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ELECTROCOAGULATION/FLOTATION TREATMENT OF SYNTHETIC SURFACE WATER

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Bachelor of Science in Chemical Engineering

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ELECTROCOAGULATION/FLOTATION [ECF] TREATMENT OF SYNTHETIC SURFACE WATER

SAMPATH GUNUKULA

ABSTRACT

Rainfall generated surface runoff water could contaminate groundwater through transportation of suspended solids and organic matter in to the aquifer. Surface runoff water composition mainly depends on soil amendment. Surface runoff mainly contains clay, minerals, organic and inorganic matter, total dissolved lead, zinc. ECF technology presents an alternative for the removal of total suspended solids, turbidity, and organic matter from generated surface runoff water. This research presents development of bench scale ECF unit for the treatment of synthetic surface water. Experiments were conducted in a 10 liter Plexiglas unit provided with two aluminum electrodes, one serving as cathode, and other as anode. Direct current was applied to the electrodes by an external power supply. Optimal operational parameters were varied depends up on strength of the surface water. For low strength synthetic surface water the optimal operational variables were determined as an applied current of I = 2 ampere and a treatment time of 30 minutes. The overall turbidity removal efficiency was found to be 80 % and % transmittance was found 94.1 % under such conditions. For medium strength synthetic water the optimal operational variables were determined as an applied current of I = 3 ampere and a treatment time of 30 minutes. The overall turbidity removal efficiency was found 70 % and % transmittance was found 93 % under such conditions. Further experimentation was carried out on the determination combined maximum organic matter

and turbidity removal efficiencies. Effect of chemical coagulants lime, aluminum sulfate octa decahydrate and ferric sulfate in ECF treatment was investigated.
Key words: ECF reactor, total suspended solids, turbidity, organic matter, % transmittance, chemical coagulants.

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CHAPTER I

INTRODUCTION

1.1 Introduction

In 1889 England proposed treatment of water using electricity. In 1909 the United States applied Electro coagulation (EC) using Iron and aluminum electrodes to treat drinking water on a larger scale. EC was a promising technology in the early 19th century but it disappeared in 1930s because of its high capital investment and maintenance cost .[10] However its simplicity, efficiency, environmental compatibility, safety, selectivity, flexibility, reduction of sludge generation, minimization of the addition of chemicals, short residence time made Electrochemical technology is more important from 1990s. [14]. Current density, electrolysis time, current efficiency are the most important parameters used in electro chemical technology for controlling the reaction rate. Current density is defined as current per area of a electrode which determines rate of a process, units of current density are mA/m^2. Ratio of current consumed by electrode in producing ions to the total current consumption is ascertained as current efficiency. [10] Time required to dissolute electrode in to ions is defined as electrolysis time, and its unit is time. [11] Before going to discuss about Electrocoagulation flotation process [ECF]

two terms should be defined. First electro coagulation is defined as insitu formation of coagulants by dissolving electrically metal electrodes; next electro flotation is a process that floats pollutant to the surface of a water body by tiny bubbles of hydrogen and oxygen gases generated from electrolysis. The main objectives of this research were to determine the optimal operational parameters associated with a bench scale ECF unit used for the treatment of synthetic surface water containing variable initial turbidity concentrations of clay and to observe the effect that TOC loads might have upon treatment efficiency.

1.2 Objectives of the study

The purpose of the thesis is to investigate the suitability of Electrocoagulation/flotation technology for the treatment of synthetic surface water containing total suspended solids, and to observe the influence that variable TOC loads, lime, aluminum sulfate octa decahydrate and ferric sulfate upon the treatment process. Primary objective of this work was to determine TOC removal efficiency for various organic loads.

- The thesis will address selection of operational parameters in the treatment of low, medium, and high strength synthetic surface water by Electrocoagulation/flotation reactor.
- This thesis will investigate the effect of different chemical coagulants on treatment efficiency upon addition to the Electrocoagulation/flotation reactor.
- Analyze removal efficiency based on the strength of synthetic surface water and based on various current inputs to the reactor.

CHAPTER II

LITERATURE REVIEW

2.1 The Electro coagulation/Flotation [ECF] process

2.1.1 Definition of a process

Electrocoagulation/flotation [ECF] is the process of destabilizing suspended emulsified or dissolved contaminants in an aqueous medium by introducing an electric current in to the medium [1]. ECF process treats wastewater containing soluble or colloidal pollutants; it also treats drinking water to reduce fluoride and lead concentrations. ECF reactor contains two electrodes anode and cathode known as sacrificial electrodes. In ECF process direct current is applied to the electrodes in a reactor containing water. The produced current breaks water molecules in to hydrogen and oxygen gases as shown in equation 1:

$2H_2O \leftrightarrow 2H_2 + O_2$ …….. (1)

Anode: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ ……... (2)

Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH$…… (3)

Moles of oxygen and hydrogen depend up on total metal concentration, pH, and amount of other species present in the solution. We can see within the above reaction through the cathode where hydrogen gas is evolved and through the anode where oxygen gas is evolved. If the anode is made up with metal having lower oxidation potential than water, it produces metal ions. Produced metal ions will react with hydroxyl ions and produce metal hydroxides, oxyhydroxides and polymeric hydroxides. [2, 3]

The following reactions occur in the ECF reactor when anode is made up with a metal the aluminum (Al), following reactions occur in the ECF process.

Anode:

$Al \rightarrow Al_3^+ + 3e^-$…….. (4)

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ …… (5)

In solution:

$Al_3+ + 3H_2O \leftrightarrow Al(OH)_3 + 3H^+$ …… (6)

Cathode:

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ …….. (7)

Charged Aluminum hydroxides bond together with the pollutants and forms a mass also called as sludge. Produced sludge could be removed by sedimentation, filtration or floats to the surface by cathode generated hydrogen and anode generated oxygen. In ECF it is hard to remove pollutants which undergo direct electrolysis and form oxidation

compounds. [3, 4] ECF process used to treat municipal solid waste leachate [5], decolorization and COD reduction of paper effluent [6], refectory oily wastewater [7], reactive textile dyes and textile wastewater [8], removal of sulfide, sulfate, sulfite ions [9], removal of hardness of water [10], treatment of baker's yeast wastewater [11] and removal of heavy metals from water [12].

2.1.2 Mechanisms involved in the ECF process

The mechanism of ECF depends up on pH, electrical conductivity, and chemistry of aqueous medium and chemical constituent. The ECF process occurs in three steps. First, electro oxidation of electrodes produces coagulants. Next, bubbles are generated from anode and cathode and the pollutants have been stabilized. In the last step stabilized pollutants agglomerated with each other forming flocs that float to the top by the bubbles [13].

To summarize, a diffused double layer is compressed by the interactions of ions produced by the anode oxidation. [14] Counter ions produced by electrochemical dissolution of anode neutralize the charge on the pollutants in the wastewater. "These counter ions reduce the electrostatic inter particle repulsion to the extent that the van der Waals attraction predominates, thus causing coagulation. A zero net charge results in the process." [14] For floc formation: coagulation forms floc, creating a sludge blanket that entraps colloidal particles left in the wastewater. [14]

2.2 Factors effecting ECF process

2.2.1 Type of Electrode

The majority of ECF studies use aluminum and Iron electrodes were employed to treat wastewater in ECF reactor. Dissolution of aluminum electrode depends upon electrolysis

time, current density, pH of wastewater. The relationship between amount of aluminum produced to electrolysis time and current could be explained from Faraday's law. Faraday's law relates the theoretical amount of aluminum or Iron ions (M) and hydroxyl ions generated in the reactor to the current flow (I in time t)[13]

$$m = ItM/n*F \quad (8)$$

Where n is the number of electrons transferred in the reaction at the electrode, M is the molecular weight of electrode metal, I is current flow and F is faraday's constant (96,486 C/mol)

According to Faraday's law amount of aluminum goes into solution is

$$C_{AL(T)} = ItM_{(AL)}/ZFV \quad (9)$$

Where $C_{AL(T)}$, *Z*, *F*, *V*, and *M*(Al) are the theoretical concentration of Al3+ (g/m3), aluminum valance, Faraday constant (96,500 C/mol), volume of electro box (m3), and the molecular weight of aluminum (g/mol), respectively.[15]

Aluminium electrode dissolute into various forms of ions based on pH of the aqueous medium. Produced ions provide active surface for the adsorption of pollutants [4, 14]. At a pH of 2.0 to 3.0 dissolution of aluminum electrode forms Al^{3+} and $Al(OH)^{2+}$. $Al_{13}O_4(OH)_{24}^{7+}$[polymeric, form of aluminum] was formed and precipitated as $Al(OH)_3$ [an amorphous form of aluminum] at a pH of 4- 9. The predominant chemical species [$Al(OH)^{4-}$] formed at pH 10.0. An amorphous form of aluminum adsorbs organic compounds, colloidal particles, and salts more quickly due to of its high superficial area. COD removal efficiency is same for both aluminum and Iron electrodes. [4]

$$Al + 3H^+ \rightarrow Al_3^+ \quad pH = 2 \text{ to } 3 \quad (10)$$

$$Al_3^+ + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \quad pH = 4 \text{ to } 9 \quad (11)$$

$Al(OH)_3 + OH^- \rightarrow Al(OH)^-$ (12) pH = 10…….. (12)

In EC using Iron electrode experiments prevailing flake $Fe(OH)_2^+$ formed at a pH of 6.0 and $Fe(OH)_3$ formed at a pH of 8.0. Because of their low solubility in water and high aggregation tendency leads to organic and inorganic materials of the effluent to coagulate. EC using Iron electrodes forms turbid solutions Fe (II) ions present in the solution oxidized to Fe (III) ions by dissolving oxygen. Iron electrodes should be cleaned thoroughly to avoid corrosion. [16]

2.2.2 Current Density and Charge loading

Current density in ECF reactor affects coagulant production, the velocity and quantity of hydrogen bubbles formation. [4] The amount of Al^{3+} and Fe^{2+} ions produced from respective electrodes depends upon applied current to the ECF system. For a given voltage large current is produced in an ECF reactor having smaller area, as compared to a reactor having a larger area. If produced current is too large then there is a chance of wasting electrical energy to increase the temperature of water, thus in a small reactor as the current density increases there is a significant decrease in current efficiency. When operating an ECF reactor for a long time, one needs to maintain a current density in the reactor between 20 to 25 A/m^2. The size of gas bubbles are also influenced by current density, as a decrease of bubble size resulted with an increase of current density. Hydrophobicity, pH, temperature as well as flow rate will affect the selection of current density. Pollutant removal from wastewater depends up on amount of ions produced. [17]

2.2.3 Arrangement of Electrodes

Electrodes may be arranged either in mono polar or bipolar. In monopolar mode, a conductive plate introduced in between electrodes and it is either connected to other

electrodes or to the DC source. Monopolar electrodes may be connected in series or parallel.

"A conductive plate is placed in between two electrodes having opposite charges**.** In bipolar mode, a conductive plate is neither connected to other electrodes nor to the DC power supply. However, without any electrical connection, the two neutral sides of the plate transform to charged sides which have an opposite charge compared to the parallel beside the electrode**.** This plate is commonly called the bipolar electrode." Arrangement of conductive plate may be in series or parallel. Negligible drop in electrode potential and more efficient distribution made bipolar electrode most suitable for the treatment of industrial wastewater. [18] In the bipolar electrolysis turbidity removal is optimum at a pH of 5 to 9 and turbidity removal drops dramatically at a pH >4 and pH < 9. [19]

2.2.4 Presence of Sodium Chloride

Sodium chloride (NaCl) increases the conductivity of wastewater by decreasing its internal resistance. Salt is the best electrolyte because of its high efficiency and low environmental impact. NaCl on electrolysis forms chloride ions, but applied voltage in ECF reactor is not enough to produce large amount of chloride ions. [4] Small amount of chloride ions (Cl^-) decreases adverse affect of anions HCO_3^-, sulfate (SO_4^{2-}) present in the solution which reacts with carbonate (Ca^{2+}), or magnesium (Mg^{2+}) ions, forms Aluminium sulfate octadecahydrate (provide the empirical formula) sieve layer, and reduces efficiency of electrode. Therefore, the presence of sodium chloride hinders the formation of Aluminium sulfate octadecahydrate sieve layer.

2.2.5 pH effect

Coagulation is strongly depends on the pH of a solution [20]. Water or wastewater pH effects current efficiency, solubility of metal hydroxides, and chloride ions present in the solution. The amount of aluminum ions are highly produced at acidic and basic conditions than at neutral conditions. Due to the variation of conductivity, power consumption is high at neutral pH. The effluent pH would increase for an acidic influent and decrease at an alkaline influent after treatment of wastewater through ECF reactor. The evolution of hydrogen at the cathode results in an increase of pH and the production of oxygen at the anode results in a decrease of pH [17, 21]. At the end of the treatment, pH of the aqueous medium tends to neutralized. This phenomenon could be explained by the following reactions:

$Al + 3H^{+} \rightarrow (Al^{+3})$…… (13)

$Al_3^{+} + 3H_2O \rightarrow Al\,(OH)_3 + 3H^{+}$……. (14)

$Al\,(OH)_3 + OH^{-} \rightarrow Al\,(OH)^{-}$ ……. (15)

$HCO_3^{-} + OH^{-} \rightarrow CO_2^{-} + H_2O$ ……. ……. (16)

$Ca2^{+} + CO32^{-} \rightarrow CaCO_3$……. ……. (17)

$Mg_2^{+} + CO_2^{-} \rightarrow MgCO_3$…… (18)

As shown in above reactions ECF process generates H_2 and O_2 gas bubbles which help to produce CO_2 from the wastewater. Production of CO_2 and consumption of H^{+} ions by the dissolution of Al electrode causes increase in pH of the solution. At a high pH condition, the precipitation of calcium and magnesium will take place (reactions 17 to 18), which

reduces the pH of the aqueous medium.[19] Sodium carbonate or hydrochloric acid could be added to maintain pH of the solution.[15] Precipitation of carbonate and sulfate ions forms insulating layer on the electrode surface, decreases current efficiency. At an alternative current, sodium chloride is used to remove insulating layer [4, 16].

2.2.6 Effect of bubble size

In an ECF reactor, bubbles are produced through electrolysis by means of helping mechanical agitation and the complete mixing of liquid solution. These processes help to float the aggregated particles by reducing their relative density. Decrease in the size of a bubble increases its interfacial area, overall improving the removal efficiency of pollutant. The size of a bubble depends upon pH, length of electrode, and the current density**.** Hydrogen (H_2) bubble size is smallest at neutral pH than acidic and basic conditions. Increasing in current density increases the generation of bubbles and decreases the size of a bubble. A typical size of a hydrogen bubble ranges between 20 to 70 micro meters. [22]

2.2.7 Effect of HRT on ECF reactor

Hydraulic retention time (HRT) is defined as the ratio of the total volume of the electrochemical reactor to wastewater flow rate. [10] ECF reactor performance was assessed by pollutant removal efficiency and current consumption [23].

There are two ways in which colloidal removal is affected—the transfer time required for the colloidal particle to reach anode surface and the time required for actual coagulation occurs. Transfer time is negligible compared to the rate of actual coagulation. [24] As the current density increases residence time will decreases on the other hand energy consumption would increase. [25]

2.2.8 Typical design of ECF reactor

To get the maximum efficiency from the ECF reactor, one needs to deal with following factors

Internal resistance (IR) drop between electrodes, the mass transfer between electrodes, and elimination of insulating layer.

- IR drop between electrodes could be minimized by reducing the space between electrodes and using a solution having highly conductance.
- A turbulence level in the wastewater is induced by an **i**ncrease in flow rate not only enhances the mass transfer between electrodes, but also reduces insulation layer near the electrode surface.
- A generated hydrogen and oxygen bubble accumulates onto the electrode surface forms an insulating layer. Due to this layer, a large electrical energy required to achieve optimum removal efficiency. Turbulence in the flow sweep out the bubbles formed near the electrode surface. [3]

Mollah (2004) has proposed five different types of reactors for the ECF treatment process.

a. **Tall vertical plate reactor**

A tall vertical plate reactor outer case consists of a PVC pipe. The inner tube contains conducive plates whose horizontal dimensions less than vertical dimensions. Within these reactors, plates are typically arranged in a case that may be closed or open at the top. Closed types require submerged contacts, while open case allows electrical contact above a solution level. If submerged conducive plate surface are not coated with insulating material it corroded at faster rate. [3]

b. Long, Horizontal reactors

This reactor, uses horizontal plates lying either flat or on edge. Plates are mounted within a rectangular non-conductive case with slots to maintain spacing. It's impossible to remove these plates after corrosion. In flat-plate arrangement, oxygen gas forms scales on the plate which falls on the bottom of the reactor causing short circuits between the plates

c. Short, horizontal plate reactor

In this reactor, plates arranged in a non-conducive case are parallel, square, or horizontal are set apart by grooves. Serpentine flow occurs in this reactor, helping the solution to pass spaces between the plates. This reactor allows water to contact both anode and cathode, which helps to complete treatment in a single pass. Unlike the long, horizontal plate reactor, treatment does not produce corrosion of plates and electrical connections in this reactor. These types of reactors are most effective in treating high concentrations of waste. [3]

d. Perforated plate reactor

Perforated plate reactor has flat, horizontal parallel plates placed in a non conducive unit. The design of this reactor same as solid tube reactor, with the exception of that the cathode and anode are made up with a perforated plate. Wastewater flow occurs through the perforation within the plates are compared to being in-between the plates. There are a few drawbacks in this reactor design which made it commercially not suitable. Solids present in wastewater deposits on perforations causing electrical short circuit and fouling. Corrosion of plates and fouling reduces velocity of wastewater through the plates. [3]

e. Solid Tube Reactor

A reactor having two concentric tubes acting as sacrificial electrodes are placed in a non-conducive plate used to treat wastewater. In this reactor one tube acts as a cathode, and the other acts as an anode. Spacing between the tubes should be kept at a minimum to increase the fluid velocity and decrease the reaction voltage. [3]

2.3 Comparison between Conventional Coagulation and EC

2.3.1 Definition of Coagulation

Coagulation is defined as precipitation of colloidal particles with a destabilizing agent. The purpose of coagulation is aggregation of colloidal particles with destabilizing agent forming flocs and heavy particles which could be removed by settling or flotation [5].

2.3.2 Advantages of EC

In electro coagulation, coagulants are produced via electrodes, while chemical coagulation uses chemicals to produce coagulation and precipitation. [13] ECF process can remove smallest colloidal particles where as conventional chemical coagulation cannot. [26] Compared to the conventional coagulation ECF offers some advantages. First, ECF process does not produce any sulfites and chlorides, which are generally associated with natural coagulants. The coagulants produced from dissolution of electrodes are more efficient and required little dosage, as compared to the conventional electrodes, where it requires high chemical dosages at low efficiencies. ECF is operated at high pH ranges, so it does not require any pH adjustment. Finally in ECF process, the micro bubbles produced at the anode and cathode could also contribute to the separation of pollutants through flotation. [27]

2.3.3 Disadvantages of EC

There are many disadvantages of ECF. The main disadvantage of EC reactor is lack of exact reactor design and modeling procedures because its design depends up on complex interactions between electrochemistry, colloidal forces and hydrodynamics. [3]. Additional disadvantages include the consumption of electrical energy; continuous replacement of electrodes made EC unit is not cost effective. Also in EC it is difficult to maintain a constant pH because one cannot control production of H^+, OH^- and Cl^- ions. Toxic chlorinated organic compound may be formed in the case of treating organic wastewater containing chlorides using EC. In the case of treating wastewater containing humic and fluvic acid using EC, forms toxic trihalomethanes in the effluent.

2.4 Wastewater treatment using ECF reactor

2.4.1 Treatment of Oil wastewater

Sources of oily wastewater include petroleum refining, metals manufacturing, machining, and food processing. Generated waste water from metal working process contains cutting and grinding oils, lubrication fluids, and oil-water emulsions. Generally primary and secondary treatment is used to treat oily waste water. Primary treatment separates the floatable oils from water and emulsified oil solution by specific gravities differences, while secondary treatment breaks the oil-water emulsion and separates the oil from water. Conventionally, gravity separators and dissolved air flotation (DAF) are used in primary treatment. Physical, chemical, and electrical methods are used in the secondary treatment to break emulsified oils. Emulsified oils can be treated by either chemical or physical treatment. Ferric and alum salts are used chemical coagulation, while heating,

centrifugation, precoat filtration, ultra filtration, and membrane process are used in the physical treatment. [2]

However EC applies current to the sacrificial electrodes by generating coagulants to destabilize the emulsion of neutralizing the charge on droplets and then precipitates as hydroxides forming flocs. Electro floatation was responsible to float the flocs formed during electro coagulation.[1] As the retention time of wastewater in the reactor increases the ionic strength of the solution increases. Micelles are formed in the aqueous solution by the stabilization of oil droplets using surfactant. Surface charges on the surfactant molecules are neutralized by electro generated cations. Due to above electro chemical reactions pH of the solution will rise and the emulsion is destabilized. The destabilized emulsion absorbed on to the surface of metal hydroxides and forms sludge. The produced sludge floats to the surface by cathode generated hydrogen gas. [2] Using aluminum anode and graphite cathode electro coagulation removal efficiency for COD, SS, were 55.7%, 97.5% respectively. [28]

2.4.2 Treatment of Textile wastewater

Wastewater from textile industry contains more than 100 chemical substances which include dyestuff, wetting, scouring agents, size and de-size auxiliaries, complexion agents, dispersants, stabilizers, reducing agents, lubricants, softeners, and alkali. Textile wastewater is a big problem because of its high color, COD content and poor biodegradability. The conventional treatment for textile wastewater combines biological and physicochemical treatments within two steps. First, primary treatment consists of physical treatment (sedimentation), followed by coagulation for the purpose of removing large particle suspended solids, oil and fat. Secondary treatment uses

biological treatment to remove the dissolved or colloidal organic water contents. Sedimentation followed by coagulation has drawbacks due to excessive coagulant consumption, sludge production, lengthy time interval, and space occupation. Bubble size has a significant effect on flotation**. [29]** Biological treatment is not suitable to complete color removal because dye toxicity wastewater inhibits bacteria growth. [3]

Electrocoagulation is used to remove color and COD from textile wastewater. In this process, gas bubbles produced from the cathode carries pollutants to the top of the solution where they can be concentrated, collected and removed. Dissolution of anode produces hydroxides which destabilizes the pollutants by neutralization are removed by precipitation and flotation.

