of incubation at 20°C for 5 days
P = Decimal volumetric fractions of sample used

P = volume of sample used / volume of dilution water + wastewater……………………. 3

2.3.3 Chemical Oxygen Demand

The standard laboratory method for determining COD was used as described in the APHA manual (1998).
COD was then determined using the formula;

COD = (a-b) N X 8000/V………………………………………………4

Where,

a = volume of ferrous ammonium sulphate used for the blank (ml)
b = volume of ferrous ammonium sulphate used or the sample (ml)
N = volume of sample (ml)
8000 is the multiplier to express COD (mg/l)

2.3.4 Total Suspended Solids (TSS)

TSS of wastewater was determined using the standard method described in the APHA Manual (1998). TSS in mg/l was calculated using the following formulae;

TSS (mg/l) = Wd X 10^6 / V…………………………………………………………………5

Where, Wd = weight of dry content in grams
V = the volume of the sample in ml

2.3.5 Turbidity
Turbidity of the water was determined by use of the Lovibond photometer (in NTU).
2.3.6 Total Alkalinity
Total alkalinity of the raw and treated wastewater was measured by applying the standard titration method as described in the APHA Manual (1998). Total alkalinity was obtained using the formulae;

Alkalinity (mg CaCo₃/L) + A X N X 50,000/Ml Sample…………………………………......... 6

Where;

A = ml standard acid used (V_2)
N = normality of standard acid (0.02N)
Ml sample = volume of sample used (50ml)

2.3.7 PH and Temperature
These were measured using pH meter and thermometer respectively.
The results obtained were analyzed using descriptive statistics, specifically mean values which were then used to plot graphs in excel that were used to provide summary of the findings and to describe trends for each parameter for both iron and aluminum type of electrodes.

3. Results and Discussion
3.1 Characterization of Wastewater from the Slaughterhouse
In order to characterize the wastewater, an average of all the samples used in the analysis (30 samples of water for the iron plates and 12 samples for aluminum plates) was used. There was no much difference in the values for the different sampling dates. Wastewater was found to have the following characteristics in terms of BOD_5, COD, total alkalinity, conductivity, turbidity, TSS and pH before treatment (Table 3.1). Also presented are the recommended limits by WHO and the Kenyan government.

Table1: Characterization of Untreated Slaughterhouse Wastewater and Comparison with Government of Kenya (GoK) and WHO Standards for Treated Water.

PARAMETER	VALUE FOR RAW WASTEATER SAMPLES	WHO STANDARDS	GOVERNMENT OF KENYA STANDARDS
BOD_5 (mg/l)	1278±7.44 mg/l	5	30
COD (mg/l)	1425±14.59 mg/l	5	50
Total Alkalinity (mg/l)	258±76.43 mg/l	200	500
Conductivity (µS/cm)	369± 45.38 µS/cm	EC<500µS/cm	EC<500µS/cm
Turbidity NTU	978±10.30NTU	<1NTU	5NTU
TSS (mg/l)	405±2.61 mg/l	30	30
pH	6.3±0.1	6.5-8.5	6.5-8.5

The findings in Table 1 demonstrate that slaughterhouse wastewaters contain high organic matter presented by the high BOD. This indicates that slaughterhouse wastewater is highly biodegradable. It also indicates that it will be harmful if it is discharged directly into the environment without being treated. According to Budiyono *et al.,* (2011), effluent wastes discharged from slaughterhouses causes deoxygenation of rivers and also contaminate ground water. Slaughterhouse wastewater was also found to contain high concentrations of total solids which included grit, manure, hair, undigested feed, pieces of fat, skin and grease. These insoluble materials contribute to biodegradable organic matter in the wastewater.

It is clear that COD, BOD_5, Turbidity, TSS, Total and Alkalinity of the wastewater from the slaughterhouse were way above the recommended standards while conductivity was found to lie within the recommended range of not more than 500µS/cm. The pH of the water was found to be lower than is required by the standards. Lower pH indicates acidity of the wastewater due to presence of blood (Budiyono *et al*., 2011). Consequently, the slaughterhouse effluent needed to be treated prior to discharge into the environment or before discharge to the receiving water body or used for domestic purposes.

