ALTERNATIVE APPROACHES TO ELECTROFLOCCULATION AND ELECTROCOAGULATION APPLICATION AT INDUSTRIAL WASTEWATERS

ENDÜSTRİYEL ATIKSULARDA ELEKTROFLOKÜLASYON VE ELEKTROKOAGÜLASYON UYGULAMALARINDA ALTERNATİF YAKLAŞIMLAR

SELÇUK BULUT

ASSOC. PROF. DR. SELİM L. SANİN
Supervisor

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Assoc. Prof. Dr. A. Gamze Yücel Işıldar ....
Head

Assoc. Prof. Dr. Selim L. Sanin ....
Supervisor

Prof. Dr. Gülen Güllü ....
Member

Prof. Dr. Hülya Yavuz Ersan ....
Member

Assoc. Prof. Dr. Merih Aydınalp Köksal ....
Member

This thesis has been approved as a thesis for the degree of **MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING** by the board of Directions of the Institute for Graduate School of Science and Engineering

Prof. Dr. Menemşe Gümüşderelioğlu
Director of the Institute of
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Mustafa Kemal ATATÜRK

Whatever you do, you must never let the voice in your head control the brain in your hearth

Steve JOBS

Hayatım boyumca yanımda olan ve destekçim olan değerli ablam Birsen BULUT'a atfedilmiştir.

ABSTRACT

ELECTROFLOCCULATION AND ELECTROCOAGULAION APPLICATION AT INDUSTRIAL WASTEWATERS

Selçuk BULUT
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The evolving industry and consumption growth are causing many different kinds of productions and waste to be produced as a result of these productions. As a result of the production processes in the industrial plants, wastewaters of various pollutant concentrations and pollution loads are formed. In this study, electro-flocculation purification which is the electrochemical treatment method in these pollutants, has been investigated based on basic pollutants in various industrial waters.

In the studies, the area occupied by the wastewater type of the electro-flocculation process was evaluated depending on the parameters such as the feed pH, conductivity, electrode material, current density and process time in the basic pollutant.

The pollutant parameters determined according to the wastewater type were analyzed by analyzing the changes in the electrode types, current densities and process durations at different pH values in the prepared reactor. It has been observed that the process time and the applied current density have a direct effect on the wastewater of all industries, but the electrode material and pH factors are not a significant influence on the wastewater of some of the studied industries. Basically, in the process mechanism, it was observed that the greatest factor was the applied current, and as the current value increased, the process time shortened, and the efficiency increased. However, this efficiency started to have a negative effect after having a certain value due to the wastewater characteristic with a threshold value electro-flocculation technology has been found to have high purification efficiencies when suitable current and pH balances are established in pollutants such as heavy metals, but it has been found that effluent parameters such as organic heavy pollution wastewaters and nitrogen are not within desired ranges

With the results obtained, the main pollutant models that can be preferred to the system and wastewater and industrial usability have been revealed and it has been revealed how important factors of current density, pH, electrode material factors play in the efficiency of the treatment.

Keywords: Electroflocculation, industrial wastewater, electrode, heavy metals, current density.

ÖZET

ENDÜSTRİYEL ATIKSULARDA ELEKTROFLOKÜLASYON VE ELEKTROKOAGÜLASYON UYGULAMALARI

Selçuk BULUT
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Gelişen endüstri ve artan tüketim ihtiyacı birçok alanda üretimlere ve bu üretimler sonucunda atıkların oluşmasına sebep olmaktadır. Endüstriyel tesislerde gerçekleşen üretim süreçlerinde gerçekleşen işlemler sonucunda çeşitli kirletici konsantrasyonlarına ve kirlilik yüklerine ait atıksular oluşmaktadır. Bu çalışmada çeşitli endüstriyel sularda temel kirleticiler esas alınarak bu kirleticilerde elektrokimyasal arıtım metodu olan elektroflokülasyonun arıtma verimi incelenmiştir. Çalışmalarda elektroflokülasyon prosesinin atıksu tipine göre sularda yer alan temel kirleticilerdeki verimi pH, iletkenlik, elektrot materyali, akım yoğunluğu ve proses süresi gibi parametrelere bağlı olarak değerlendirilmiştir.

Atıksu tipine bağlı olarak belirlenen kirletici parametreler hazırlanan reaktörde farklı farklı pH değerlerinde, elektrot tiplerinde ve akım yoğunluklarında ve proses sürelerinde değişiklikler yapılarak analiz edilmiş ve ayrıca arıtma verimindeki değişiklikler analiz edilmiştir. Proses süresinin ve uygulanan akım yoğunluğunun çalışılan bütün endüstrilerin atıksularında verime direk etki ettiği ancak elektrot materyali ve pH faktörlerinin çalışılan endüstrilerden bazılarının atıksularında verime önemli bir etkisi olmadığı görülmüştür. Temel olarak proses mekanizmasına en büyük etken faktörün uygulanan akım olduğu belirlenen çalışmada akım değeri arttıkça proses süresinin kısaldığı ve verimin arttığı gözlenmiştir ancak bu verim bir eşik değere sahip olmakla birlikte atıksu karakterine bağlı olarak değer belirli bir değerden sonra negatif etki yapmaya başlamıştır. Yapılan çalışmalarda elektroflokülasyon teknolojisinin özellikle ağır metal gibi kirleticilerde uygun akım ve pH dengeleri oluşturulduğunda yüksek arıtma verimlerine sahip olduğu görülmüş ancak organik ağırlıklı kirliliği olan atıksularda ve azot gibi parametrelerde verimin istenilen aralıklarda olmadığı görülmüştür.

Elde edilen sonuçlar ile sistemin tercih edilebileceği başlıca kirletici modelleri ve atıksular ile endüstriyel kullanılabilirliği ortaya konulmuş ve akım yoğunluğu, pH, elektrot materyali faktörlerinin arıtma veriminde ne kadar önemli rol oynadığı ortaya konulmuştur.

Anahtar Kelimeler: Elektroflokülasyon, endüstriyel atıksu, Elektrot, ağır metaller, akım yoğunluğu.

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SYMBOLS AND ACRONYMS

Symbols

A	Ampere
M	Metal
Cu	Copper
Ni	Nickel

Acronyms

WHO	World Health Organization
COD	Chemical Oxygen Demand
E&E	Electroflocculation and Electrocoagulation
TSS	Total Suspended Solids
BOD	Biochemical Oxygen Demand
ASP	Activated Sludge Process
PAC	Polyaluminium Chloride
OECD	The Organization for Economic Cooperation and Development
LFL	Landfill Leachate
DOM	Dissolved Organic Matter
HS	Humic Substances
SSM	Suspended Solid Matter
TSM	Total Suspended Matter

EISTR	Electrocoagulation Simple Induced Settling Tank Reactor
DOC	Dissolved Organic Carbon
O&G	Oil and Grease
PEI	Polyéthylèneimine
TN	Total Nitrogen
TP	Total Phosphorus

1. INTRODUCTION

Although work on the production and the resources are being carried out to reduce these pollution values, when viewed from environmental aspects the wastewater which is discharged to the environment plays an important role in contamination of groundwater and surface waters.

Uncontrolled wastewater is beginning to threaten human and animal health, plant growth, and create effects that will disrupt the ecosystem balance that will make the life of living things difficult. Due to these reasons, it is necessary to make certain regulations on pollutants in wastewaters and to plan to contain the maximum concentrations that can be found in wastewater and to control these wastewaters.

According to the World Health Organization (WHO), pollutant effects in the water can be examined in 9 categories. These categories:

- Organic pollutants
- Contaminants causing microbial diseases (microorganisms)
- Contaminants causing abnormal growth of plants
- Agrochemicals
- Synthetic organic pollutants
- Inorganic Pollutants
- Sedimentary Origin Polluters
- Radioactive Pollutants
- Pollution from waste heat are given.

The basic pollution parameters in industrial wastewaters are composed of organic and inorganic pollutants and these parameters have been evaluated during the studies.

Today, there are many technologies used in wastewater treatment. In this study, basic pollutants in five different industrial wastewaters were investigated using electro-flocculation technology and electrocoagulation technology.

These five industries are preferred because of their high concentrations of both organic and inorganic pollutant loads, as well as difficulties in the treatment of metal coatings, minerals, vegetable oils, textiles and waste leaking wastewaters.

Heavy metals in wastewaters in these sectors have a great effect on the contamination of surface and ground waters with parameters such as Total Nitrogen, total phosphorus, Chemical Oxygen Demand (COD) and color. Contaminated pollutants are present in the plant growing, eutrophication, causing agricultural activities and toxic effects of environmental impact. Especially heavy metal pollutants have toxic effects for many living species.

Electroflocculation and Electrocoagulation (E&E) technology has been preferred to be able to create alternative technologies and to be able to compare the efficiencies in these industries, which have been selected with the difficulties of treatment and pollutant effects.

1.1. Wastewater and Classification of Wastewater

Wastewater is contaminated because of domestic, industrial, agricultural and other uses, water partially or totally altered in its properties, water from mineral quarries and ore preparation facilities, impervious surfaces in residential areas and water from the regions that participate in surface and subsurface flow. Wastewaters are generally assessed in 3 main classes. (Water Pollution Control Regulation)

- Domestic Wastewater
- Industrial wastewater
- Urban Wastewater

In the control and classification of wastewater in our country, water pollution control regulation and urban wastewater treatment regulations are applied, and various standards are introduced for pollutant values. In these regulations, polluted surface and groundwater qualities due to the discharged wastewater are given in the Table 1.1.

Table 1.1. Water Quality Classes.

	Water Quality Classes			
Water Quality Parameters	I	II	III	IV
A) Physical and Chemical Parameters				
1) Temperature (°C)	25	25	30	>30
2)pH	6.5-8.5	6.5-8.5	6.0-9.0	out of 6.0-9.0
3) Dissolved Oxygen (mg O2/L)[a]	8	6	3	<3
4) Oxygen Saturation (%)[a]	90	70	40	<40

5) Chloride ion (mg Cl - /L)	25	200	400[b]	>400
6) Sulfate ion (mg SO4 - 2/L)	200	200	400	>400
7) Ammonium Nitrogen (mg NH4 + -N/L)	0.2°	1[e]	2[C]	>2
8) Nitrite Nitrogen (mg NO2 - -N/L)	0.002	0.01	0.05	>0.05
9) Nitrate Nitrogen (mg NO3 - -N/L)	5	10	20	>20
10) Total Phosphorous (mg P/L)	0.02	0.16	0.65	>0.65
11) Total Dissolved Matter (mg/lt)	500	1500	5000	>5000
12) Color (Pt-Co unit)	5	50	300	>300
13) Sodium (mg Na^+/lt)	125	125	250	>250
B) Organic parameters				
1) Chemical Oxygen Demand (COD) (mg/lt)	25	50	70	>70
2) Biochemical Oxygen Demand (BOD) (mg/lt)	4	8	20	>20
3) Total Organic Carbon (mg/lt)	5	8	12	>12
4) Total Kjeldahl Nitrogen (mg/lt)	0.5	1.5	5	>5
5) Oil and Grease (mg/lt)	0.02	0.3	0.5	>0.5
6) Surface active matters giving reaction with methylene blue (MBAS) (mg/lt)	0.05	0.2	1	>1.5
7) Phenolic matters (volatile) (mg/lt)	0.002	0.01	0.1	>0.1
8) Oils and their derivations(mg/lt)	0.02	0.1	0.5	>0.5
9) Total pesticide (mg/lt)	0.001	0.01	0.1	>0.1
C) Inorganic pollutant parameters[d]				
1) Mercury (µg Hg/lt)	0.1	0.5	2	>2
2) Cadmium (µg Cd/lt)	3	5	10	>10
3) Lead (µg Pb/lt)	10	20	50	>50
4) Arsenic (µg As/lt)	20	50	100	>100
5) Copper (µg Cu/lt)	20	50	200	>200
6) Chrome (total) (µg Cr/lt)	20	50	200	>200
7) Chrome (µg Cr^{+6}/lt)	Not measurable	20	50	>50
8) Cobalt (µg Co/lt)	10	20	200	>200
9) Nickel (µg Ni/lt)	20	50	200	>200
10) Zinc (µg Zn/lt)	200	500	2000	>2000
11) Cyanide (total) (µg CN/lt)	10	50	100	>100
12) Fluoride (µg F/ lt)	1000	1500	2000	>2000
13) Free Chloride (µg Cl_2/lt)	10	10	50	>50
14) Sulphur (µg S^{-2} /lt)	2	2	10	>10
15) Iron (µg Fe/lt)	300	1000	5000	>5000
16) Manganese (µg, Mn/lt)	100	500	3000	>3000
17) Boron (µg B/lt)	1000[e]	1000[e]	1000[e]	>1000
18) Selenium (µg Se/lt	10	10	20	>20

19) Barium (µg Ba/lt)	1000	2000	2000	>2000
20) Aluminum (µg Al/lt)	0.3	0.3	1	>1
21) Radioactivity (pCi/lt)				
alfa-activity	1	10	10	>10
beta-activity	10	100	100	>100
D) Bacteriological Parameters				
1) Fecal Coliform (EMS/100 mL)	10	200	2000	>2000
2) Total Coliform (EMS/100 mL)	100	20000	100000	>100000

1.2. Industrial Wastewater

Wastewaters originating from processing of raw materials and production processes in industrial facilities are called "industrial wastewater". These wastewaters can be caused by washing, cooking, heating, extraction, reaction products, separation, transportation and quality control processes. Water contamination occurs when the amount of potential pollutant is in the quantity causing undesirable change in water quality. Industrial wastewater also includes domestic waters from bathrooms, hospitals and dining halls.

The industrial wastewater industry differs greatly from one another depending on the type of product and the raw material processed. Some industrial wastewater may be extremely organic, readily biodegradable, highly inorganic or toxic. That is, the total suspended solids (TSS), BOD and COD can vary from a few mg/L to several thousand mg/L [1].

While industrial wastewaters may be very rich in some parameters, they may be extremely poor in terms of other parameters required for treatment. It may not be at the appropriate pH value for discharging to the environment or the sewerage (pH: 6-9). In an industrial plant, the wastewater formed by the time and the process and the stages may be quite different from the others.

1.2.1. Classification of Industrial Wastewater

In industries, water is used in the process or outside the process and for employees' needs. For this reason, while the industrial wastewater sources are classified, the place of use and pollutant properties of the water are considered. According to this, the industrial wastewaters are divided into three main classes [2, 3] are expressed as:

- Process wastewater
- Non-Process Wastewater
- Domestic Wastewater.

Process wastewaters are wastewaters that are formed and contaminated in the process as a result of water use or during processing. Process wastewater can be given as an example.

- Painting of coating baths during metal finishing
- Reaction waters and product washing waters in the production of plasticine
- Main solution wastewaters in fertilizer production
- Tank wash wastewater in the plastic industry
- It is because of leakage of stored substances and rain water
- Cleaning and washing waters

Non-waste wastewaters are wastewaters that are contaminated or contain little contaminants and whose treatment needs are limited. Examples of non-waste wastewaters include:

- Non-contact cooling water
- Boiler water (softening unit) preparation wastewater
- Regeneration wastewater
- Untreated site drainage waters
- Rainwater

Household wastewater is wastewater result of staff use such as shower, toilet, cafeteria, dining hall, guest house. Although the pollutants resemble domestic wastewaters, the values of the pollutant parameters and the proportions to each other may differ from domestic wastewater.

1.3. Industry and Wastewater Characteristics Preferred in the Study

Wastewaters originating from five different industries were preferred in the studies conducted. These industries:

- Metal coating industry
- Mining industry (nickel mine)
- Textile Industry

- Herbal oil industry
- Landfill Leachate Wastewater

1.3.1. Metal Coating and Mining Industry Wastewaters

Industrial wastewaters like coating, plating and mine wastewaters contain a different kinds of toxic substances wastes. Oil,cynanides, degreasing solvents, metals and fats can be example of this toxic wastes. Metals like a silver, nickel, zinc, copper, chromium generally discharge the nature with no treatment. Some technologies applied for the treatment of this metals like biosorption, electrodialysis, precipitation, membrane separation, ion-exchange and adsorption. Precipitation is the most applicable among these techniques and is the most economical among them. It is a process of chemical coagulation. This methods includes lime dose for the pH increase and iron or aluminum salts for removal of the colloidal matters. Although, it is shown to be quite effective in treating industrial effluents, the chemical coagulation may induce secondary pollution caused by added chemical substances. This drawback, together with the need for low cost effective treatment, encouraged many studies on the use of electrocoagulation for the treatment of several industrial effluents [4].

1.3.2. Textile Industry Wastewater

The textile industry is one of many industries that utilizes large volumes of water in the manufacturing process. This water, used in the dyeing and finishing processes, ends up as wastewater, which needs to be treated before its final discharge. Frequent changes of the dyestuff employed in the process cause considerable variation in the wastewater characteristics, such as intense color, high COD, dissolved solids values and highly fluctuating pH, the last being especially troublesome because pH tolerance of conventional biological and chemical treatment systems is very limited. Hence, without continuous pH adjustment, normal operation of the treatment process is impossible.

Color is one of the most important water quality parameters. During the dying process, about 5 - 20% of the dye are lost due to its partial adsorption on the fibers. Dyes are manufactured to have high chemical resistance because they are normally chemical species that are very difficult to degrade (aromatic dyes). Moreover, dye solutions usually contain antibacterial and antifungal agents, which are used to give the fibers more resistance to biological degradation. Even at relatively low concentrations, the intense color associated with the dye affects not only the aesthetics, but also the transparency of waters, thus interfering in photosynthesis, and the solubilization of gases in lakes, rivers and other surface water bodies. It damages both the aquatic flora and fauna. Furthermore, colored effluents may contain considerable amounts of toxic compounds, especially azo dyes, that are known to be highly carcinogenic [5].

1.3.3. Vegetable Oil Production Industry

Vegetable nature factory wastewater contains high COD and BOD. Also wastewater charecteristics of this industry can be changes to raw material, production type if solvent and oil are added depending on the need in production, it will affect pollution load. For this, conventional treatment units such as activated sludge have problems in the filtration of vegetable oil industry wastewater. It was thus proposed to subject the wastewater to physico-chemical treatment, using different coagulants and coagulant aids. Commonly available coagulants like lime, alum, ferrous sulfate, ferric chloride, polyaluminium chloride (PAC) and also polyelectrolyte were studied [6].

According to The Organization for Economic Cooperation and Development (OECD) report from 2013 vegetable oil production in Europe reaches 21,829,000.00 Mg per year. Therefore, the emission of poor quality effluents by the oilseed processing facilities is posing a dangerous threat to the fresh water resources. The oilseed is usually processed in five stages: seed receiving and storage, seed preparation, solvent extraction unit, refining of crude oil and packaging of oil. However, the harmful effluent is mostly discharged from degumming, deacidification and deodorization stages, although the wastewater content and quality may significantly differ from one edible oil industry to another [7].

1.3.4. Landfill Leachate Wastewater

Among widespread and high quantity landfill leachate (LFL) wastewater is one of the most dangerous and difficult wastewater for treatment. First of all, LFL flow is largely dependent on storage age and season and secondly it is depends on the on the amount of precipitation, on the type of land fill, its characteristic and the operation of years. Also LFL wastewaters got high concentrations of ammonia and toxicity, a low BOD / COD ratio and the presence of heavy metals pollutants. As LFL gets older, the more complex dissolved organic matter (DOM) are produced out of simple ones, dramatically decreasing the COD removal efficiency of biological treatment; hence, physio-chemical processes installation seems to be inevitable for proper elimination of recalcitrant DOM. Intense brown coloration of old landfill leachate indicates the presence of these DOM with high molecular weight, known as humic substances (HS), which act as the best media for adsorption of metal and emerging contaminants. In addition, LFL has the highest detection rate among wastewaters and the resulting pollutant diversity.[8].

Landfill leachate is the result of water percolating through waste deposits that have undergone aerobic and anaerobic microbial decomposition. Its composition is a function of the type of waste in the landfill, landfill age, climate conditions, and hydrogeology of the landfill site. A landfill site will produce leachate throughout its working life and for several hundred years after it is decommissioned. The control of a landfill site, and appropriate treatment of the leachate it produces, is paramount in the protection of the surrounding environment, as leachate contamination of groundwater, rivers, lakes and soils has the potential to negatively affect local habitats, resources and human health [9].

1.4. Electroflocculation And Electrocoagulation (E&E)

E&E process is an increasingly important alternative treatment method in recent years including various complex physical and chemical treatment mechanisms such as flotation, coagulation, flocculation, adsorption, redox reactions, particle trapping.

E&E reactor is an electrochemical cell includes anodes and cathodes. During the reaction, iron or aluminum on anode undergoes oxidation to become iron and aluminum cations. Thus, the coagulation process is carried out by utilizing the iron and aluminum ions formed during the anodic reactions without addition of a chemical to the reaction medium. On the other hand, in the cathode, hydrogen gas is formed by reduction of the water, and the flow of the generated hydrogen gas provides the pollutant molecules to be separated from the water by flotation.

With this treatment technology, the wastewater components which have high oil and grease, volatile organic compounds, suspended and colloidal solid matters, dissolved organic and inorganic pollutants, phosphate, and limited quantities (about

25%, as effluent <20 mg/L for domestic wastewaters) can be removed by "phase transfer"

A low-volume, easy-to-dry solid / sludge phase formed in the reactor is removed from the medium by stripping.

It is possible to provide effective treatment through multiple physical and chemical mechanisms in the same system. For this reason, it can be applied with high performances, both domestic and industrial wastewater (textile, leather, food, petrochemical, detergent, automotive, metal final process etc.).

In addition to the high treatment performance, chlorine gas (Cl_2) is formed in the anode compartment because of the oxidation of chloride salt (NaCl) which is used as an electrolyte. Thus, if the pH values in the treated water is stable between 6-8, disinfection effect of HOCl can be seen according to following reactions [10, 11].