Electrocoagulation alone cannot reduce COD or color to acceptable limits. Effective parameters on the decolorization process were found to be cell voltage, electrolysis time, and current density. Aluminum electrodes were most efficient than Iron electrodes because of low absorption capacity of ferrous ions. Color removal efficiency is more in ECF cell with monopolar electrodes than bipolar electrodes. [1] Combined chemical and Electrocoagulation helps enhance COD removal efficiency from 23 to 78 % with an addition of alum and a operating time of 5 min [30].

2.4.3 Deflouridation

According to US EPA Standards Fluoride concentration in drinking water should be in between 0.5 and 1.5 mg/L, traditionally, lime precipitation, chemical coagulation, ion exchange, adsorption, membrane process are the common methods employed to treat fluoride. Lime precipitation using either quicklime (CaO) or hydrated lime (CaOH) reacts with F^- ions can remove fluorine as CaF_2. However, precipitation increases the hardness

of the effluent and reduces the fluoride concentration only to 10 mg/l. Chemical coagulation generates large volumes of sludge, a component considered as hazardous waste because of metal hydroxides. Ion exchange and adsorption processes can only reduce fluoride concentration to less than 5 mg/l. [31].

Electrocoagulation/flotation is an efficient method to reduce fluoride from potable water. This is because the dissolution of electrode produces hydroxides at anode and hydrogen at cathode, Fluoride ions (F^{-}) in the wastewater moves towards anode where it combines with hydroxide ions and forms flocs. The flocs float to the surface by hydrogen gas. ECF processes using aluminum electrodes were more efficient than Iron electrodes in the Deflouridation of water and wastewater. Fluorine removal efficiency from solution in ECF reactor was almost 100 % and removal efficiency of fluorine was more effective at a pH between 6 and 8 [31].

2.4.4 Algae removal

One of the biggest algal species of concern is Cyanobacteria. The density of Cyanobacteria is less than that of water which cannot be removed by sedimentation. Therefore, it can be suggested that the ECF process can remove Cyanobacteria with relatively low energy consumption. For this treatment, Aluminum electrodes proved to be more efficient than Iron because of higher current efficiency generated by aluminum. Current density plays a major role in reaction kinetics and energy consumption, as it varies proportionally with operating time in ECF process. If the current density is low, it will take more time to remove algae from wastewater than having a high current density. Low pH is favorable for algae removal, as the ECF exhibited poor algae removal under alkaline condition. Temperature also plays an important role in the reduction of algae by

ECF process. Higher temperature reduces the viscosity of wastewater, which enhances the particle transport and collision rate. An increase in temperature also increases the dissolving rate of electrolytes, which could also accelerate the algae removal and shorten the electrolysis thus decreasing electrolysis time. [27]

2.4.5 Treatment of chemical polishing wastewater

Chemical mechanical polishing wastewater (CMP) contains mainly sulfur dioxide (SiO2) particles dissolved from silicon, dispersants/surfactants, oxidizing agents, and heavy metal ions. Chemical coagulation method is not a conventional method to treat CMP wastewater because it requires large area of land. However, ECF process cannot alone remove pollutants completely because the solid loading of the wastewater is high and the collective efficiency of hydrogen gas is low. Adding cetyltrimethylammonium bromide (CTAB) surfactant to the reactor would increase the contact angle rupture the thin film and expand the three-phase-contact (TPC) between the gas and solid interface. Expansion of the TPC perimeter produces a large contact area and a strong attachment force between the bubble and particle. This phenomenon can enhance the performance of flotation. [32]

2.4.6 Treatment of Laundry wastewater

Various combinations of biological, physical and chemical methods were used to treat laundry wastewater. Because of high suspended solids, phosphate, and surfactant content, traditional methods were proven to be inadequate [10]. ECF reactors with monopolar electrodes effectively removed COD, turbidity, phosphate and surfactant content. Further treatment with ultrasound, increases the voltage and chlorine. This application increases the removal efficiency of COD. The highest removal efficiency achieved by ECF reactor having mono polar electrodes at applied voltage of 5 V is 999mgdm−3 kWh−1. [33]

2.4.7 Treatment of boron wastewater

In nature boron exists in the form of sodium calcium borates ($NaCaB_5O_6(OH)_6$-H_2O). Boron could be used in fertilizers, insecticides, and dyestuff production. A major problem with boron is that it accumulates into ground water and forms complex compounds with heavy metals which are more toxic.

According to World Health Organization (WHO), boron concentration in drinking water should be less than 0.3 mg/l. Initial pH and initial boron concentration, amount of coagulant and temperature of solution effect boron removal from wastewater in the EC reactor. EC efficiency increases with increase of pH up to 8.0. Any further increase in pH decreases the removal efficiency of boron. Using the same initial concentration and a pH of 8, an EC reactor can achieve 94% removal of boron, while chemical coagulation achieves only 24% of removal efficiency. An increase in current density increases coagulant generation which improves the removal efficiency of boron in electro coagulation reactor. In EC at high temperatures, the reactor was more effective in the removal of boron from wastewater. [13]

2.4.8 Treatment of pulp wastewater

The Biochemical Oxygen Demand/Chemical Oxygen Demand (BOD/COD) ratio is defined as biodegradability index, and according to US EPA it should be at least 0.40 for effluent to reach complete Biodegradation. Influent from pulp industry contains COD of 1310 mg/l, and a BOD/COD Index of 0.12. and therefore requires treatment before discharge. Usually, Biological treatment is used for treatment of pulp industry water. Recently, ECF and heterogeneous Photo catalysis with titanium dioxide are proposed to

treat effluent. After 30 min ECF reduces 55 % of COD and almost removes the color, phosphate ion, decontamination for nitrite, sulphate and N-ammoniac of wastewater. [5]

2.4.9 Treatment of Leachate waste

Leachate is formed by the decomposition of garbage or percolation of rainwater through a landfill. Characteristics of the leachate depend upon the region where the landfill present, and it also changes dramatically with advancing time. Leachate contains high pollutant loads and posses highly complex structure [34]. Leachate may contaminate both soil and groundwater without adequate treatment. Many pretreatment and combined methods were proposed to treat Leachate. Aluminium sulfate octadecahydrate Biodegradation, Reverse Osmosis, Fenton, Powdered Activated Carbon Adsorption, lagoon treatment, and anaerobic membrane reactors are employed to treat Leachate, but it has found that this process is inefficient to treat middle and old age Leachate. Over the Aluminium sulfate octadecahydrate, the electrochemical process found suitable to treat off site land fill Leachate. It was found that using ECF process operated at a pH range of 8.2 to 9.2, 10V and reaction time of 20 min using Fe-Cu electrode 30 to 50 percent of Leachate COD is removed. **[**5].

2.4.10 Treatment of surface water

Surface runoff consists mainly of clay, minerals, organic and inorganic matter [35], total dissolved lead, zinc [36]. Surface runoff water composition mainly depends on soil amendment. Rainfall generated from surface runoff water can contaminate groundwater through transportation of suspended organic matter in to the aquifer. There is several Conventional treatment methods were preferred to treat surface water [37]. These include Biological treatment method, chemical coagulation, Ultrafiltration method [33],

flocculation using organic flocculants and sedimentation [38, 39]. Presence of organic content in the raw water could decrease the coagulant efficiency. [40] To treat raw water of low to medium turbidity conventional coagulation and sedimentation process are more suitable. [41]

a. Chemical coagulation treatment

This method is more effective in the treatment of runoff water containing colloidal and organic matter. [42] Poly aluminum chloride, poly aluminum silicate chloride and poly aluminum ferric sulfate, anhydrous ferric chloride (FeCl3 N 6H2O) [42, 43] are the coagulants generally employed in chemical coagulation process to treat surface runoff water. Its efficiency in removing turbidity depends up on pH. It is more effective at a pH of 6, 7.5 and 9. [43]

b. Biological Treatment for Surface Runoff

Sand filters were used to treat runoff water. Geotextiles were embedded in the sand filter to support the growth of biomass. A good geotextiles is one which supports biomass growth and also avoids clogging. Non-woven needle punched geotextiles were proved the best choice for the treatment of surface runoff which reduces BOD_5 and TSS to less than 12 mg/l from 30 to 70 mg/l [44].

CHAPTER III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Clay: used for the purposed of producing raw surface water. Clay was donated by Dr.Khan from Stillwell Hall Geotechnical lab.

3.1.2 Milk Powder: used for the purposed of producing milk waste wastewater.

3.1.3 Aluminum Electrodes: Aluminum sheet and electrical wires were purchased from Home Depot. Cleveland State University Fenn College of Engineering Laboratory technician, Mr. Ali made electrodes using sheet and wires.

3.1.4 Sample bottles: 50 mL air tight plastic containers were used to store the sample solution in a refrigerator after every treatment to determine TOC and TSS.

3.1.5 Shimadzu TOC Analyzer 5050: Shimadzu TOC analyzer 5050 was used to measure TOC for each collected sample.

3.1.6 Whatman Glass Filter Paper: Whatman Glass Filter Paper was used during the filtration of a collected sample. Each filter consisted of a pore size of 1.5 μm and a diameter of 4.7 cm. When filtering each sample using vacuum filtration, a glass filter paper was used to fulfill filtration of each sample.

3.1.7 Spectronic 20D+: Spectronic 20D+ was used to measure Transmissivity for each collected sample**.**

3.1.8 Electrocoagulation/Flotation reactor [ECF]: ECF reactor was made by Plexiglas with the help of Cleveland state university technicians, the reactor was already present in the laboratory.

3.1.9 Fisher Isotemp Oven Model 175: Fisher Isotemp Oven was used to dry the crucible at 103^0 to 105^0 for 1 hr.

3.1.10 Turbidity meter Hach Model 2100 A: The Turbidity meter was used to measure the Turbidity of a sample.

3.2 Methods

3.2.1 Synthetic raw surface water

- Measure 200g of clay on a Petri dish. Weigh and record.
- Take 2 L beaker and fill with cold tap water, add 200 g of clay to the water and stir using a magnetic stirrer until clay dissolves in water.
- Transfer each 500 ml of solution in to 1 L beaker and add 500 ml tap water to it. Let the solution settle for one hour.
- Pour the supernatant from each 1L beaker in to an ECF reactor.
- Repeat above steps until to effluent in a ECF reactor to reach 50 NTU, 100 NTU and 150 NTU [NTU is the unit of turbidity which could be measured by Turbidity meter]

3.2.2 Synthetic organic wastewater

- After achieving required turbidity measurements, Weight of 50g, 100g, 150g, of salt in a three separate Petri dish and then transfer milk powder to a 500 ml beaker.
- Add water to a measured milk powder in a 500 ml beaker and stir until completely dissolves.
- Add milk powder solution to the raw surface water in ECF reactor.

3.2.3 Preparation of sodium chloride solution

- Weight of 40g, 80g, 100g, of salt in a three separate Petri dish
- Dissolve salt in a 500 ml beaker by magnetic stirrer.
- Then add salt water to the ECF reactor containing surface raw water and milk wastewater.

3.2.4 Preparation of chemical coagulant solution.

This research used Aluminum sulfate octadecahydrate, ferric sulfate, and lime as chemical coagulants.

- Measure 10 g of chemical coagulant in a Petri dish, and transfer into a 100 ml beaker.
- Add 60 ml tap water to the coagulant, stir by magnetic stirrer until coagulant completely dissolves in water.
- Add coagulant solution to the ECF reactor.

3.2.5 Turbidity measurement

- Collect effluent from ECF reactor at specified time intervals in a sample bottle.
- Mix thoroughly stirred by a magnetic stirrer.
- Turn on turbid meter, warm up the machine, and calibrate using 100 NTU and 1000 NTU rods.
- After calibration, thoroughly rinsed three times with tap water.
- Add 25 mL of the stirred sample into the calibrated cylinder. Measure and record turbidity.
- Calculate average turbidity by taking the sum of the three turbidity measurements. All turbidity measurements are in NTU (Nephelometric turbidity unit). Example calculation for average turbidity:

  (T1 + T2 + T3)/3 = Tave.

3.2.6 Transmissivity measurement

- Turn on the machine and warm it up for 15 min.
- Set wavelength
- Select filter position
- Set 0%T
- Set mode to %T
- Insert Blank
- Set 100 %T
- Insert Sample
- Read % T

3.2.7 Filtration

- Collect effluent from ECF reactor at specified time intervals and place in a sample bottle.
- Take filter paper from tray and place it in to a Gooch crucible.
- Insert plastic tube in to a volumetric flask.
- Place rubber on top of the volumetric flask and insert Gooch crucible in to it.
- Pour small amount of tap water on filter paper and turn on vacuum filtration.
- Transfer 25 ml of collected effluent in to graduate cylinder from sample collected bottles and pour onto filter paper
- Remove filter paper from crucible and place it on dryer to determine TSS
- Transfer filtered sample from plastic tube into a 50 mL sample bottle. Store in refrigerator
- Repeat above steps for every collected sample from ECF reactor.

3.2.8 TSS measurement

- Measure empty weight (W_0) of a crucible.
- After filtration, remove filter paper from Gooch Crucible and place onto the crucible.
- Measure weight of the crucible (W_1) using scale.
- Turn on Fisher Isotemp oven. Use dial to adjust temperature to 103^0
- Dry the crucible in an oven at 103 to 105 ºC for 1 hr.
- After one hour, remove crucible from oven and put into a desiccators for 2 hrs. Weigh desiccated sample (W_2).
- Calculate the different between W_1 and W_2 to determine TSS.

3.2.9 TOC preparation

- Remove filtered sample from refrigerator.
- Transfer filtered sample in to a Schimazu glass sample vial.
- Place vial onto the holder located on the TOC machine.
- Follow operating instructions for the determination of TOC

3.3 Run Descriptions

Run # 1 ECF treatment of low strength synthetic surface water at current I = 1ampere

Run # 2 ECF treatment of low strength synthetic surface water at current I = 2ampere

Run # 3 ECF treatment of low strength synthetic surface water at current I = 3ampere

Run # 4 ECF treatment of medium strength synthetic surface water at current I = 1ampere

Run # 5 ECF treatment of medium strength synthetic surface water at current I = 2ampere

Run # 6 ECF treatment of medium strength synthetic surface water at current I = 3ampere

Run # 7 ECF treatment of high strength synthetic surface water at current I =1ampere

Run # 8 ECF treatment of high strength synthetic surface water at current I = 2ampere

Run # 9 ECF treatment of high strength synthetic surface water at current I = 3ampere

Run # 10 ECF treatment of low strength synthetic surface water containing organic content at current I = 1ampere

Run # 11 ECF treatment of low strength synthetic surface water containing organic content at current I = 2 ampere

Run # 12 ECF treatment of low strength synthetic surface water containing organic content at current I = 3 ampere

Run # 13 ECF treatment of medium strength synthetic surface water containing organic content at current I = 1ampere

Run # 14 ECF treatment of medium strength synthetic surface water containing organic content at current I = 2ampere

Run # 15 ECF treatment of medium strength synthetic surface water containing organic content at current I = 3 ampere

Run # 16 ECF treatment of high strength synthetic surface water containing organic content at current I = 1ampere

Run # 17 ECF treatment of high strength synthetic surface water containing organic content at current I = 2ampere

Run # 18 ECF treatment of high strength synthetic surface water containing organic content at current I = 3ampere

Run # 19 ECF treatment of low strength synthetic surface water containing organic content at current I = 1ampere using Aluminium sulfate octadecahydrate

Run # 20 ECF treatment of low strength synthetic surface water containing organic content at current I = 2ampere using Aluminium sulfate octadecahydrate

Run # 21 ECF treatment of low strength synthetic surface water containing organic content at current I = 3 ampere using Aluminium sulfate octadecahydrate

Run # 22 ECF treatment of medium strength synthetic surface water containing organic content at current I = 1ampere using Aluminium sulfate octadecahydrate

Run # 23 ECF treatment of medium strength synthetic surface water containing organic content at current I = 2 ampere using Aluminium sulfate octadecahydrate

Run # 24 ECF treatment of medium strength synthetic surface water containing organic content at current I = 3 ampere using Aluminium sulfate octadecahydrate

Run # 25 ECF treatment of high strength synthetic surface water containing organic content at current I = 1ampere using Aluminium sulfate octadecahydrate

Run # 26 ECF treatment of high strength synthetic surface water containing organic content at current I = 2 ampere using Aluminium sulfate octadecahydrate

Run # 27 ECF treatment of high strength synthetic surface water containing organic content at current I = 3 ampere using Aluminium sulfate octadecahydrate.

Run # 28 ECF treatment of low strength synthetic surface water containing organic content at current I = 1ampere with the addition of lime

Run # 29 ECF treatment of low strength synthetic surface water containing organic content at current I = 2 ampere with the addition of lime

Run # 30 ECF treatment of low strength synthetic surface water containing organic content at current I = 3 ampere with the addition of lime

Run # 31 ECF treatment of medium strength synthetic surface water containing organic content at current I = 1ampere with the addition of lime

Run # 32 ECF treatment of medium strength synthetic surface water containing organic content at current I = 2 ampere with the addition of lime

Run # 33 ECF treatment of medium strength synthetic surface water containing organic content at current I = 3 ampere with the addition of lime

Run # 34 ECF treatment of high strength synthetic surface water containing organic content at current I = 1ampere with the addition of lime

Run # 35 ECF treatment of high strength synthetic surface water containing organic content at current I = 2 ampere with the addition of lime

Run # 36 ECF treatment of high strength synthetic surface water containing organic content at current I = 3 ampere with the addition of lime

Run # 37 ECF treatment of low strength synthetic surface water containing organic content at current I = 1 ampere with the addition of Ferric Sulfate

Run # 38 ECF treatment of low strength synthetic surface water containing organic content at current I = 3 ampere with the addition of Ferric Sulfate

Run # 39 ECF treatment of high strength synthetic surface water containing organic content at current I = 1 ampere with the addition of Ferric sulfate

Run # 40 ECF treatment of high strength synthetic surface water containing organic content at current I = 2 ampere with the addition of Ferric Sulfate

Run # 41 ECF treatment of high strength synthetic surface water containing organic content at current I = 3 ampere with the addition of Ferric Sulfate.

Run # 42 ECF treatment of low strength synthetic milk waste water at current I = 1 ampere.

Run # 43 ECF treatment of low strength synthetic milk waste water at current I = 2 ampere.

Run # 44 ECF treatment of low strength synthetic milk waste water at current I = 3 ampere.

Run # 45 ECF treatment of Medium strength synthetic milk waste water at current I = 1 ampere.

Run # 46 ECF treatment of Medium strength synthetic milk waste water at current I = 2 ampere.

Run # 47 ECF treatment of Medium strength synthetic milk waste water at current I = 3 ampere.

Run # 48 ECF treatment of High strength synthetic milk waste water at current I = 1 ampere.

Run # 49 ECF treatment of High strength synthetic milk waste water at current I = 2 ampere.

Run # 50 ECF treatment of High strength synthetic milk waste water at current I = 3 ampere.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results from the experiments that were conducted to find the optimal operational parameters for the ECF batch reactor for treatment of synthetic surface water. Solutions were prepared as discussed in Chapter 4: Materials & Methods. Total suspended solids (TSS), turbidity, % transmittance were determined for solutions with turbidity strengths of 50, 100 and 150 NTU by applying various current levels across the reactor. Samples reflecting the final turbidity, % transmittance and total suspended metal concentration were withdrawn from the reactor at treatment time of 5, 10, 20 and 30 minutes. It also observed the effect of organic carbon and coagulants lime, Aluminium sulfate octa decahydrate and ferric sulfate on treatment efficiency of ECF batch reactor.

4.2 Synthetic surface water using ECF reactor

4.2.1 Results of Runs # 1-3

Runs 1-3 considered low strength synthetic surface water (50NTU) removal efficiency of turbidity, TSS, and % transmittance at three various current levels. Analyses were done over a 30 minutes time frame. Figure 1 depicts turbidity versus time at when applying 1, 2, and 3 amperes. From Figure 1 it was observed that removal of turbidity increases by increasing treatment time. Samples withdrawn after 30 minutes of treatment time demonstrated that turbidity removal efficiencies within 70 to 80 % for entire current range of current 1 to 3 ampere.

Maximum efficiency occurs at a current of 2 ampere and treatment time of 30 minutes, where turbidity removal is 80 %, 72% TSS removal, and 94% transmittance. Also, high efficiency is shown in Figure 1 at a current of 3 ampere and a treatment time of 30 minutes, where 70% turbidity removal, 75% TSS removal and 92% transmittance was achieved by the ECF reactor. From the above results, it was observed that turbidity removal efficiency decreased for ECF reactor operating with a treatment time of 30 minutes for 3 ampere as compared to 2 ampere. This is because presence of free coagulant appears in the ECF reactor after 20 minutes. The above conclusion was supported by Figure 3 which depicts TSS removal efficiency was maximum for 3 ampere and treatment time of 30 minutes.

4.2.2 Results of Runs # 4-6

Runs 4-6 was performed to determine treatment efficiency of ECF batch reactor operated at various current levels with medium strength synthetic surface water (100 NTU). Samples were taken at when treatment time reached 5, 10, 20 and 30 minutes. Samples

withdrawn after 10 minutes of treatment time demonstrated a range of turbidity removal efficiencies between 0 and 30 %, TSS removal efficiencies between 0 and 25 %, and % transmittance varies from 62 to 75 % for entire current range of 1 to 3 amperes. From the results It was concluded that the maximum turbidity, TSS removal efficiency achieved was 65% and 87.5 % at a current of 3 ampere and treatment time of 30 minutes.