3.2 Effectiveness of Electrocoagulation in Treating Slaughterhouse Wastewaters
Electrocoagulation (EC) experiments were conducted using aluminum and iron electrodes in order to investigate the effectiveness of EC process in removal of BOD_5, COD, TSS, Turbidity, total alkalinity, and conductivity. The surface area of the electrodes was varied from 10 cm^2 to 100 cm^2 and the voltage from 0 to 25V to determine the optimum surface area for each type of electrode and voltage for pollutants removal. The results obtained on performance of the EC process in treating the wastewater using iron and aluminum electrodes for each parameter are presented figures below.

3.2.1 Effectiveness of Electrocoagulation in reducing BOD in Slaughterhouse Wastewater

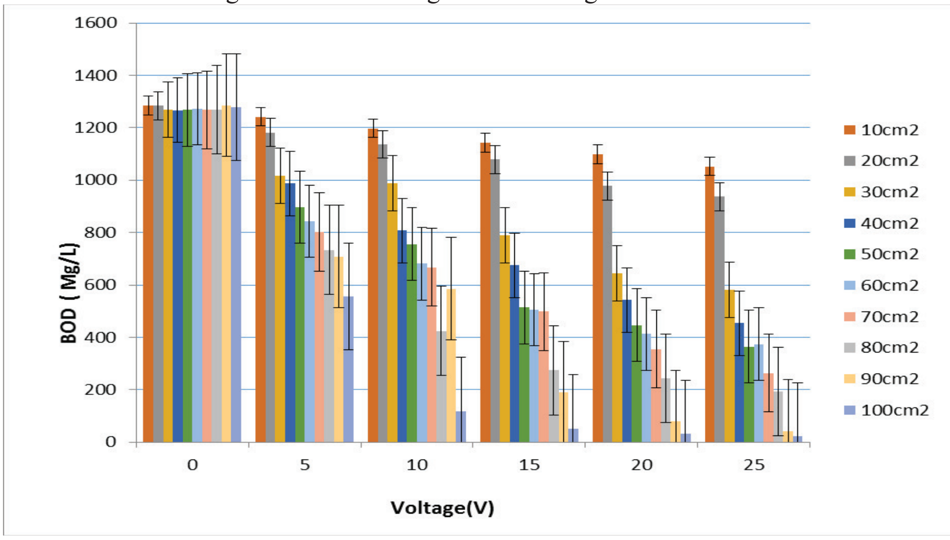

Figure 6: Graph of BOD against Voltage for the different surface area of Iron electrodes after 2 hours

Figure 6 shows graph of BOD concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

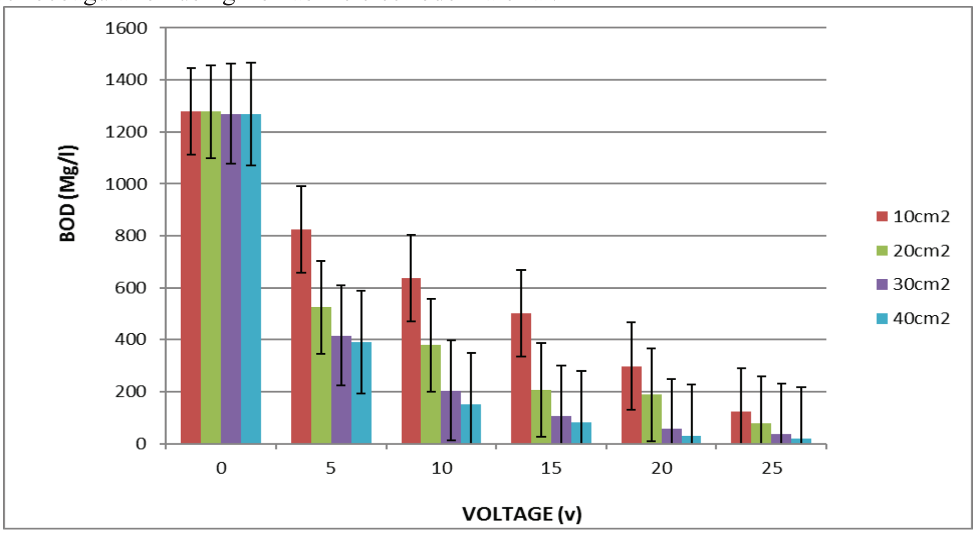

Figure 7: Graph of BOD against Voltage for the different surface area of Aluminium electrodes after 2 hours

Figure 7 shows graph of BOD concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

Figures 6 and 7 indicate decrease in BOD concentration in the slaughterhouse wastewater with increasing surface area and with increase in voltage. The results demonstrate that the decrease was sharper when aluminum electrodes were used than when iron electrodes were used for the same surface area as well as voltage.