Anode reaction:

$2Cl^- + 2e^- \rightarrow Cl_2$ (1)

Ionization by hydrolysis in the aqueous phase;

$Cl_2 + H_2O \leftrightarrow HOCl + HCl$ (2)

$HOCl \leftrightarrow H^+ + OCl^-$ (3)

1.5. Fundamental Principles and Mechanism of E&E Process

1.5.1. Fundamental Principles

Chemical coagulation is the process of neutralizing the charged particles being inside colloidal suspension by colliding with oppositely charged ions and ensuring that their precipitator is provided by banded together. For this purpose, proper chemical substances (alum, iron sulfate etc.) are added. Coagulation is realized as a result of the collection of colloidal particles with sufficient Van der Waals force to accumulate due to the trapping of the electrostatic repulsive force resulting in the reduction of the net surface charge [12]. Decline in electric double layer’s repulsion potential that is taken place because of opposite charges in electrolyte is ensured with the decrease of surface charge. Different from chemical coagulation, coagulant in electrocoagulation process is originated in consequence of electrolytic oxidation of proper sacrificial anode material. In this process, charged ion types and metal ions dissolved from anode bring metal hydroxide flocks into being. On the other hand, features of the flocks formed in electrocoagulation is more different than flocks formed with chemical coagulation; flocks formed in electrocoagulation are in tendency to less water binding or in other words, they have less water content and for this reason, their volume is also low. Flocks could be easily filtrated since they have lower resistance [11, 13, 14].

Mechanism of electrocoagulation is dependent on physicochemical characteristics and conductivity of atmosphere. Moreover, pH, size of colloidal particles in atmosphere and concentration of chemical types also affect electrocoagulation process. Besides them, surface charges of formed chemical sludge play important role in treatment efficiency. Strengths and weaknesses of electrocoagulation process when compared with other wastewater treatments are summarized in below [14].

Strengths of electrocoagulation process:

- Required simple equipment and operation conditions.
- Colorless, unscented and clear water is attained as a result of refining wastewater with electrocoagulation.
- Sludge produced could be readily stabilized and dewatered because it consists of metal oxide and hydroxide. Therefore, the amount of sludge is lesser.
- While formed flocks are like chemical flocks, they have tendency to be bigger flocks and consist of less relative water. As being much more resistant and stabile in acidic atmosphere, they could be disintegrated with filtration.
- When compared with chemical treatment, electrocoagulation exit water is composed of less total of dissolved solid. In case of reused these water, low total solid level contributes recycling drain to be lower.
- Electrocoagulation process have the advantage to removal the smallest colloidal particles because electric field applied by devices provides them to move quickly and this situation makes easier the coagulation.
- Use of chemical substances is avoided in electrocoagulation and so that the problem of extreme chemicals neutralization and secondary contamination

possibility that may be resulted from chemical substances in high concentration added in chemical coagulation are being blocked.

- Gas bubbles produced during electrolyze could relocate contaminants to solution surface and they could be separated more easily.
- Electrodes into electrocoagulation cell are stable, controlled as electrical and in this way, they are needed less maintenance.
- Electrocoagulation process could be applied by using solar panels added at unit in rural areas where electric usage is not enough.

Iron, stainless steel and aluminum electrodes are being used as the most common materials in electrocoagulation. These electrodes are preferred because they are cheap, supplied easily and their effectiveness are approved [13].

It is generally accepted that there are three consecutive stages in electrocoagulation process [14].

- Formation of electrode dissolved in electrolytic oxidation and coagulant types
- Destabilization of contaminants, particle suspensions and breaking of emulsions.
- Collection of flocks in destabilized phases.

Breaking of an emulsion, particle suspension and Destabilization mechanism of contaminants are explained in the below [11].

Because of current passing through solution, compression of charged species as a result of interaction of ions formed by dissolution of dissolved electrodes, dispersed double layer surrounding formed ions are provided.

Neutralization of charges of ionic species existing in the water is provided with opposite ions produced by electrodes dissolved as electrochemically.

1.5.2. Process Mechanism

A simple electrocoagulation battery is composed of an anode plunged into an electrolyte and a cathode. When a power from an external power supply is used, cathode stars to reduction and anode starts to oxidation. In this condition, anode is going to dissolve as electrochemically whereas cathode is going to expose to passivation. So that metal electrodes dissolve sufficiently, used electrodes must have large surface area and there should be a specific distance among them. M metal and electrochemical reactions in cathode and anode are as follows [13].

Can be summarized as:

In Anode:

$$M_{(s)} \rightarrow Mn^{+}_{(d)} + ne^{-} \tag{4}$$

$$2H_2O_{(a)} \rightarrow 4H^{+}_{(ç)} + O_{2(d)} + 4e^{-} \tag{5}$$

In Cathode:

$$Mn^{+}_{(d)} + ne^{-} \rightarrow M_{(s)} \tag{6}$$

$$2H_2O_{(a)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-} \tag{7}$$

1.6. Main Factors Affecting E&E Process

Parameters playing role on process efficiency of electrocoagulation practice are enumerated as current density, presence of NaCl as electrolyte in the atmosphere, pH and temperature. Effects of these parameters in electrocoagulation practice are summarized in below.

1.6.1. Current Density

The amount of current applied in electrocoagulation system determines the amount of Al_3^{+} dissolved from electrode or Fe^{+2} ions. While electrochemical equivalent mass for aluminum is 335.6 mg/ (A hour), this value for iron is 1041 mg/ (A hour). High current values state a small electrocoagulation unit. In ultrahigh current values, the possibility of using electric energy for warming the water is quite high and this decreases the efficiency of process. In other words, very-high current density value could cause an important decline in current efficiency (the amount of contaminant removed per unit energy). It is suggested that the value of current density should be between 20-25 A/m^2 to use electrocoagulation system without needed maintenance for a long time. The selection of current density should be performed together with other operational parameters such as pH, temperature and flow to provide high current efficiency. Current efficiency for aluminum electrode is 120-140%; on the other hand, it is around 100% for iron electrode. The condition of that current efficiency in aluminum is higher than 100% depends on pitting corrosion impact especially when there are chloride ions in the environment. Current efficiency is dependent upon the types of anions in environment along with current density [11, 13]. The quality of treated water depends on the number of produced ions (mg) or charge loading. The values of current density or charge loading could be found experimentally. In every experimental study, there is a required critic charge loading value. The fact that the charge loading reaching the critical value means that there is going to be no important improvement in the quality of exit water at the subsequent water increases [10, 13].

1.6.2. Electrolyte Type and Its Concentration

Inert salts such as sodium nitrite and sodium sulfate, halogenated salts like sodium and potassium chloride or deionized water are being used to increase the efficiency of electrocoagulation and bring the conductivity of waste water to the desired level. These arrangements lead to approximately 0.3-unit change in beginning pH of waste water [10, 15].

In case that potassium chloride is used as electrolyte, dye molecules could be disintegrated quickly; on the other hand, hypochlorite being in the first place, the formation possibility of active chlorine and chloric organic compounds as side reaction product emerges. The organic compounds must be completely resolved to prevent the formation of these compounds that are unwanted because of its negative environmental effects and toxicity. In other saying, adequately long electrolyze time is required.

Using inert salts such as sodium nitrite, sodium sulfate and manganese sulfate for color removal originated from indigo dyes with electrocoagulation method is not seen sufficient in terms of not only the level of color removal but also energy consumption. If sodium metabisulfite is used in electrocoagulation (NaS_2O_5), there is a more different mechanism than salts including halogen. The transformation of an electric current of S_2O_5 to S_2O_4 is provided. S_2O_4 is a reducing substance that converts dye molecules to faded yellow color leuco form. Addition of this reducing substance to dye solution ends up with almost sudden color removal. However, this method is not accepted as effective because there is no decrease in the content of organic substances and dye molecules do not convert much more simple structure. In addition to them, leuco form could be oxidized easily to colorful form [16, 17].

The best results could be achieved with NaCI in terms of color removal and electric consumption. Moreover, generally this could be already found in wastewaters of textile industry as it is used in electrolyte dyeing process. NaCI by generally rectifying is used to increase conductivity of water or wastewater. Along with ionic contribution in conduction of electrical charge, it also reduces the negative impacts of anions like HCO_3^-, SO_4^{2-}. Carbonate or sulfate ions might cause sedimentation of calcium or magnesium ions forming a nonconductor layer in electrode surface [18]. This layer increases potential among electrodes suddenly, also leads to a significant decline in current efficiency. For this reason, it is recommended that the amount of chloride among present ions should be near 20% to be operated electrocoagulation process in wastewater treatment.

Sodium chloride addition also brings about decreasing of energy consumption because of increased conductivity. Furthermore, it is known fact that chloride produced as electrochemical is effective in disinfection [10, 17].

An increasing in conductivity of wastewater decreases the consumption of energy (W=current, I x voltage, U) and electrode materials. In conclusion, it could be argued that an increase in conductivity is desired condition for high process efficiency [15].

1.6.3. Reaction pH Value

The value of pH being realized electrocoagulation practice in water and wastewater rectification has an important role on system efficiency. pH is a crucial parameter that determines the solubility of metal hydroxides and its charge formed during electrocoagulation. At the very acidic and basic pH values, there will be significant increases in metal hydroxide solubility so that in the formation of flocks, serious declines are going to be observed. This could cause notable declines in process efficiency. Nevertheless, in case that there is NaCI as electrolyte in the environment, chloride and hypochlorous acid emerge in anode [10, 14]. As a result of these reactions, acidic pH is going to provide opportunity the formation of HOCI that is more powerful oxidant. On the other hand, in neutral or light alkalic pHs, OCI^- is going to be dominant type. In spite of that in very high pHs (pH>11), because of OCI_3^- and OCI_4^- formations, important decreases in oxidation power is going to happen. It is known that current efficiencies of aluminum electrodes are higher in acidic or alkali conditions in respect on neutral conditions. The best contaminant removal is obtained around pH 7 as well as rectification performance depends on the structure of contaminant. Moreover, power consumption is higher in neutral pH because of the changes in conductivity. In case that conductivity is high, the effect of pH is not important [10]. One strength of electrocoagulation process is that pH of exit water after rectification with electrocoagulation tends to increase for acidic wastewaters and it tends to decrease for alkali wastewaters. In case of acidic conditions, it is confirmed that the reason of this increase in pH is related with hydrogen formed in cathodes. Besides, in reality hydrogen formation, the formation of $Al(OH)_3$ near anode decreases pH due to the formation of H^+. Additionally, oxygen formation reaction can also cause pH decline. pH increases in acidic wastewater could be explained as CO^2 formation during the formation of hydrogen bubbles, the formation of sediment in Al^{+3} and other anions and the left shift of the equilibrium for reactions forming H^+. On the other hand, it is thought that pH decline in case of alkali conditions emerges because of the formation of hydroxide sediments in other cations and $Al(OH)_4$ formation [10]. When aluminum electrode is used, it is determined that the best contaminant removal efficiency is obtained around neutral pH. Iron electrode usage in textile printing and dyeing wastewater rectification provides better color and COD removal than aluminum because of alkali characteristics of textile wastewater [10].

1.6.4. Electrode Material

Electrode materials used in electrocoagulation are generally aluminum and iron (stainless steel). Iron electrode is experienced in oxidizing halogen-bonded organic compounds and applied successfully, also it is preferred electrode material because of its successful usage in textile industry and wastewaters whose salt content is high and its low when compared with other anode materials for electro-oxidation [19]. Electrodes could be made in the form of plates and flushing place surface regularly could be beneficial. For the removal of contaminant amount given the system, the amount of required metal ion is certain and generally for wastewater rectification, iron/steel and for water rectification aluminum electrodes are used. In proportion to aluminum, iron is cheaper material. Aluminum plates are applied together with the combination of iron plates or stand-alone because of high coagulation efficiency of Al^{+3} in wastewater rectification. If there are significant amount of Ca^{+2} or Mg^{+2} (hardness) in the water, it is recommended that as cathode material stainless steel should be used [10]. Electrode configuration could be also as sticks.

1.6.5. Distance Among Electrodes

While not having an important impact on electrocoagulation, when distance among electrodes is increased, a slight increase in process efficiency could be seen. This change occurs probably as a result of the dependency of electrostatic impacts to distance among electrodes. In case of increase in these distances, the movement of produced ions is slowing down and the probability of forming flocks is increasing. Also, these flocks have the more dye absorption talent for the example of textile industry wastewater [11].

1.6.6. Reaction Time

During electrolyze while positive electrode exposes to anodic reactions, cathodic reactions emerge in negative electrodes. Ions released from electrodes neutralize the charges of particles and so that coagulation starts. In case of increasing in electrolyze time, an increase in ion concentration and hydroxide flocks of ions occurs [20].

In practices used aluminum and iron electrodes such as textile industry wastewater rectification, sedimentation problems in aluminum electrodes and solid level in higher hanger are observed and when iron electrodes are used, fast sedimentation and solid level in lower hanger could be observed [21]. Generally, reaction times are quite short in electrocoagulation process and in many practices, reaction is completed as around minutes.

1.6.7. Temperature

Although electrocoagulation is known more than a hundred years, influence of temperature on this method is not been investigated sufficiently. However, electrocoagulation reaction velocity also increases when the temperature of solution increased like other chemical reactions. When temperature is more than 27˚C, the movement of produced ions increase and the chance of flocculation and forming metal hydroxide flocks of these ions decrease. Finally, a significant decline on a specific temperature in process efficiency is observed [10, 20].

Current efficiency for aluminum increases to 60°C that is maximum current efficiency together with temperature in the beginning. Continues increase in temperature leads to decline in current efficiency. Increasing current efficiency together with temperature is seen parallel with decaying aluminum oxide film layer in electrode surface. When temperature reaches to high values, it could be observed that large stomas of aluminum hydroxide gel shrinks, and this shrinkage brings about accumulation in electrode surface and the formation of more sufficient flocks. As like current efficiency but with lower temperature, energy consumption can also reach maximum value. This value for oily wastewater is determined as 35 °C. This situation could explain with the adverse effect of temperature on current efficiency and conductivity. As temperature increases, conductivity also increases and consequently energy consumption decreases [10].

1.7. Literature Summary

Bejankiwar and others examine the electrochemical oxidation of wastewaters in photography industry by using cast iron electrode. In this study, the reason of why cast iron is preferred is explain as the fact that these materials were experimented in textile wastewater and wastewaters including high amount of salt and these are much more economical rather than other anode materials. The mass of reactor used in this experimental study is 650 ml. wastewater studied on is a sample which is quite acidic (pH 2.10-4.35) and has high COD (14220 mg/L–16340 mg/L) and low BOD_5 120 mg/L-145 mg/L). Moreover, as understood from low Suspended Solid Matter (SSM) concentration (< 80 mg/L) of wastewater, almost all organic substances are in the dissolved form. In the conducted experimental study, during electro-oxidation, a significant increase took place in pH value and despite acidic character of sample, pH was in the interval of 6.5-8.4 in refined currents [22].

Murugananthan and others analyze the impact of current density and electrode materials on SSM, chrome, sulfate, COD and other contaminant removals in treatment of leather industry wastewater by electro-flotation. In this experimental study three different wastewater samples were used. Initial COD contents of these wastewater samples are 3092 mg/L, 3179 mg/L and 4417 mg/L, their BOI_5 values are 1750 mg/L, 1273 mg/L and 2250 mg/L and finally values of SSM parameter are 3036 mg/L, 1386 mg/L and 5080 mg/L respectively. The size of reactor used in this study is 15 cm x 15 cm x 15 cm. The length of electrodes is 11 cm and their diameter are 0,6 and they are placed as parallel. In this study, distance between electrodes is chosen as 2 mm. Additionally, it is determined that when Fe and Al electrodes are used in the treatment of tanning wastewater, almost all suspended solid and when titanium electrodes are used, just a part of them are removed. The reason of decline in efficiency is explained as once soluble anode such as Fe and Al are used, the separation of suspended solid materials from liquid is realized by coagulation and when stable anode like titanium is used, coagulation is not realized due to the formation of oxygen bubbles. Similar to SSM removal efficiency, it is reported that by the time Fe and Al electrodes are used, rather high efficiencies and SO_3^{-2} , Cr^{+3}, calcium and magnesium removal are realized. At the same time, in this study approximately 50-10% of COD and BOD removal are obtained [23].

Manisankar and others are obtained the highest removal efficiency as 6 A/dm^2 current density in the experiment where instead of graphite using anodized (anode is kept in 1 M H_2SO_4 solution and then by ousting cleaned with distilled water) graphite anode in the study examining electrochemical treatment and indirect oxidation process by using graphite anode and cathodes of alcohol production wastewater. According to results, 85% KOI, 94% $BOİ_5$ and 98% color removal are provided. These reached removal efficiencies are higher only than results of experiments used graphite. Although a significant color removed is observed in this study, the condition that COD removal is not high as expected is explained with the formation of residual organics having low molecule weight during treatment. In this study, graphite whose sizes are 4.5 cm x 8.2 cm x 0.5 cm are used. As pH, current density and auxiliary electrolyte, effects of NaCl, NaF and NaBr on process efficiency are investigated separately. Alcohol wastewater used in the study contains melanoidin that is a brown pigment. COD of aforementioned wastewater is 12000-15000 mg/L, its BOD_5 is 7000-7200 mg/L and finally its TSM is 2400 mg/L. While beginning pH of wastewater is changing between 6.9-7.2, after treatment in various experimental conditions, there is no significant change in its pH and pH in its output current is measured around 6.7.[24]

In the study that is electrocoagulation refinability study performed by using wastewater of a textile industry and aluminum and iron electrodes studies by Bayramoğlu and others, the impact of operation time on process efficiency is examined in constant current density (100 A/m^2). Whereas 15 minutes reaction time is sufficient to obtain active color and COD removal data in aluminum electrodes, it is seen that only 10 minutes as reaction time with iron electrodes give better results and removal data does not change much more. On the other side, because current density and reaction time indicate similar effects in process performance, it is concluded that these two variables could be expressed together. This generated new variable is stated as charge loading (unit volume of water or Faraday charge consumed per mass; C/m^3 or C/kg). [25]

Inan and others examine electrocoagulation process and refinability to serve as basis a refining pre-process for biological refining in olive oil production wastewater (glaucoma). Wastewater used in this study is obtained from an olive oil production plant and its COD, SSM and color parameter (absorbance value) are 48500 mg/L, 1780 mg/L, 2120 m^{-1} respectively. In conducted experiments, the reactor voltage is 1.2 V, interval of current density is 10-40 mA/m^2, pH values are 4, 6, 7 and 9 and finally interval of process time is 2-30 minutes. Iron and aluminum is used because they are cheap as electrode material and their production is easier. Two different combinations that are firstly Fe/Al and secondly Al/Fe are applied. In this experimental study optimum time is confirmed as 10-15 minutes. In case that both iron and aluminum are used, an increase in color removal is observed together with increasing process time. Even in the short time like two minutes, color removal efficiency is found in high values as like 78% for iron and 82% for aluminum. In case that process time is selected in between 10-30 minutes, removal efficiencies are reached to 96%. For this reason, in consideration of optimum COD removal percentages, optimum process time for wastewater and conditions used in the study is accepted as 10 minutes. Moreover, SSM removal is evaluated for different process times. When Fe and Al anodes are tested in stable pH (6.2) and constant current density (20 mA/m^2) values, it is seen that increase in process time (from 2 minutes to 20 minutes) leads to an increase in SSM removal (from 48% to 68%).[26]

Ge and others used bipolar electrocoagulation – electroflotation process in the treatment of laundry wastewater. The reason of why mentioned reactor is chosen is explained as to neutralize the contaminant charge, form ultra-thin bubbles and separate the flocks being coagulum from the water. In the study 3 aluminum plates, 2 titanium having opposite charges are positioned inside electrode. Anode reactions in positive side and cathode reaction in negative side take place. the reason of why titanium is selected as anode material is explained as because it is cheap. The volume of reactor used in experiment is 2.8 dm^3 and the volume of separator is 11.2 dm^3. Only Ti electrodes are connected to power source. The sizes of Ti and Al electrodes are selected as 100 mm x 60 mm x 2 mm and 100 mm x 60 mm x 3 mm respectively. Gap between reactors is designed as to be 8 mm and effective area of every electrodes is confirmed as to be 50 cm^2. In the experimental study, COD, surface active materials, orthophosphate ($PO^{-4}P$) and blurriness measurements are realized to investigate critical variables to affect process such as hydraulic holding period, initial pH and current density. Optimum pH is found in between 5 and 9 for turbidity, surface active materials, COD and phosphate removal. In case that turbidity removal efficiency is less than pH 4 and more than 9, a dramatic decline is determined. When pH>10, a slight decline is detected in COD, phosphate and surface-active material removal. These results attained from experimental study are explained with the type distribution of aluminum ions. After electrocoagulation – electro flotation process, it is reported that pH of solution is neutralized up to specific value.[20]

In the study that is about treatment of textile industry wastewater with electrocoagulation conducted by Can and others, the impact of chemical coagulant addition such as polyaluminium chloride (PAC) or alum (aluminum sulfite) to COD removal is researched and operational cost analysis has been realized in terms of electric energy, electrode and chemical substance consumption. Whereas in the classic jar test experiment in case that PAC and aluminum sulfide are used as chemical coagulant COD removal could be found as 78%, in case that in electrocoagulation current density is 100 A/m^2, reaction time is 10 minutes and in the original pH of textile wastewaters (6.90-7.0) COD removal is found 50%. In order to obtain higher removal data, it is expressed that pH should be decreased in the beginning and pH should be lower than 6 during electrocoagulation. On the other hand, in the beginning chemical coagulant addition like PAC or alum in wastewater is seen more proper. In electrocoagulation based on the amount of aluminum produced as electrochemically and added in the first place together with PAC, the better results are obtained when compared with alum in COD removal velocity and efficiency; however, efficiencies of these two salts are alike with regards to their operation cost. At the beginning aluminum has caused the more sweep flocks formation adsorbed particles and organic compounds dissolved in wastewater. In this way, performance and speed of electrocoagulation are improved and a decline in energy consumption has provided a significant decrease in operation cost.[21]

Alinsafi and others emphasize in their study about treatment of a textile industry wastewater with electrocoagulation that characteristics of industrial wastewater could change from day to day and therefore, it is difficult to decide what the optimum values of operation parameters are; in relation with that optimum operation condition is electrolyze time provided color removal rate in between 90-95% and optimum current density. According to that, in the mentioned study, optimum electrolyze time is confirmed as 105 minutes. [18]

On the other hand, in the study conducted by Rajkumar and Kim , removal of 9 different dye compounds including azo, anthraquinone and triazane groups is researched with electrochemical process in the environment containing active chloride. While NaCI is being used due to its lost cost, used electrode was titanium based. Cathode is made from stainless steel. Anode and cathode are positioned as vertical and horizontal and their active surface areas are 27.7 and 50 cm^2 respectively. Distance among electrodes is determined as 10 mm. Mass of reactors used in the experimental study is selected as 1 liter. Solution is being mixed with magnetic stirrer whose speed is 300 rpm consistently. It is reported that initial pH increased from 4 to 9 has no important impact on color removal. The reason of this could be explained as the formation of chloride/hypochlorite does not depend on the conditions of initial pH. [27]