4.2.3 Results of Runs # 7-9

Runs 7-9 considered high strength synthetic surface water **(**150 NTU) removal efficiency of turbidity, TSS and transmittance by the reactor operated at 1,2, and 3 amperes. Figure 7 depicts turbidity removal efficiency versus time at various applied currents. Samples taken after 5 minutes of treatment time demonstrated that turbidity removal efficiencies were between 0 and 26% for all currents.

As shown in Figure 7, the turbidity removal efficiency ranged between 40 and 83.5 % when the treatment time was 30 minutes. Figure 8 represents a plot of % transmittance and time at various currents. Results demonstrated that highest transmittance of 93.4 was achieved at higher current of 3 ampere and treatment time of 30 minutes. Figure 9 depicts TSS removal efficiency versus time at various applied currents. Samples taken after 5 minutes of treatment time demonstrated that TSS removal efficiencies were between 0 and 15% for the entire current range. Maximum TSS removal efficiency achieved by ECF reactor with high strength influent was 86% operated at a current of 3 ampere and treatment time of 30 minutes.

4.3 Treatment of synthetic surface water containing organic content using ECF reactor

4.3.1 Results of Runs # 10-12

Figure 10 depicts turbidity removal efficiency of low strength synthetic surface water and milk waste water for currents 1,2, and 3 amperes. As shown in Figure 10, turbidity removal efficiency increases over time. Figure 10 represents a plot of the effect of current on the turbidity removal efficiency of ECF reactor. From Figure 10, it was observed that turbidity increased in the solution when the current was either 1 or 2 ampere and treatment time between 0 minutes to 10 minutes because presence dissolved carbon in the solution increased the turbidity. For the samples taken after 30 minutes of treatment time found turbidity removal efficiencies between 37% and 64 % for the entire applied current range. The maximum turbidity removal efficiency was achieved at a current of 1 ampere and treatment time of 30 minutes. Also, Figure 11 indicates that % transmittance increases over time.

4.3.2 Results of Runs # 13-15

Runs 13- 15 considered medium strength synthetic surface water and milk waste water removal efficiency of turbidity and % transmittance at currents 1,2, and 3 amperes. Samples taken after 10 minutes of treatment time demonstrated that the turbidity removal was between 0 and 16% and % of transmittance between 60 and 62 for all three currents. Figure 13 turbidity versus time shows that an increase in current improves the turbidity removal. The maximum turbidity removal efficiency 83.5% was achieved at a current of 3 ampere and treatment time of 30 minutes. Figure 14 depicts that maximum

transmittance of 94 % was achieved at a current of 3 ampere and treatment time of 30 minutes.

4.3.3 Results of Runs # 16-18

Runs 16-18 considered high strength synthetic surface water and milk waste water removal efficiency of turbidity and % transmittance at currents of 1,2, and 3 amperes. Samples taken after 30 minutes of treatment time demonstrated that the turbidity removal efficiency was between 44 % and 93.3 % and % of transmittance within 71 to 96 for the entire current range. Figure 16 and 17 shows that treatment efficiency of ECF batch reactor is related to increasing the current and treatment time.

4.4 Treatment of synthetic surface water by ECF addition of aluminum sulfate octadecahydrate as the coagulant

4.4.1 Results of Runs # 19-21

Runs 19 to 21 considered treatment of low strength synthetic surface water by the addition of 1 g/l of chemical coagulant aluminum sulfate octadecahydrate. Turbidity removal efficiency and % transmittance were investigated. Figure 19 is plot of turbidity versus time, where it was determined that removal efficiency of turbidity increases as treatment time increases. Samples taken after treatment time of 30 minutes demonstrated that turbidity removal efficiencies are between 20 and 60% and % transmittance between 87 and 94 for the entire current range.

4.4.2 Results of Runs # 22-24

Runs 22 to 24 considered the treatment of medium strength synthetic wastewater by the addition of 1 g/l chemical coagulant Aluminium sulfate octadecahydrate. From Figures 22 and 23, it was demonstrated that treatment efficiency increases over increasing current

and treatment time. Samples taken after treatment time of 30 minutes demonstrated that the turbidity removal efficiency between 50 and 65 % and % of transmittance between 80 and 86 for the entire current range.

4.4.3 Results of Runs # 25-27

Runs 25-27 considered the treatment of high strength synthetic wastewater by the addition of 1 g/l chemical coagulant Aluminium sulfate octadecahydrate. Removal of turbidity and transmittance was low at a current of 1 amp as shown in Figures 25 and 26. Figures 25 and 26 show that turbidity removal efficiency and % transmittance increases with increasing current and treatment time. The maximum turbidity removal efficiency of 74 % was achieved at a current of 3 ampere and treatment time of 30 minutes.

4.5 Treatment of synthetic surface water by ECF with the addition of lime as the coagulant

4.5.1 Results of Runs # 28-30

Runs 28-30 considered solutions of low strength synthetic surface water supplied with 500 mg/l of lime as coagulant. Samples were taken from the reactor at predetermined treatment times values of 5, 10, 20 and 30 minutes. Figure 28 depicts turbidity versus treatment time. By observing plotted results, it may be concluded that turbidity removal efficiency increases with treatment time. Addition of lime to the influent increases its initial turbidity by tenfold as shown in Figure 28. These results were plotted with the objective of observing the relationship of treatment efficiency across different ranges of current. Samples withdrawn after treatment time of 30 minutes demonstrated that turbidity removal efficiencies between 60 and 64% for the entire current range.

4.5.2 Results of Runs # 31-33

Runs 31-33 considered the treatment of medium strength synthetic surface water at currents 1,2, and 3 by the addition of 500 mg/l lime. Samples taken after treatment time of 30 minutes demonstrated that turbidity removal efficiencies within 72 to 80% for the entire current range. It was observed that treatment efficiency increases improved at 2 ampere compared to 1 ampere.

4.5.3 Results of Runs # 34-36

Runs 34-36 considered the treatment of high strength synthetic surface water at various current by the addition of 500 mg/l lime. Samples taken after treatment time of 30 minutes demonstrated that turbidity removal efficiencies was between 33 and 83% for the entire current range. It was also observed that treatment efficiency improves at 3 ampere compared with 1 and 2 ampere.

4.6 Treatment of synthetic surface water by ECF with the addition of chemical coagulant ferric sulfate

4.6.1 Results of Runs # 37-41

Runs 37-41 considered the treatment of synthetic surface water by the addition of 500 mg/l of chemical coagulant ferric sulfate. From Figures 34, 35, 36, and 37, it was observed that addition of ferric sulfate does not produce satisfactory results.

4.7 Comparison of Results

This section discusses treatment of different influents by ECF batch reactor at various current and wastewater types—synthetic surface water, synthetic surface water and milk wastewater mixture, addition of lime to a mixture of synthetic surface water and synthetic

milk waste water, and the addition of aluminum sulfate octa decahydrate to the mixture of synthetic surface water and milk waste water.

4.7.1 Treatment of low strength synthetic surface water at a current I = 1 ampere

Figure 39 and 40 shows that maximum turbidity removal efficiency achieved was 60% and maximum % transmittance achieved was 98%. According to the results, there are three patterns observed. First, treatment efficiency increases linearly for all runs except Run #10. In Run #10, the presence of organic carbon decreases turbidity removal efficiency and % transmittance at the beginning of the experiment, but after 10 minutes of treatment time the removal efficiency increases with increases in treatment time. Second, the application of chemical coagulant aluminum sulfate octa decahydrate increases turbidity and Transmissivity of influent by two times and the EC at a current I = 3 ampere is not enough to treat such a high turbidity concentration, so this coagulant does not produce good results. Third, the application of lime increases turbidity of the synthetic surface water, achieving maximum turbidity removal efficiency after 30 minutes.

4.7.2 Treatment of medium strength synthetic surface water at a current I =1 ampere

Figure 41 and 42 depicts that the samples withdrawn after treatment time of 30 minutes demonstrated that application of lime to the synthetic surface water produces highest turbidity removal efficiency of 80% and % Transmittance of 95.1 %.

4.7.3 Treatment of high strength synthetic surface water at a current I = 1 ampere

It can be concluded from Figures 43 and 44 that treatment efficiency of ECF batch reactor with high strength influent operating at 1 ampere does not produce satisfactory

results. The maximum turbidity removal efficiency of 43.3 % and maximum % Transmittance of 71.2 was achieved in run # 16.

4.7.4 Analysis

Electrocoagulation/flotation treatment of low and medium strength synthetic surface water achieves good results by the addition of lime to the synthetic surface water. A current of 1 ampere is not enough for the treatment of high strength synthetic surface water.

4.7.5 Treatment of low strength synthetic surface water at a current I = 2 ampere

As shown in Figure 45, the maximum turbidity removal efficiency of 80 % is achieved in ECF reactor with an influent containing only synthetic surface water. Samples taken at a treatment time of 30 minutes demonstrated that influent containing surface water and milk waste water achieves only 24 % turbidity removal and 60 % turbidity removal was achieved by the addition of chemical coagulants. As shown in Figure 46**,** maximum transmittance of 94.1 % was achieved by ECF reactor in the treatment of influent containing only surface water. Turbidity removal efficiency and % transmittance increases in ECF reactor with treatment of low strength influent operating at a current 2 ampere as compared to 1 ampere.

4.7.6 Treatment of medium strength synthetic surface water at a current I = 2 ampere

From Figure 47, it was observed that a maximum turbidity removal efficiency of 78% was achieved in treatment of medium strength surface water containing both synthetic surface water and synthetic milk wastewater. From the figure, it can be concluded that turbidity removal efficiency decreases with increasing strength of the

influent. Figure 48 demonstrated that 92 % of transmittance was achieved by the treatment of influent containing both surface water and milk waste water a current of 2 ampere.

4.7.7 Treatment of high strength synthetic surface water at a current I = 2 ampere

Figures 49 and 50 show that the samples taken at a treatment time of 30 minutes demonstrated that mixture of synthetic surface water and synthetic milk waste water produces highest turbidity removal efficiency of 84% and % Transmittance of 95%.

4.7.8 Analysis

Treatment of low medium and high strength surface water by ECF reactor operated 2 ampere produced good results as compared to 1 ampere. Maximum treatment efficiencies were achieved with a mixture containing synthetic surface water and synthetic milk waste water.

4.8 Overall Analysis

4.8.1 Low strength waste water treatment by ECF reactor at various currents

a. Synthetic surface water

Samples taken at 30 minutes of treatment time demonstrated that turbidity removal efficiencies are between 70 and 80 % and % transmittance is between 92.3% and 94.1% for a range of currents. Maximum treatment efficiency achieved in the treatment of synthetic surface water by ECF reactor operated at a current of 2 ampere.

b. Synthetic surface water and synthetic milk waste water

From the results, it was concluded that turbidity removal efficiency decreases as current increases in the ECF batch reactor with an influent containing both synthetic surface

water and synthetic milk waste water. Samples taken at 30 minutes of treatment time demonstrated that turbidity removal efficiencies between 70 and 80 % and % transmittance between 24% and 60% for all currents. Maximum treatment efficiency achieved in the treatment of synthetic surface water by ECF reactor operated at a current of 1 ampere. It was noticed that the treatment efficiency decreases in ECF reactor with an influent containing mixture of synthetic surface water and milk waste water than influent containing only synthetic surface water.

c. Addition of lime to synthetic surface water

It was noticed from the results that the initial addition of lime increases turbidity of the influent by three fold. But at the end of the treatment, lime presence improves in treatment efficiency Samples were taken at 30 minutes of treatment time demonstrated that turbidity removal efficiencies between 60 and 64 % and % transmittance between 98% and 99% for a range of currents. Maximum treatment efficiency achieved in the treatment of synthetic surface water was at a current of 3 ampere.

d. Addition of Aluminium sulfate octa decahydrate to synthetic surface water

From the results**,** it was demonstrated that treatment of synthetic surface water by ECF reactor with addition of chemical coagulant Aluminium sulfate octa decahydrate does not produce satisfactory results.

4.8.2 Medium strength waste water treatment by ECF reactor at various currents

a. Synthetic surface water

From the results**,** it was concluded that turbidity removal efficiency increases as current increases with an influent containing both synthetic surface water. Samples taken after 30 minutes of treatment time demonstrated that turbidity removal efficiencies between 65

and 70 % and % transmittance between 87% and 93 % for all currents. Maximum treatment efficiency achieved in the treatment of synthetic surface water by ECF reactor operated at a current of 3 ampere. It was concluded that treatment efficiency of ECF reactor for an influent containing medium strength surface water increases as current increases.

b. Synthetic surface water and milk waste water

From the results, it was concluded that turbidity removal efficiency increases as current increases with an influent containing both synthetic surface water and synthetic milk waste water. Samples withdrawn after 30 minutes of treatment time demonstrated that turbidity removal efficiencies between 65 and 80 % and % transmittance between 84 % and 94 % for all currents. Maximum treatment efficiency achieved in the treatment of synthetic surface water by ECF reactor operated at a current of 3 ampere. It was noticed that the treatment efficiency increases with an influent containing mixture of synthetic surface water and milk waste water than influent containing only synthetic surface water.

c. Addition of lime to synthetic surface water

Addition of lime to synthetic surface water improves treatment efficiency of ECF batch reactor operated at a current of 1 ampere by 15 %. From the above results, it was concluded that addition of lime improves the treatment efficiency of ECF reactor operated at low current.

d. Addition of Aluminium sulfate octa decahydrate to synthetic surface water

From the results, it was demonstrated that treatment of synthetic surface water by ECF reactor with addition of chemical coagulant Aluminium sulfate octa decahydrate does not produce satisfactory results.

4.8.3 High strength waste water treatment by ECF reactor at various currents

a. Synthetic surface water

From the results, it was observed that a current of 1 ampere achieves only 40 % turbidity removal efficiency and it increases with increase of current. In addition, 73.3 % of turbidity removal efficiency was achieved at a current of 2 ampere and 83.3 % a current of 3 ampere. It also observed that % transmittance increases with increase of current.

b. Synthetic surface water and milk waste water

From the results, it was observed that at a current of 1 ampere achieves only 43 % turbidity removal efficiency and it increases with increase of current. In addition, 83.3 % of turbidity removal efficiency was achieved at a current of 2 ampere and 86 % for 3 ampere. It was also observed that presence of organic carbon improves the treatment efficiency compared to the previous results.

c. Analysis

From the above results it was concluded that medium strength synthetic surface water treatment increases with current density. Maximum treatment efficiency achieved at a current of 3 ampere and treatment time of 30 minutes.

4.8.4 Addition of coagulants

a. Addition of lime to synthetic surface water

Addition of lime to the high strength synthetic surface water does not improve treatment efficiency.

b. Addition of Aluminium sulfate octa decahydrate to synthetic surface water

From the results it was demonstrated that treatment of synthetic surface water by ECF reactor with addition of chemical coagulant Aluminium sulfate octa decahydrate does not produce satisfactory results.

4.8.5 Conclusions

The ECF process successfully reduced the turbidity, total suspended solids and increased the % transmittance in synthetic surface water. Turbidity removal efficiencies for all applied current levels ranged between averages of 24 % to 80 % for treatment time of 30 minutes. Under the influence of lime as a coagulant ECF reactor produced satisfactory results at applied current of 1 ampere. Addition of chemical coagulants ferric sulfate and Aluminium sulfate octa decahydrate do not produce satisfactory results. It was determined that an applied current of 1 ampere with a treatment time of 30 minutes was enough to remove turbidity and total suspended solids from low strength surface water, and an applied current of 3 ampere with a treatment time of 30 minutes was enough to achieve treatment efficiency for medium and high strength surface water.

Synthetic surface water treatment efficiency under the influence of organic loads was also considered. From plotted results showed that treatment efficiency ranging between 43% and 87% for various strengths of influent and treatment times of 30 minutes at various applied currents. TOC removal efficiency of these studies ranged about 50 % at an applied current of 3 ampere.

CHAPTER V

DETERMINING ORGANIC REMOVAL EFFICIENCY BY ECF REACTOR

5.1 Introduction

This chapter presents studies performed to determine the suitability of the ECF batch reactor for the treatment of synthetic milk waste water containing various concentrations of organic carbon. The first part of this chapter emphasizes treatment of low, medium and high strength synthetic milk waste water by ECF batch reactor at various currents. The second part of this chapter presents the results of organic removal efficiency by ECF reactor with an influent containing both synthetic surface water and synthetic milk waste water. The main objective of this chapter is to determine effect of presence of clay in synthetic surface water on TOC removal efficiency.

5.2 Treatment of synthetic milk waste water treatment by ECF reactor at various currents.

5.2.1 Run # 42-44 Results

The feed strength for runs #42-44 was 100 mg/l of milk powder where the reactor operated at 1,2, and 3 amperes. As shown in Figure 57, there was a significant difference in TOC removal by the ECF reactor. For ECF reactor operating at current of 1 ampere,

the percentage removal of TOC concentration for effluent after treatment time of 30 minutes was 20.57 %. The corresponding value for ECF reactor operating at current of 2 ampere was 29.70 %, and 32.26 % for ECF reactor operating at a current of 3 ampere. Figure 54 depicts that TOC removal efficiency increases with increasing current.

5.2.2 Run # 45-47 Results

The feed strength for runs # 45-47 was 150 mg/l of milk powder where the reactor operated at 1,2, and 3 amperes. As shown in Figure 58, samples taken after treatment time of 30 minutes demonstrated that the TOC removal efficiencies ranged between 28.7 % and 32.22 % for a range of currents. The maximum TOC removal efficiency of 32.22 % was achieved by ECF batch reactor operating at a current of 3 ampere.

5.2.3 Run # 48-50 Results

The feed strength for runs #48-50 was 200 mg/l of milk powder and the reactor operated at currents 1,2,and 3 amperes. As shown in Figure 59, there was a significant difference in TOC removal. When operating at 1 ampere, the removal of TOC concentration for effluent after treatment time of 30 minutes was 27.52 %. The corresponding value for ECF reactor operating at 2 ampere was 35.29 % and 41.18 % at 3 ampere. The TOC removal efficiency increased at this high loading compared to the previous runs.

5.3 Treatment of synthetic surface water by the ECF batch reactor with the presence of organic [milk powder] loads

5.3.1 Run # 10-12 Results

The feed strength for runs # 10-12 was 100 mg/l of milk powder and 50 NTU of synthetic surface water. Figure 12 depicts TOC concentration vs. times for ECF reactors operated at various currents. The TOC concentrations were 45.21, 36.26 and 44.13 mg/l for

influent of ECF reactors operating at 1, 2 and 3 ampere respectively. After the treatment time of 30 minutes, the corresponding TOC effluent values are 21.56, 24.89, and 29.33 mg/l. The removal efficiencies was between 21.5 % and 33.5 %. The maximum removal efficiency of 33.5 % was achieved for ECF reactor operating at 3 ampere, which is higher compared to previous runs done at without presence of synthetic surface water.

5.3.2 Run # 13-15 Results

The feed strength for runs # 13-15 was 150 mg/l of milk powder and 100 NTU of synthetic surface water. Figure 16 depicts TOC concentration vs. times for ECF reactors operated at various currents. The TOC concentrations were 47.83, 59.1 and 65.2 mg/l for influent of ECF reactors operating 1, 2 and 3 ampere respectively. After the treatment time of 30 minutes in ECF reactor the corresponding TOC effluent values are 38.68, 42.23 and 35.06 mg/l. The removal efficiencies ranged between 19.13 % and 30.14%. The maximum removal efficiency of 30.14 was achieved for ECF reactor operating at 3 amperes.

5.3.3 Run # 16-18 Results

The feed strength for runs #16-18 was 200 mg/l of milk powder and 150 NTU synthetic surface water with currents at 1,2, and 3 amperes. As shown in Figure 19, there was a significant difference in TOC removal. For ECF reactor operating at a current of 1 ampere, the removal of TOC concentration for effluent after treatment time of 30 minutes was 30.61 % The corresponding value for ECF reactor operating at current of 2 ampere was 44.73 % and 49.18 % for ECF reactor operating a current of 3 ampere. The TOC removal efficiency increased at this high loading compared to the previous runs.

5.4 Comparison of Results

5.4.1 Low strength organic load [100 mg/l] treatment by ECF reactor operating at I =1, 2 and 3 ampere

Figures 60, 63, and 66 depict the % TOC removed vs. time in the bulk electrolyte solution. The plots demonstrate a general tendency of the TOC removal efficiency to the treatment time and the applied current. It was also observed from the plots that TOC removal efficiency is maximum for an influent containing both synthetic surface water and synthetic milk waste water. Comparing applied currents at 30 minutes of treatment time, the TOC removal efficiencies within 20.577 to 21.56% for an applied current of 1 ampere. A considerable increase in this value was observable for applied current levels (2 and 3 ampere) at the same treatment time. Maximum TOC removal efficiency of 33.53 % was achieved by ECF reactor operating at a current of 3 ampere with an influent containing mixture of both synthetic surface water and synthetic milk waste water.

5.4.2 Medium strength organic load [100 mg/l] treatment by ECF reactor operating at I =1, 2 and 3 ampere

Figures 62, 65, and 67 shows the TOC removal efficiencies of two different influents versus treatment time for all applied currents in the ECF reactor. The figures depict TOC removal efficiency increases with increase in applied current and treatment time. The maximum TOC removal efficiency of 49.18 % was achieved by ECF reactor with an influent containing both synthetic surface water and synthetic milk waste water. From the above results it was concluded that TOC removal efficiency increases with increase in strength of organic load.