When iron was used as the electrode material, the recommended BOD_5 level was achieved after two hours at surface area of 100cm^2 and 25V. At this point, BOD_5 was reduced to 23.2mg/l which is within the recommended GoK standards of 30mg/l. When aluminum was used for electrodes, the recommended GoK standard for BOD_5 of 30mg/l was reached at surface area of 30cm^2 and 20V. The optimum surface area and voltage for aluminum electrodes were found to be 40cm^2 and 25V respectively after two hours of treatment. At this point, BOD_5 of 20.78mg/l was achieved. The results indicate that electrocoagulation is effective in reducing BOD_5 in slaughterhouse wastewaters to levels that lie within the recommended standards. These findings are similar to those by previous studies including Bayar *et al*., (2011), Tezcan *et al*., (2009) and Asselin *et al*., (2008). It was also demonstrated that Al performs significantly better than Fe for the same surface area as well as voltage in treating wastewater of BOD through EC.

3.2.2 Effectiveness of Electrocoagulation in reducing COD in Slaughterhouse Wastewater

The results obtained when effectiveness of EC in treating slaughterhouse wastewater of COD was examined are presented in figures 8 and 9 below;

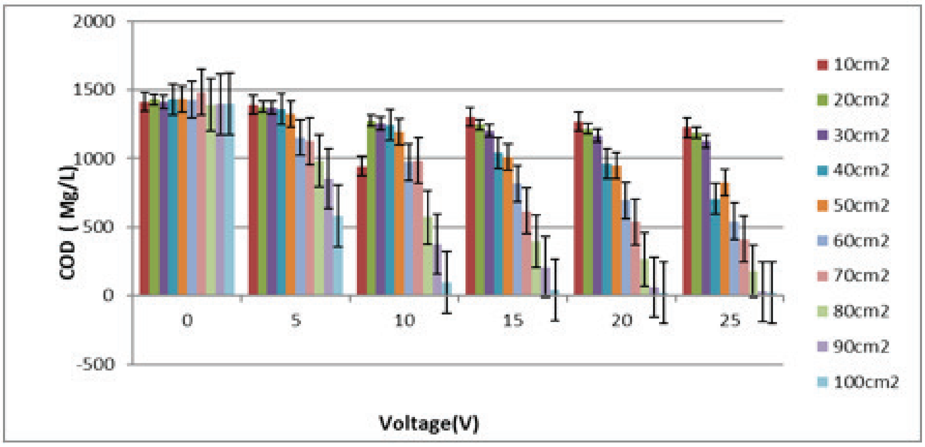

Figure 8: Graph of COD against Voltage for the different surface area of Iron electrodes after 2 hours

Figure 8 shows graph of COD concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

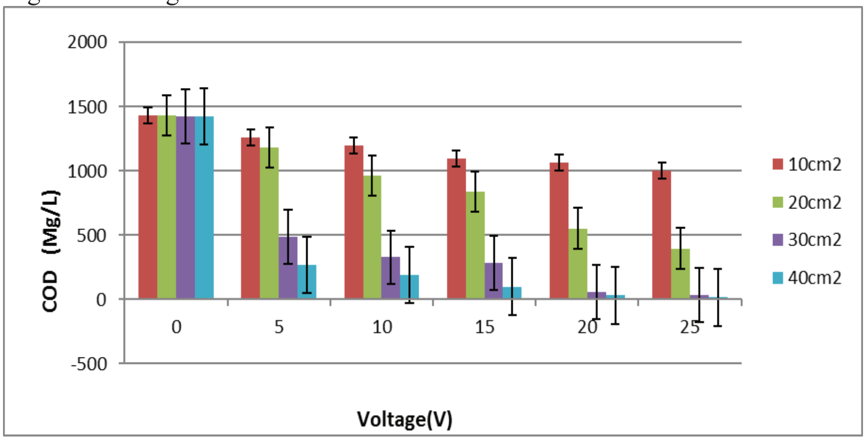

Figure 9: Graph of COD against Voltage for different surface area of Aluminum electrodes after 2 hours

Figure 9 shows graph of COD concentration plotted against voltage when wastewater was being treated through electrocoagulation using aluminum as the electrode material.