Ilhan and others have conducted a research about treatment of solid waste garbage leachate water with the method of electrocoagulation by using aluminum and iron electrodes. In this study, the impact of electrode materials in the method of electrocoagulation on current density, pH, treatment material, treatment time process efficiency is evaluated in terms of COD and NH_4-N removal. At the same time electrocoagulation method has been compared with chemical coagulant method. $Al_2(SO_4)_3.18H_2O$ and $Fe_2(SO_4)_3$ have been used in coagulation and COD removal, mud and sulfide formation are being examined for both metal type. When iron is used in coagulation process, COD in the level of 12800 mg/L is removed by 22%; on the other hand, in electrocoagulation process it is being removed by 33%. While sulfide being 32 mg/L is removed by 90% with electrocoagulation in the end of 30 minutes contact, in chemical coagulation it increases due to sulfide addition in coagulant. Also, when used iron in NH_4-N, 200 mg/L amount is just removed by 11% with the method of electrocoagulation. Moreover, used aluminum COD is removed by 45% with electrocoagulation while removed by 31% with chemical coagulation. In sulfide removal aluminum is behaving as iron in electrode and it is observed that with the method of electrocoagulation, removal is more than 90%. Finally, in NH_4-N removal is determined as 14% when aluminum is used in coagulation. [28]

El-Naas and others examine in their experimental study the removal of sulfide and COD with the electrocoagulation process in petroleum refinery wastewater. Wastewater samples have been taken from two different points of petroleum refinery wastewater treatment system and they are treated in a discreet electrocoagulation by using aluminum, stainless steel and iron electrodes. Experimental study shows that SO_4^{-2} concentration and COD content of wastewater are being removed as 93% and 63% respectively with the electrocoagulation method. Using aluminum as electrode material is seen as the most effective selection for sulfide and COD removal. It is discovered that the most influential factor affecting electrocoagulation performance is the content of wastewater (environmental characteristics). The best conditions for electrocoagulation process are confirmed as pH = 8 and T= 25˚C. Based on obtained results, using electrocoagulation process in pre- treatment of petroleum refinery wastewaters is appropriate. [29]

Sun and others studied nickel (Ni) removal on a syntheticly prepared water sample. In this study they used a hybrid method in which electroflocculation (EF) reactor was supported by mechanical filtration, microfiltration, ultrafiltration and ventilation. A waste water sample with 1.5mS/cm conductivity and Ni concentration of 20 mg/l was prepared to be used in the study. Waste water was submitted to 30 minutes of reaction time in an EF reactor with fixed current of 4.2 Ampers. Water sample that was retrieved at EF reaction exit was put through 11 micron mechanical filters then microfiltration and ultrafiltration. Tests were first performed with ventilation and then without ventilation. In this study it was found that decomposed oxygen elevated by ventilation had an important role on EF performance, EF reactor exit supported by ventilation had higher efficiency yet same results can be achieved in an unventilated EF process with microfiltration. When ultrafiltration added to a ventilated EF reactor exit combined with microfiltration it had no effect on removal and therefore deemed unnecessary. [30]

Ozyonar and others studied the treatablity of textile industry wastewater with Electroagulation process. For that pupose they used monopolar, parallel aluminium electrodes. They research effects of starting pH, current density and electrolyze time on combined organic carbon (TOC), chemical oxygen need (COD), colour and turbidity removal efficiency. As a result, they found the optimal conditions for EC process to be starting pH:3, current density 100A/m2 and electrolyze time 20 minutes. TOC, COD, colour and turbidity removal efficiencey was found as %82.6-72.5-97.7 and 98.7 respectively. In summary EC process in treating textile industury waste water was found to be an effective method. [31]

Dubrawski et al. Have studied the optimization of electrocoagulation reactor design and they worked on the natural organic matter removal of the iron electrodes in the reactors where they made these optimization works. During the optimization studies, they were investigated the effects of flow density, nutrient loading, pH adjustment and dosing type. In these studies, current density 2.43- 26.8 mA/cm^2, Feeding Pollution load and flocculation method (Slow and Fast) was tested. The ideal current density for natural organic matter removal efficiency was 10 mA / cm^2 and when charge loading rate decrease studies shows dissolved organic carbon efficiency was increase. In this study, several important points were highlighted within the EC tests.These points are detected as coagulant dosing, electric consumption, process speed, post-EC flocculation requirement and studies have shown that slower processes are better suited for large applications but fast processes are better suited for in small applications.[32]

Cerqueira and others examine effect of direct and alternative current on the treatment of oily water in an electroflocculation process.Aim of this study was calculating oil and grease removal of the electroflocculation process with different type of currents for this study they prepare 2L a synthetic oil/water (O/W) emulsion and 2 different batch and Continuous flow reactor. All test, batch and continious flow reactor conducted with 2 type of electrolytic unit. At the end of test all the results of studies given the given in the following Table 1.2. [33].

Table 1.2. Effect of current density (CD) on the removal efficiency of O&G, energy and electrode consumption using AC and DC. Initial O&G, 690 mg/L; conductivity, 100,7 uS/cm and initial pH, 9.0.

CD (A)	AC			DC		
	Removel efficiency (%)	Energy consumption (kWh/m^3)	Electrode consumption (kg/m^3)	Removel efficiency (%)	Energy consumption (kWh/m^3)	Electrode consumption (kg/m^3)
1	81.0± 2.0	0.09± 0.01	0.07± 0.01	75.8± 3.1	0.07± 0.01	0.11± 0.01
2	91.0± 1.7	0.18± 0.01	0.09± 0.01	90.3± 2.1	0.17± 0.01	0.15± 0.02
3	94.3± 0.6	0.28± 0.00	0.12± 0.10	94.1± 0.6	0.28± 0.02	0.18± 0.10
4	92.7± 0.6	0.38± 0.04	0.15± 0.20	93.5± 0.6	0.46± 0.03	0.22± 0.20
5	93.7± 0.6	0.48± 0.10	0.18± 0.20	94.2± 0.6	0.69± 0.10	0.26± 0.30

Govindan et al. was fabricated a simple induced settling tank reactor (EISTR) for their study and investigated the removal and sedimentation kinetics of Amido Black 10B, Methyl Violet, Eosin Yellow, Malachite Green, Methylene Blue, Rhodamine 6G. An 8 cm internal diameter and 59 cm height graduated polypropylene cylinder with provisions for hanging two 13.5 x 5.2 x 0.5 cm Fe or Al electrodes was used as the electrocoagulation induced settling tank reactor (EISTR). the electrodes are placed parallel to each other with a distance of 2 cm. A 25 cm long 900 rpm stainless steel mixer was placed between the electrodes. When work is completed with current density, duration of electrolysis, appropriate pH value and NaCl concentrations efficiency of color removal observed 81-99% and COD removal observed 54-68%.[34]

Costa Marques et al. aim was to examine the oil and oil field production wastewater effect on the seed germination and seedling growth of sunflowers. (Helianthus annuus L.). In comparison, as treated by electroflocculation, oilfieldproduced water, with lower oil and organic matter content, was also used. Electroflocculation treatment of oilfield-produced water achieved significant removals of chemical oxygen demand (COD) (94%), oil and grease (O&G) (96%), color (97%), and turbidity (99%). Different O&G, COD, and salt levels of untreated and treated oilfield produced water did not influence germination process and seedling biomass production. Normal seedlings percentage and vigor tended to decrease more intensely in O&G and COD levels, higher than 337.5 mg L^{-1} and 1321 mg O$_2$L^{-1}, respectively, using untreated oilfield-produced water. These results shows these industrial wastewaters must be treated in order to avoid adverse seedling growth. This way, electroflocculation process appears as a alternative for removal of the oil and souble organic matter from oilfield produced wastewater and increasing seed germination and seedling growth of sunflowers and also reducing the potential of wastewater to damage water resources, soil and biota.[35]

Melchiors et al. investigate the efficiency of electroflocculation for the treatment of wastewater from the dairy industry and the recovery of solid whey on their study. They use a electrochemical apparatus with 2 aluminum or iron electrodes. They monitored to electroflocculation time, initial pH of wastewater and applied potential intensity parameters. Distance between electrodes chose 2 cm and they apply 60 min reaction time at 5V potential intensity. The removal rates of organic matter based on the measure of chemical oxygen demand and turbidity when employing aluminum electrodes were 97.0 ± 0.02% and 99.6 ± 3.00 x 10^{-4} %, respectively, with a final pH of 6.72. The removal rates of organic matter when employing iron electrodes were 97.4 ± 0.01% and 99.1 ± 1.00 x 10^{-4} %, respectively, with a final pH of 7.38. As a their conclusion electroflocculation is an excellent alternative for the dairy wastewater treatment in comparison to conventional treatment methods.[36]

Hakizimana et al. was to examine the feasibility of a hybrid electrocoagulation/electroflotation/electrodisinfection (EC/EF/ED) process in treating seawater prior to desalination treatment using reverse osmosis process. Residual dissolved organic carbon (DOC) and heterotrophic bacteria concentrations were measured. They use a aluminum electrodes with a continuous flow treatment and this system leads to complex solid-gas-liquid mixture in enhanced pollution, aluminum flocs and hydrogen gas removal. Observed to increase on doc removal efficiency when the flow rate decrease and current density increase. The best performance of DOC removal (69.0%) was recorded while imposing 20 mA/cm2 and 320 s residence time when inflow pH was 4. Heterotrophic bacteria were completely removed for the highest current densities (20 mA/cm^2). In the EC process, a low concentration of total chlorine species (up to 0.45 mg/L) resulting from the oxidation of chloride anions was formed, which promoted the removal of microorganisms, even though these were mainly removed by the coupled effects of the electric field and the bacteria entrapment in hydroxide flocs. Finally, EC/EF/ED as a one-step pretreatment method was shown to be efficient to replace the conventional methods prior to desalination by reverse osmosis as it was proved to remove efficiently organic matter and microorganisms from seawater: with 0.8 L/h and 14 mA/cm2, 50% of DOC and nearly all the microorganisms could be removed at less than 0.5 kW h/m3.[37]

In the study of Brahmi et al. (2017) investigated the parameters efficiency of the new technology: ballasted electro-flocculation (BEF) and they choose their electrode type as a aluminum for using at mining wastewater and examine to removal of zinc and cadmium. Main condition of this process is based to use polyelectrolyte and micro-sand together. This condition supply to heavier flocs and also effect to radically changes on the elecrokoagulation and electroflocculation principles. When the operation conditions examine one by one, 2 A current density got the best removal, with the 20 L/h flowrate, a micro-sand dose of 6 g/L, a polyéthylèneimine (PEI) polymer dose of 100 mg, the contact times of 30 min, a stirring speed of 50 RPM, a monopolar configuration of the electrodes, and an electrodes number of 10. The results showed that the flow rate and the current density have a preponderant effection the variability of the quality of the settled water. In comparison, filterability was found to be more sensitive to number of electrodes, micro sand dosages and current density. It was dependent on the ratio of micro sand to PEI polymer dosage, and improved when this ratio increased. Method for examine to electrode number, current density and polymer dose was surface methodology The removal of Cd and Zn from industrial MWW was done for very low cost of 0.1 TND/m^3 equivalent to 0.04 D /m3. The investigation of BEF process proposes a highly cost-effective wastewater treatment method if compared to Actiflo TM and electrocoagulation.[38]

Table 1.3. Studies with electrocoagulation and electroflocculation technologies

Paper Name	Author	Year	description
Electrochemical pretreatment of wastewater from color photograph processing unit	R. S. Bejankiwar, K. Lokesh, and T. H. Gowda	2003	-Using Iron electorde -650 ml. Mass reactor was used - pH (2.10-4.35), COD, (14220mg/L-16340 mg/L), BOD_5 (120 mg/L-145 mg/L) -pH increase 6.5-8.4
Separation of pollutants from tannery effluents by electro flotation	M. Murugananthan, G. B. Raju, and S. Prabhakar	2004	-Analyze impact of Current Density,electrode material -Study on SSM,Chrome,Sulfate,COD removal in leather ındustry -Reactor size 15 cm x 15 cm x 15 cm. -Electrode length 11 cm and diameter 0.6 and placed as parallel
Effect of halides in the electrochemical treatment of distillery effluent	P. Manisankar, C. Rani, and S. Viswanathan	2004	-6 A/dm^2 current density - using graphite anode and cathodes of alcohol production wastewater. - graphite whose sizes are 4.5 cm x 8.2 cm x 0.5 cm are used -85% KOI, 94% $BOİ_5$ and 98% color removal are provided - As pH, current density and auxiliary electrolyte, effects of NaCI, NaF and NaBr on process efficiency are investigated separately
Operating cost analysis of electrocoagulation of textile dye wastewater	M. Bayramoglu, M. Kobya, O. T. Can, and M. Sozbir	2004	-mainly focused on the technical performance of this process, while its economic aspect has been usually neglected - examined in constant current density (100 A/m^2). -10 minutes as reaction time with iron electrodes -15 minutes reaction time with aluminum electrodes
Olive oil mill wastewater treatment by means of electro-coagulation	H. Inan, A. Dimoglo, H. Şimşek, and M. Karpuzcu	2004	- The removal of COD, color and suspended solid (SS) from olive oil mill wastewater

			- reactor voltage is 1.2 V, interval of current density is 10-40 mA/m^2, pH values are 4, 6, 7 and 9 and finally interval of process time is 2-30 minutes. - optimum time is confirmed as 10-15 minutes
New bipolar electrocoagulation–electroflotation process for the treatment of laundry wastewater	J. Ge, J. Qu, P. Lei, and H. Liu	2004	- used bipolar electrocoagulation – electroflotation process in the treatment of laundry wastewater -3 aluminum plates, 2 titanium having opposite charges are positioned inside electrode - volume of reactor used in experiment is 2.8 dm^3 - the volume of separator is 11.2 dm^3 - Optimum pH is found in between 5 and 9 for turbidity, surface active materials, COD and phosphate removal.
Electro-coagulation of reactive textile dyes and textile wastewater	A.Alinsafi, M.Khemis, M.N.Pons, J.P.Leclerc, A.Yaacoubi, A.Benhammou, A.Nejmeddine	2005	- study about treatment of a textile industry wastewater with electrocoagulation - 100 ml electrocoagulator made out of Pyrex glass were used - color removal rate in between 90-95% and optimum current density. - electrolyze time is confirmed as 105 minutes.
Treatment of the textile wastewater by combined electrocoagulation	O. Can, M. Kobya, E. Demirbas, and M. Bayramoglu	2006	-the impact of chemical coagulant addition such as polyaluminium chloride (PAC) or alum (aluminum sulfite) to COD removal is researched and operational cost analysis has been realized in terms of electric energy, electrode and chemical substance consumption - current density is 100 A/m^2 - reaction time is 10 minutes and in the original pH of textile wastewaters(6.90-7.0)
Oxidation of various reactive dyes with in situ	D. Rajkumar and J. G. Kim	2006	-Removal of 9 different dye compounds including azo, anthraquinone and

electro-generated active chlorine for textile dyeing industry wastewater treatment			triazane groups is researched with electrochemical process in the environment containing active chloride - Anode and cathode are positioned as vertical and horizontal and their active surface areas are 27.7 and 50 cm^2 -Distance among electrodes is determined as 10 mm
Treatment of leachate by electrocoagulation using aluminum and iron electrodes	F. Ilhan, U. Kurt, O. Apaydin, and M. T. Gonullu	2008	- research about treatment of solid waste garbage leachate water with the method of electrocoagulation by using aluminum and iron electrodes. - the impact of electrode materials in the method of electrocoagulation on current density, pH, treatment material, treatment time process efficiency is evaluated in terms of COD and NH_4-N removal - electrocoagulation method has been compared with chemical coagulant method
Assessment of electrocoagulation for the treatment of petroleum refinery wastewater	M. H. El-Naas, S. Al-Zuhair, A. Al-Lobaney, and S. Makhlouf	2009	- examine to removal of sulfide and COD with the electrocoagulation process in petroleum refinery wastewater - study shows that SO_4^{2-} concentration and COD content of wastewater are being removed as 93% and 63% respectively with the electrocoagulation method - process are confirmed as pH = 8 and T= 25˚C
Nickel removal from wastewater by electroflocculation-filtration hybridization	L. Sun, E. Miznikov, L. Wang, and A. Adin	2009	- studied nickel (Ni) removal on a syntheticly prepared water sample - used a hybrid method in which electroflocculation (EF) reactor was supported by mechanical filtration, microfiltration, ultrafiltration and ventilation.

			- water sample with 1.5mS/cm conductivity, Ni concentration of 20 mg/l - current 4.2 Ampers
Elektrokoagülasyon Prosesi ile Tekstil Sanayi Atıksuyunun Arıtımı Treatment of Textile Wastewater by Electrocoagulation Process	F. ÖZYONAR and B. KARAGÖZOĞLU	2012	- studied the treatablity of textile industry waste water with Electroagulation process. - used monopolar, parallel aluminium electrodes. - starting pH:3, current density 100A/m2 and electrolyze time 20 minutes - TOC, COD, colour and turbidity removal efficiencey was found as %82.6-72.5-97.7 and 98.7
Standardizing electrocoagulation reactor design: Iron electrodes for NOM removal	Kristian L. Dubrawski, Madjid Mohseni	2013	- studied the optimization of electrocoagulation reactor design - they were investigated the effects of flow density, nutrient loading, pH adjustment and dosing type - current density 2.43- 26.8 mA/cm^2, Feeding Pollution load and flocculation method (Slow and Fast) was tested - The ideal current density for natural organic matter removal efficiency was 10 mA / cm^2
Effects of direct and alternating current on the treatment of oily water in an electroflocculation process	A. A. Cerqueira, P. S. A. Souza, and M. R. C. Marques	2014	- examine effect of direct and alternative current on the treatment of oily water - prepare 2L a synthetic oil/water (O/W) emulsion and 2 different batch and Continuous flow reactor. -. All test, batch and continious flow reactor conducted with 2 type of electrolytic unit.
Effect of dye molecules and electrode material on the settling behavior of flocs in an electrocoagulation induced settling tank reactor(EISTR)	Kadarkarai Govindan, Yoram Oren, Michael Noel,	2014	- was fabricated a simple induced settling tank reactor (EISTR) - investigated the removal and sedimentation kinetics of Amido Black 10B, Methyl Violet, Eosin Yellow, Malachite Green, Methylene Blue, Rhodamine 6G

			-8 cm internal diameter and 59 cm height graduated polypropylene cylinder with provisions for hanging two 13.5 x 5.2 x 0.5 cm Fe or Al electrodes was used - efficiency of color removal observed 81-99% and COD removal observed 54-68%.
Effects of untreated and treated oilfield-produced water on seed germination, seedling development, and biomass production of sunflower (Helianthus annuus L.)	Mônica Regina da Costa Marques & Paulo Sérgio Alves de Souza & Michelle Machado Rigo & Alexandre Andrade Cerqueira & Julieta L. de Paiva & Fábio Merçon & Daniel Vidal Perez	2015	- aims to evaluate possible toxic effects of oil and other contaminants from oilfield-produced water from oil exploration and production - Electroflocculation treatment of oilfieldproduced water achieved significant removals of chemical oxygen demand (COD) (94 %), oil and grease (O&G) (96 %), color (97 %), and turbidity (99 %). -, electroflocculation treatment appears as an interesting alternative to removing oil and soluble organic matter in excess from oilfield-produced water improving sunflower's seedling developmen
Treatment of wastewater from the dairy industry using electroflocculation and solid whey recovery	Marina S. Melchiors, Mauricio Piovesan, Vitor R. Becegato, Valter A. Becegato, Elias B. Tambourgi, Alexandre T. Paulino	2016	-Investigate the efficiency of electroflocculation for the treatment of wastewater from the dairy industry and the recovery of solid whey on their study. - They monitored to electroflocculation time, initial pH of wastewater and applied potential intensity parameters. - Distance between electrodes chose 2 cm and they apply 60 min reaction time at 5V potential intensity. -Removal rates of COD and turbidity with aluminum electrode 97.0 ± 0.02% and 99.6 ± 3.00 x 10^{-4} % - Removal rates of COD and turbidity with iron electrode 97.4 ± 0.01% and 99.1 ± 1.00 x 10^{-4} %
Hybrid electrocoagulation –	Jean Nepo Hakizimana, Noura	2017	-examine the feasibility of a hybrid electrocoagulation/electroflotation/electr

electroflotation - electrodisinfection process as a pretreatment for seawater desalination	Najid, Bouchaib Gourich, Christophe Vial, Youssef Stiriba, Jamal Naja		odisinfection (EC/EF/ED) process in treating seawater prior to desalination treatment using reverse osmosis process. - A continuous treatment using aluminium electrodes was investigated - Experimental results showed that DOC removal efficiency increased when the current density increased and when the input flow rate decreased - The best performance of DOC removal (69.0%) was recorded while imposing 20 mA/cm2 and 320 s residence time when inflow pH was 4 - highest current densities 20 mA/cm^2
Treatment of heavy metal polluted industrial wastewater by a newwater treatment process: ballasted electroflocculation	Khaled Brahmi, Wided Bouguerra, Soumaya Harbi, Elimame Elaloui, Mouna Loungouc, Béchir Hamrounia	2017	- investigated the parameters efficiency of the new technology: ballasted electro-flocculation (BEF) using aluminum (Al) electrodes to remove cadmium and zinc from industrial mining wastewater (MWW). - the best removal percentage was obtained at a current intensity of 2 A, a the flowrate of 20 L/h, a micro-sand dose of 6 g/L, a polyéthylèneimine (PEI) polymer dose of 100 mg, the contacttimes of 30 min, a stirring speed of 50 RPM, a monopolar configuration of the electrodes, and an electrodes number of 10. - The removal of Cd and Zn from industrial MWW was done for very low cost of 0.1 TND/m^3 equivalent to 0.04 D /m3.