5.4.3 High strength organic load [100 mg/l] treatment by ECF reactor operating at I =1, 2 and 3 ampere

As shown in Figure 61, removal efficiencies of samples withdrawn after 5 minutes of treatment time were within 22.8 % and 5.902 % for influent containing no clay and influent containing clay. But samples taken after 30 minutes demonstrated that maximum removal efficiency of 29.83 % was achieved by effluent containing clay. Figure 63 depicts TOC removal efficiencies of samples withdrawn after 5 minutes of treatment time within 19.16 % to 15.39 % for influent containing no clay and influent containing clay. But samples taken after 30 minutes demonstrated that maximum removal efficiency of 34.97% was achieved by effluent containing clay. Previously for the middle strength synthetic waste water**,** it was observed that only 28. 83% was achieved at a current of 1 ampere. It was concluded from the results that TOC removal efficiency increases with current.

5.4.4 Conclusions

Based on the above experimental results, it may be concluded that Electrocoagulation/flotation process may successfully used for the treatment of synthetic surface water that contains variable concentrations of organic matter. This part of research emphasized the suitability of Electrocoagulation/flotation batch reactor to remove organic matter from waste water. The results demonstrate that presence of clay in synthetic surface water may have an effect upon TOC removal efficiency by absorbing organic matter. It was determined that the optimal operational parameters appeared to be an applied current 3 ampere and treatment time of 30 minutes.

CHAPTER VI

CONCLUSIONS, ENGINEERING SIGNIFICANCE AND RECOMMENDATIONS FOR FURTHER STUDIES

6.1 Conclusions

The analysis of results demonstrates that total suspended solids, organic matter may be removed from wastewater by the electro coagulation/flotation process. The technology demonstrated to be efficient allowing turbidity, organic matter and total suspended solids removal efficiencies. The results showed that treatment efficiencies based on treatment time, applied current and strength of synthetic surface water.

From the experimental results it was observed that the ECF batch reactor may be used for the treatment of synthetic surface water containing variable strengths of initial turbidity and % transmittance. High turbidity removal efficiencies in the order of 86% were obtained after the treatment time of 30 minutes. With the help of the coagulant lime, the reactor was able to reduce % turbidity to 80 % operated at 1 ampere. Addition of chemical coagulants Aluminium sulfate octadecahydrate and ferric sulfate to the reactor do not produce satisfactory results. In addition, the reactor was capable of reducing an initial TOC of 87. 22 mg/l to 41.175 mg/l after 30 minutes of treatment time which is 41.17 % TOC removal efficiency. On the other contrary, treatment of organic load along

with surface water the reactor was capable of reducing initial TOC of 70.81 mg/l to 49.18 mg/l after 30 minutes treatment time which is nearly 50 % of TOC removal efficiency.

6.2 The Engineering significance of this study

- The influence of chemical coagulants and organic loads upon the treatment efficiency of the ECF technology used for the treatment of synthetic surface water. This study demonstrated that organic loads and coagulant lime have considerable effect in the treatment efficiency of surface water
- The utilization of aluminum sheet as an electrode material. It was observed that for every two or three runs the electrodes were corroded, because of possible chemical reactions occurring during the process at electrodes. Therefore Aluminium being lost by the electrode helps in the coagulation process.

6.3 Recommendations

- Further research could be conducted at various pH conditions to determine the effect of pH on treatment efficiency.
- Experiments needed to be conducted using stainless steel as cathode and Aluminium as anode at various currents.

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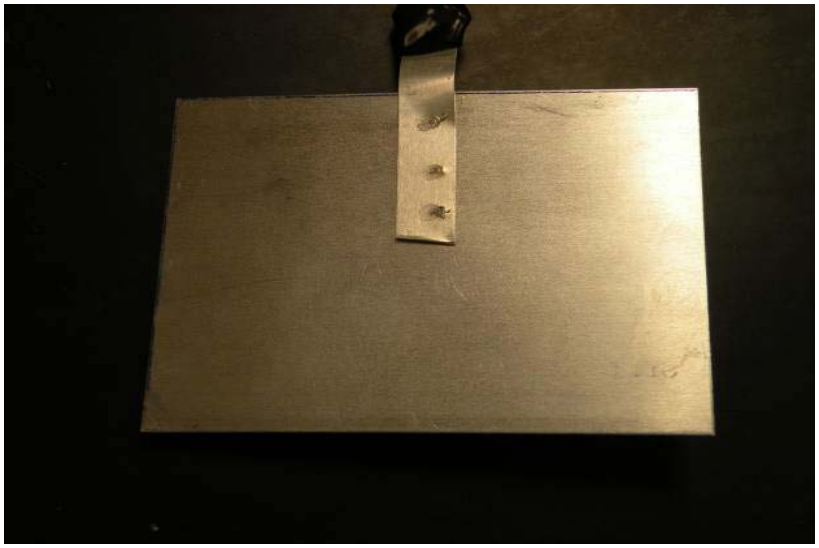
APPENDICES

APPENDIX A
PHOTOGRAPHS OF AN EXPERIMENT

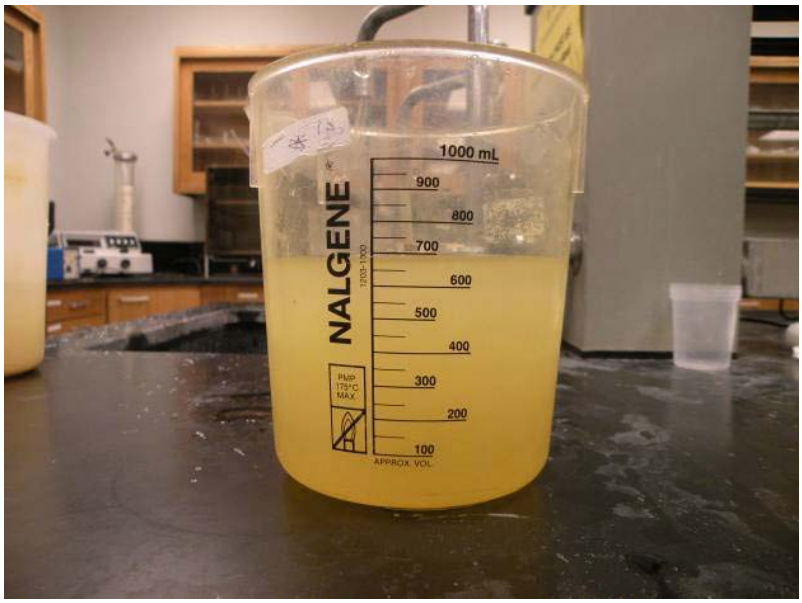
ECF REACTROR:

NEW ELECTRODE:



CORRODED ELECTRODE

SURFACE WATER BEFORE TREATMENT:



SURFACEWATER AFTER TREATMENT:

APPENDIX B
LIST OF TABLES

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	50	76	140	0	0
5	50	76.2	140	0	0
10	50	78	140	0	14.28
20	32	89.2	70	36	71.42
30	30	93.2	70	40	71.42

I. Run # 1 Low strength synthetic surface water [50 NTU] treatment using ECF reactor operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	50	76.4	140	0	0
5	45	80	140	10	0
10	40	82	140	20	14.28
20	20	91.6	40	60	71.42
30	10	94.1	40	80	71.42

II. Run # 2 Low strength synthetic surface water [50 NTU] treatment using ECF reactor operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	50	76.2	160	0	0
5	40	82.6	160	20	0
10	35	85.7	140	30	12.5
20	25	90.3	100	50	37.5
30	15	92.3	40	70	75

III. Run # 3 Low strength synthetic surface water [50 NTU] treatment using ECF reactor operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	100	60.8	280	0	0
5	100	60.8	280	0	0
10	100	62	280	0	0
20	40	80.1	100	60	64.28
30	35	84	70	65	75

IV. Medium strength synthetic surface water [100 NTU] treatment using ECF reactor operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	100	66	140	300	0
5	100	66	140	300	0
10	95	68	140	280	6.66
20	50	88	40	100	66.66
30	40	92	40	50	83.33

V. Medium strength synthetic surface water [100 NTU] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	100	63.8	320	0	0
5	85	69	280	15	12.5
10	70	74.5	240	30	25
20	40	88.2	100	60	68.75
30	45	85.1	40	55	87.5

VI. Run # 6 medium strength synthetic surface water [100 NTU] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	150	40	280	0	0
5	150	40	280	0	0
10	120	59	220	20	21.42
20	110	62	180	26.66	35.71
30	90	69	140	40	50

VII. Run # 7 high strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	155	41.6	220	0	0
5	135	55.2	210	12.90	4.54
10	115	60.5	200	25.80	9.09
20	50	77.7	100	67.74	54.54
30	40	90.2	60	74.19	72.72

VIII. Run # 8 high strength synthetic surface water [50 NTU] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TSS (mg/l)	%Turbidity removal	%TSS removal
0	150	41.6	280	0	0
5	110	62.3	240	26.66	14.28
10	50	76.3	160	66.66	42.85
20	35	90.6	100	76.66	64.28
30	25	93.4	40	83.33	85.71

IX. Run # 9 High strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	55	72.6	45.21	0	0
5	60	71.6	41.28	-9.98	6.70
10	75	73.4	38.03	-27.27	15.88
20	35	83.2	35.84	36.36	20.72
30	20	94	35.46	63.63	21.78

X. Run # 10 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	60	78.9	44.13	0	0
5	70	82	40.03	-16.66	8.10
10	80	89	37.08	-33.33	15.38
20	55	96.7	34.66	8.33	20.13
30	32	87.9	29.33	36.33	31.35

XI. Run # 11 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	60	72.6	44.13	0	0
5	40	71.6	40.03	33.33	9.29
10	32	73.4	37.18	46.66	15.97
20	25	83.2	34.66	58.83	21.45
30	35	94	29.33	41.63	33.53

XII. Run # 12 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at a Current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	120	61.2	47.83	0	0
5	120	61.2	45.3	0	5.28
10	120	62	42.1	0	11.97
20	90	74	41.51	41.51	13.21
30	40	87	38.68	38.68	19.13

XIII. Run # 13 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor Operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	120	54.6	65.23	0	0
5	110	59	54.2	8.33	11
10	100	62	44.8	16.66	20.4
20	55	76	41.83	54.16	23.37
30	20	94	35.06	83.33	30.14

XIV. Run # 14 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	160	48.2	85.18	0	0
5	160	49	79.2	0	7.02
10	160	49	71.4	0	16.24
20	135	58	65	14.70	23.69
30	85	71.2	59.1	44.11	30.61

XV. Run # 15 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor Operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	160	58	59.64	0	0
5	135	66	47.23	15.6	20.8
10	110	75	38.62	31.2	35.2
20	25	93	36.71	84.3	38.4
30	24	95	39.2	85	44.7

XVI. Run # 16 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor Operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	TOC (mg/l)	%Turbidity removal	%TOC removal
0	160	57	70.8	0	0
5	130	68	58	20	18.0
10	100	80	37.6	40	46.8
20	25	92	36.7	90	48.2
30	20	96	36	93.3	49.1

XVII. Run # 17 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor Operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	75	67	-50
5	68	75	-36
10	60	89.6	-20
20	25	91.3	50
30	22	93	56

XVIII. Run # 18 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	75	74.8	-50
5	62	78	-24
10	50	85	0
20	25	92.4	50
30	20	94	60

XIX. Run # 19 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor With the addition of 1g/l aluminum sulfate octadecahydrate operating at a Current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	75	67	-50
5	60	79	-20
10	50	82	0
20	45	85	10
30	40	87	20

XX. Run # 20 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	120	62.5	-20
5	110	66	-10
10	100	68	0
20	60	79	40
30	50	80	50

XXI. Run # 21 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	115	62	-15
5	75	74	25
10	50	76.6	50
20	45	81.6	55
30	40	84	60

XXII. Run # 22 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	115	49.2	-15
5	82	78	18
10	75	71	25
20	40	83.4	60
30	35	86	65

XXIII. Run # 23 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	180	30.8	-20
5	180	31.2	-20
10	180	35	-20
20	140	38	6.6
30	125	42.5	16.6

XXIV. Run # 24 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current ampere

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	180	53.5	-20
5	175	58	-16.6
10	160	60.1	0
20	100	73.5	33.3
30	43	90	71.3

XXV. Run # 25 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	170	31.4	-13.3
5	105	65.8	30
10	80	72.6	46.6
20	55	90.4	63.3
30	40	90.4	73.3

XXVI. Run # 26 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l aluminum sulfate octadecahydrate operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	350	37.4	-600
5	270	43.5	-440
10	150	63.8	-200
20	40	93.5	20
30	20	98.1	60

XXVII. Run # 27 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	300	44.4	-500
5	180	60.7	-260
10	65	81.7	-30
20	25	96.4	50
30	20	97.1	60

XXVIII. Run # 28 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	300	50.5	-500
5	150	64	-200
10	50	88	0
20	20	96.4	50
30	18	99	64

XXIX. Run # 29 Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	300	36.4	-250
5	280	46.6	-180
10	160	62.9	-60
20	40	91.5	60
30	20	95	80

XXX. Run # 30 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	300	39.1	-200
5	240	46.3	-140
10	120	68.3	-20
20	28	94	72
30	28	94.3	72

XXXI. Run # 31 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	350	36.4	-250
5	280	46.3	-180
10	160	62.9	-60
20	40	91.5	60
30	20	95	80

XXXII. Run # 32 medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	450	35	-200
5	320	40	-113.3
10	250	45	-66.6
20	100	70	33.3
30	100	70	33.3

XXXIII. Run # 33 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	400	28.8	-166.6
5	250	44.5	-66.6
10	110	71.8	26.6
20	30	95.2	80
30	32	95.2	78.6

XXXIV. Run # 34 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	400	43.8	-166.6
5	220	50	-46.6
10	65	76.5	56.6
20	28	93.7	81.3
30	25	95.5	83.3

XXXV. Run # 35 high strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	80	53.3	-60
5	95	41.6	-90
10	110	28.8	-120
20	200	13.5	-300
30	240	11.0	-380

XXXVI. Run # 36 low strength synthetic surface water [50 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at a current I = 1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	80	49.3	-60
5	100	40.3	-100
10	120	19.2	-140
20	300	10.8	-500
30	350	7.8	-600

XXXVII. Run # 37 low strength synthetic surface water [50 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at a current I = 3 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	150	12	0
5	190	9	-13.3
10	245	8.0	-26.6
20	280	5.5	-13.3
30	300	3.0	0

XXXVIII. Run # 38 high strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at a current I =1 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	150	18.5	0
5	155	18.8	-3.3
10	180	26.8	-20.0
20	200	11.2	-33.3
30	200	11.0	-33.3

XXXIX. Run # 39 high strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at a current I =2 ampere.

Time (min)	Turbidity (NTU)	%Transmissivity	%Turbidity removal
0	150	19.6	0
5	170	19.6	-13.3
10	190	22.3	-26.6
20	170	25	-13.3
30	150	26.2	0

XL. Run # 40 high strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at a current I =3 ampere.

Time (min)	TOC	%TOC removed
0	42.2	0
5	34.9	17.4
10	34.0	19.5
20	34.0	19.6
30	33.5	20.5

XLI. Run # 41 Low strength synthetic milk waste water [100 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 1ampere.

Time (min)	TOC	%TOC removed
0	48.47	0
5	40.32	16.8
10	38.2	21.1
20	37.6	22.3
30	34.0	29.7

XLII. Run # 42 Low strength synthetic milk waste water [100 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2ampere.

Time (min)	TOC	%TOC removed
0	50	0
5	43.8	12.2
10	37.9	24.1
20	36.6	26.8
30	33.3	32.2

XLIII. Run # 43 Low strength synthetic milk waste water [100 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 3 ampere.

Time (min)	TOC	%TOC removed
0	53.51	0
5	41.27	22.8
10	40.2	24.7
20	38.1	28.6
30	38.1	28.7

XLIV. Run # 44 Medium strength synthetic milk waste water [150 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 1ampere.

Time (min)	TOC	%TOC removed
0	67.0	0
5	54.2	19.16
10	49.0	26.9
20	45.7	31.8
30	45.4	32.2

XLV. Run # 45 Medium strength synthetic milk waste water [150 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	TOC	%TOC removed
0	90.32	0
5	69.9	22.5
10	63.0	30.2
20	59.0	33.8
30	58.4	35.2

XLVI. Run # 46 High strength synthetic milk waste water [200 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 2 ampere.

Time (min)	TOC	%TOC removed
0	80	0
5	69.2	13.4
10	60	25.2
20	59.0	27.2
30	58.2	27

XLVII. Run # 47 High strength synthetic milk waste water [200 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 1 ampere.

Time (min)	TOC	%TOC removed
0	87.2	0
5	63.0	27.6
10	57.4	34.1
20	57.3	34.2
30	51.3	41.8

XLVII. Run # 48 High strength synthetic milk waste water [200 mg/l] treatment using Electro Coagulation/ Flotation reactor operating at a current I = 3 ampere.

APPENDIX C
LIST OF FIGURES

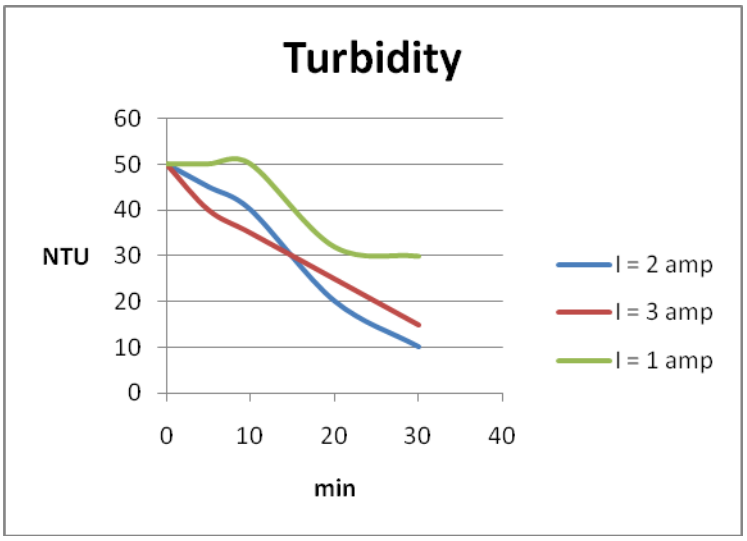


Figure 1: Treatment of low strength synthetic surface water for the entire range of current 1to 3 ampere Turbidity (NTU) vs. Time (min)

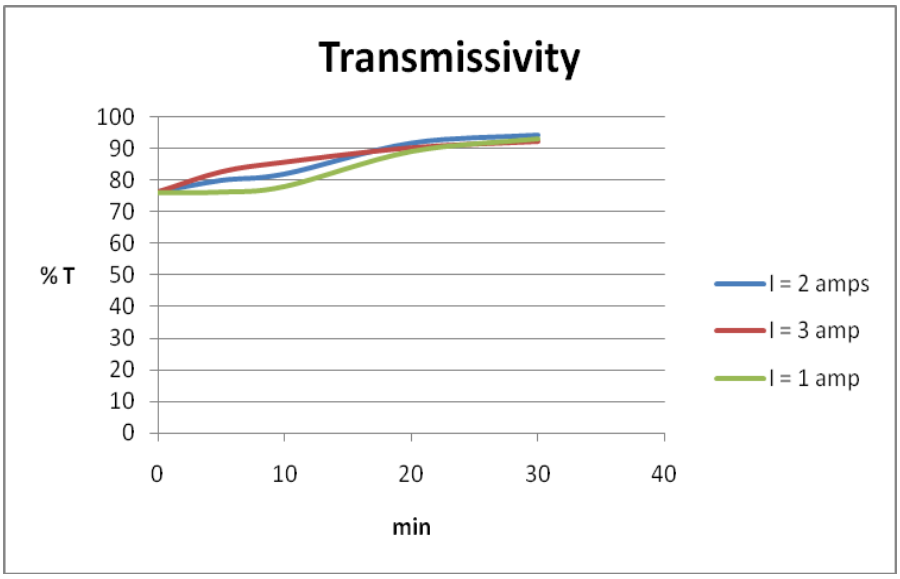


Figure 2: Treatment of low strength synthetic surface water for the entire range of current 1 to 3 ampere %Transmittance (%T) vs. Time (min)

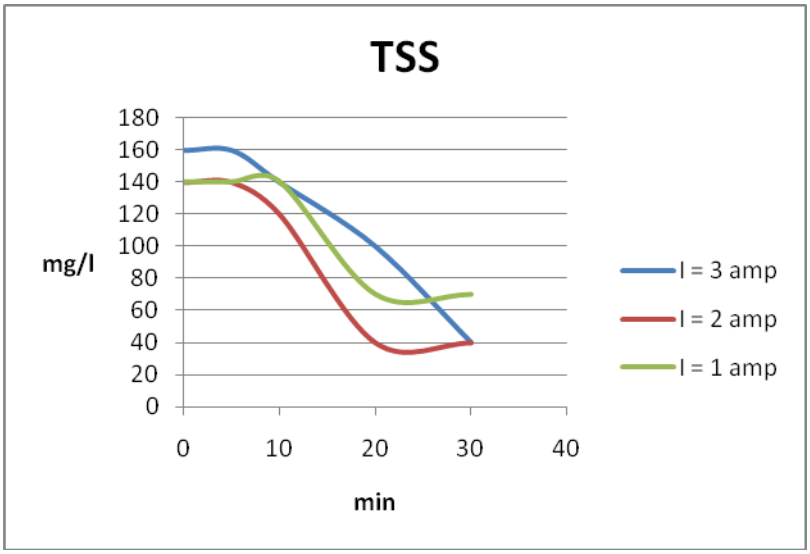


Figure 3: Treatment of low strength synthetic surface water for the entire range of Current 1 to 3 ampere TSS (mg/l) vs. time (min)