Higher levels of chemical oxygen demand (COD) were recorded for the raw wastewater from the slaughterhouse. This is undesirable since continuous discharge of untreated effluent has impacted the receiving water body to some extent and this may have negative effects on the quality of the freshwater and subsequently cause harm to the aquatic life especially fish, downstream (Kanu & Achi 2011).

Figures 8 and 9 indicate that there was decrease in COD concentration in the slaughterhouse wastewater with increasing surface area as well as voltage. The results however demonstrate that the decrease was sharper when aluminum electrodes were used compared to iron electrodes for the same surface area and same voltage. According to the findings, when iron electrodes were used, the recommended Government of Kenya (GoK) standards of maximum 50ml/g was reached at surface area of 90cm^2 and 25V (30mg/l). Further decrease of COD was observed at 100cm^2 and 25V giving a COD value of 18.67mg/l. 90cm^2 and 25V were found to be the optimum surface area and voltage for BOD removal using iron electrodes. When aluminum was used for electrodes, the recommended GOK standards for COD (50mg/l) were attained at a much smaller surface area of 30cm^2 and 25V. COD value of 16.33 mg/l was achieved at surface area of 40cm^2 and 25V.

The results demonstrate that electrocoagulation is very effective in reducing COD in slaughterhouse wastewaters to levels that lie within the recommended standards. These findings are similar to those found by previous studies including Eryuruk *et al*. (2011), Tezcan *et al*., (2009), and Asselin *et al*., (2008) who found that electrocoagulation was 98% effective in treating slaughterhouse wastewaters of COD. The results also show Al to be a better electrode material as it performed significantly better than Fe for the same surface area as well as voltage in removing COD.

3.2.3 Effectiveness of Electrocoagulation in reducing Total Alkalinity

Results of effectiveness of EC in treating wastewater from slaughterhouses of total alkalinity are presented in figures 10 and 11 below,

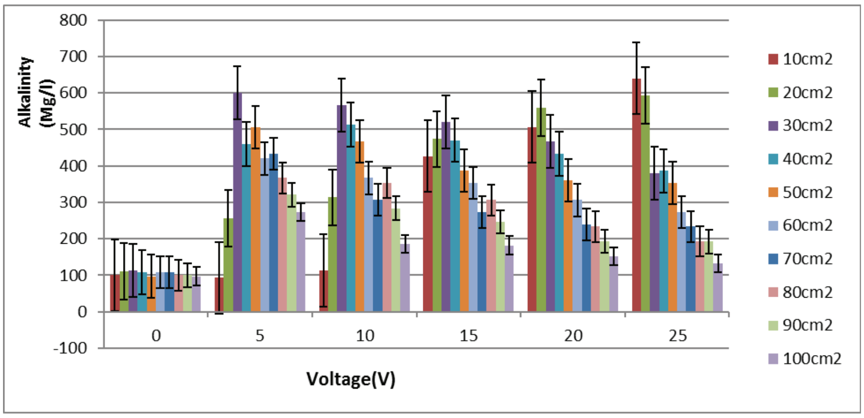

Figure 10: Graph of Total Alkalinity against Voltage for different surface area of Iron Electrodes after 2 hours

Figure 10 shows graph of total alkalinity concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

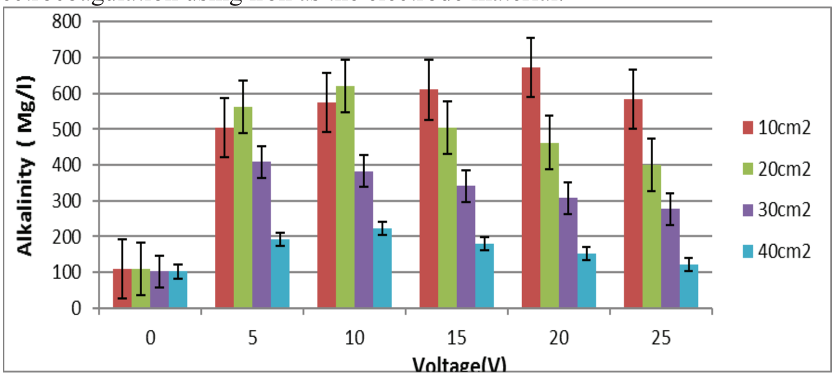

Figure 11: Graph of Total Alkalinity against Voltage for different surface area of Aluminum electrodes after 2 hours