2. OBJECTIVE AND SCOPE

The main scope of this thesis is to develop alternative technologies and methods to play a role in the treatment of the wastewater of some industries which are difficult to treat, and which are high in environmental pollution. It is also one of the purposes of the study that the revealing of the potential being a stand-alone treatment system in the industrial field by examining the limits and treatment efficiencies of E&E technology in detail. In this context, the examination of many variables affecting test conditions and efficiencies in the study constitutes the sub-objectives of the study. Moreover, the each of industrial wastewater studied have presented different purposes. Other purposes in this scope are below:

- Investigation of effects on the efficiency changes in E&E process of pH variations and the determination of the optimum feed pH required for the system as well as the examination of the effects of pH changes after the output of the reactor on the wastewater,
- Examination of the influences of current density on treatment efficiency and electrode consumption and determination of a general optimum current density,
- Selection of electrode material and comparison of treatment efficiencies of single type or mixed electrodes in accordance with industrial changes,
- Determination of the impact of reaction time on the efficiency and the effect of the current density on the efficiency in different reaction time.

The wastewater of all the companies performed in this study was evaluated independently and different working conditions and methods were applied for all of them. According to the characteristics of the wastewater, the parameters to be given priority in the study were determined and evaluated these parameters depending on the wastewater.

In this context, the usage of E&E process for each type of wastewater within the scope of the determined pollutant was revealed, and the differences in operating costs revealed by making the cost calculation with the different technologies used in the industries that can be taken data.

3. MATERIALS AND METHODS

Materials and methods employed in the thesis are given both industrial and material scale in order to be easier and more understandable.

3.1. Materials

An electrocoagulation reactor, with the following characteristics was designed and used in the studies. The reactor volume was 22050 cm^3 with dimensions of 14 cm x 42 cm x 37.5 cm. The reactor was constructed to handle 0.045 L/s flow rate, from plexiglass material. Aluminum, iron and chrome plates with dimensions of 14 cm x 0,50 cm x 37,5 cm were used in this system and 19 plates were placed in the reactor. The volume of electrodes were 262.5 cm^3.

In the system, Al and Fe electrodes with +3 valences are used as the electrode material.

The energy panel was chosen in the range of 0 - 300 A and 0 - 40 V, and the effects of the current and volt values on the treatment efficiency were investigated and paper filters with a diameter of 20 – 50 micron pore diameter were used to filter the treated water at the end of the system.

The design drawings and pictures of the reactors used are presented between Figure 3.1. and Figure 3.3.

Figure 3.1. Electrode configuration in Electrocoagulation and Electroflocculation reactors.

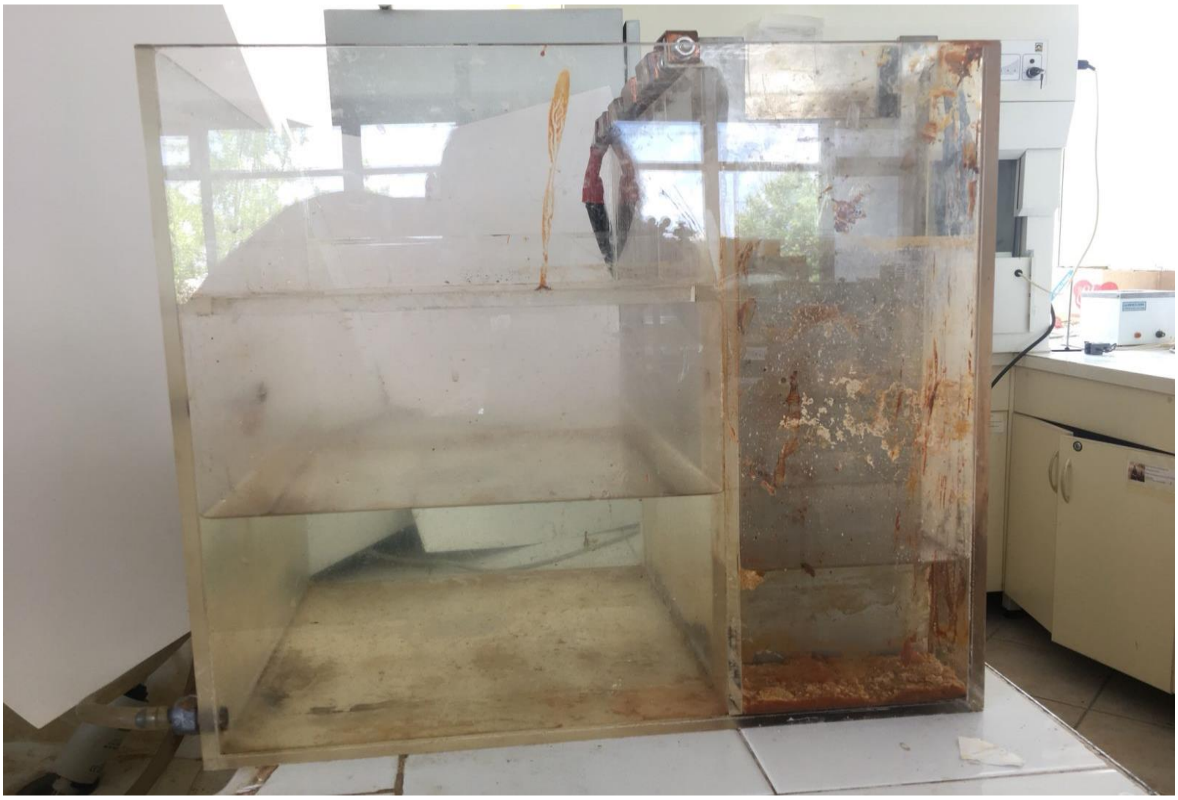


Figure 3.2. Electrocoagulation and Electroflocculation reactors.

Figure 3.3. Electrocoagulation and Electroflocculation reactors.

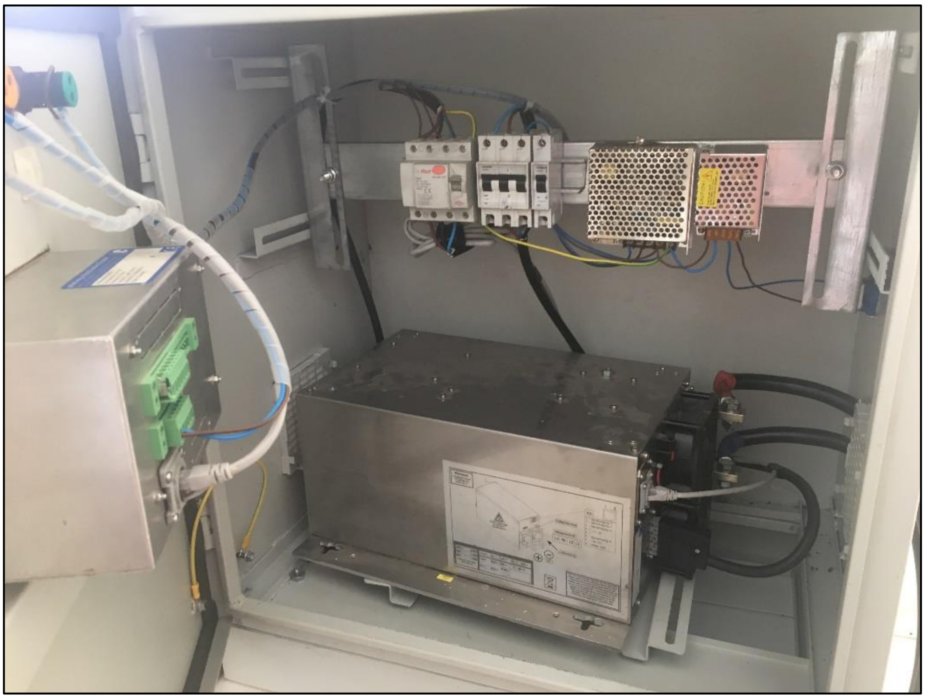


Figure 3.4. E&E process reactor power supply.

Figure 3.5. E&E process reactor control panel.

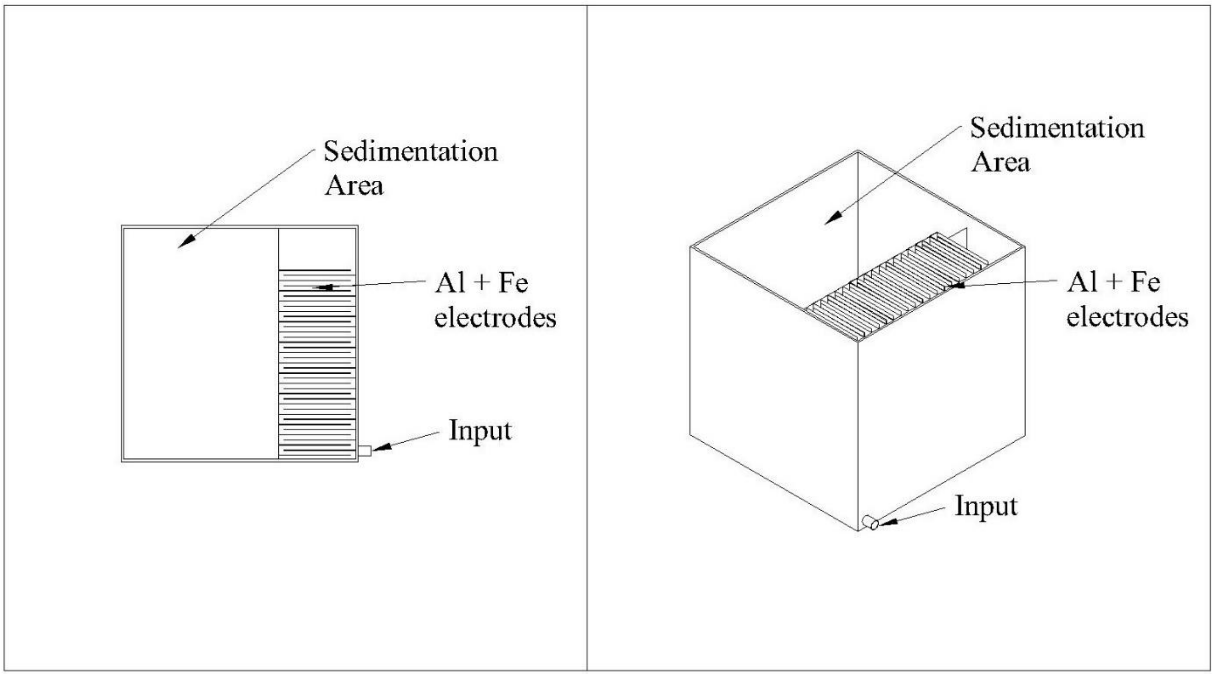


Figure 3.6. Reactor top and 3D view

Figure 3.7. Fe and Al electrodes

3.2. Methods depending on the industries

Table 3.1. Methods used in this study are given in terms of industry type.

	100	150	200	250	300
Metal Coating Industry	-Nickel,Copper Tested -Ph balanced both reactor input and output -Fe and Al electrodes used separately	-Nickel,Copper Tested -Ph balanced both reactor input and output -Fe and Al electrodes used separately	Nickel,Copper Tested -Ph balanced both reactor input and output -Double reaction time also tested -Fe and Al electrodes used separately	Nickel,Copper Tested -Ph balanced both reactor input and output -Double reaction time also tested -Fe and Al electrodes used separately	Nickel,Copper Tested -Ph balanced both reactor input and output -Double reaction time also tested -Fe and Al electrodes used separately
Mining Industry			-Manganese, Aluminum, Magnesium, Nickel Tested -Fe electrode used -Ph balanced reactor output	Manganese, Aluminum, Magnesium, Nickel Tested -Fe and Al electrode used - Ph balanced reactor output	Manganese, Aluminum, Magnesium, Nickel Tested -Fe and Al electrode used - Ph balanced both reactor input and output
Textile Industry		-COD, Color removal tested -Only Al electrode and Al+Fe combine electrode used			-COD, Color removal tested -Only Al electrode and Al+Fe combine electrode used -Double reaction time tested for COD
Vegetable Oil	-COD tested	COD tested	-COD tested	-COD, TN, TP tested -Different reaction time applied -Optimum reaction time 3 minutes	-COD tested
Landfill Leachate		-Nitrite, Nitrate, Ammonium, Phosphate,TSS tested - Only Al electrode and Al+Fe combine electrode used --Double reaction time also tested		-Nitrite, Nitrate, Ammonium, Phosphate,TSS tested - Al+Fe combine electrode used -Double reaction time also tested	

A commercially available anoionic polyelectrolyte (ENFLOC 340 AP) was used for flocculation in all studies. And chemical information for polyelectrolyte given the table 3.2.

Table 3.2. Polyelectrolyte Specifications

Ionic Character	Anionic
The charge density	Medium
Grain Size	%>10 mesh: 2 %<10 mesh: 6
Approximate Bulk Density	0,75
Brookfield Viscosity (cps)	@5.0 g/l ----- 1320
	@2.5 g/l ----- 680
	@1.0 g/l ----- 60
pH @ 5g/l	6-8

3.3. Metal Coating and Mining Industry

Stainless Steel as anode material and Iron and/or Aluminum plates as cathode material are used in E&E process reactors. Each of two metals has the ability to form stable compounds with coagulant effect and contaminating ions during dissolution. During the test runs, the following reactor and metal combinations were studied.

1. Completely Iron Cathode electrode
2. Completely Aluminum Cathode electrode
3. Both Iron and Aluminum Cathode electrodes

In the E&E process, the pH of the water has a vital importance on the providing coagulation and precipitation in the reactions within the process and in the effluent. Process and coagulation studies were performed at different pH levels for each combination of cathode materials in test runs.

1. Reaction of raw wastewater with original pH;

Coagulation studies at pH 7, pH 9, pH 11 levels at the outlet of the reactor.

2. Providing of coagulation at the end of the E&E reactor by increasing pH of the raw water to 11 before not entering to reactor.

The pH adjustment during the test runs was provided by different combinations of NaOH and $CaCO_3$ or each of them.

The given conditions were performed at different current values under the same conditions and the results and efficiencies were calculated.

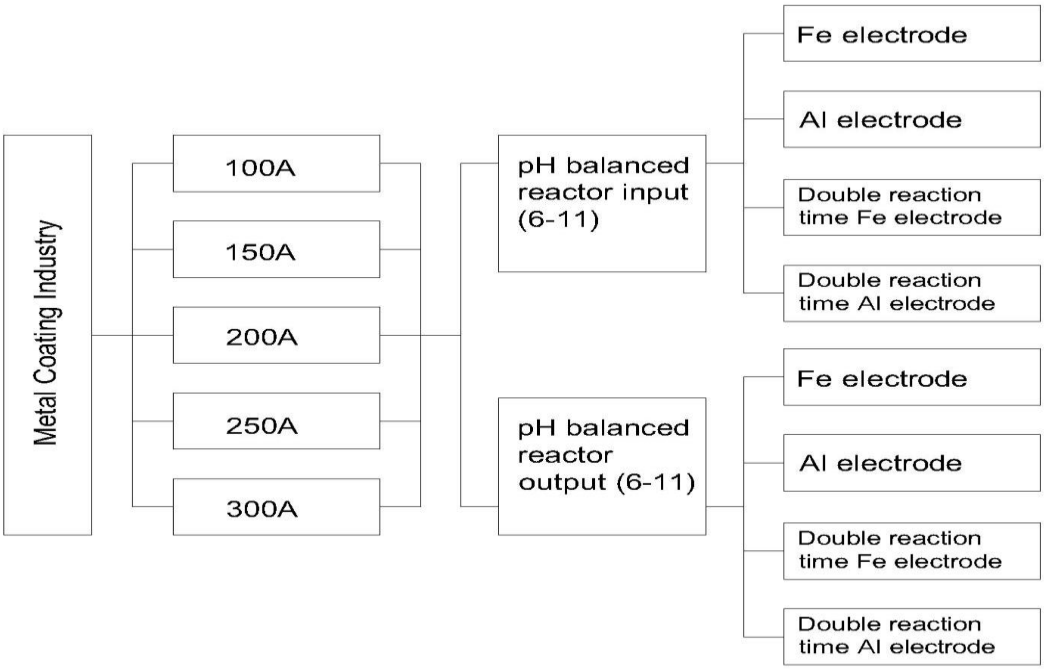


Figure 3.8. Metal Coating Industry study methods

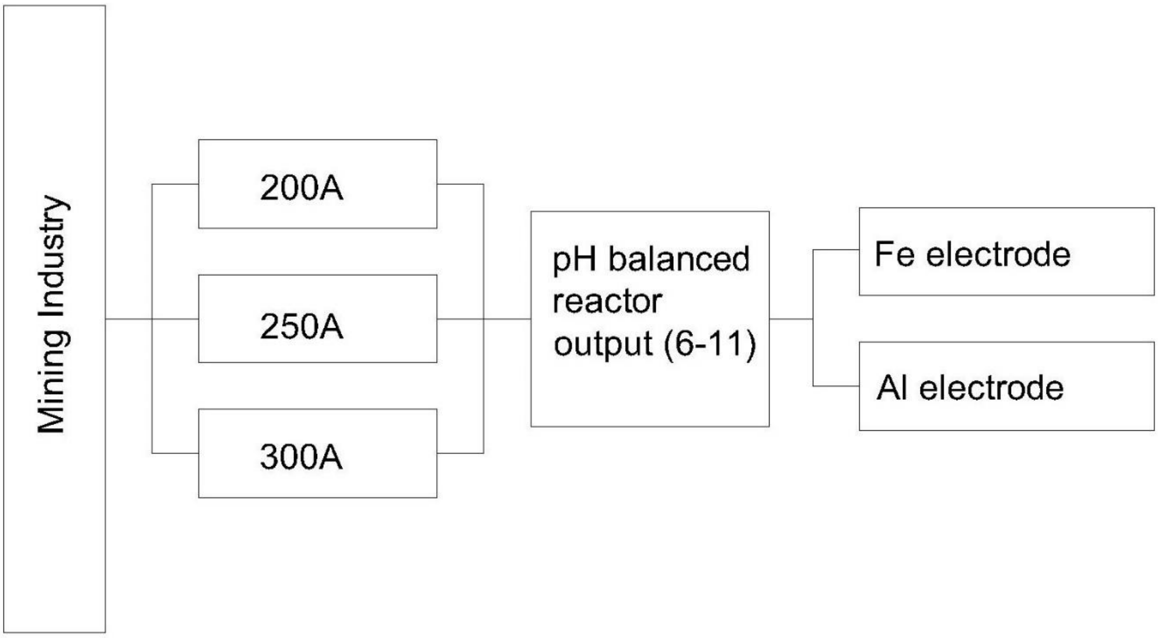


Figure 3.9. Mining Industry study methods

3.4. Textile Industry

In this industry, studies were carried out on the color removal which is one of the main pollutant parameters. Because of this reason, auxiliary coagulant was used to apply in the effluent and tests were done to find the most suitable auxiliary coagulant.

After the most suitable auxiliary coagulant was found, the tests were carried out by changing the current densities in the reactor containing both iron and aluminum electrodes. After the determination of the current density and the optimum current, the experiment was repeated under the same conditions by increasing the process time in the determination of the effects of the process time on the textile wastewater to observe the efficiency changes in both the color and Chemical Oxygen Demand (COD) parameters. the experiment was repeated.

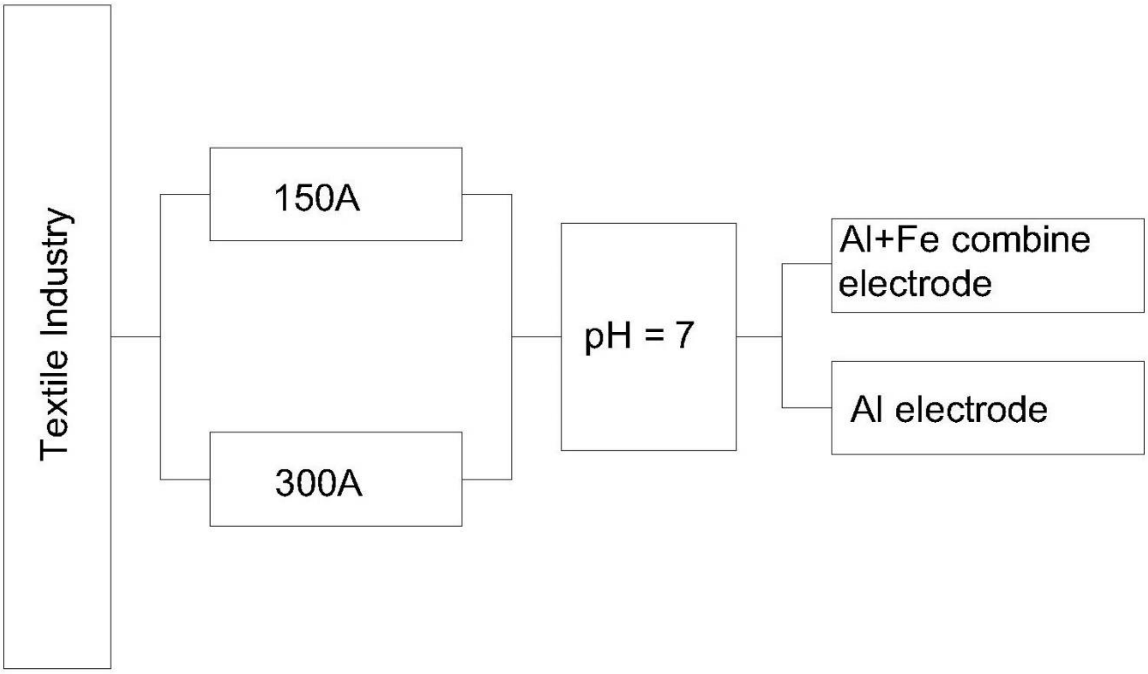


Figure 3.10. Textile Industry study methods

3.5. Vegetable Oil Production Industry

In this study, the treatability of the vegetable oil industry wastewater by means of electroflocculation process has been studied. Wastewater sample and datas taken and studied collectively with scientific research project in Giresun University project named and number with “**Fen-Bap-A-140316-73 Treatment Of Mıxed Herbal Oıl Processıng Factory Wastewaters By Pılot-Scale Electrocoagulatıon Unıt: Technıcal And Economıcal Aspects”** under the coordinated of Prof. Dr. Başak Taşeli. In this studies the following methods have been applied for the studies.

1. Calculation of optimum pH value on raw water
2. Selection of suitable polyelectrolyte
3. Optimization of current
4. Optimization of reaction time

Firstly, anionic and cationic polymers were tried on wastewater for the selection of suitable polymer and the most suitable type of polymer was found. After the determination of the polymer, determination of the most suitable current density was made by changing the current densities on the reactor and after this current density was determined, the effects of the reaction period on the efficiency were examined at the most appropriate current density.