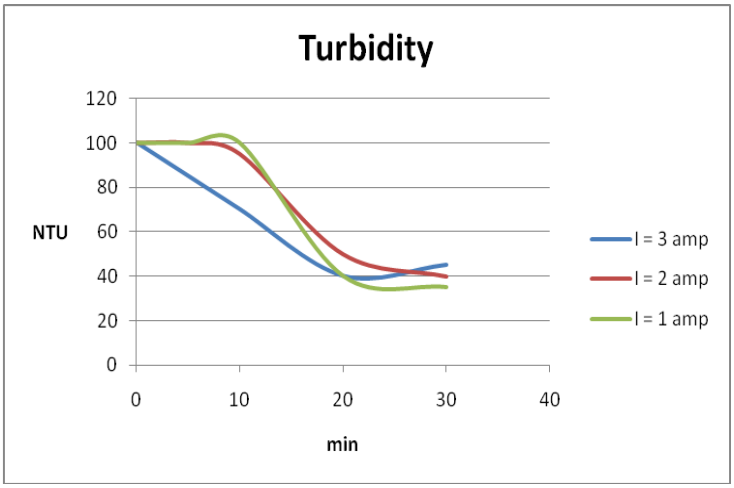


Figure 4: Treatment of medium strength synthetic surface water for the entire range of current 1 to 3 ampere Turbidity (NTU) vs. time (min)

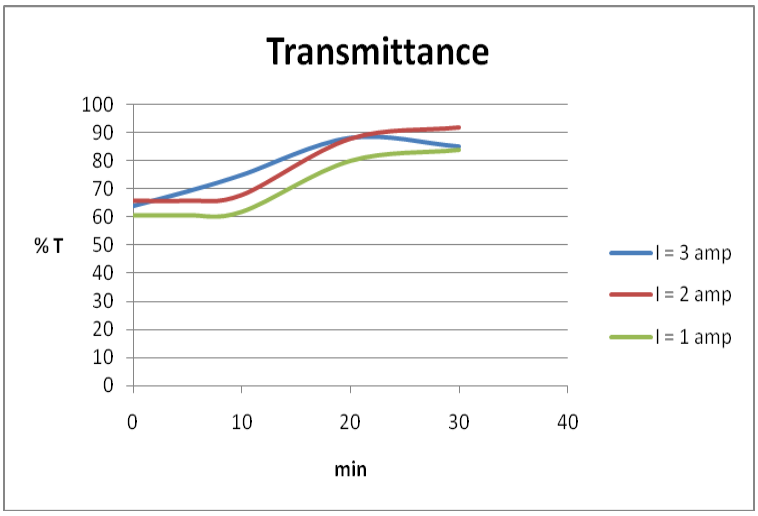


Figure 5: Treatment of medium strength synthetic surface water for the entire range of current 1 to 3 ampere Transmittance (%T) vs. time (min)

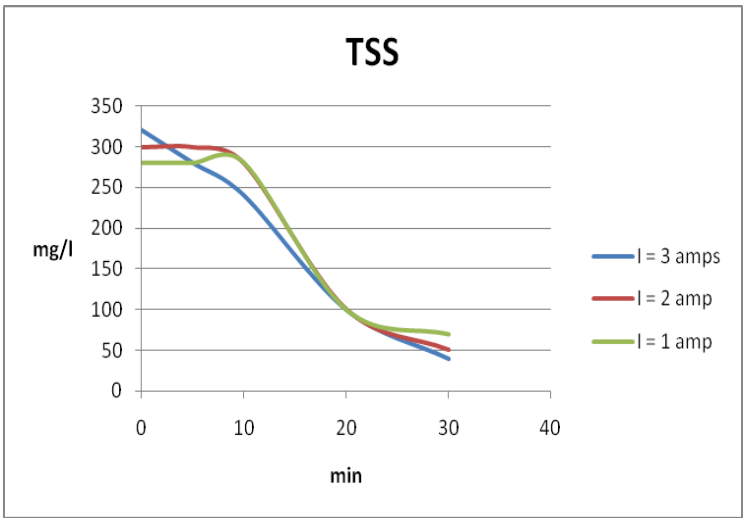


Figure 6: Treatment of medium strength synthetic surface water for the entire range of current 1 to 3 ampere TSS (mg/l) vs. time (min)

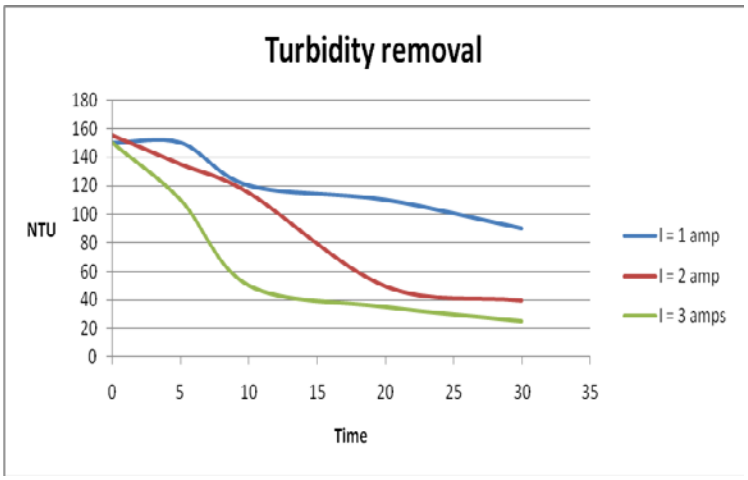


Figure 7: Treatment of high strength synthetic surface water for the entire range of Current 1 to 3 ampere Turbidity (NTU) vs. time (min)

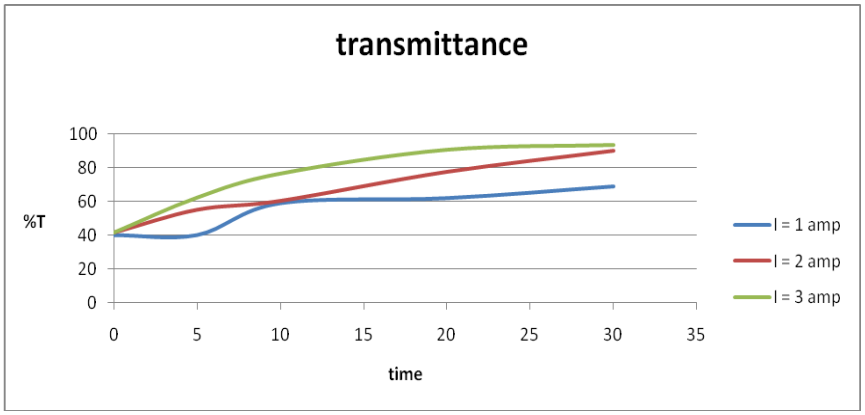


Figure 8: Treatment of high strength synthetic surface water for the entire range of Current 1 to 3 ampere Transmittance (%T) vs. time (min)

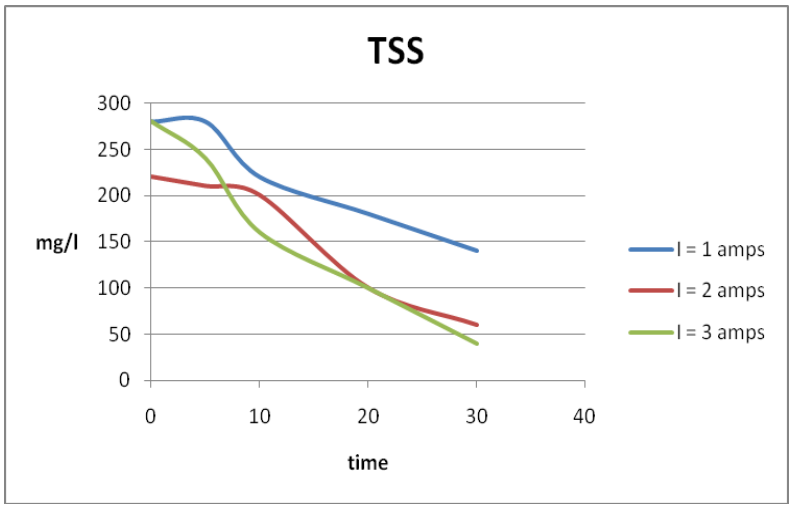


Figure 9: Treatment of high strength synthetic surface water for the entire range of current 1 to 3 ampere. TSS (mg/l) vs. time (min)

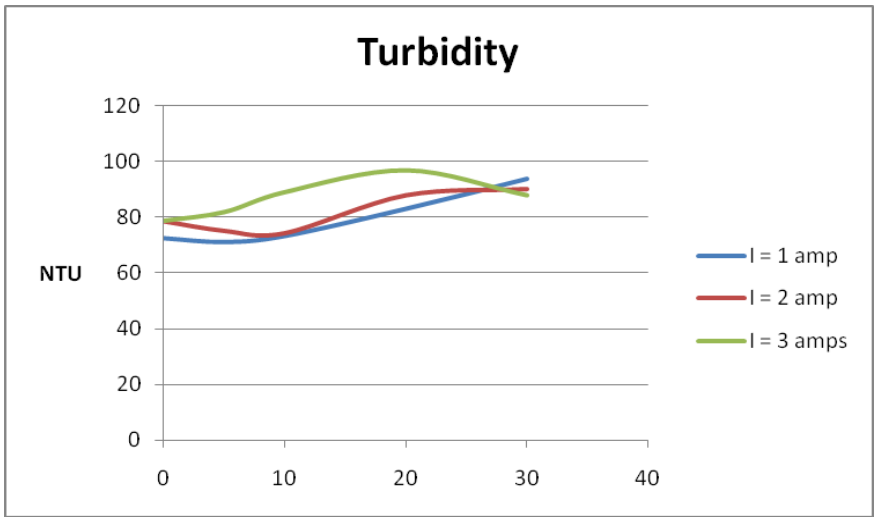


Figure10: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. Turbidity (NTU) vs. time (min)

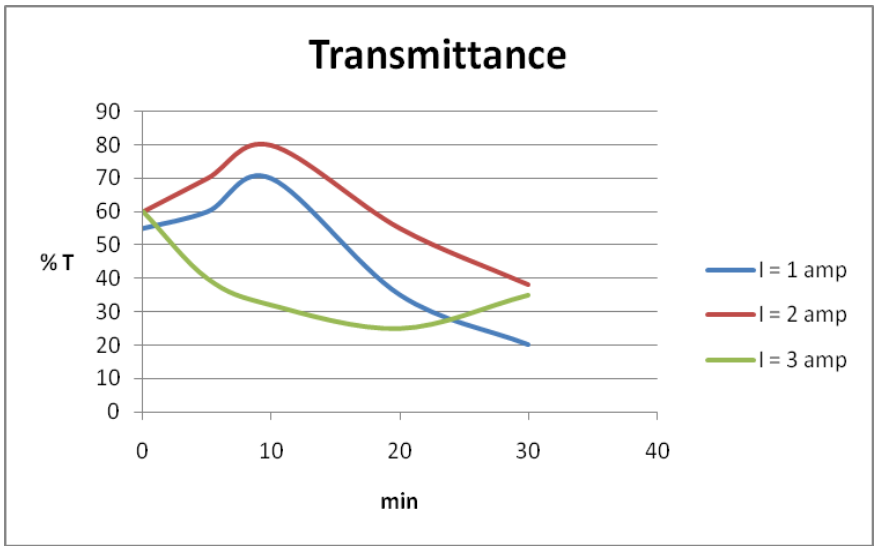


Figure 11: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. Transmittance (%T) vs. time (min)

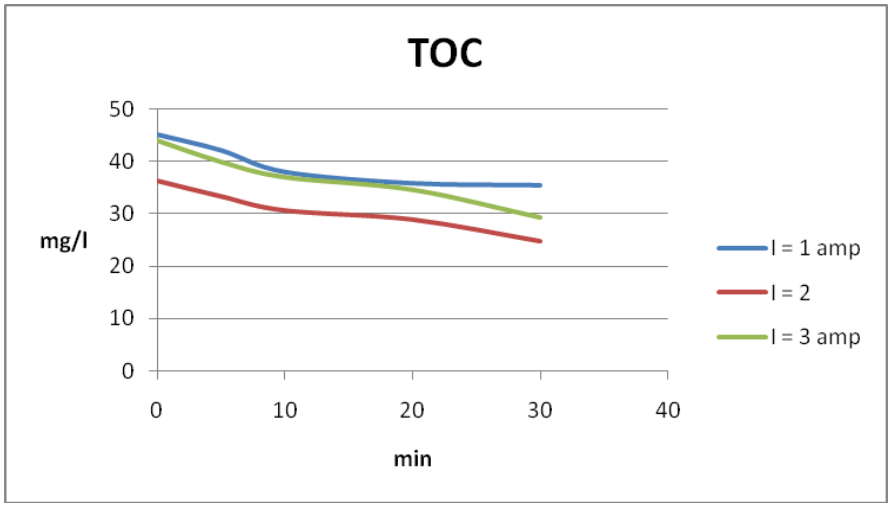


Figure 12: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. TOC (mg/l) vs. time (min).

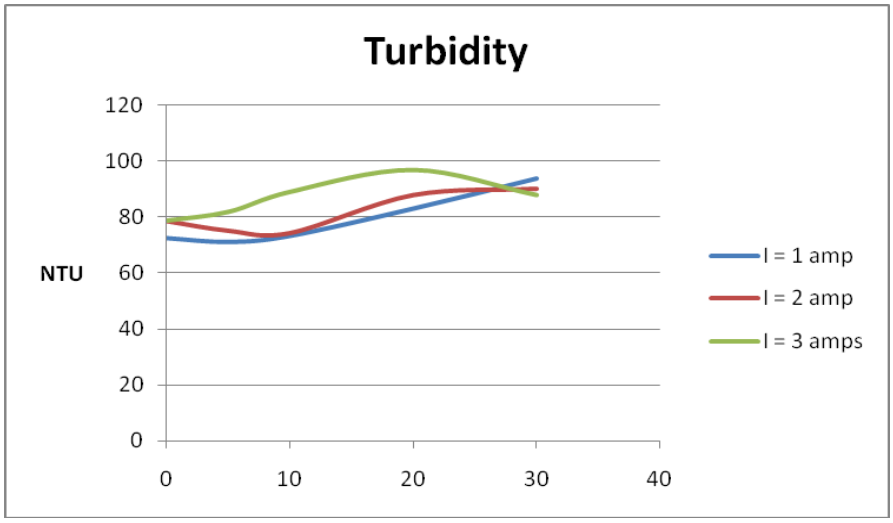


Figure 13: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. Turbidity (NTU) vs. time (min)

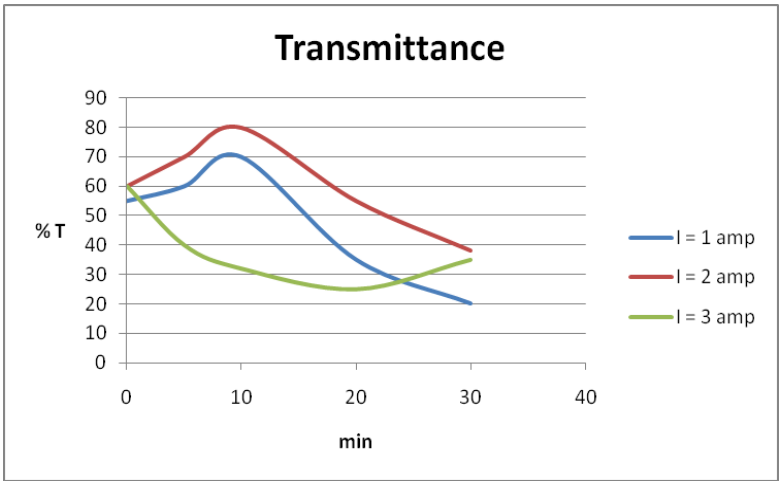


Figure 14: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. Transmittance (%T) vs. time (min)

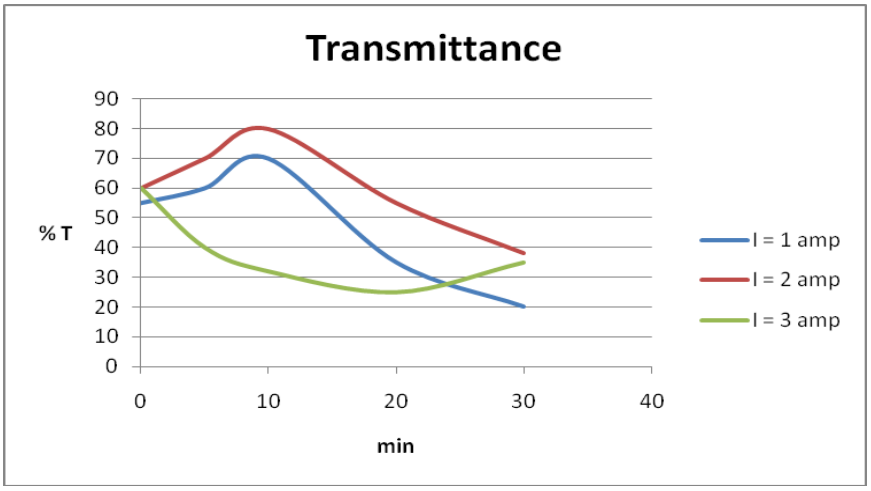


Figure 15: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. Transmittance (%T) vs. time (min)

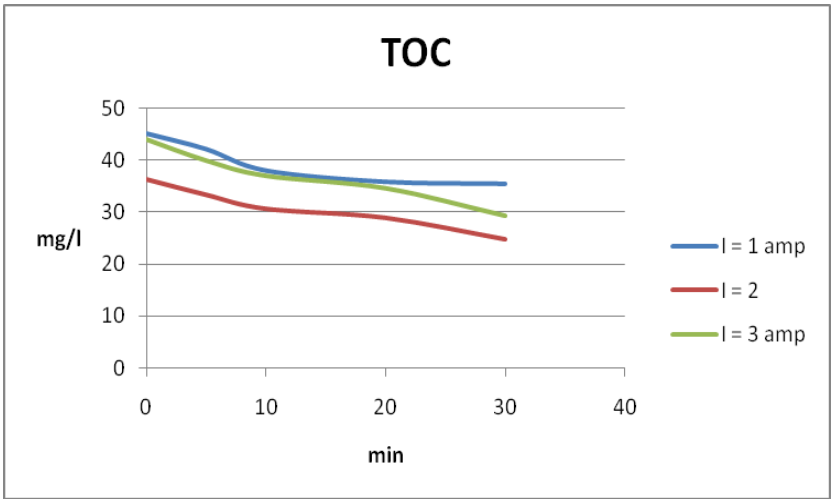


Figure 16: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents. TOC (mg/l) vs. time (min)

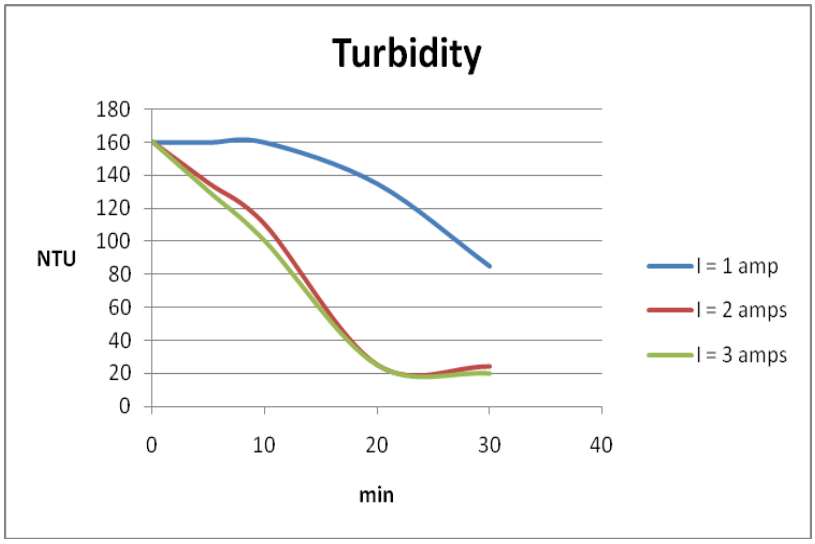


Figure 17: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents: Turbidity (NTU) vs. time (min)

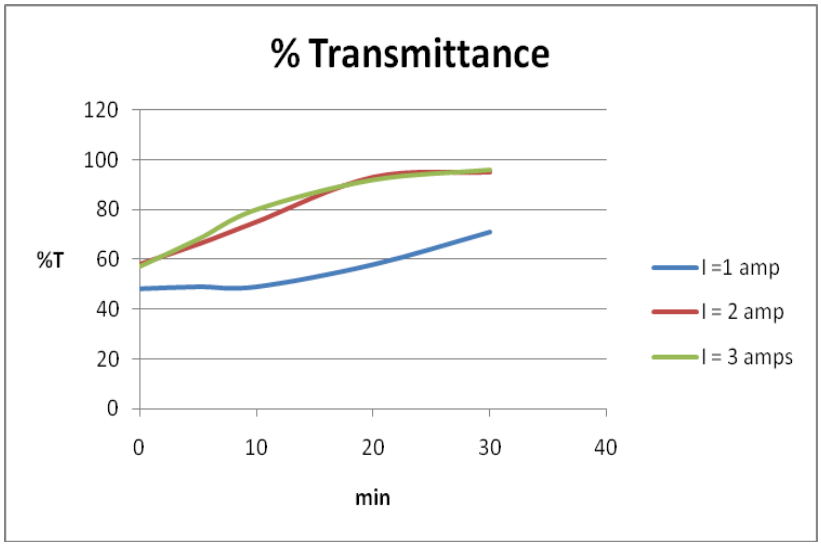


Figure18: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents: Transmittance (%T) vs. time (min)

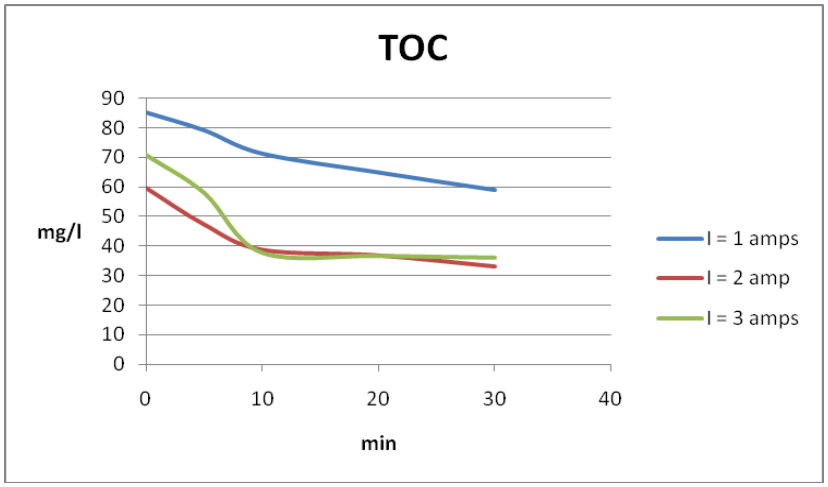


Figure19: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor operating at various currents: TOC (mg/l) vs. time (min).