Figure 11 shows graph of total alkalinity concentration plotted against voltage when wastewater was being treated through electrocoagulation using aluminum as the electrode material.

Results presented in figures 10 and 11 above demonstrate that there was an initial increase in Total Alkalinity of the wastewater with increase in voltage and surface which later decreased. Previous studies on EC as a method for treating wastewater have not considered total alkalinity as a parameter. However, Wang *et al.* (2010) also discovered that there was a relationship between an increase of pH and alkalinity with increase in temperature, and electrolysis time. These authors found that increase in pH and temperature increased total alkalinity in the present study, the initial increase in total alkalinity is attributed to increased OH^- ions in the wastewater due to action of current on the Al and Fe electrodes before formation of coagulants. Formation of CO_3^- ions due to presence of organic matter in the wastewater is also a possible explanation.

Figures 10 and 11 demonstrate unusual pattern in the values of total alkalinity as the experiments proceeded. The Total alkalinity values fluctuated throughout the experimental period, though relatively satisfactory values were observed throughout the follow-up process. In Figure 7 which presents results obtained with iron electrodes, there was an initial increase in Total Alkalinity of the wastewater at surface area of 10cm^2 as the experiment began at 5V. These values however decrease gradually with increase in surface area and voltage until at surface area of 100cm^2 and 25v where a value of 136mg/l which is within the standards was attained. Figure 8 also demonstrates a similar pattern whereby there was an initial sharp increase in total alkalinity at surface areas of 10cm^2 and 20cm^2 at low voltages. These values however decrease sharply as surface and voltage is increased until a value of 120.67mg/l which is within the accepted GoK standard values was achieved at 40cm^2 and 25V.

The initial increase is attributed to increased OH^- ions in the wastewater due to action of current on the electrodes before formation of coagulants. Higher dissociation constants force a higher concentration of bicarbonate and carbonate to be present for a given concentration of carbonic acid. Hence, they result in a higher alkalinity as explained by Rajakumar *et al.,* (2012). As pH increases, the rate of hardness and total alkalinity removal also increase as the effect of pH on coagulants depends on the produced reactions on different conditions (Malakootian & Yousefi, 2009). Evidenced literature demonstrates that there is strong correlation between alkalinity and partial acid build-up with the composition of the wastewater. Protein-rich effluents, such as those from slaughterhouses, the acids accumulate in the same proportion, but pH and total alkalinity tend to increase due, probably, to the formation of ammonia during anaerobic degradation of proteins (Rajakumar *et al*., 2012).
The findings indicate that electrocoagulation process is effective in treating total alkalinity in slaughterhouse

wastewater to the recommended levels of 130-200mg/l. These findings are similar to those found by Malakootian and Yousefi (2009) who found electrocoagulation to be effective in removal of alkalinity and harness from water. They also demonstrate that that Al performed significantly better than Fe for the same surface area as well as voltage in treating wastewater of total alkalinity hence is a better electrode than Iron.

3.2.4 Effectiveness of Electrocoagulation in reducing total soluble solids (TSS)

The results obtained when effectiveness of EC in reducing TSS in slaughterhouse wastewater was examined are presented in figures 12 and 13 below:

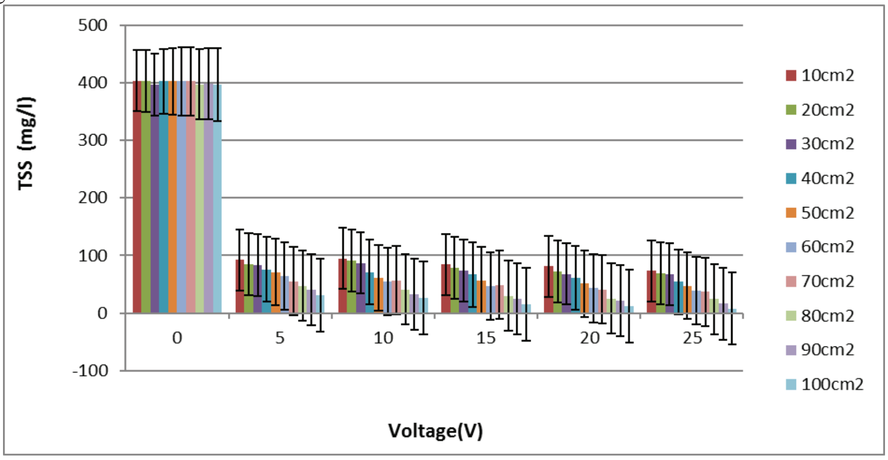

Figure 12: Graph of Total Soluble Solids against Voltage for different surface area of Iron electrodes after 2 hours

Figure 12 shows graph of total soluble solids concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

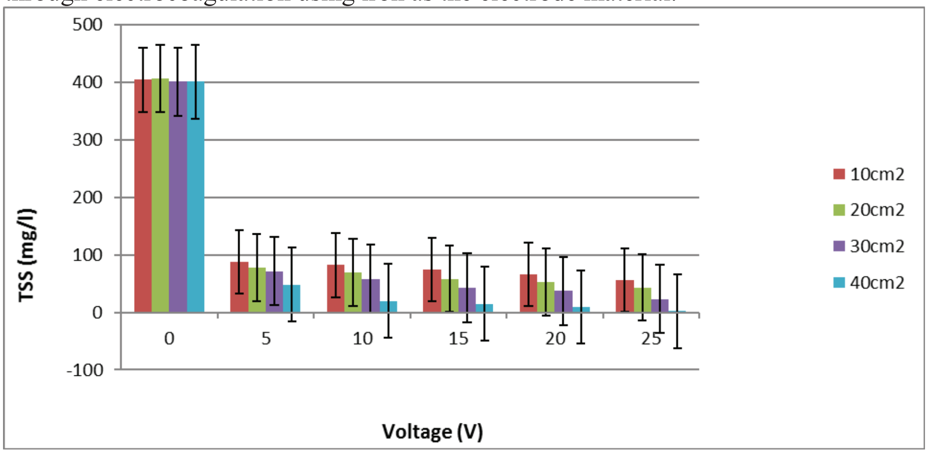

Figure 13: Graph of Total Soluble Solids against Voltage for different surface area of Aluminum electrodes after 2 hours

Figure 13 shows graph of total soluble solids concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

Untreated wastewater was found to have high concentration of TSS (406mg/l). Treatment of the wastewater through EC using Al and Fe electrodes however reduced the TSS concentration and even surpassed the recommended GoK standards. The graphs in Figure 12 demonstrate that when Iron was used as electrode material, there was a very sharp decrease in TSS in the wastewater with increase in surface area of the electrode as well as with voltage from the initial value of 405 mg/l. Increase in voltage and surface area increased the process. The recommended GoK standards of 30mg/l was reached at surface area of 80m^2 (8 plates) and 15v when Iron was used as electrode material. TSS value of 6.0 mg/l was achieved at surface area of 100m^2 (10 plates) and 25v.

Figure 13 indicates that when aluminum was used as electrode material, there was also a very sharp decrease in amount of TSS in the wastewater. The concentration of TSS decreased as the aluminum electrode surface area was increased as well as with increase in voltage. The observed decrease with aluminum electrodes was much sharper than that observed when Iron electrodes were used. The recommended Government of Kenya standard of 30mg/l was reached at surface area of 30cm^2 (3 plates) and 25v when Al was used as the electrode material. TSS of 2mg/l was achieved at 40cm^2 and 25v, implying an efficiency level of almost 100 percent as the TSS was almost completely removed.

These findings are consistent with those established by Bazrafshan *et al.,* (2012) who conducted an investigation of treatment of slaughterhouse wastewater using combined chemical coagulation and electrocoagulation process. Removal efficiency of 65% was registered in this study. Asselin *et al*., (2008) also found that TSS was removed at 89% using the EC method.