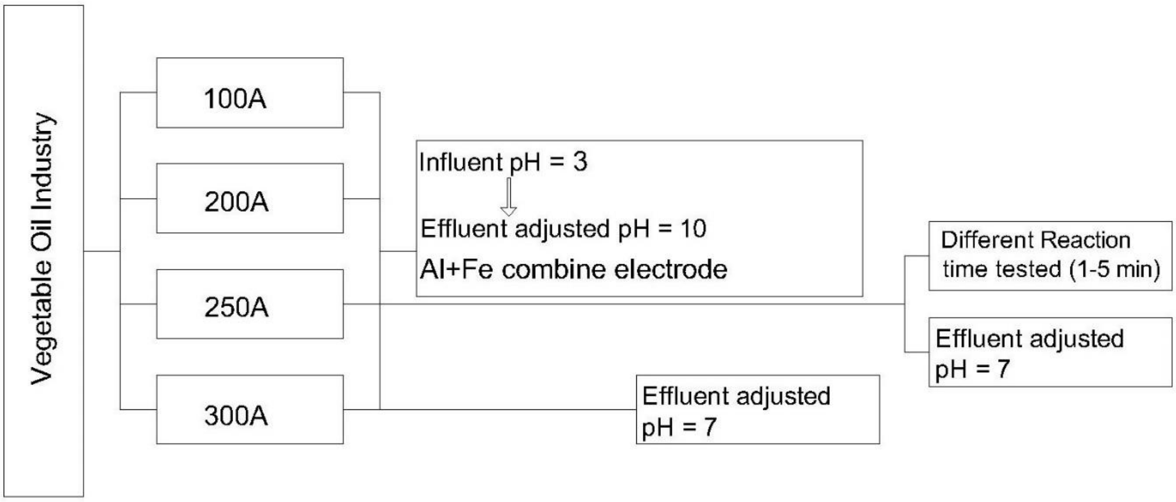


Figure 3.11. Vegetable Industry study methods

3.6. Landfill Leachate Wastewater

Due to the high pollutant concentration values of the landfill leachate, aeration process was applied to the E&E process before feeding and the E&E system was used as a combined system together with aeration. At the first part of the study, raw wastewater was aerated for 1 hour and aeration process was applied to all experiments, equally.

Because of the low amount of wastewater and difficulty in accessibility, the current density, which is one of the main factors in test runs, was performed in two ranges and the results were found in accordance with these ranges. Moreover, the results were obtained by working on completely iron and completely aluminum electrodes as well as mixed electrode types for wastewater examined.

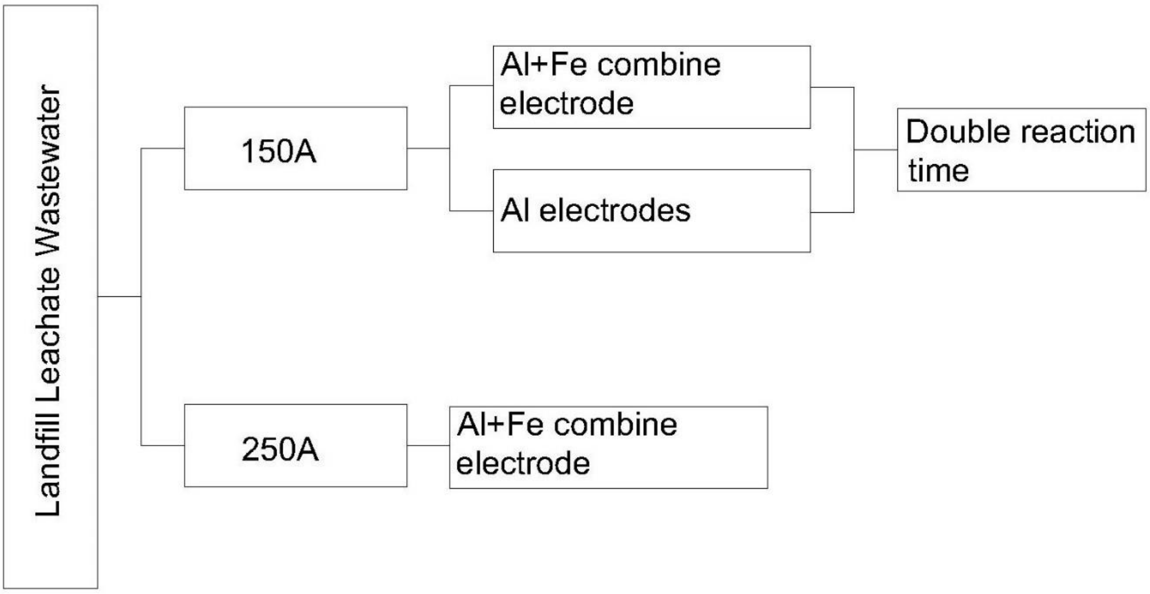


Figure 3.12. Landfill Leachate Wastewater study methods

4. RESULTS AND DISCUSSION

Experimental results were analyzed in six sub-sections. These subheadings are based on the work done for reactor identification and on the type of industrial wastewater being studied.

4.1. Reactor Definition and Tracer Tests

2 tracer tests were performed for reactor. For these tests 2 different solution with methylene blue and conductivity were used, and results given to the Table 4.1. and Table 4.2. The first experiment was carried out with a salt solution with a conductivity of 36000 µS. Conductivity change at the endpoint of the test is given in the following Table 4.1.

Table 4.1. Conductivity tracer test results.

Input	1. Min	2. Min	3. Min	4. Min	5. Min	6. Min	7. Min	8. Min	9. Min	10. Min
251	251	254	411	288	261	256	256	255	255	254

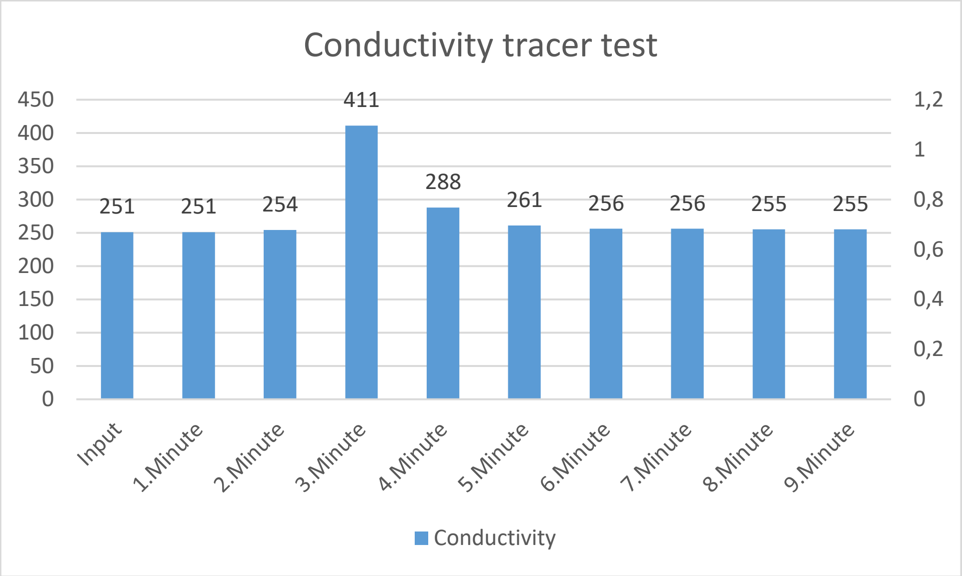


Figure 4.1. Conductivity tracer test results.

In the second experiment, methylene blue solution was added in order to monitor the movement of the water sample in the reactor and the color changes at the exit point were observed within minutes.

Table 4.2. Methylene blue tracer test results.

Input	1.Min	2.Min	3.Min	4.Min	5.Min	6.Min	7.Min	8.Min	9.Min
0,005	0,005	0,01	0,172	0,431	0,8	0,76	0,15	0,07	0,005

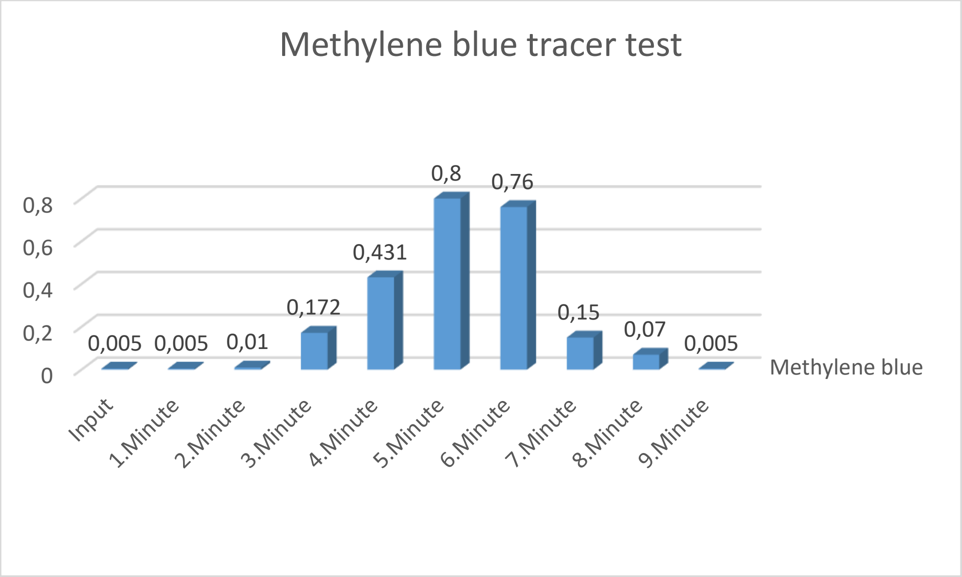


Figure 4.2. Methylene blue tracer test results.

After the work done, the definition of the reactor was made. Given the operating conditions and data, it is seen that the reactor is working as a piston flow reactor.

Also, in the studies performed to see the effect of the current density on the cathodes, the dissipation amounts of the plates at the current values of 100 and 200 ampere were calculated for 1 hour and together with the calculation of the changes in the amounts dissolved Al and Fe in the water both in the 1 hour work and in the continuous flow operation given the following Table 4.3. and Table 4.4.

Table 4.3. Dissipation number of electrodes with different current density for 1 hour.

Current Density	Al Plates		Fe Plates	
	Influent (g)	Effluent (g)	Influent (g)	Effluent (g)
100 A	798	792.5	2,330	2,315
200 A	787	780	2,300	2,266

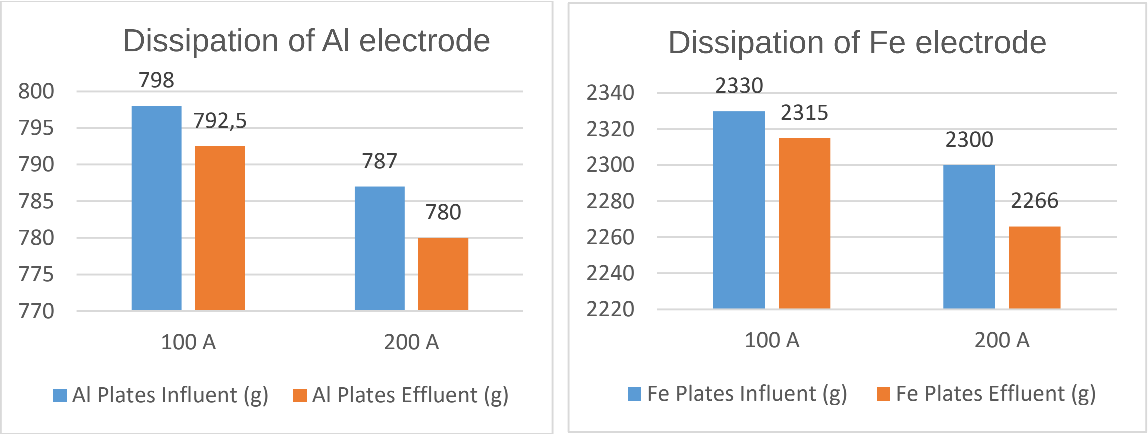


Figure 4.3. Dissipation number of electrodes with different current density for 1 hour.

Table 4.4. Dissolved Al and Fe in the water both in the 1-hour work and in the continuous flow operation. Dissolved Al and Fe concentration in the water.

Current Density	Al (ppm)		Fe (ppm)	
	Influent	Effluent	Influent	Effluent
100 A Batch	1.375	84.69	3.143	2.026
200 A Batch	1.375	780.000	3.143	2.695
100 A Continues Flow	0.021	0.242	0.051	0.022
200 A Continues Flow	0.021	22.83	0.051	0.036

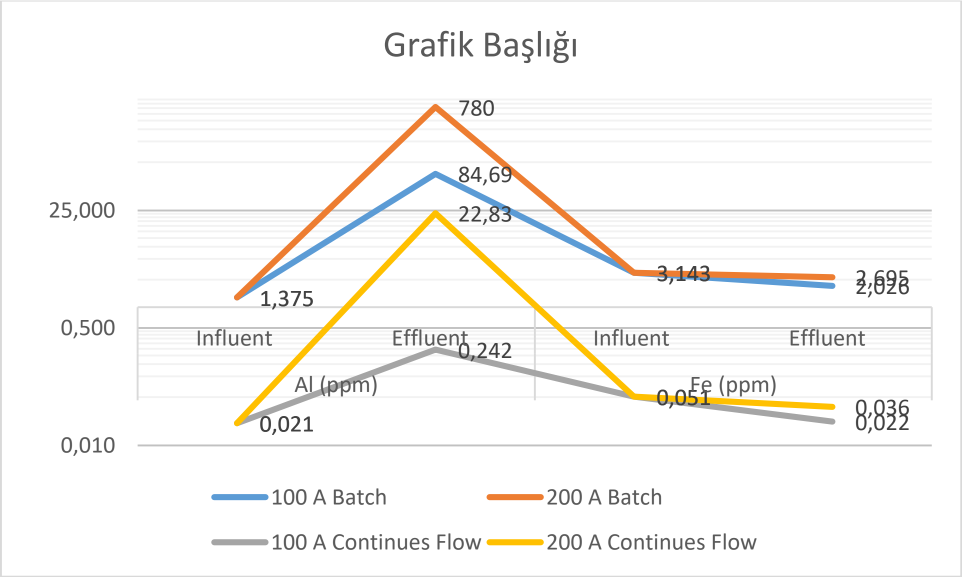


Figure 4.4. Dissolved Al and Fe in the water both in the 1-hour work and in the continuous flow operation. Dissolved Al and Fe concentration in the water.

4.2. Evaluation of E&E removal performance in Metal Coating Industry wastewaters

During the study, E & E performance of iron electrodes at different current densities and pH values was first investigated. All the tests were also performed before and after wastewater pH E & E and the results of the removal were calculated. The following pollutants as basic pollution parameters were studied in this study.

- Copper (Cu)
- Nickel (Ni)

The raw water input pH was calculated to be 3 in all studies. The results of the studies and the efficiency calculations are given in the Table 4.5 and 4.6.

Table 4.5. Studies with iron electrodes and pH balanced at E&E output.

		Nickel		Copper	
Current (A)	pH	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
100	6	153,00	121,00	51,80	9,80
	7	150,00	119,00	60,00	12,40
	8	60,00	21,60	81,00	35,00
	9	29,00	24,50	50,00	32,46
	10	160,10	11,00	56,90	36,45
	11	156,00	9,11	101,60	10,81
150	6	152,00	126,00	50,60	9,73
	7	149,00	121,40	65,90	9,00
	8	60,00	12,40	80,00	33,00
	9	19,00	7,85	37,00	18,90
	10	165,00	16,70	121,30	10,26
	11	161,90	9,00	82,00	34,00
200	6	150,00	131,20	45,30	9,16
	7	153,00	116,00	46,00	9,67
	8	61,70	23,00	81,60	34,90
	9	125,00	63,00	98,40	25,00
	10	160,00	11,00	110,00	39,40
	11	160,20	9,80	110,00	31,60
250	6	153,00	133,00	47,50	6,84
	7	148,00	139,00	71,00	7,98
	8	60,20	22,00	71,00	34,20
	9	43,50	18,50	47,70	17,20
	10	160,20	14,10	42,20	4,95
	11	160,20	9,40	43,60	4,21
300	6	159,00	112,00	63,20	12,00

	7	96,00	69,00	122,00	13,74
	8	63,80	20,60	72,00	34,80
	9	56,60	6,80	48,20	14,00
	10	164,10	10,00	114,00	37,32
	11	164,10	8,60	116,00	29,80

Table 4.6. Efficiency of studies with iron electrodes and pH balanced at E&E output.

		Efficiency (%)				Efficiency (%)	
		Nickel	Copper			Nickel	Copper
Current (A)	pH			Current (A)	pH		
100	6	20,9	81,1	250	6	13,1	85,6
	7	79,3	20,7		7	6,1	88,8
	8	65,9	56,8		8	63,5	51,8
	9	15,5	35,1		9	57,5	63,9
	10	93,1	35,9		10	91,2	88,3
	11	94,2	89,4		11	94,1	90,3
150	6	17,1	80,8	300	6	29,6	81,0
	7	18,5	86,3		7	28,1	88,7
	8	79,3	58,8		8	67,7	51,7
	9	58,7	48,9		9	88,0	71,0
	10	89,9	91,5		10	93,9	67,3
	11	94,4	58,5		11	94,8	74,3
200	6	12,5	79,8				
	7	24,2	79,0				
	8	62,7	57,2				
	9	49,6	74,6				
	10	93,1	67,3				
	11	93,9	71,3				

Efficiency graphs of the studies performed are presented in the following Figure 4.5. and 4.8. respectively.

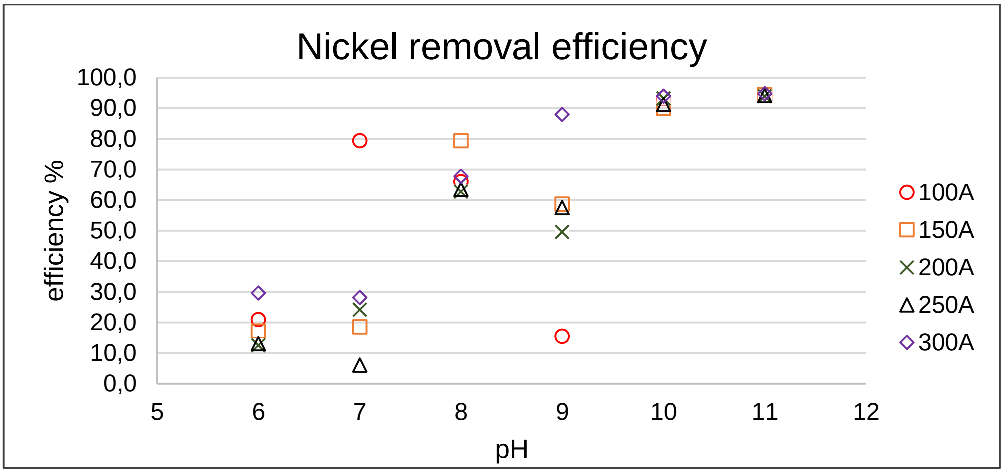


Figure 4.5. Nickel removal efficiency with iron electrodes and pH balanced at E&E output

Table 4.7. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	600,641	4	150,16	0,13	0,9718
Within groups	29895,1	25	1195,81		
Total (Corr.)	30495,8	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

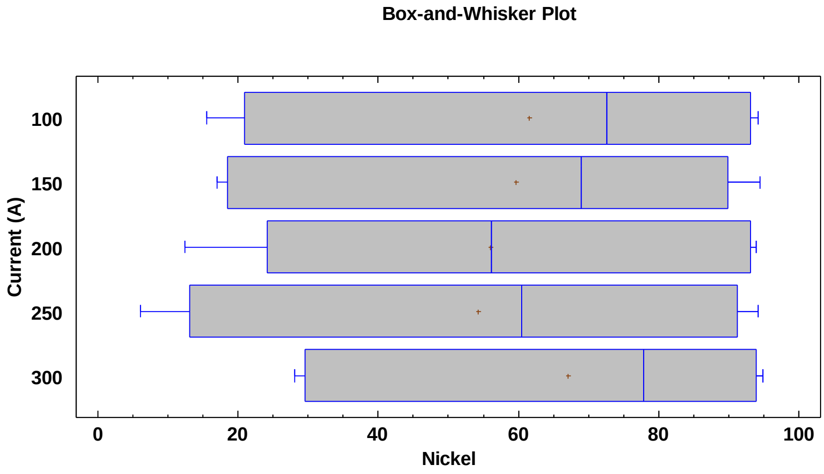


Figure 4.6. Box and Whisker Plot for Nickel by Current (A)

Table 4.8. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	24252,8	5	4850,56	18,65	0,0000
Within groups	6242,98	24	260,124		
Total (Corr.)	30495,8	29			

Anova table shows us the pH level did make a statistically significant difference on the nickel removal because of the p value in the anova table was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the Nickel.