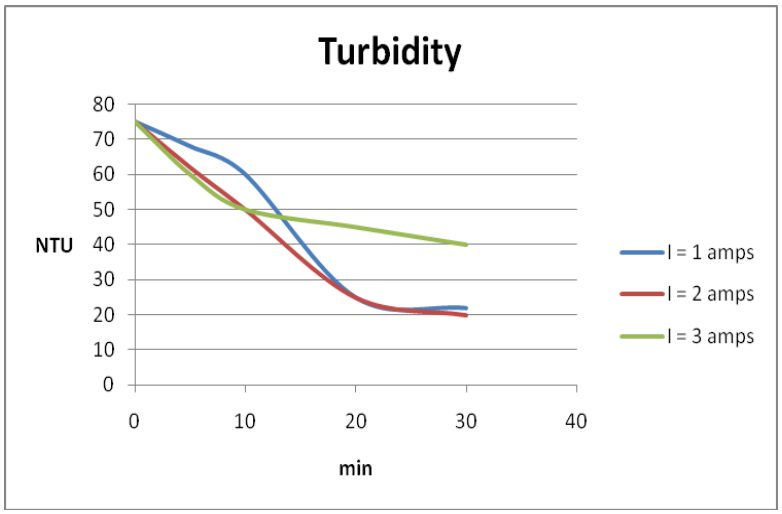


Figure 20: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. Turbidity (NTU) vs. time (min).

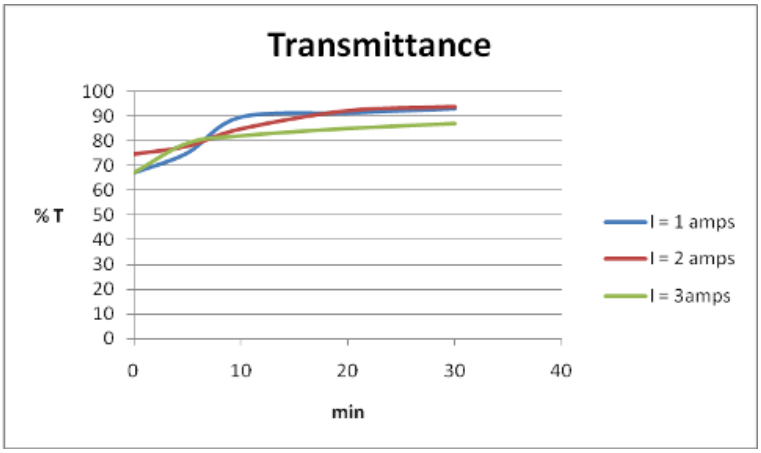


Figure21:Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. Transmissivity (%T) vs. time (min)

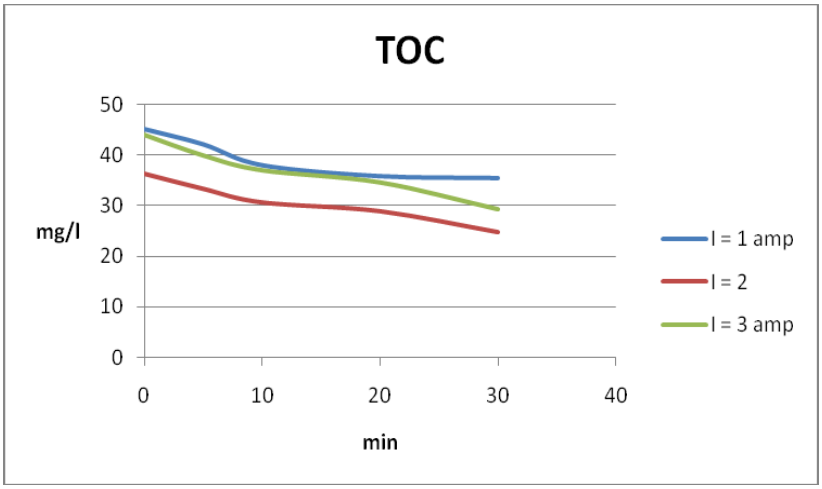


Figure 22: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. TOC (mg/l) vs. time (min)

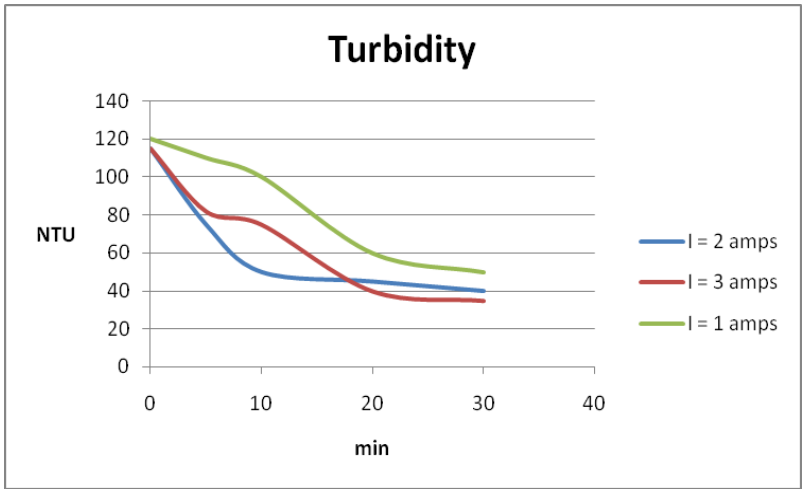


Figure 23: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate. Turbidity (NTU) vs. time (min)

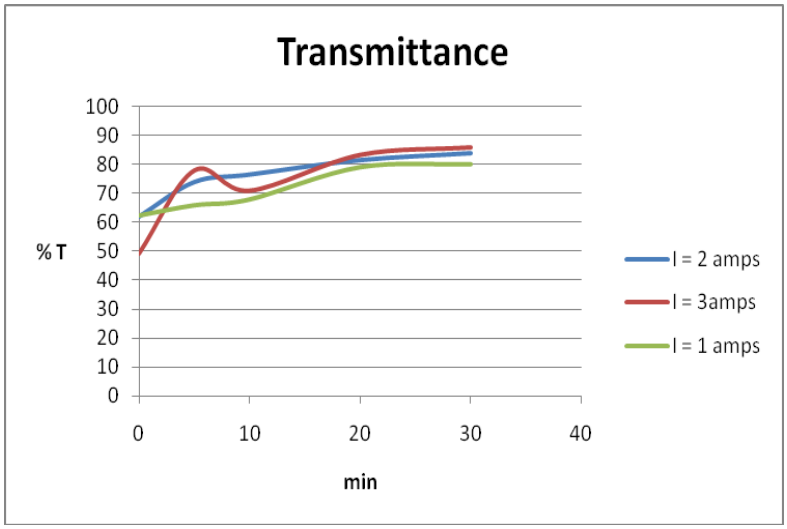


Figure 24: Medium strength synthetic surface water [100 NTU] containing 150 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. Transmittance (%T) vs. time (min)

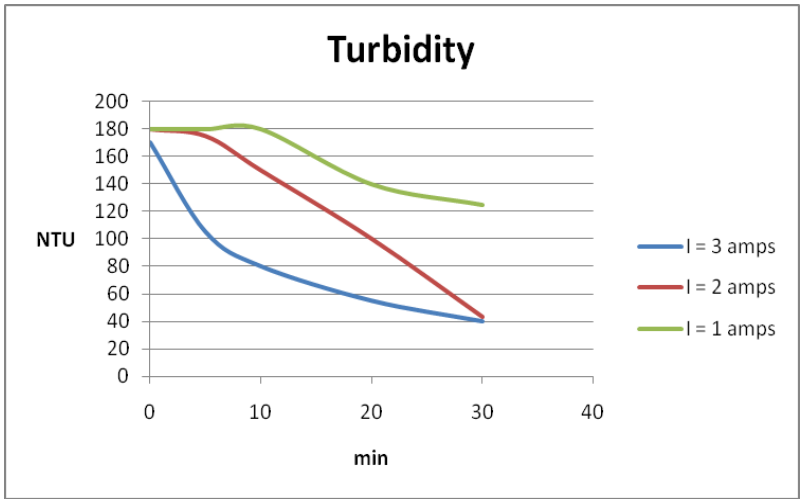


Figure 25: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. Turbidity (NTU) vs. time (min)

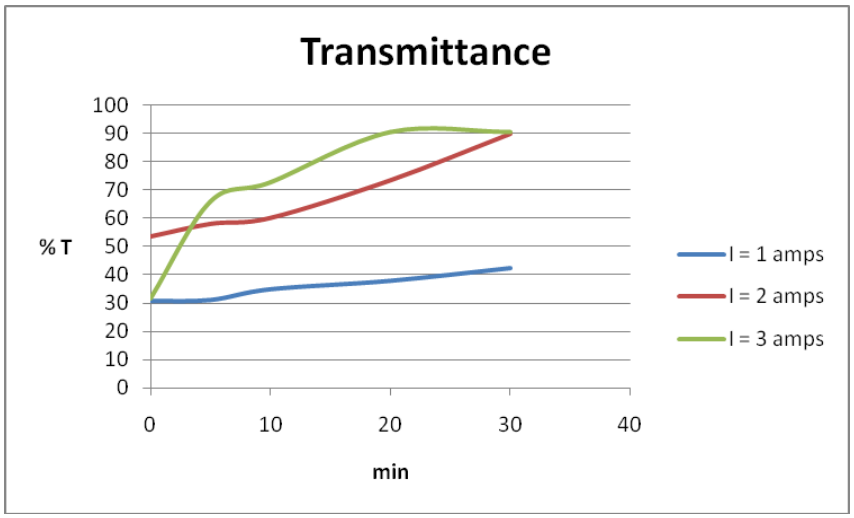


Figure 26: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 1g/l Aluminum sulfate octadecahydrate operating at various currents. Transmittance (%T) vs. time(min)

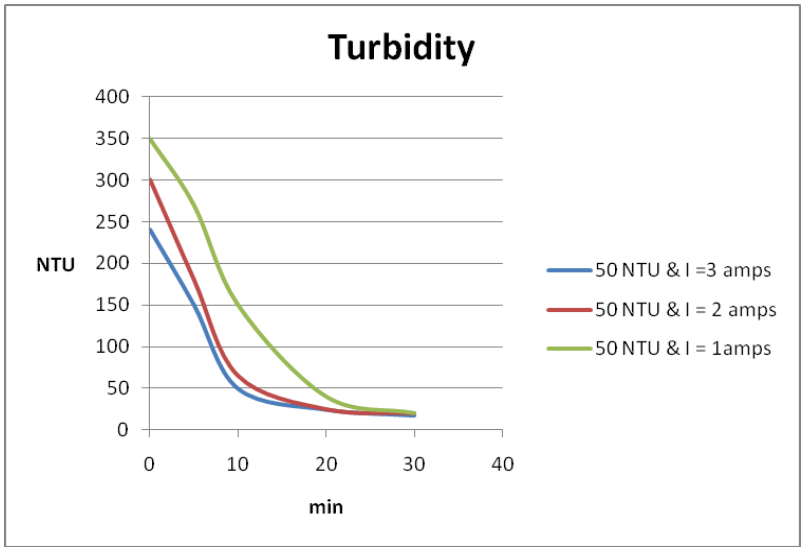


Figure 27: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Turbidity (NTU) vs. time

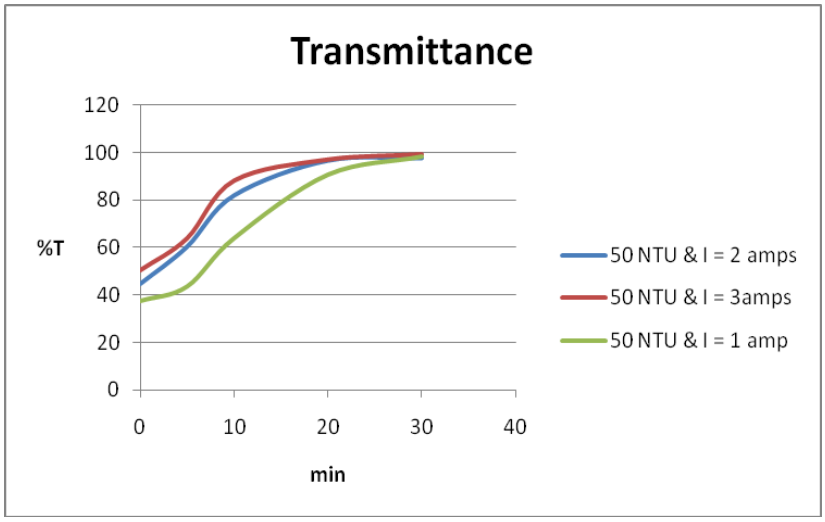


Figure 28: Low strength synthetic surface water [50 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Transmittance (%T) vs. time

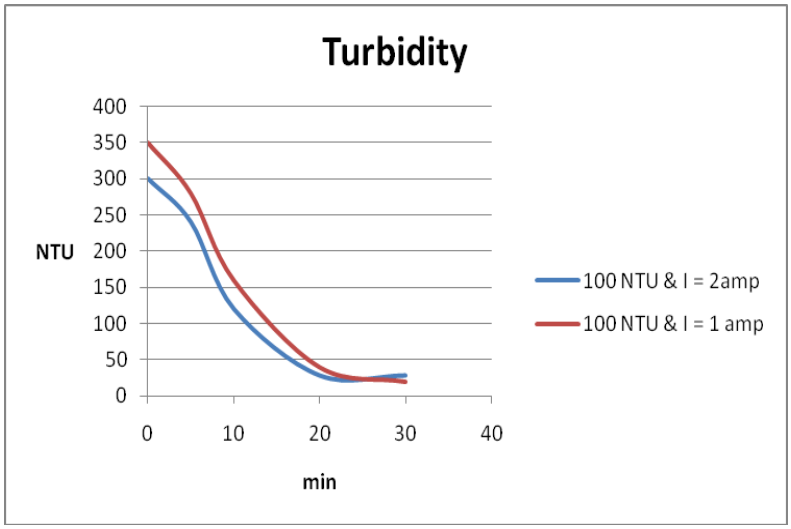


Figure 29: Medium strength synthetic surface water [100 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Turbidity (NTU) vs. time

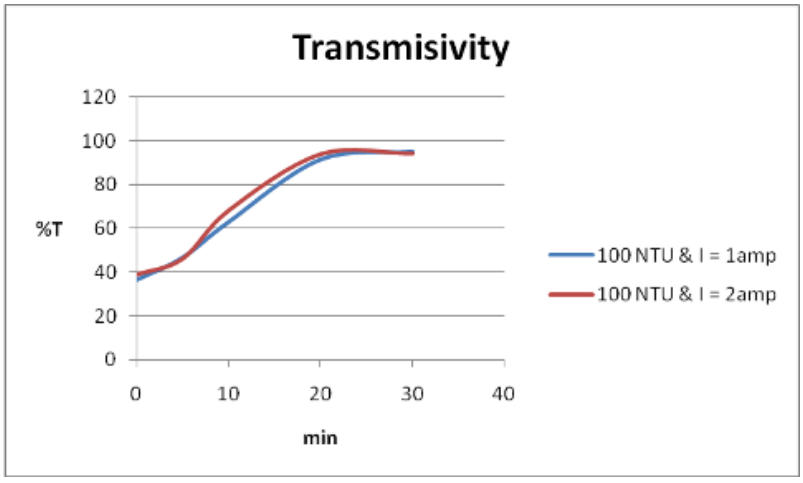


Figure 30: Medium strength synthetic surface water [100 NTU] containing 100 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Transmittance (%T) vs. time

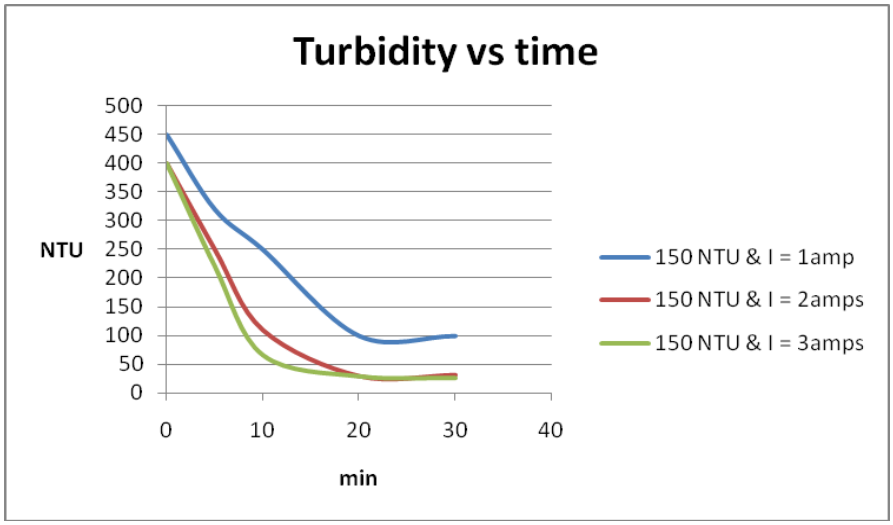


Figure 31: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Turbidity (NTU) vs. time

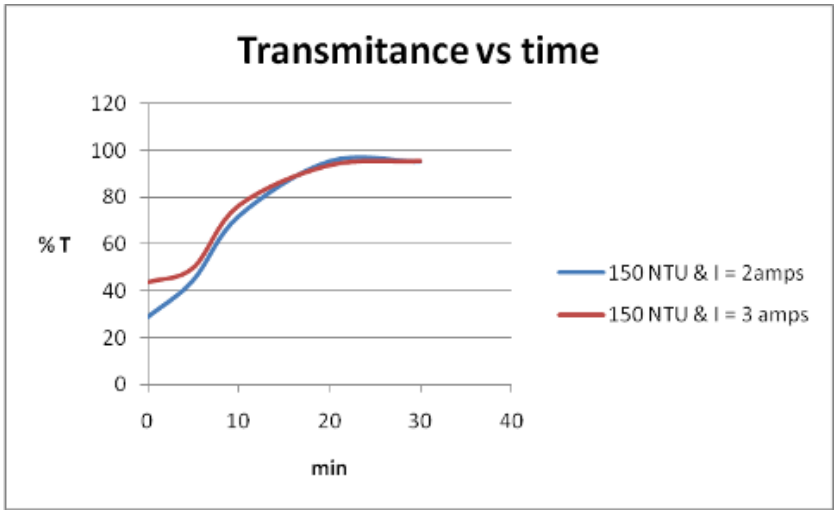


Figure 32: High strength synthetic surface water [150 NTU] containing 200 mg/l of organic content treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l lime operating at various currents. Transmittance (%T) vs. time

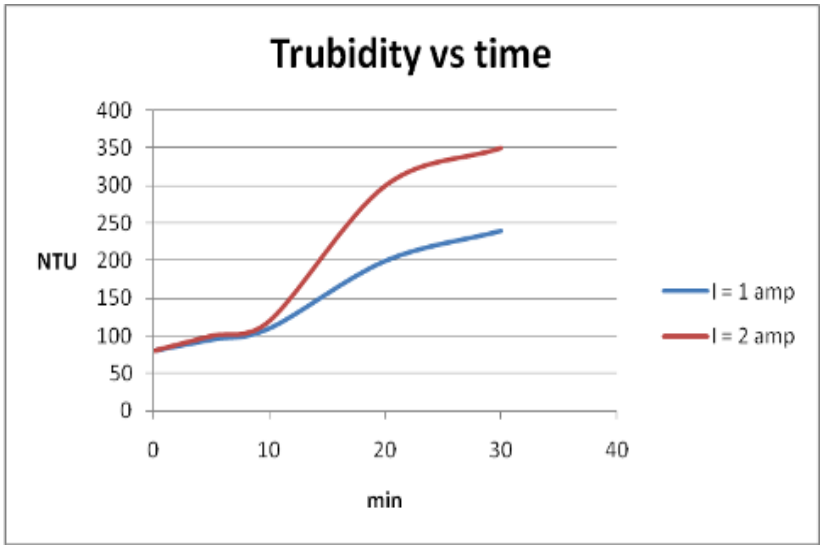


Figure 33: Low strength synthetic surface water [50 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at various currents. Turbidity (NTU) vs. time (min)