The results also indicate that Al performed significantly better than Fe for the same surface area as well as voltage in removing TSS hence is a better electrode than Iron.

3.2.5 Effectiveness of Electrocoagulation in reducing Turbidity in Slaughterhouse Wastewater

When examination of effectiveness of EC in reducing TSS in slaughterhouse wastewater was examined using Iron and aluminum electrodes, the results obtained are as are presented in tables 14 and 15 below;

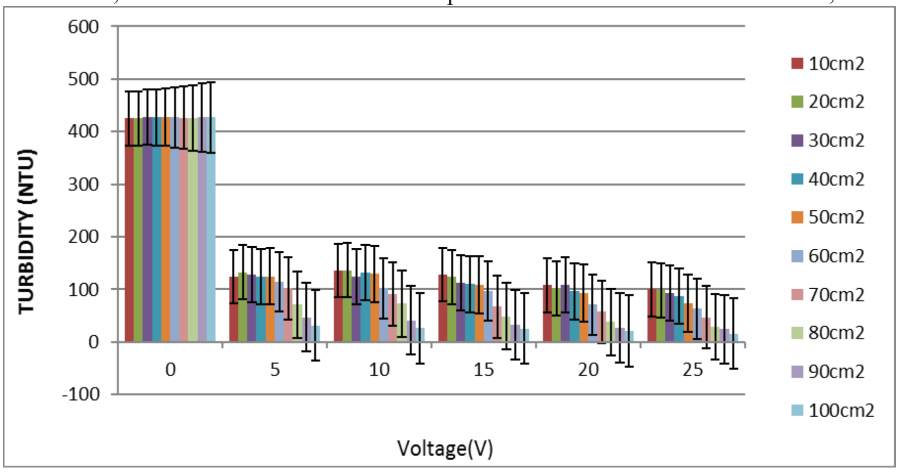

Figure 14: Graph of Turbidity against Voltage for Different Surface Area of Iron electrodes after 2 Hours

Figure 14 shows graph of total soluble solids concentration plotted against voltage when wastewater was being treated through electrocoagulation using iron as the electrode material.

The results presented in Figure 14 demonstrate that when Iron was used as electrode material, there was a sharp decrease in the wastewater's turbidity from the initial value of 978 NTU. Turbidity was observed to decrease sharply with increase in surface area of the iron electrodes as well as with increase in voltage. As electrical potential increased so did the EC process hence increasing removal efficiency.

The water became very clear at surface area of 90 cm^2 (9 plates) and 25V giving a turbidity level of 30 NTU. At surface area of 100cm^2 and 25V Turbidity of 13 NTU was achieved. This value is within the acceptable limits of 5-15 NTU required by both Government of Kenya and WHO standards for domestic water.

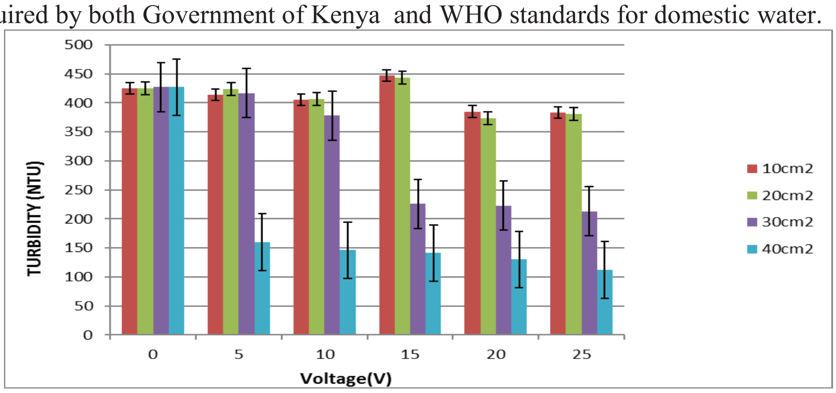

Figure 15: Graph of Turbidity against Voltage for different surface area of Aluminum Electrodes after 2 hours

Figure 15 shows graph of total soluble solids concentration plotted against voltage when wastewater was being treated through electrocoagulation using aluminum as the electrode material.