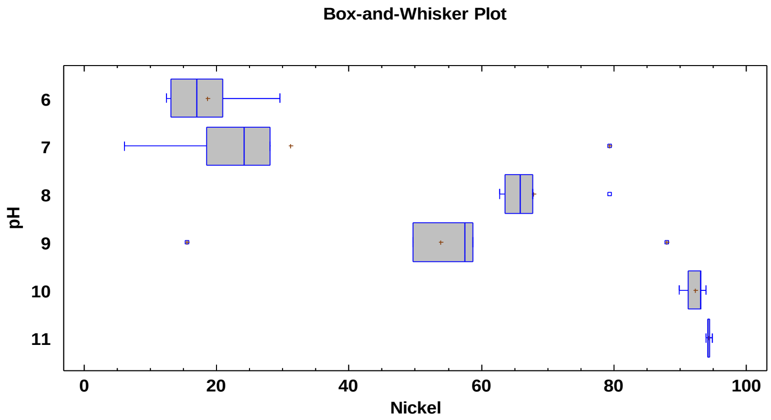


Figure 4.7. Box and Whisker Plot for Nickel by pH

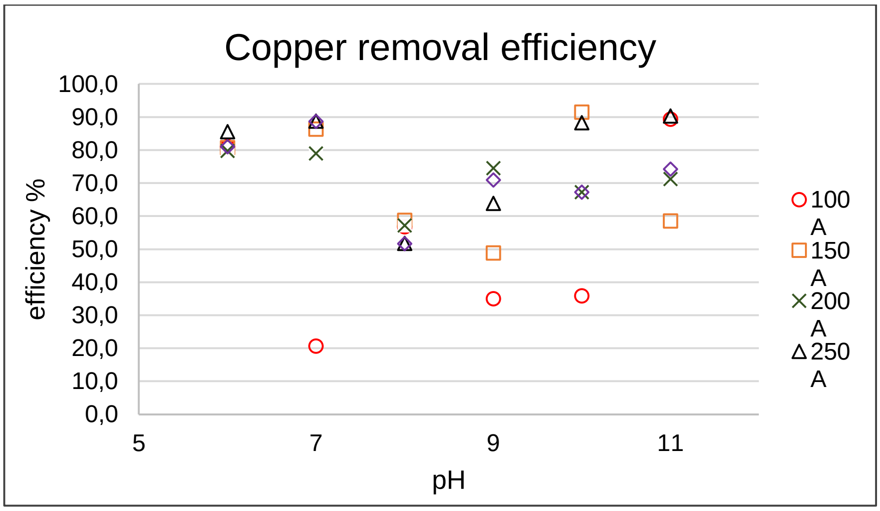


Figure 4.8. Copper removal efficiency with iron electrodes and pH balanced at E&E output

Table 4.9. ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2126,38	4	531,595	1,70	0,1808
Within groups	7802,15	25	312,086		
Total (Corr.)	9928,53	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the copper removal.

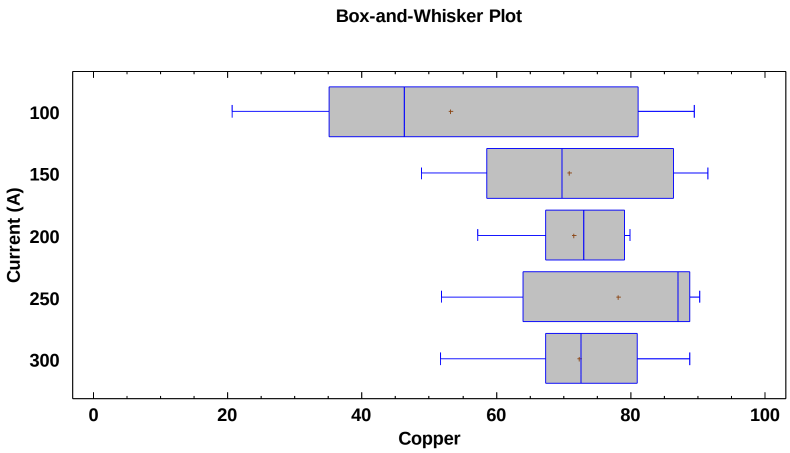


Figure 4.9. Box and Whisker Plot for Copper by Current (A)

Table 4.10. ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2649,84	5	529,968	1,75	0,1622
Within groups	7278,69	24	303,279		
Total (Corr.)	9928,53	29			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the copper removal.

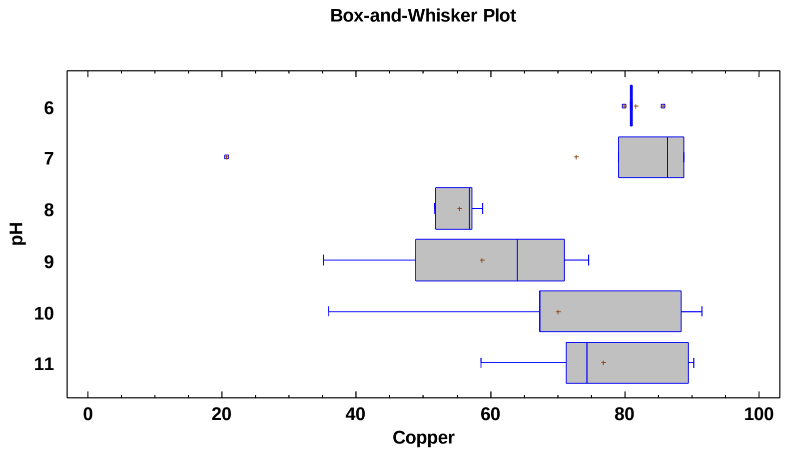


Figure 4.10. Box and Whisker Plot for Copper by pH

As can be seen in figure 4.5. in studies in which pH at reactor exit was elevated with iron electrodes, Ni removal efficiency increases alongside with pH and current density. Yet it was observed that at pH 10 and above, effect of current density was lost and almost all current density values gave same efficiency. As can be seen in figure 4.8. there were fluctuations at copper removal efficiency and in pH 6-9 range efficiency in all current densities was lower compared to the starting pH level but after pH 9 increases were seen again. Effective pH range of Fe^{+2} and Fe^{+3} ions from iron electrodes is 4-12 and also Fe^{+2} effect making its bets after pH 9.5 because of this nickel and copper removal efficiency increase mostly after pH 9. Before pH 9 Fe^{+3} ions making coagulation but after pH 9 Fe^{+2} also effect to efficiency of copper and nickel removal and this reaction increase the efficiency.[39]

Table 4.11. Studies with iron electrodes and pH balanced at E&E input.

		Nickel		Copper	
		Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
Current (A)	pH				
100	6	59,0	39,0	71,0	62,4
	7	56,9	46,2	108,0	43,9
	8	38,5	23,3	97,2	52,6
	9	63,0	52,2	138,0	115,2
	10	54,72	45,48	139,2	127,2
	11	48,0	40,0	100,0	98,6
150	6	59,0	45,85	71,0	58,37
	7	56,9	47,1	108,0	37,3
	8	38,5	28,3	97,2	33,9
	9	63,0	49,4	138,0	103,8
	10	54,72	45,6	139,2	104,4
	11	48,0	46,0	100,0	90,2
200	6	59,0	35,1	71,0	64,3
	7	56,9	48,1	108,0	47,2
	8	38,5	29,1	97,2	51,5
	9	63,0	54,7	138,0	92,6
	10	54,72	46,6	139,2	131,2
	11	48,0	30,6	100,0	90,8
250	6	59,0	33,0	71,0	63,9
	7	56,9	48,4	108,0	49,8
	8	38,5	25,0	97,2	45,8
	9	63,0	50,5	138,0	88,8
	10	54,72	49,8	139,2	84,0
	11	48,0	36,0	100,0	89,2
300	6	59,0	46,0	71,0	61,8
	7	56,9	45,7	108,0	33,9
	8	38,5	24,9	97,2	52,4
	9	63,0	60,0	138,0	60,2
	10	54,72	48,07	139,2	62,8
	11	48,0	36,0	100,0	85,2

Table 4.12. Efficiency of studies with iron electrodes and pH balanced at E&E input.

		Efficiency %				Efficiency %	
		Nickel	Copper			Nickel	Copper
Current (A)	pH			Current (A)	pH		
100	6	33,89	12,11	250	6	44,06	10,00
	7	22,48	59,35		7	18,79	53,88
	8	39,48	45,88		8	35,06	52,88
	9	17,14	16,52		9	19,84	35,65
	10	16,88	8,62		10	8,99	39,65
	11	16,66	1,4		11	0,83	10,80
150	6	22,28	17,78	300	6	22,039	12,92
	7	20,97	65,46		7	23,32	68,61
	8	26,49	65,12		8	35,32	46,09
	9	21,58	24,78		9	4,76	56,37
	10	16,66	25,00		10	11,00	54,88
	11	4,16	9,80		11	25,00	14,80
200	6	40,50	9,43				
	7	19,29	56,29				
	8	24,41	47,01				
	9	13,17	32,89				
	10	14,83	5,74				
	11	36,25	9,20				

Efficiency graphs of the studies performed are presented in the following Figure 4.11. and Figure 4.14. respectively.

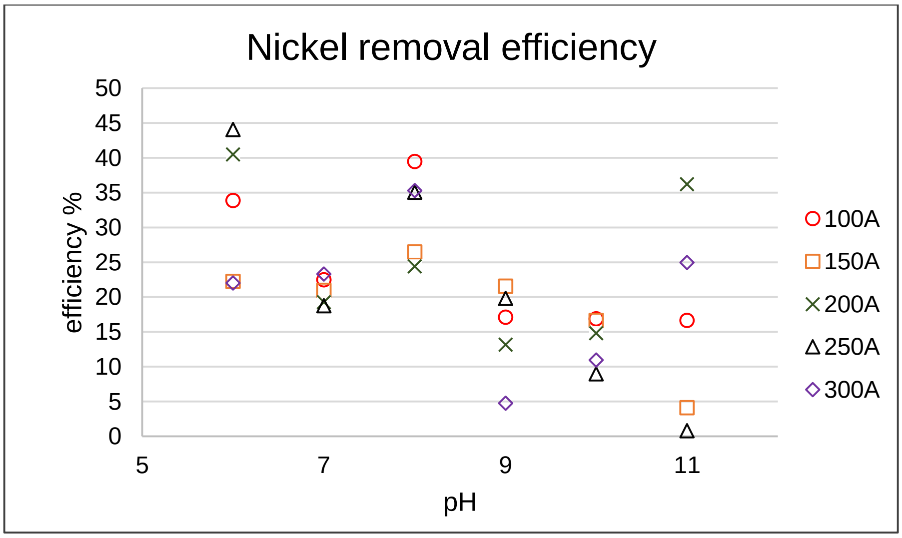


Figure 4.11. Nickel removal efficiency with iron electrodes and pH balanced at E&E input.

Table 4.13 ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	167,384	4	41,8461	0,32	0,8645
Within groups	3309,71	25	132,388		
Total (Corr.)	3477,09	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

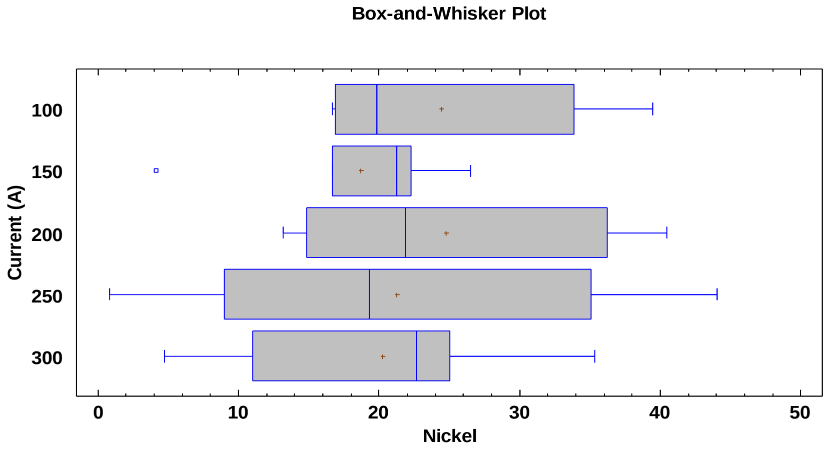


Figure 4.12. Box and Whisker Plot for Nickel by Current (A)

Table 4.14 ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1795,28	5	359,056	5,12	0,0025
Within groups	1681,81	24	70,0756		
Total (Corr.)	3477,09	29			

Anova table shows us the pH level did make a statistically significant difference on the nickel removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the Nickel.

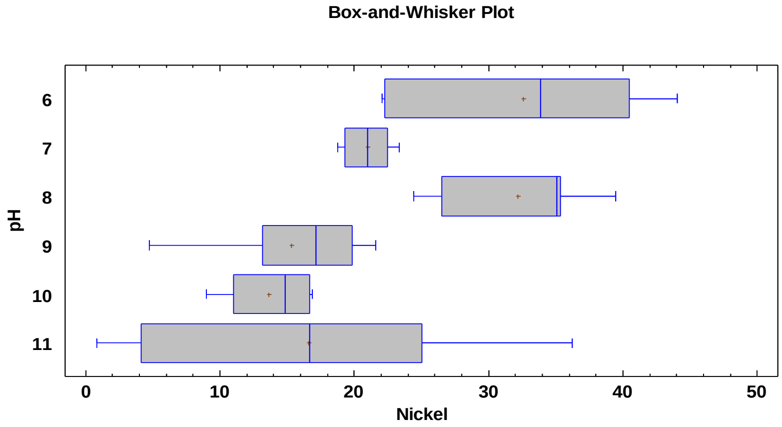


Figure 4.13. Box and Whisker Plot for Nickel by pH

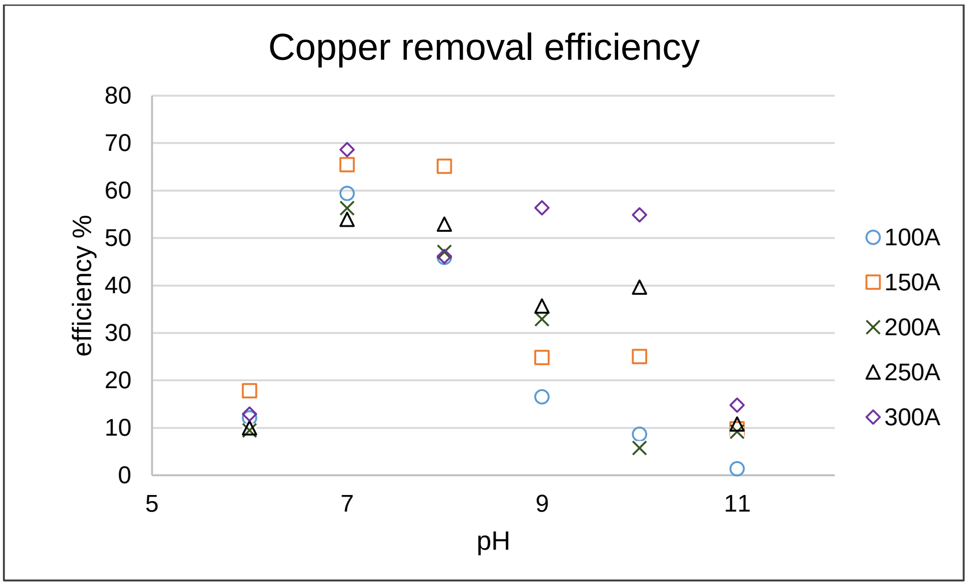


Figure 4.14. Copper removal efficiency with iron electrodes and pH balanced at E&E input

Table 4.15 ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1243,89	4	310,973	0,62	0,6543
Within groups	12596,1	25	503,843		
Total (Corr.)	13840,0	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the copper removal.

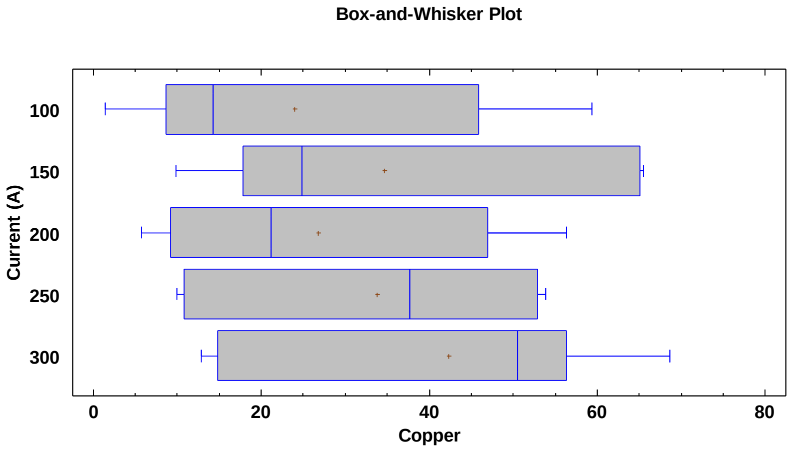


Figure 4.15. Box and Whisker Plot for Copper by Current (A)

Table 4.16 ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	10656,7	5	2131,33	16,07	0,0000
Within groups	3183,3	24	132,638		
Total (Corr.)	13840,0	29			

Anova table shows us the pH level did make a statistically significant difference on the copper removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the copper.

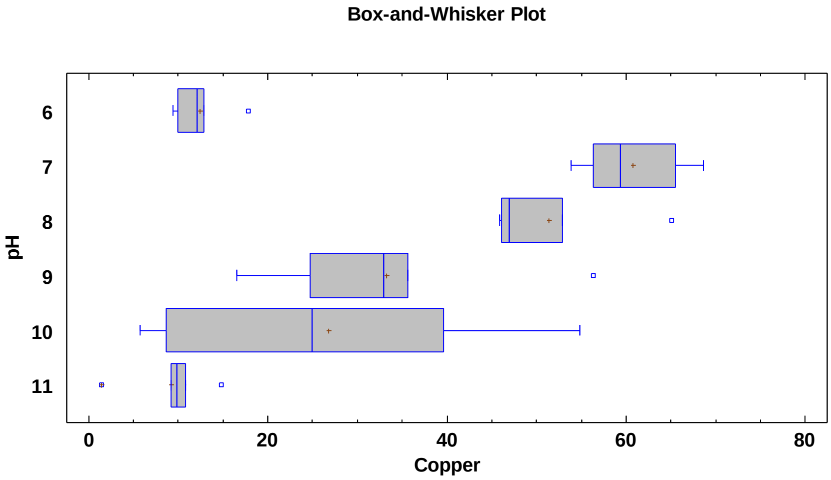


Figure 4.16. Box and Whisker Plot for Copper by pH

In the studies the pH of the reactor is adjusted at the exit using iron electrodes, as can be seen in figure 4.11, at all current density levels there is a decrease in efficiency at Ni removal as feeding pH rises. In the same studies when the copper removal efficiencies examined, in pH 7-8 range, efficiency is rising as can be seen in figure 4.14 but after this range it is decreasing in all current densities except 300A. Even though efficiency losses at current density 300A with pH levels up to 10 was not too great, after pH10 efficiency at all current densities decreases significantly. Flocculation start with OH^- groups and $Fe(OH)_2$ groups starting flocculation and coagulation but at this test when we increase pH before reactor input OH^- cannot find enough Fe ions and removal efficiency shows lower studies with iron electrodes and pH balanced at E&E.[39]

In the second part of the work, all the conditions in the first section were kept the same and the electrodes were replaced with aluminum.

Table 4.17. Studies with aluminum electrodes and pH balanced at E&E output.

		Nickel		Copper	
		Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
Current (A)	pH				
100	6	85,65	78	75,5	25,5
	7	85,65	81	75,5	20
	8	85,65	60	75,5	26
	9	85,65	50,1	75,5	25,5
	10	85,65	45,6	75,5	21
	11	85,65	14,3	75,5	22,76
150	6	85,65	76	75,5	34,4
	7	85,65	36,72	75,5	17,2
	8	85,65	20,04	75,5	17,6
	9	85,65	9,84	75,5	19,2
	10	85,65	8,76	75,5	23,6
	11	85,65	12,6	75,5	30
200	6	85,65	69,48	75,5	19,2
	7	85,65	55,56	75,5	16,8
	8	85,65	27,24	75,5	17,2
	9	85,65	27,24	75,5	20
	10	85,65	25,08	75,5	19,2
	11	85,65	11	75,5	21,4
250	6	85,65	72,4	75,5	23,8
	7	85,65	71,1	75,5	18,8
	8	85,65	63	75,5	21,2
	9	85,65	19,2	75,5	20
	10	85,65	16,3	75,5	21,2
	11	85,65	8	75,5	20,93
300	6	85,65	76,4	75,5	25
	7	85,65	56	75,5	16,2
	8	85,65	26,8	75,5	21
	9	85,65	8,14	75,5	21,4
	10	85,65	7	75,5	20,69
	11	85,65	8,2	75,5	20,5

Table 4.18. Efficiency of studies with aluminum electrodes and pH balanced at E&E output.

		Efficiency %				Efficiency %	
		Nickel	Copper			Nickel	Copper
Current (A)	pH			Current (A)	pH		
100	6	8,93	66,22	250	6	15,46	68,47
	7	5,42	73,5		7	16,98	75,09
	8	29,94	65,56		8	26,44	71,92
	9	41,5	66,22		9	77,58	73,5
	10	46,76	72,18		10	80,96	71,92
	11	83,3	69,85		11	90,65	72,27
150	6	11,26	54,43	300	6	10,79	66,88
	7	57,12	77,21		7	34,61	78,54
	8	76,6	76,68		8	68,7	72,18
	9	88,51	74,56		9	90,49	71,65
	10	89,77	68,74		10	91,82	72,59
	11	85,28	60,24		11	90,42	72,84
200	6	18,87	74,56				
	7	35,13	77,74				
	8	68,19	77,21				
	9	68,19	73,5				
	10	70,71	74,56				
	11	87,15	71,65				

Efficiency graphs of the studies performed are presented in the following Figure 4.17. and 4.20. respectively.