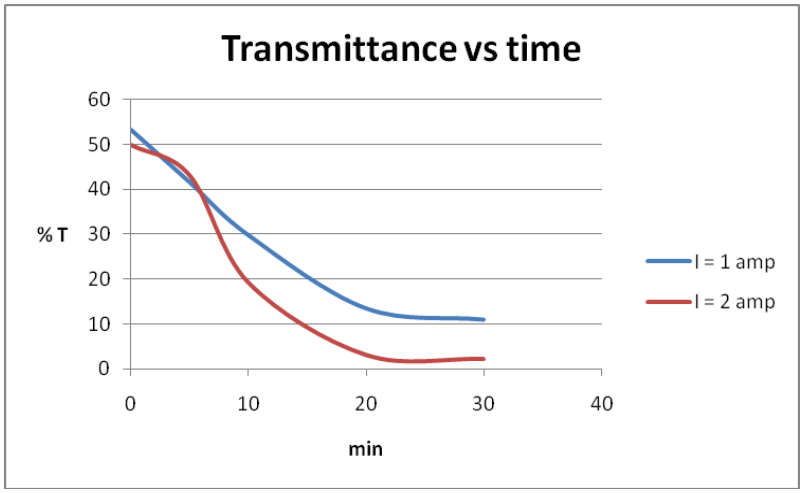


Figure 34: Low strength synthetic surface water [50 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at various currents. Transmissivity (%T) vs. time (min)

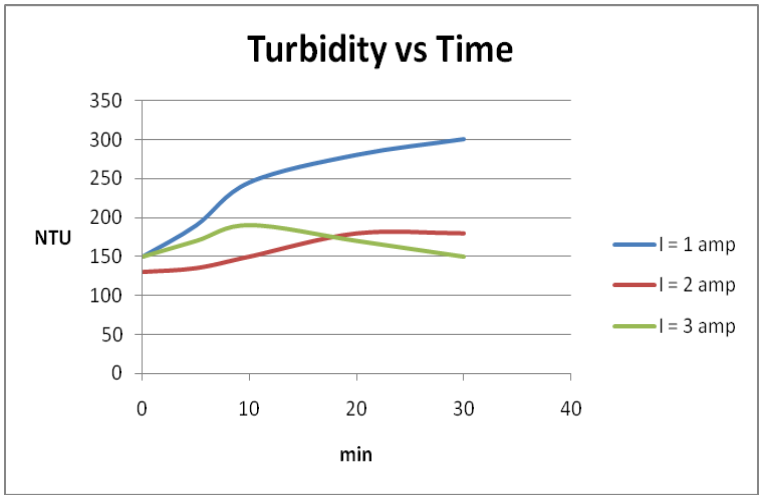


Figure 35: High strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at various currents. Turbidity (NTU) vs. time (min)

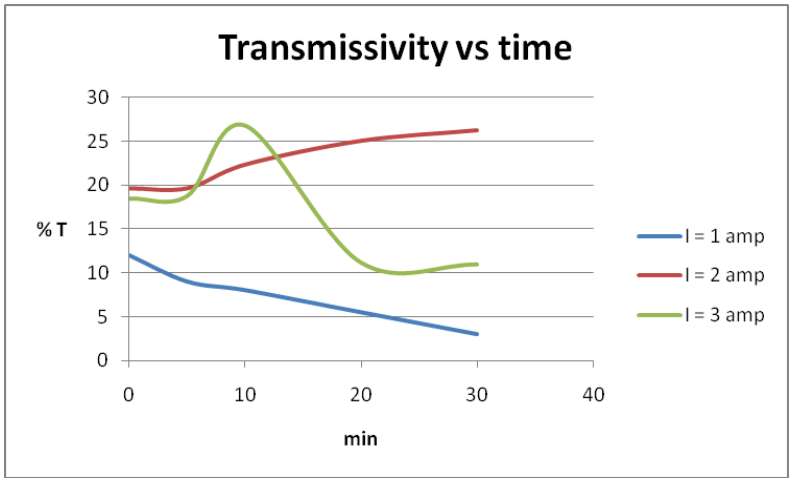


Figure 36: High strength synthetic surface water [150 NTU] treatment using Electro Coagulation/ Flotation reactor with the addition of 0.5 g/l Ferric Sulfate operating at various currents. Transmissivity (%T) vs. time (min)

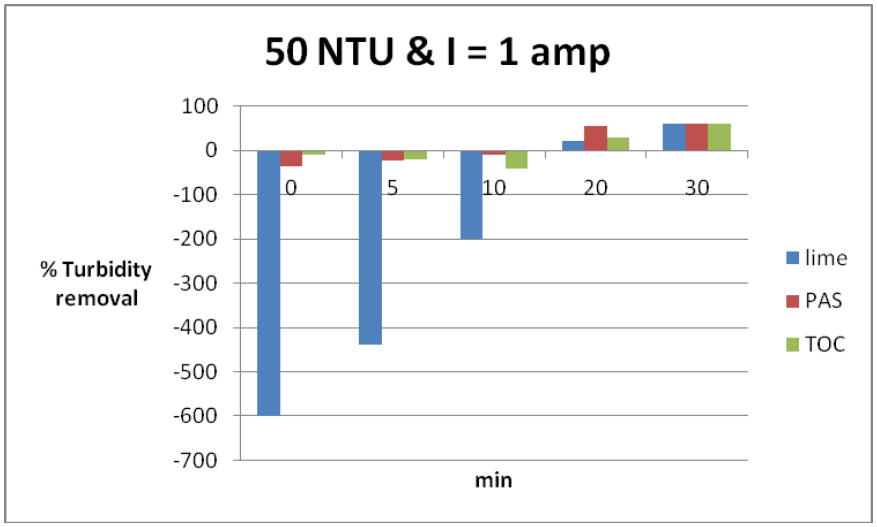


Figure 37: Low strength synthetic surface water [50 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water. %Turbidity removal vs. time

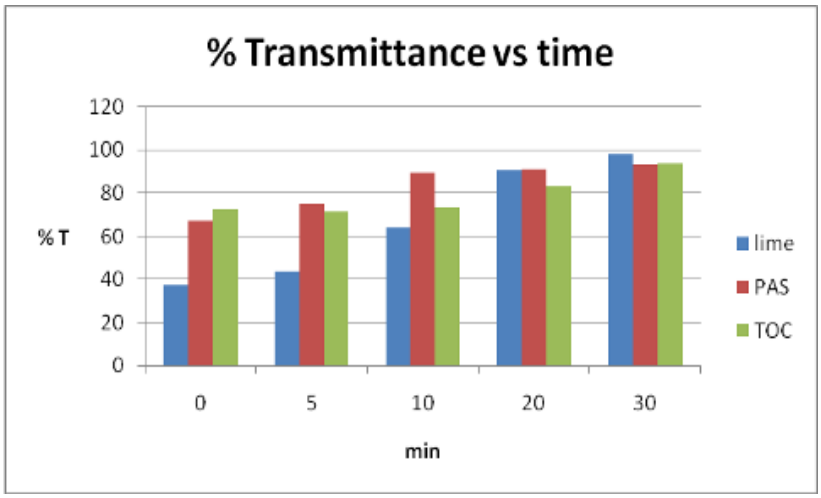


Figure 38: Low strength synthetic surface water [50 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water % Transmittance (%T) vs. time (min)

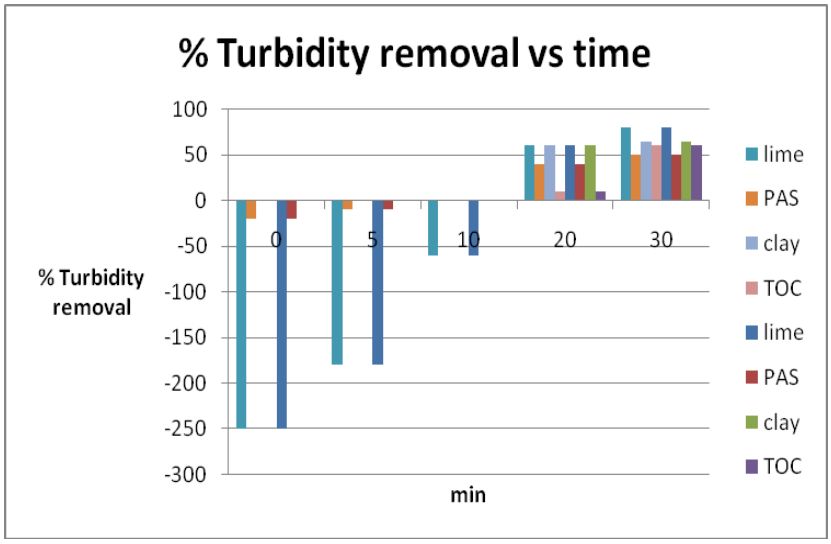


Figure 39: Medium strength synthetic surface water [100 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Turbidity removal vs. time

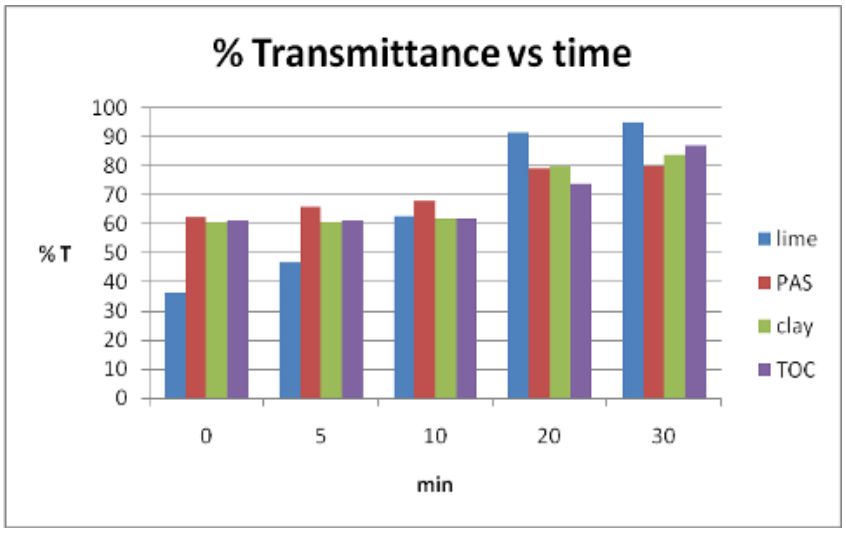


Figure 40: Medium strength synthetic surface water [100 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Transmittance (%T) vs. time (min)

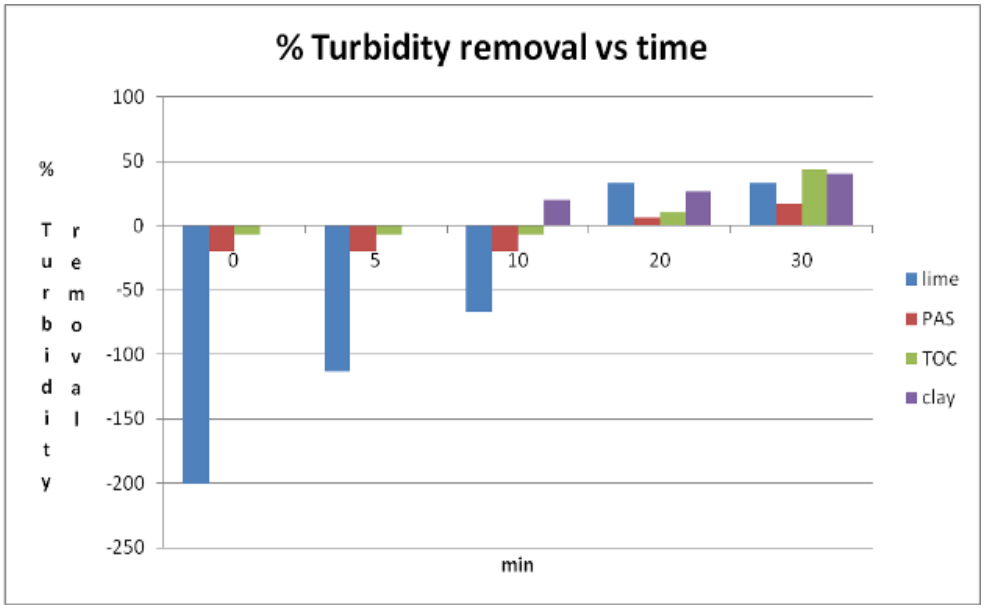


Figure 41: High strength synthetic surface water [150 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water %Turbidity removal vs. time

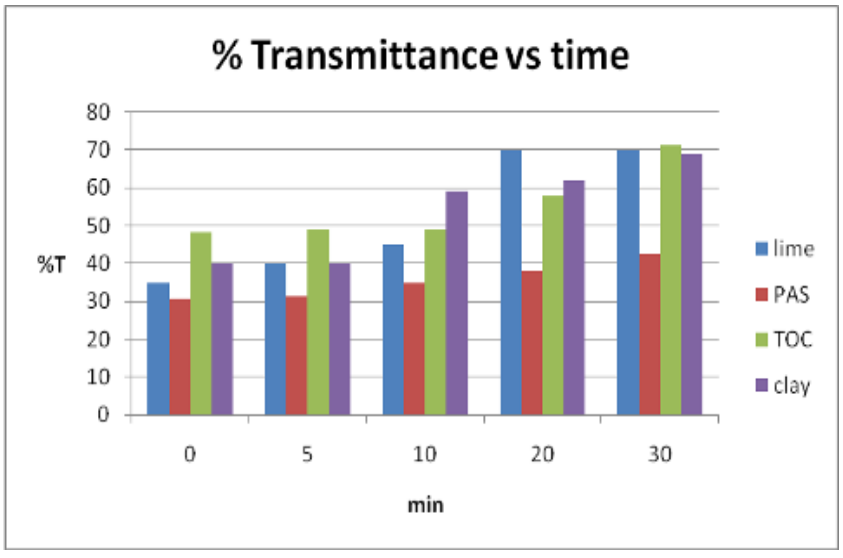


Figure 42: High strength synthetic surface water [150 NTU] treatment at current I = 1 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water % Transmittance (%T) vs. time (min)

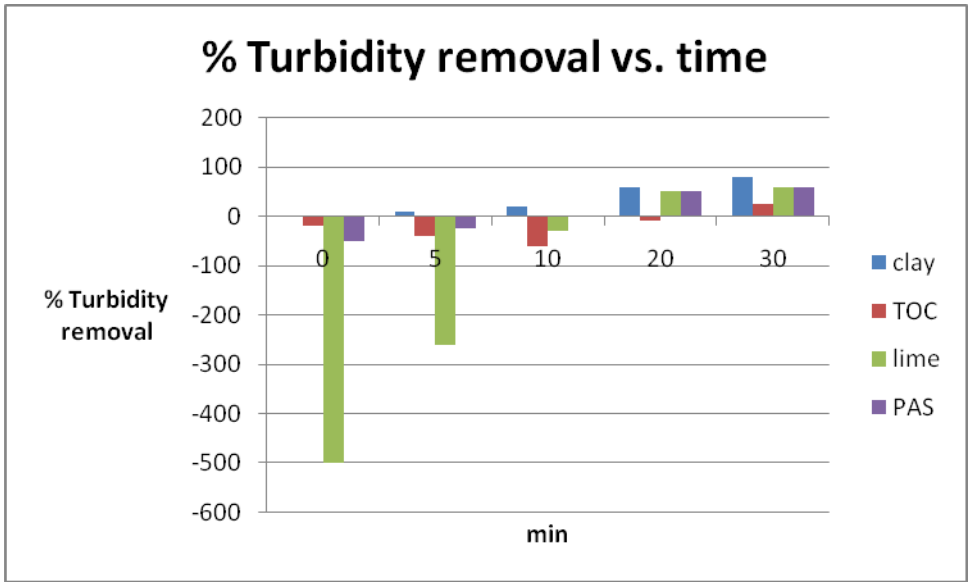


Figure 43: Low strength synthetic surface water [50 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water %Turbidity removal vs. time

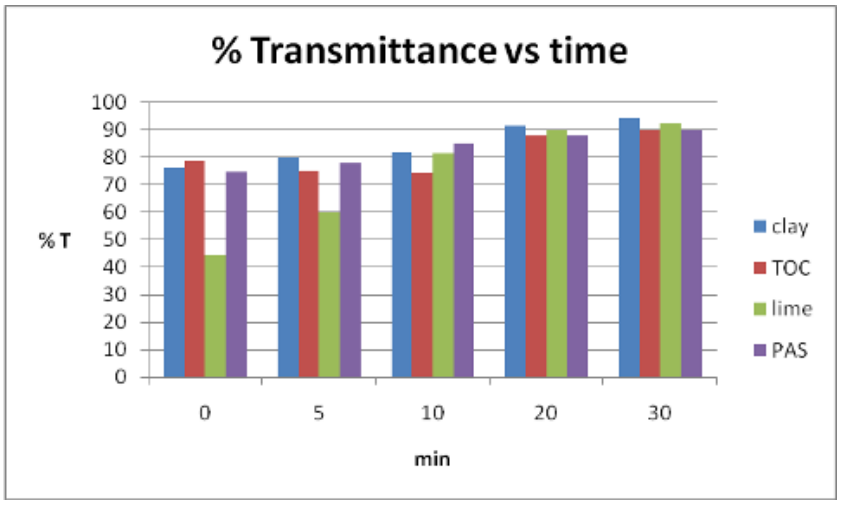


Figure 44: Low strength synthetic surface water [50 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water % Transmittance (%T) vs. time (min)

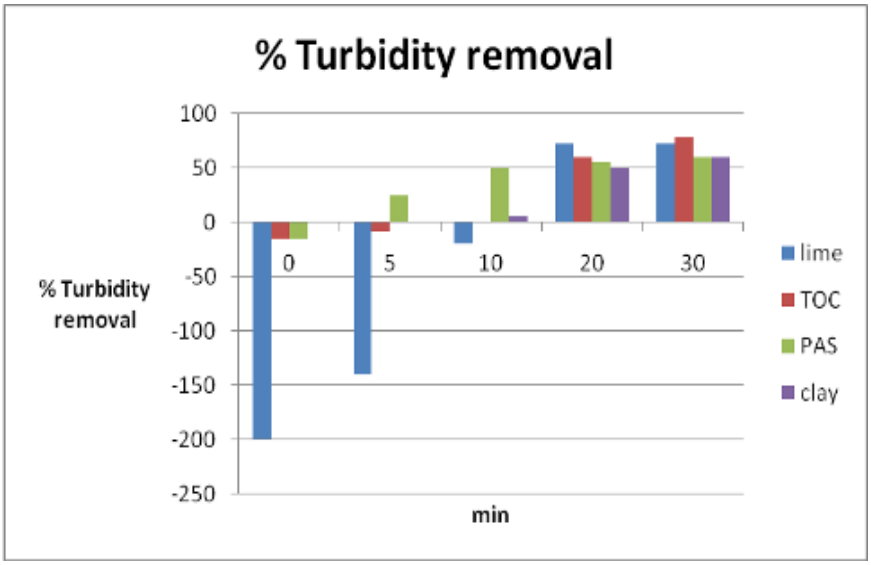


Figure 45: Medium strength synthetic surface water [100 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Turbidity removal vs. time

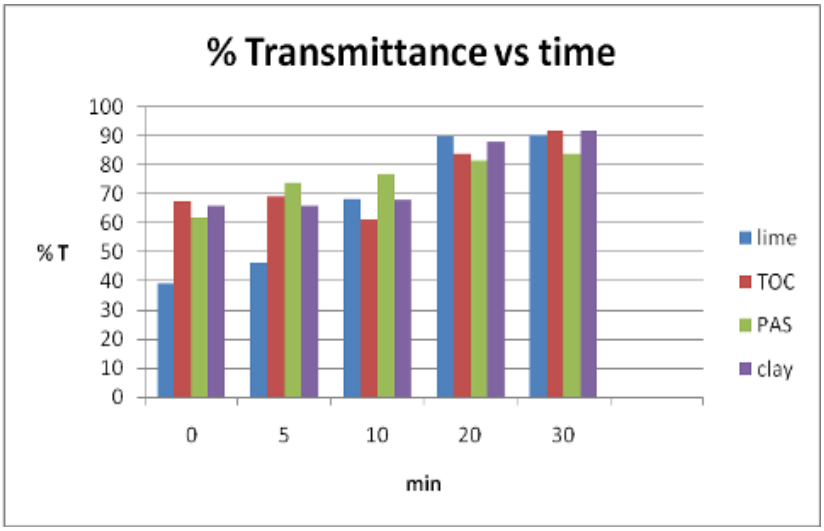


Figure 46: Medium strength synthetic surface water [100 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Transmittance (%T) vs. time (min)

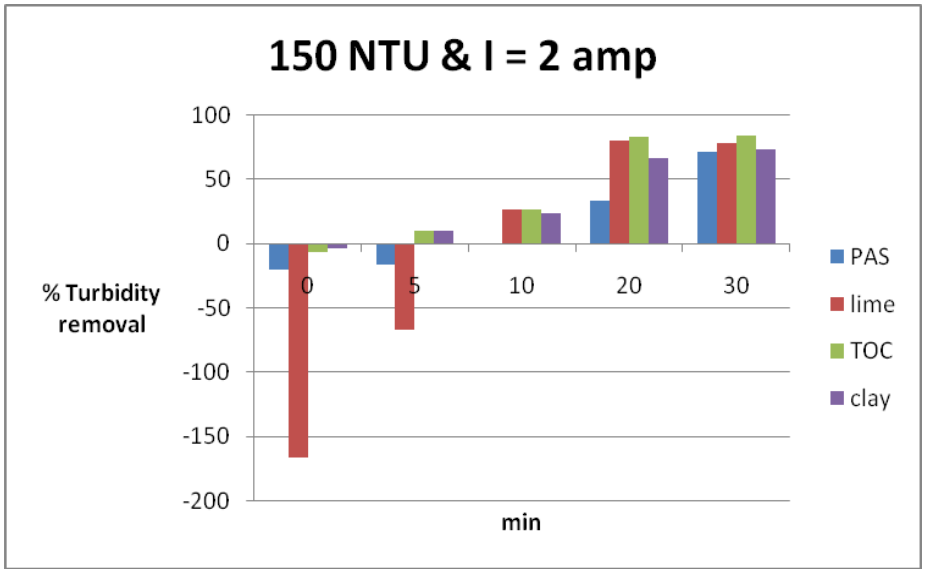


Figure 47: High strength synthetic surface water [150 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water % Turbidity removal vs. time