Figure 15 indicates that when Aluminum was used as electrode material, there was a very sharp decrease in Turbidity in the wastewater with increase in surface area as well as current. The decrease observed was much sharper than that observed with Iron electrodes of same surface area and at same voltage. The water became very clear at surface area of 20 cm^2 and 25V giving a turbidity 20.67 NTU. Turbidity of 2 NTU was achieved at surface area of 40cm^2 and 25V. This value meets WHO standards which recommend a maximum value of 15 NTU.

The turbidity profile varied significantly amongst different surface areas and voltage/current for both Al and Fe electrodes throughout the study. The turbidity values obtained from the sampling points was higher than the recommended WHO standard of 15 NTU. The values obtained using Aluminum of surface area of 40cm^2 and Iron of surface area of 100cm^2 at 25v however qualify the treated water for direct domestic use as they lie within the recommended WHO standards. The results also indicate that Al performed significantly better than Fe for the same surface area as well as current in treating the water of turbidity hence is a better electrode than Iron.

Kuokkanen *et al*., (2013) explain that turbidity in water is as a result of presence of suspended matter, in this case, clay, finely divided organic and inorganic matter, silt and other microscopic organisms. Very high removal efficiencies were achieved rapidly for both iron and aluminum electrodes and at low current just as was observed in the study conducted by Kuokkanen *et al.,* (2013). Electrocoagulation has been found to remove turbidity up to 99% with low energy consumption as demonstrated by Terrazas *et al.,* (2010) and, Kuokkanen *et al*., (2013). The findings of the current study are therefore consistent with those from other studies on EC and removal of turbidity from wastewater. The decrease in turbidity values of demonstrates that EC is effective in treating slaughterhouse wastewaters of suspended solids (SS).

4. Deductions made from the Results

The results demonstrate that electrocoagulation process removes suspended solids, turbidity, conductivity COD and BOD from slaughterhouse waste waters to the required Government of Kenya as well as WHO standards for treated water.

It was also established that efficiency of EC method increases with increase in surface area of the electrodes used as well as with increase in voltage/current.

Aluminum was found to perform better at the same voltage and surface area compared with Iron as the standard values for all the parameters being tested were achieved at surface area of 40 cm^2 (four plates) whereas it took nine plates (surface area of 90 cm^2) for the standard values for all the parameters to be achieved with Iron electrodes. The optimum surface area for iron electrodes is 90 cm^2 (9 plates each measuring 10x1cm) while that for Aluminum is 40 cm^2 (4 plates each measuring 4x1cm). The optimum voltage is 25V for both materials for BOD and COD and 15V for Turbidity, total alkalinity and TSS.

It was also noted that there was an initial increase in total alkalinity at start of treatment because of release of hydroxides into the water. This however decreases at optimum surface area and voltage to the standard value which is between 150 and 200 mg/l.

5. Conclusion and Recommendations

5.1 Conclusion

Based on the findings of the experiments, this study concludes the following;

1. Electrocoagulation is very effective in treating slaughterhouse wastewaters at optimum voltage and surface area of electrode. The treated water can be recovered and be re-used for domestic use such as cleaning and farming. It will however require further treatment for it to be used for drinking.
2. Water treated using elctrocoagulation method meets Government of Kenya standards as all the parameters were found to meet and exceed the Government of Kenya standards
3. Reduction of the tested parameters to the required standards for treated wastewater imply that at the optimal point with regard surface area, power and time, the water will be safe enough to discharge to the nearest watercourse or for reuse without causing serious disturbance to the environment.
4. These results are indicators of a satisfactory performance of the electrocoagulation method of treating wastewater.
5. No chemicals were used and since natural sources of energy such as solar or wind can be used to supply power, it can strongly be argued that electrocoagulation is an efficient and environmentally friendly process of treating water that can be adapted by both small and large institutions.

In summary, Electrocoagulation using iron and Aluminum as electrodes is a safe, reliable, convenient and efficient route for removal of COD, BOD, TSS, Turbidity, and total alkalinity from slaughterhouse wastewaters.

5.2 Recommendations

This study recommends the following;

1. Further research into which arrangement (vertical or horizontal) of electrodes is best
2. Investigation of other metals or material that may be more effective and environmentally friendly as electrodes than aluminum or Iron
3. Further inquiry into the process through which electro-coagulation reduces total alkalinity of wastewater.
4. Use of solar or wind as sources of energy in the electrocoagulation process.

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