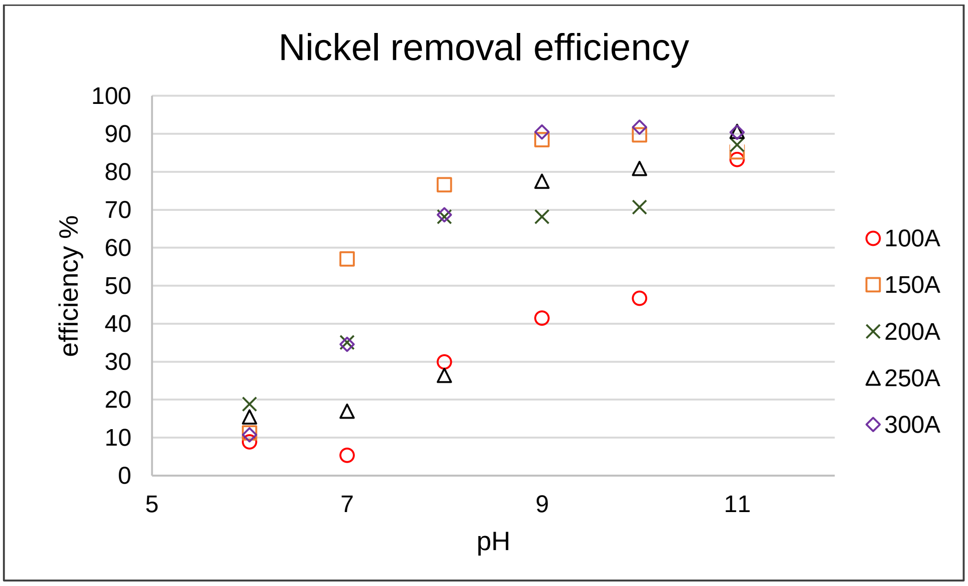


Figure 4.17. Nickel removal efficiency with Aluminum electrodes and pH balanced at E&E output

Table 4.19. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	3863,43	4	965,857	1,00	0,4242
Within groups	24054,7	25	962,186		
Total (Corr.)	27918,1	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

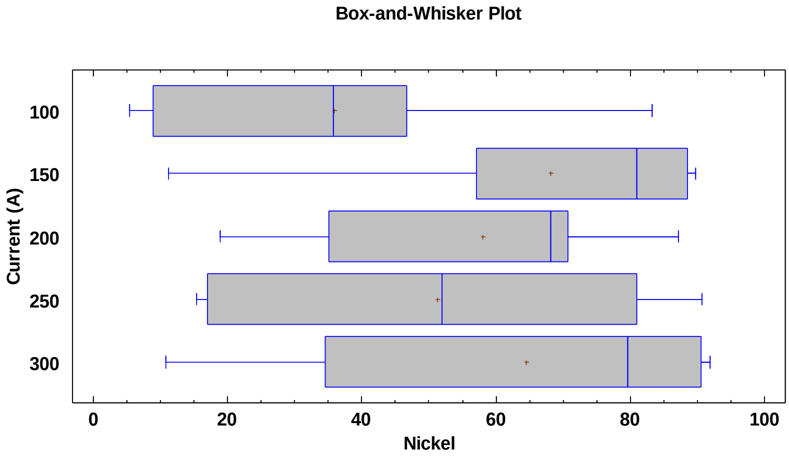


Figure 4.18. Box and Whisker Plot for Nickel by Current (A)

Table 4.20.ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	21058,8	5	4211,77	14,74	0,0000
Within groups	6859,25	24	285,802		
Total (Corr.)	27918,1	29			

Anova table shows us the pH level did make a statistically significant difference on the nickel removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the Nickel.

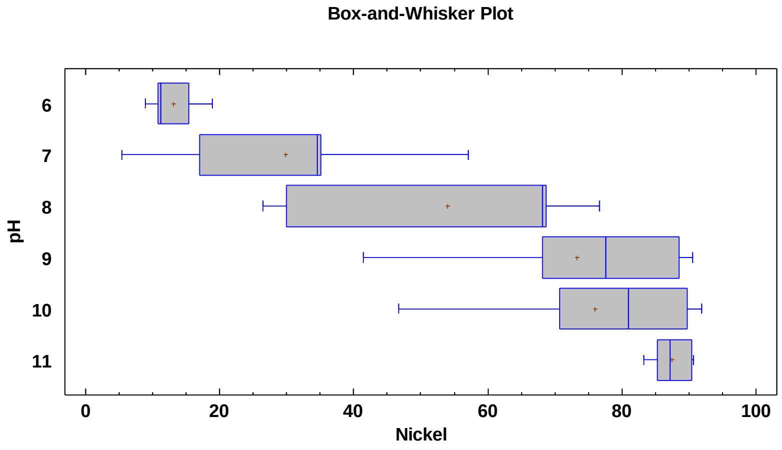


Figure 4.19. Box and Whisker Plot for Nickel by pH

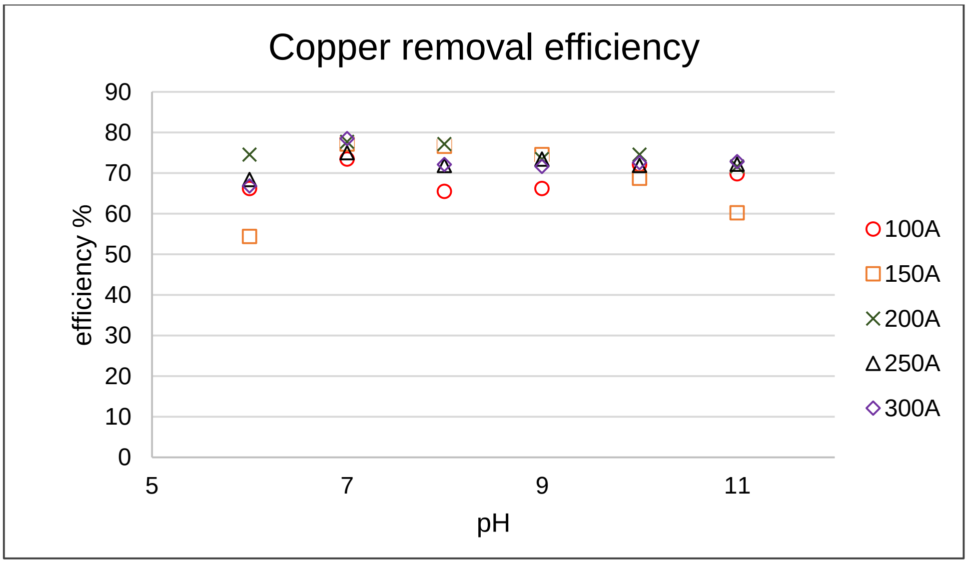


Figure 4.20.Copper removal efficiency with Aluminum electrodes and pH balanced at E&E output

Table 4.21.ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	165,052	4	41,2629	1,66	0,1919
Within groups	623,23	25	24,9292		
Total (Corr.)	788,281	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the copper removal.

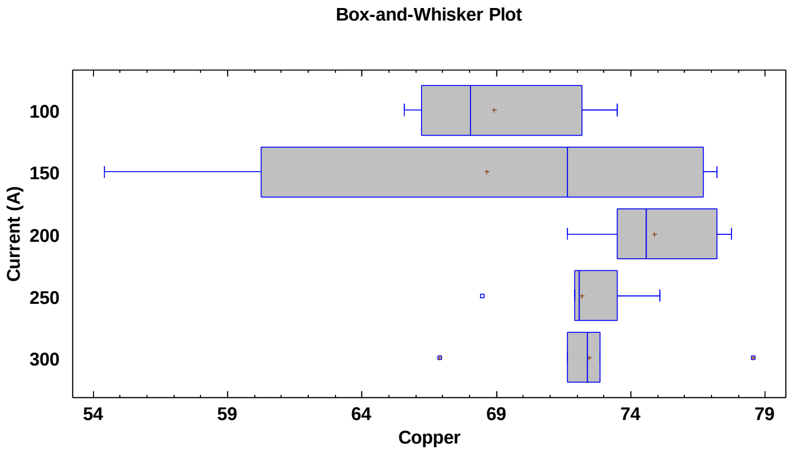


Figure 4.21. Box and Whisker Plot for Copper by Current (A)

Table 4.22. ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	297,763	5	59,5526	2,91	0,0341
Within groups	490,518	24	20,4383		
Total (Corr.)	788,281	29			

A Anova table shows us the pH level did make a statistically significant difference on the copper removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the copper.

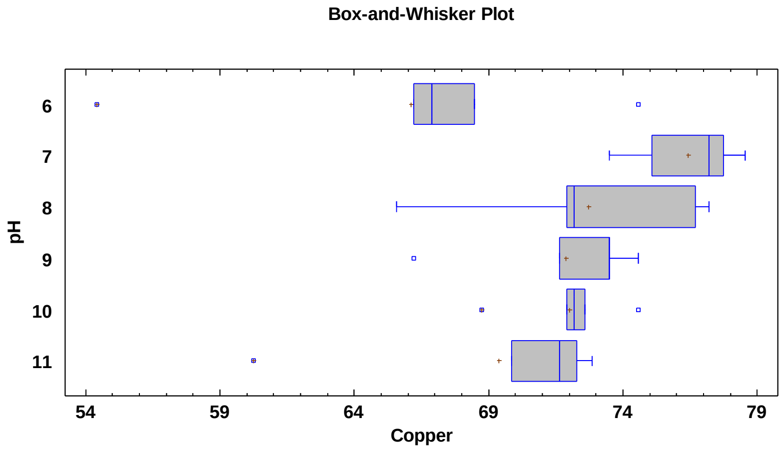


Figure 4.22. Box and Whisker Plot for Copper by pH

In studies in which pH level at reactor exit was elevated with aluminum electrodes with the increasing pH efficiency in Ni removal increased at all current densities as can be seen in figure 4.17 At pH 11 as the current density rises, combined Ni removal efficiency is higher compared to the lower current densities yet after pH 11, efficiency is close at almost all current densities. Efficiency observed in copper removal is mostly close at all pH and current density levels but as the current density rises small rises in efficiency was seen as well. $Al(OH)_3$ formation of the generated Al^{+3} effecting the flocculation. This $Al(OH)_3$ formations shows us increasing pH making a positive effect on nickel and copper removal[40]. But Al^{+3} ions most effective pH range is 4.5 – 8 and this result explain us why removal efficiency decrease after pH 9[39].

Table 4.23.Studies with aluminum electrodes and pH balanced at E&E input.

		Nickel		Copper	
		Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
Current (A)	pH				
100	6	59,4	52	17,6	13,6
	7	33,9	32,5	25	17,6
	8	57,8	56,6	31,5	24,2
	9	57,8	37,4	28,2	16,2
	10	39,2	36,5	30	21,8
	11	31,1	14,9	33,8	31,2
150	6	59,4	50,8	17,6	16
	7	33,9	31,9	25	12
	8	57,8	56,5	31,5	19,2
	9	57,8	32,2	28,2	15,8
	10	39,2	30,4	30	25,8
	11	31,1	27,3	33,8	30,8
200	6	59,4	51,9	17,6	16
	7	33,9	22,1	25	20
	8	57,8	50	31,5	18,6
	9	57,8	32,5	28,2	14,2
	10	39,2	15,1	30	19,4
	11	31,1	28,2	33,8	26,6
250	6	59,4	43,2	17,6	9
	7	33,9	27,3	25	18,4
	8	57,8	47,5	31,5	10,3
	9	57,8	32,4	28,2	10,6
	10	39,2	34,5	30	14,8
	11	31,1	17,9	33,8	19,6
300	6	59,4	27,3	17,6	8,2
	7	33,9	31,7	25	16,4
	8	57,8	54	31,5	9,1
	9	57,8	40,7	28,2	8,2
	10	39,2	23	30	14,4
	11	31,1	29,2	33,8	20

Table 4.24. Efficiency of studies with aluminum electrodes and pH balanced at E&E input.

		Efficiency %				Efficiency %	
		Nickel	Copper			Nickel	Copper
Current (A)	pH			Current (A)	pH		
100	6	12,45	22,45	250	6	27,27	48,86
	7	4,12	29,6		7	19,46	26,4
	8	2,07	23,17		8	17,82	67,3
	9	35,29	42,55		9	43,94	62,41
	10	6,88	27,33		10	11,98	50,66
	11	52,09	7,69		11	42,44	42,01
150	6	14,47	9,09	300	6	54,04	53,4
	7	5,89	52		7	6,48	34,4
	8	2,24	39,04		8	6,57	71,11
	9	44,29	43,97		9	29,58	70,92
	10	22,44	14		10	41,32	52
	11	12,21	8,87		11	6,1	40,82
200	6	12,62	9,09				
	7	34,8	20				
	8	13,49	40,95				
	9	43,77	49,64				
	10	61,47	35,33				
	11	9,32	21,3				

Efficiency graphs of the studies performed are presented in the following Figure 4.23. and 4.26. respectively

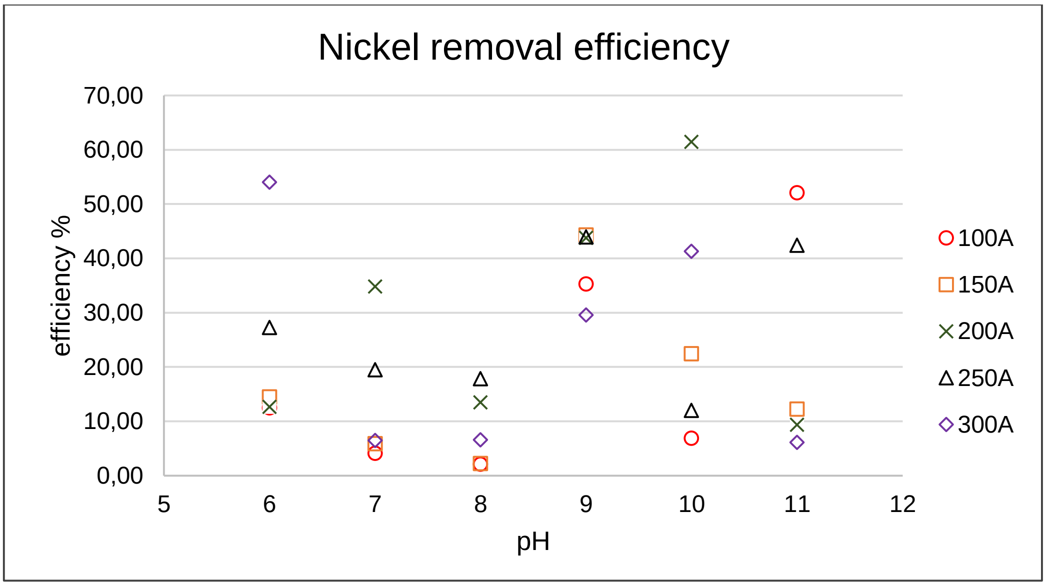


Figure 4.23. Nickel removal efficiency with Aluminum electrodes and pH balanced at E&E input

Table 4.25. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	668,565	4	167,141	0,49	0,7403
Within groups	8461,49	25	338,459		
Total (Corr.)	9130,05	29			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

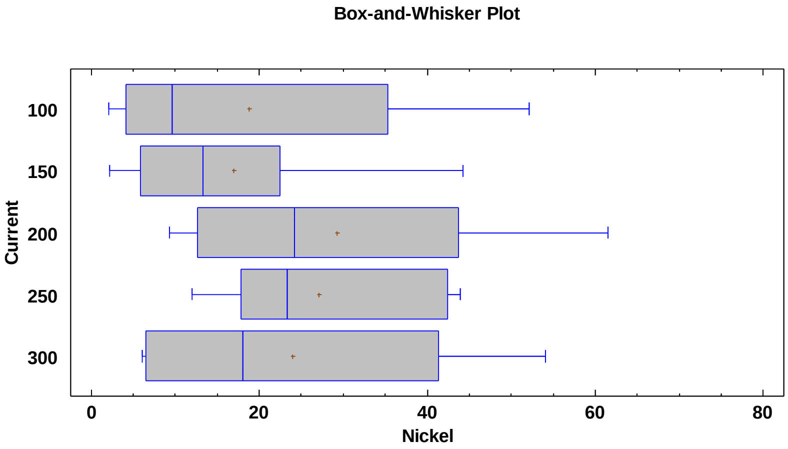


Figure 4.24. Box and Whisker Plot for Nickel by Current (A)

Table 4.26. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	2977,16	5	595,433	2,32	0,0744
Within groups	6152,89	24	256,37		
Total (Corr.)	9130,05	29			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the nickel removal.

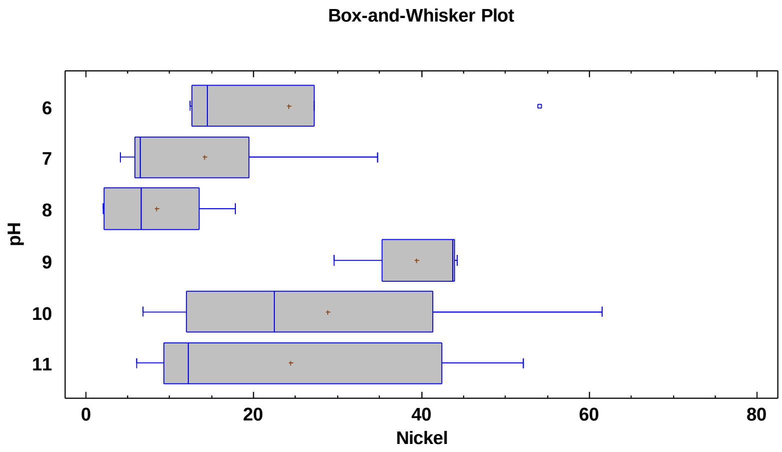


Figure 4.25. Box and Whisker Plot for Nickel by pH

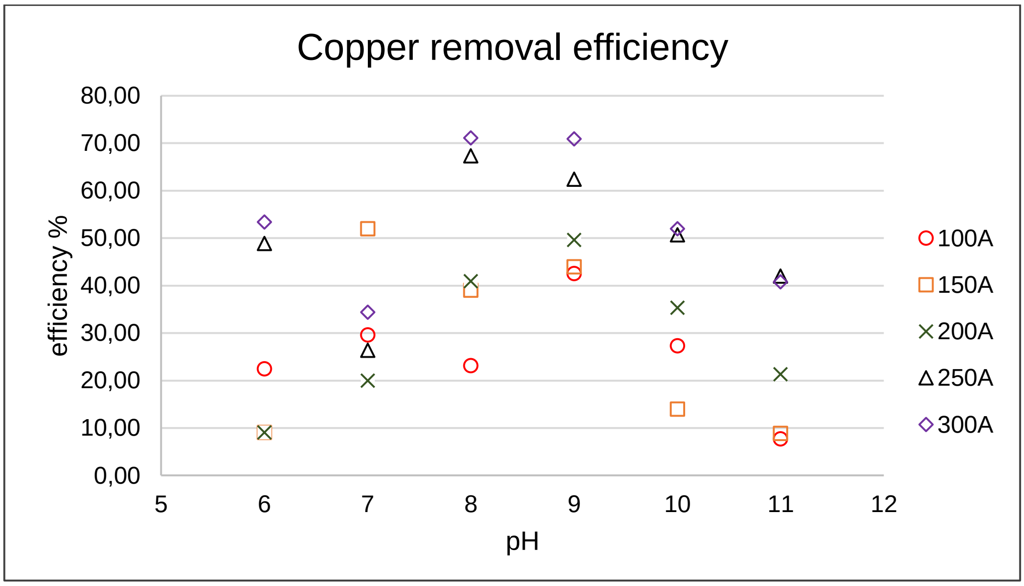


Figure 4.26.Copper removal efficiency with Aluminum electrodes and pH balanced at E&E input

Table 4.27. ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	4291,61	4	1072,9	4,57	0,0066
Within groups	5875,63	25	235,025		
Total (Corr.)	10167,2	29			

Anova table shows us the current density (A) did make a statistically significant difference on the copper removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the copper.

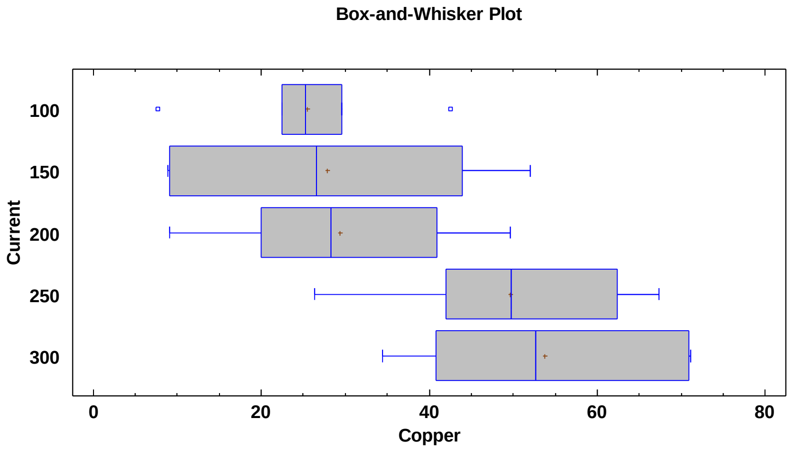


Figure 4.27. Box and Whisker Plot for Copper by Current (A)

Table 4.28. ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	3356,81	5	671,361	2,37	0,0702
Within groups	6810,43	24	283,768		
Total (Corr.)	10167,2	29			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the copper removal.

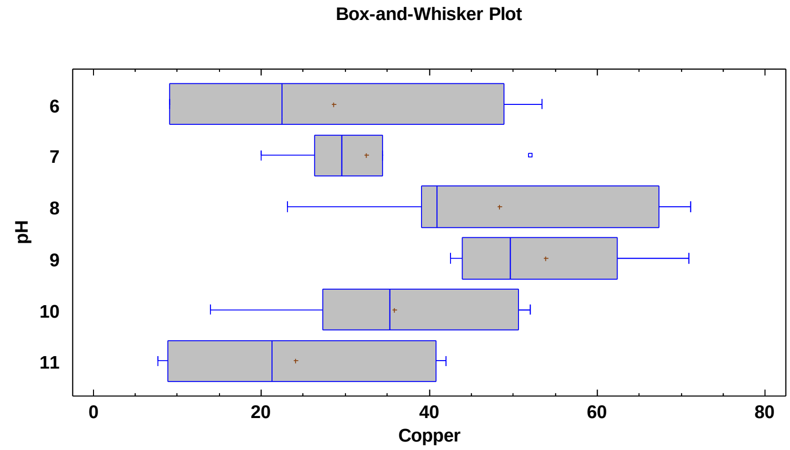


Figure 4.28. Box and Whisker Plot for Copper by pH

As the results we can see at the fig 4.23 to 4.28 removal efficiency of aluminium electrodes with pH balanced reactor input show as nearly similar result with iron electrode. But because of Al^{+3} effective pH range we can see copper removal starts to decrease after pH 9 and also when pH increase before reactor OH^- groups cannot can't find any Al^{+3} ions for coagulation and also stick to surface of anode and this reaction decrease the efficiency of tests.

At the end of the studies, the reaction time was increased to 2 times at 3 current values with the highest efficiencies and the following results were obtained. All these studies also applied with iron and aluminum electrode types and pH only balanced after E&E output.

Table 4.29. Studies with iron electrodes, double reaction time and pH balanced at E&E output

		Nickel		Copper	
Current (A)	pH	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
200	6	70,0	59,6	103,4	89,0
	7	70,0	43,1	103,4	47,6
	8	70,0	6,9	103,4	25,8
	9	70,0	2,6	103,4	13,8
	10	70,0	1,2	103,4	12,3
250	6	67,6	57,0	102,0	89,2
	7	67,6	43,7	102,0	46,5
	8	67,6	6,2	102,0	13,6
	9	67,6	3,8	102,0	9,5
	10	67,6	2,7	102,0	7,0
300	6	124,0	94,0	84,0	65,1
	7	124,0	43,0	84,0	41,4
	8	124,0	6,2	84,0	20,9
	9	124,0	10,2	84,0	19,6
	10	124,0	8,6	84,0	18,6

Table 4.30. Efficiency of studies with iron electrodes, double reaction time and pH balanced at E&E output.