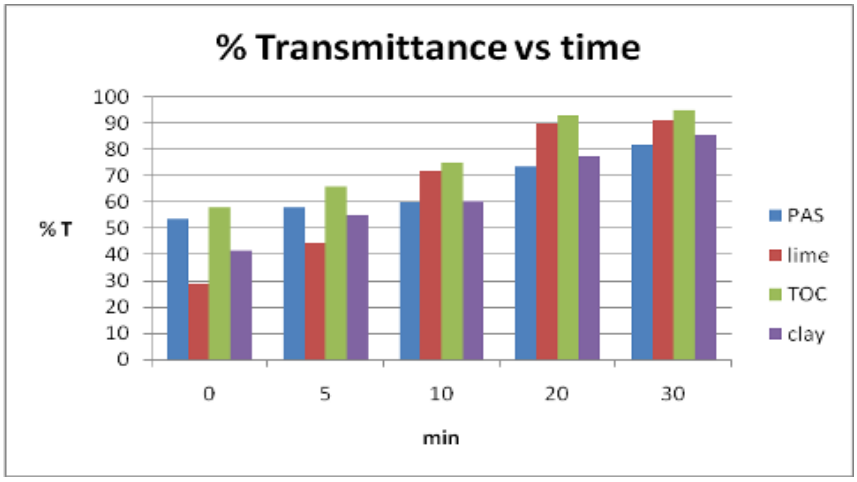


Figure 48: High strength synthetic surface water [150 NTU] treatment at current I = 2 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water % Transmittance (%T) vs. time (min)

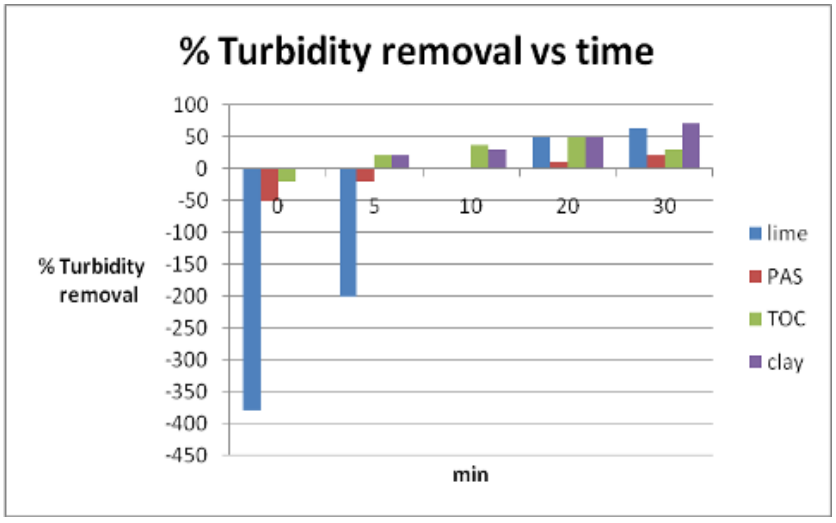


Figure 49: Low strength synthetic surface water [50 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water % Turbidity removal vs. time

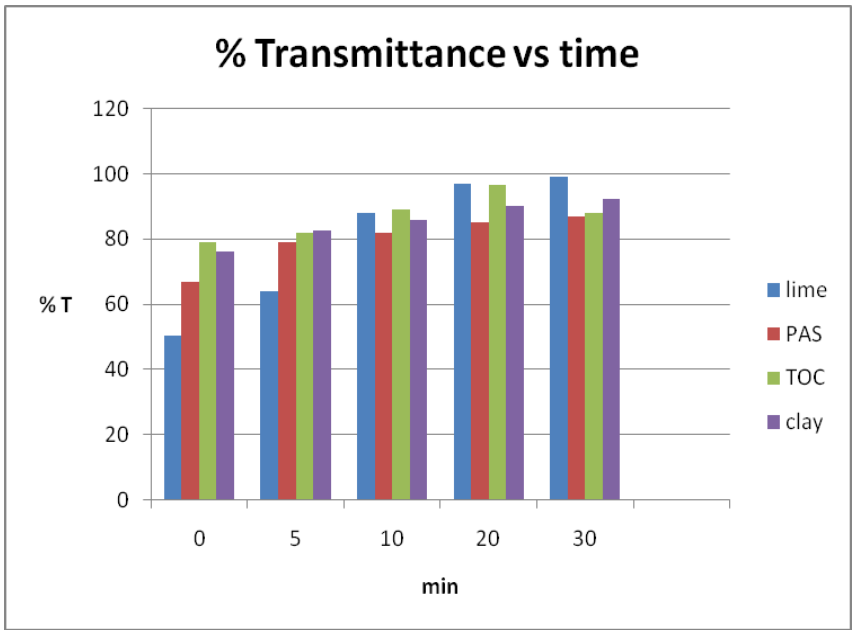


Figure 50: Low strength synthetic surface water [50 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Transmittance (%T) vs. time (min)

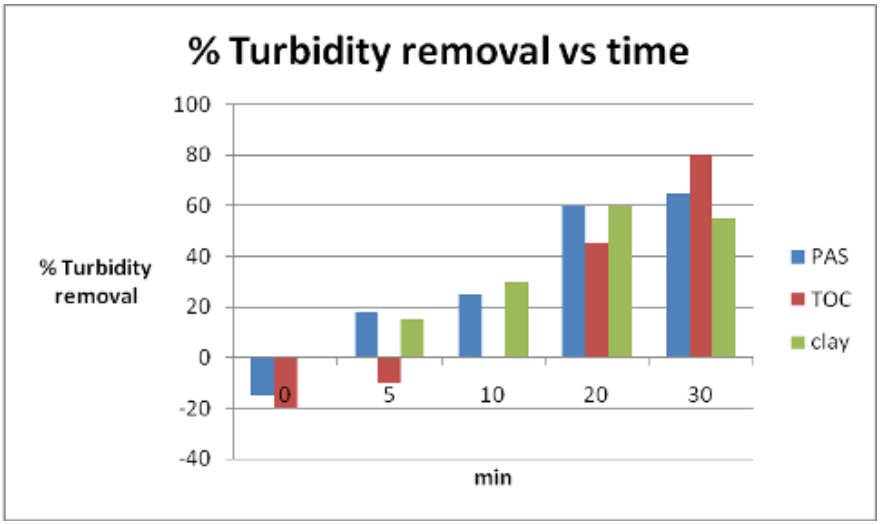


Figure 51: Medium strength synthetic surface water [100 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Turbidity removal vs. time

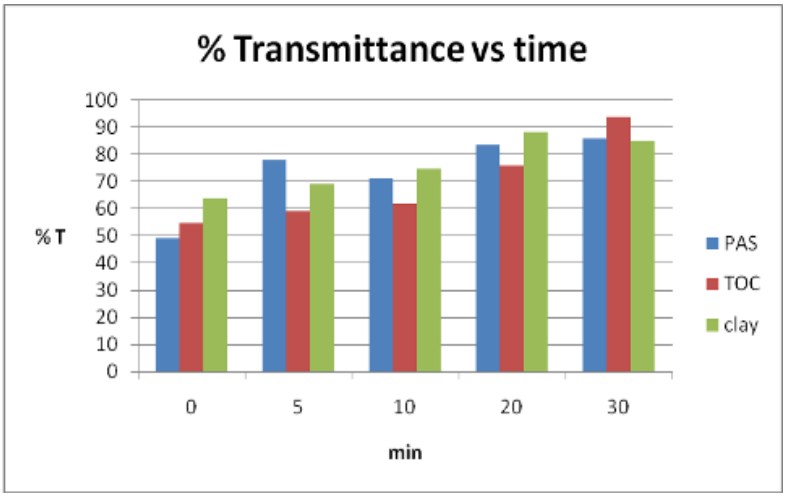


Figure 52: Medium strength synthetic surface water [100 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Transmittance (%T) vs. time (min)

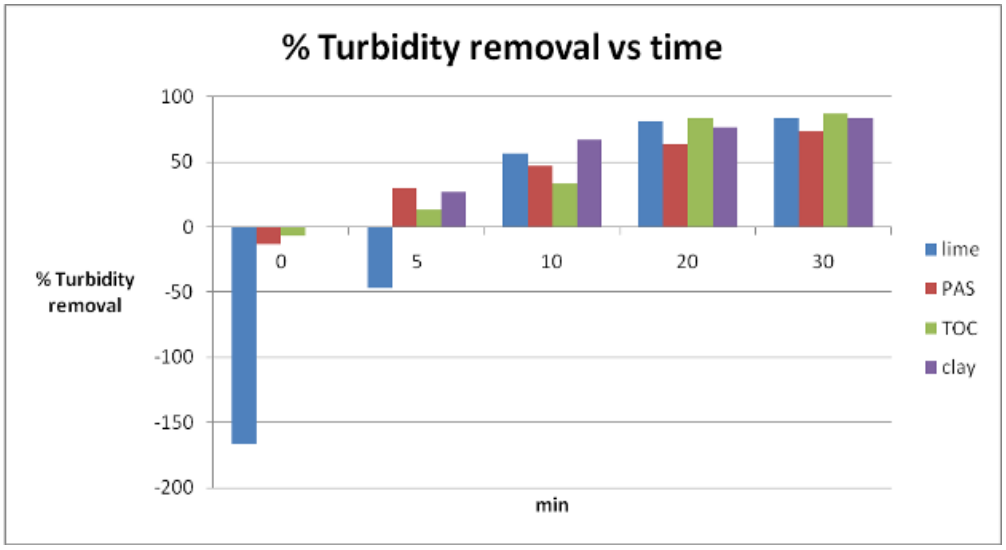


Figure 53: High strength synthetic surface water [150 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. Organic carbon vs. Raw surface water %Turbidity removal vs. time

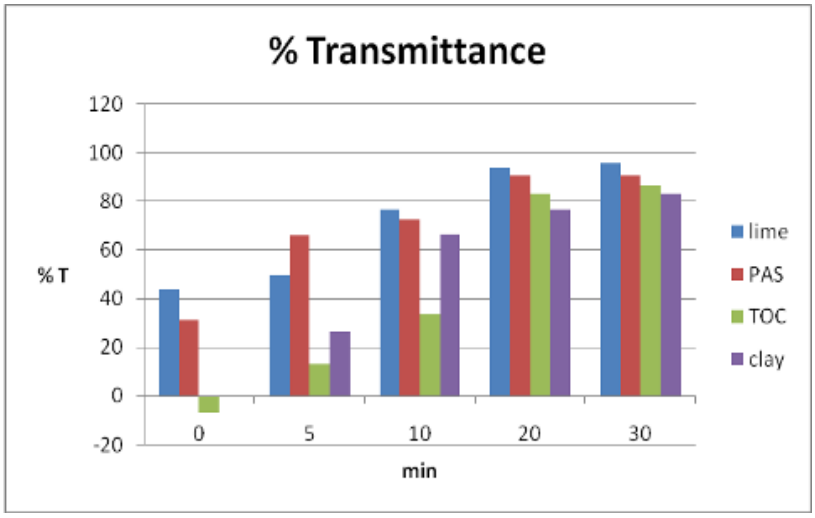


Figure 54: High strength synthetic surface water [150 NTU] treatment at current I = 3 ampere. Lime vs. Aluminum sulfate octadecahydrate vs. organic carbon vs. Raw surface water %Transmittance (%T) vs. time (min)

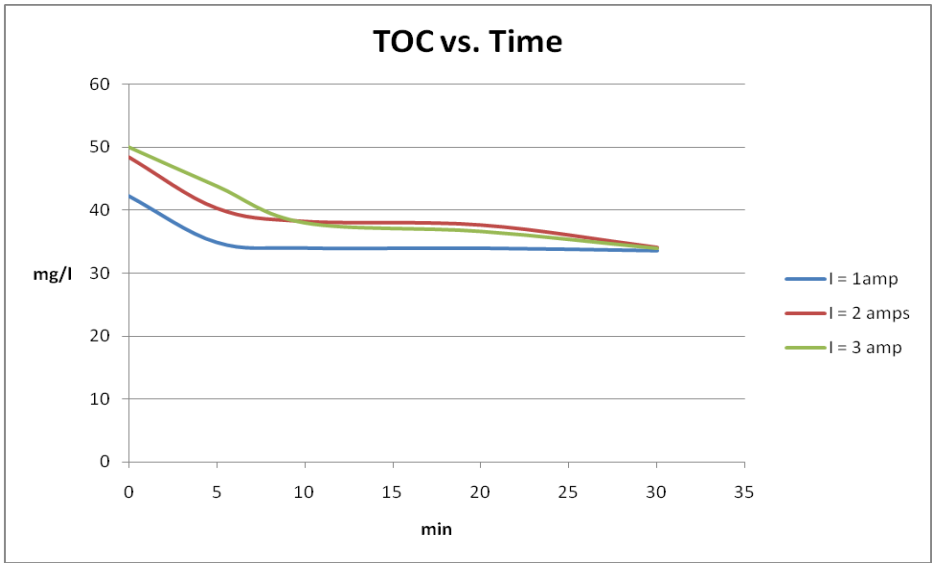


Figure 55: Low strength synthetic milk waste water [100 mg/l] treatment by ECF reactor at various currents. TOC (mg/l) vs. time (min)

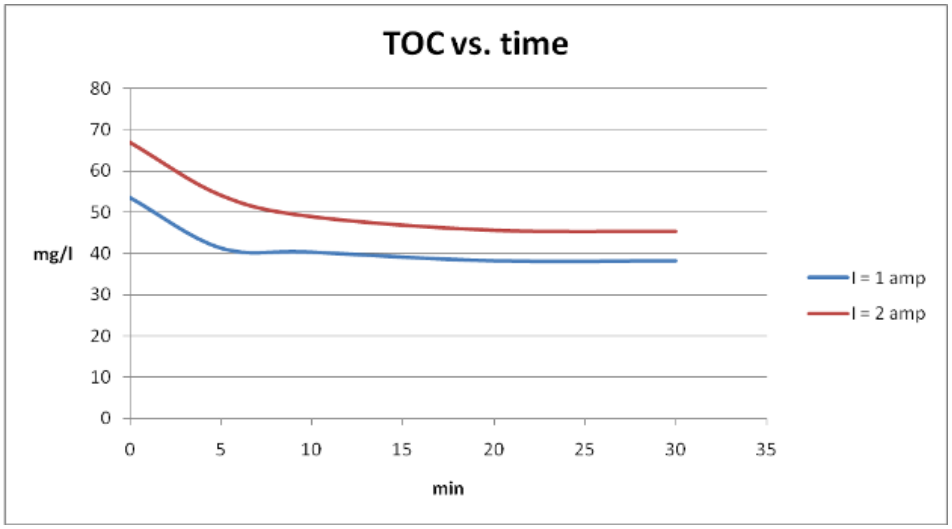


Figure 56: Medium strength synthetic milk waste water [150 mg/l] treatment by ECF reactor at various currents. TOC (mg/l) vs. time (min)

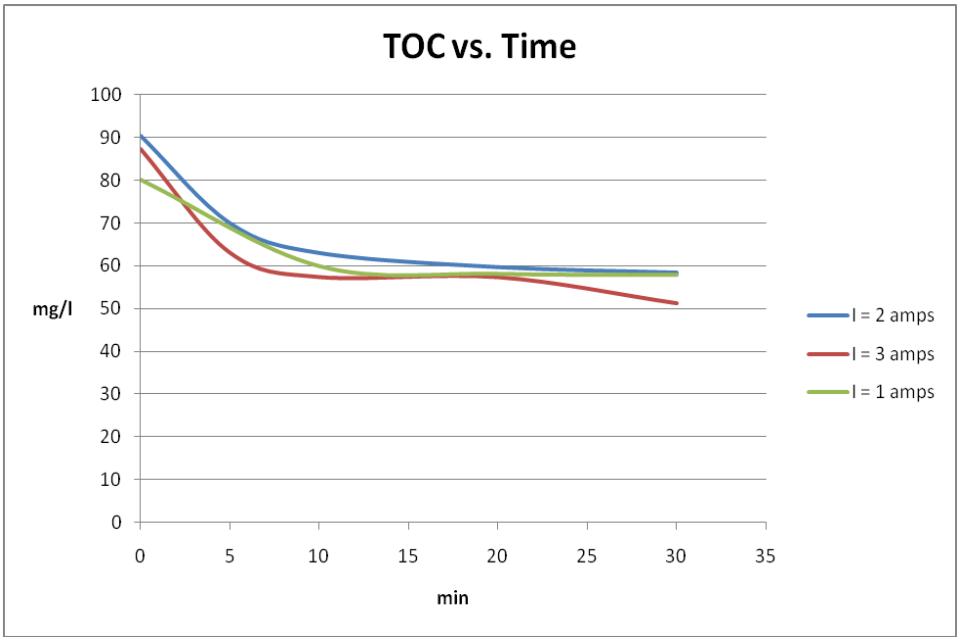


Figure 57: High strength synthetic milk waste water [200 mg/l] treatment by ECF reactor at various currents. TOC (mg/l) vs. time (min)

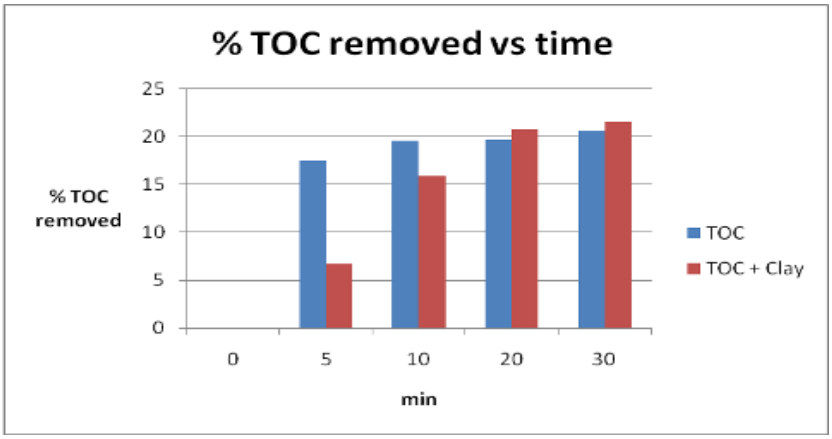


Figure 58: Low strength milk waste water treatment at a current I = 1 ampere. % TOC removed vs. time

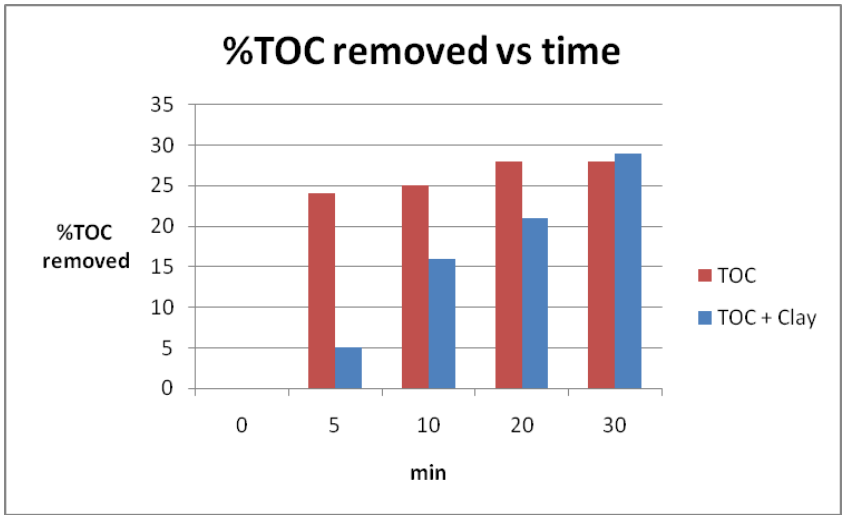


Figure 59: Medium strength milk waste water treatment at a current I = 1 ampere

%TOC removed vs. time

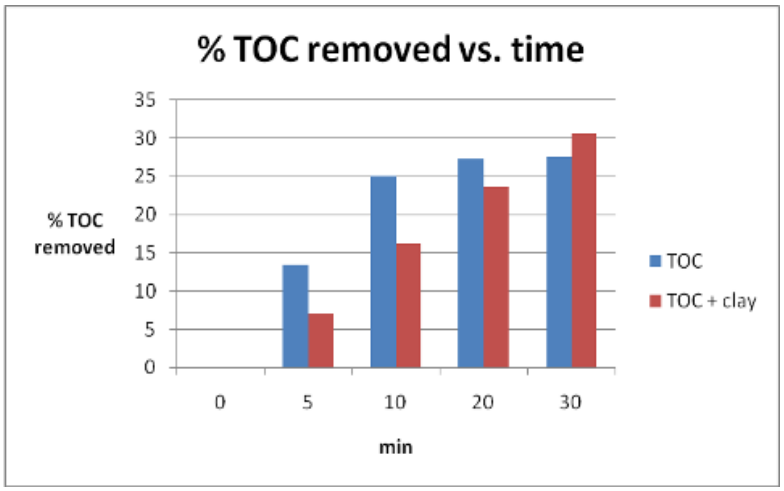


Figure 60: High strength milk waste water treatment at a current I = 1 ampere

%TOC removed vs. time

VITA

The author, Sampath Reddy Gunukula was born on August 25, 1986 in Karimnagar, Andhra Pradesh, India, the second son to parents Mr.Raji Reddy Gunukula and Mrs. Radha Reddy Gunukula. Sampath has two brothers Santhosh Reddy Gunukula and Krishna Reddy Gunukula, and two cousin sisters Harshini Reddy and Haripriya Reddy. His twin brother Santhosh taught him hard work, engineering concepts, and gave him confidence in every part of his life. In 2004, he started his bachelor degree in Chemical Engineering at Jawaharlal Nehru University, India. After receiving his bachelor degree in 2008, he came to Cleveland State University to pursue his Master's degree in Civil Engineering. He completed all the requirements of his master's degree and will graduate in May 2011.

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