		Efficiency %				Efficiency %	
		Nickel	Copper			Nickel	Copper
Current (A)	pH			Current (A)	pH		
200	6	15,3	13,9	300	6	24,2	22,5
	7	38,8	53,9		7	65,3	50,2
	8	90,2	75		8	95	75,2
	9	96,3	86,7		9	91,8	76,7
	10	98,3	88,1		10	93,1	77,9
250	6	15,7	12,5				
	7	35,4	4,4				
	8	90,8	86,7				
	9	94,4	90				
	10	96	93,1				

Efficiency graphs of the studies performed are presented in the following Figure 4.29. and 4.31. respectively

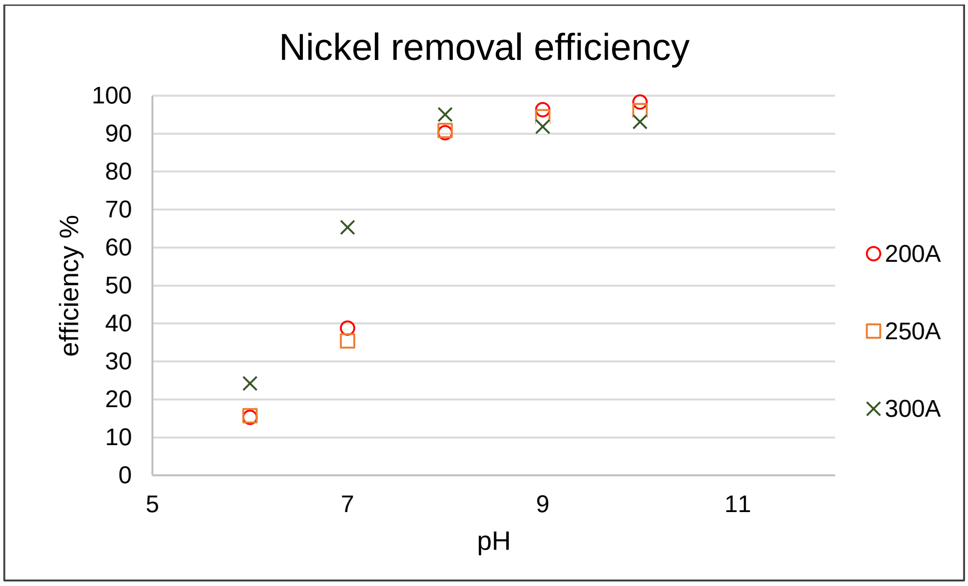


Figure 4.29. Nickel removal efficiency with iron electrodes, double reaction time and pH balanced at E&E output.

Table 4.31. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	156,681	2	78,3407	0,06	0,9407
Within groups	15306,8	12	1275,57		
Total (Corr.)	15463,5	14			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

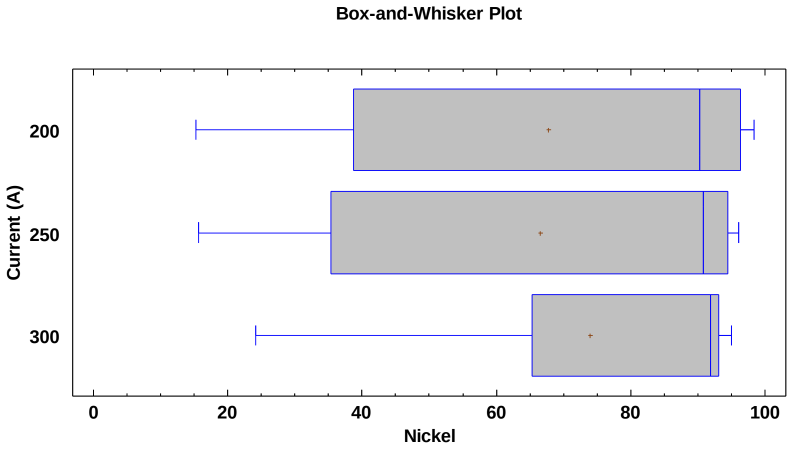


Figure 4.30. Box and Whisker Plot for Nickel by Current (A)

Table 4.32. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	14839,5	4	3709,89	59,46	0,0000
Within groups	623,947	10	62,3947		
Total (Corr.)	15463,5	14			

Anova table shows us the pH level did make a statistically significant difference on the nickel removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the Nickel.

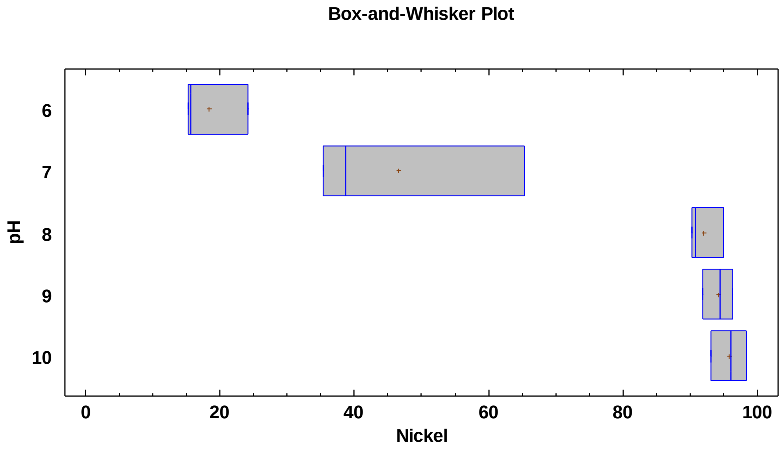


Figure 4.31. Box and Whisker Plot for Nickel by pH

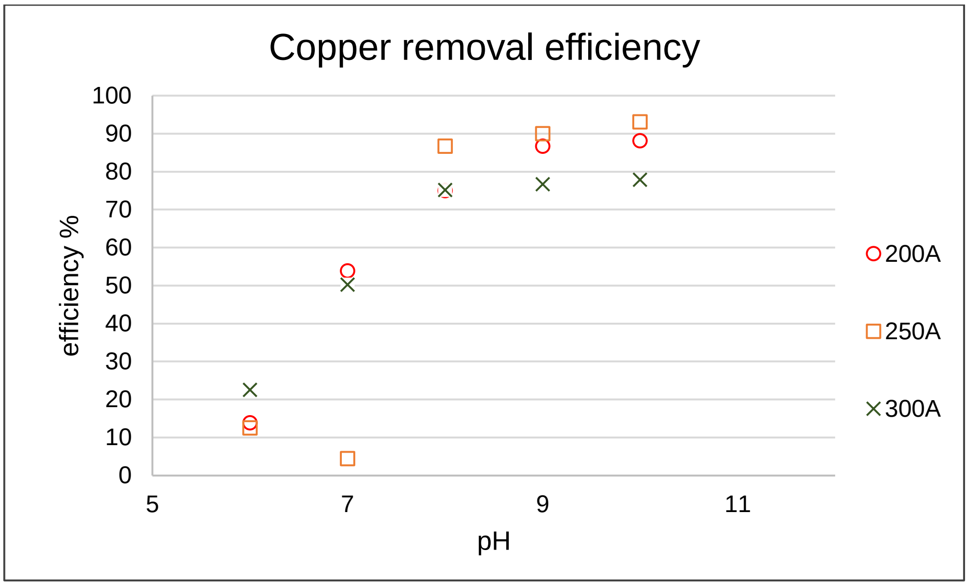


Figure 4.32. Copper removal efficiency iron electrodes, double reaction time and pH balanced at E&E output

Table 4.33. ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	95,4973	2	47,7487	0,04	0,9605
Within groups	14180,1	12	1181,67		
Total (Corr.)	14275,6	14			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the copper removal.

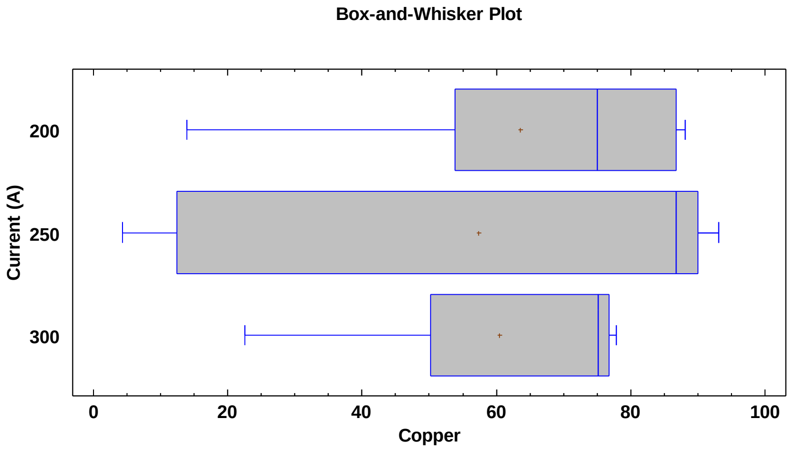


Figure 4.33. Box and Whisker Plot for Copper by Current (A)

Table 4.34. ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	12390,7	4	3097,68	16,43	0,0002
Within groups	1884,85	10	188,485		
Total (Corr.)	14275,6	14			

Anova table shows us the pH level did make a statistically significant difference on the copper removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the copper.

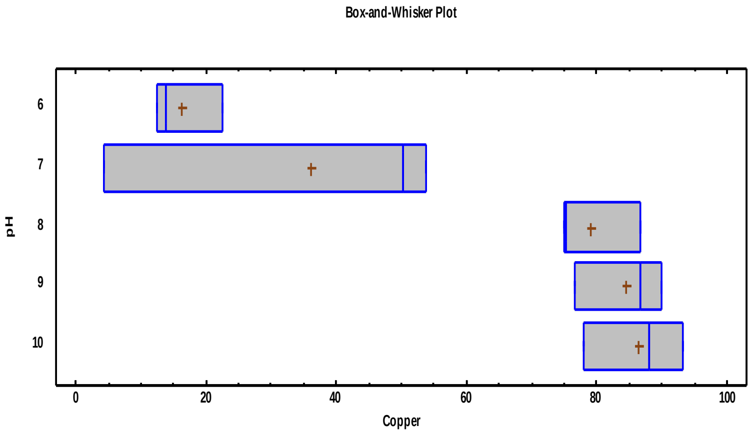


Figure 4.34. Box and Whisker Plot for Copper by pH

From the results that can be seen in figure 4.29. it was seen that in studies in which the reaction time with iron electrodes was doubled and pH at reactor exit was elevated, as the pH level rises removal efficiency rises rapidly at all current densities and after pH 8 %90 and higher efficiency was observed. In the same study copper removal efficiency that can be seen in figure 4.10 yields similar results and efficiency rises after pH 8. It was observed that the highest efficiency at copper removal was achieved at 250 A current density. That line show us curve removal efficiency at current densities. Fe^{+2} effectivitiy also increase after pH 9.5[39] and in this study also shows us the efficiency increase after pH 9.

Table 4.35. Studies with aluminum electrodes, double reaction time and pH balanced at E&E output

		Nickel		Copper	
Current (A)	pH	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
200	6	69,6	38,4	95,0	9,6
	7	69,6	37,2	95,0	9,9
	8	69,6	12,3	95,0	7,6
	9	69,6	2,0	95,0	7,6
	10	69,6	1,4	95,0	12,0
250	6	70,0	12,2	78,5	5,5
	7	70,0	4,8	78,5	8,6
	8	70,0	4,7	78,5	5,3
	9	70,0	2,2	78,5	5,6
	10	70,0	3,0	78,5	6,1
300	6	81,0	70,4	44,5	15,7
	7	81,0	57,9	44,5	9,4
	8	81,0	9,6	44,5	8,0
	9	81,0	1,0	44,5	7,0
	10	81,0	1,3	44,5	7,0

Table 4.36. Efficiency of studies with aluminum electrodes, double reaction time and pH balanced at E&E output.

Current (A)	pH	Efficiency %	
		Nickel	Copper
200	6	44,8	89,9
	7	46,6	89,6
	8	82,4	92,0
	9	97,2	92,0
	10	98,1	87,4
250	6	82,6	93,0
	7	93,1	89,0
	8	93,3	93,2
	9	96,8	92,9
	10	95,7	92,2
300	6	13,1	64,7
	7	28,5	78,9
	8	88,1	82,0
	9	98,8	84,3
	10	98,4	84,3

Efficiency graphs of the studies performed are presented in the following Figure 4.35 and 4.38. respectively.

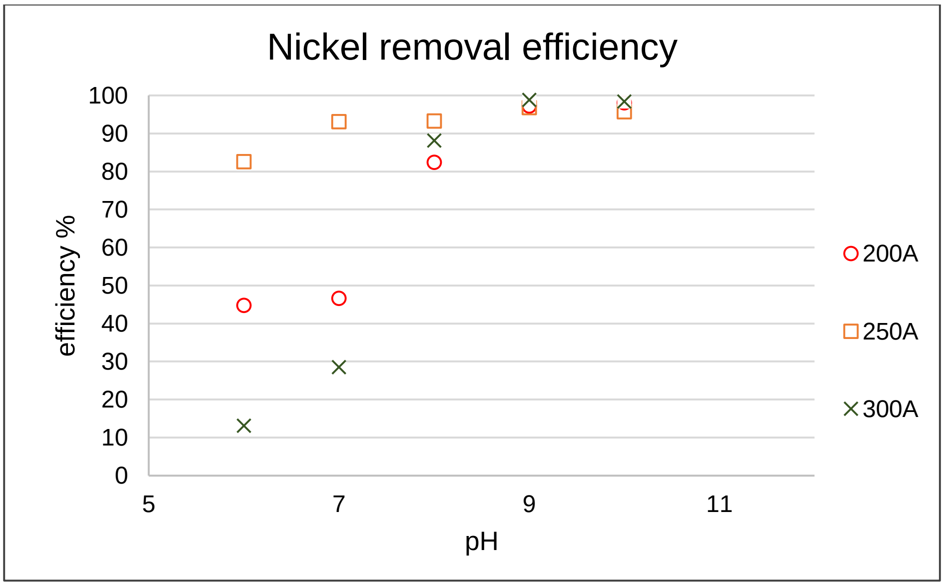


Figure 4.35. Nickel removal efficiency with aluminum electrodes, double reaction time and pH balanced at E&E output

Table 4.37. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1895,72	2	947,859	1,17	0,3439
Within groups	9737,14	12	811,428		
Total (Corr.)	11632,9	14			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

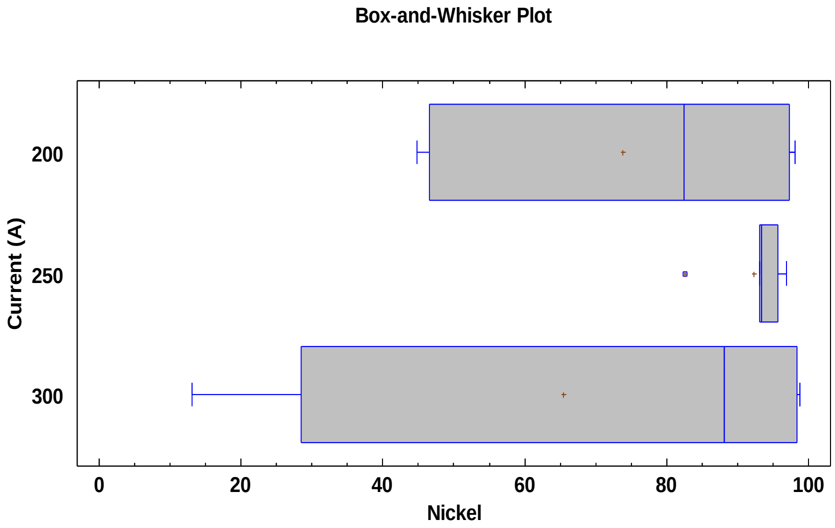


Figure 4.36. Box and Whisker Plot for Nickel by Current (A)

Table 4.38. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	6924,45	4	1731,11	3,68	0,0432
Within groups	4708,4	10	470,84		
Total (Corr.)	11632,9	14			

Anova table shows us the pH level did make a statistically significant difference on the nickel removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the nickel

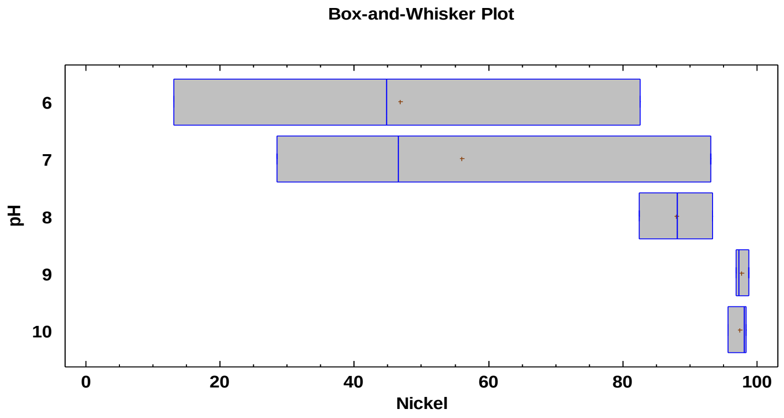


Figure 4.37. Box and Whisker Plot for Nickel by pH

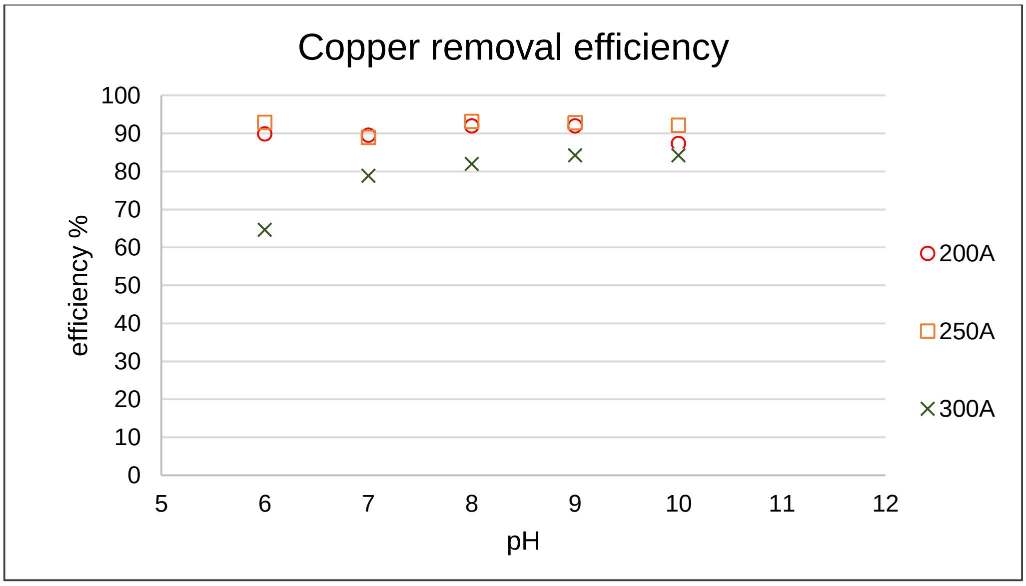


Figure 4.38. Nickel removal efficiency with aluminum electrodes, double reaction time and pH balanced at E&E output.

Table 4.39. ANOVA Table for Copper by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	511,497	2	255,749	10,35	0,0024
Within groups	296,592	12	24,716		
Total (Corr.)	808,089	14			

Anova table shows us the current density (A) did make a statistically significant difference on the copper removal because of the p was less than 0.05. Effect of current density can be seen at box-whisker plot in fig 4.38.

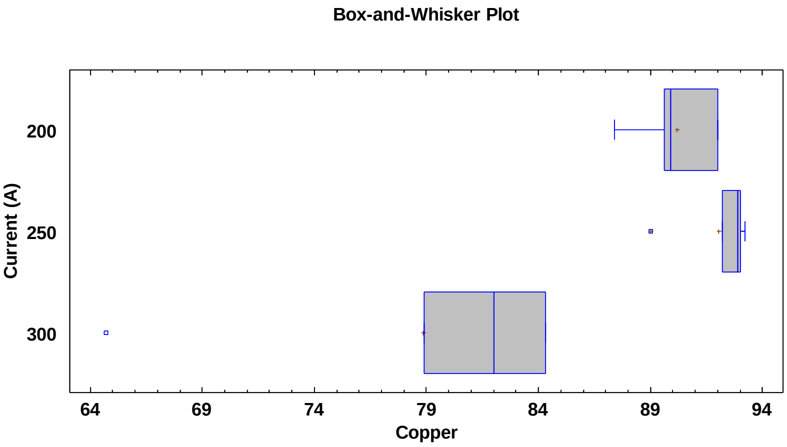


Figure 4.39. Box and Whisker Plot for Copper by Current (A)

Table 4.40. ANOVA Table for Copper by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	101,956	4	25,489	0,36	0,8309
Within groups	706,133	10	70,6133		
Total (Corr.)	808,089	14			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the copper removal.

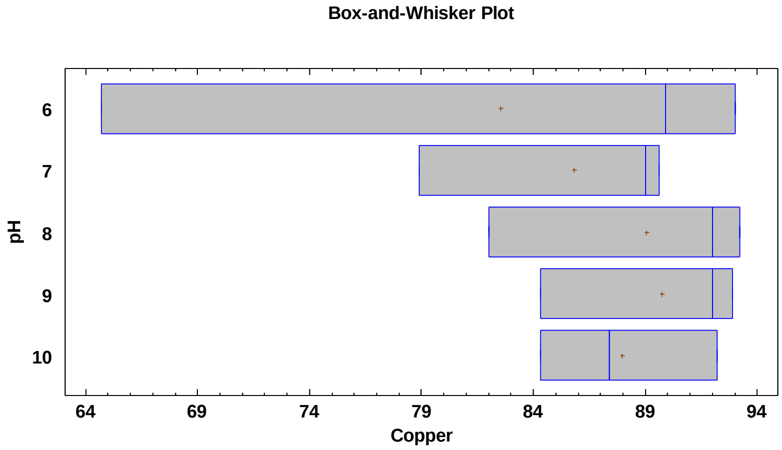


Figure 4.40. Box and Whisker Plot for Copper by pH

From the results that can be seen in figure 4.35 in the studies in which reaction time with aluminum electrodes was doubled and pH at reactor exit was elevated efficiency at Ni removal was observed to be %80 or higher at all tests that was done with 250A current density. Removal efficiency at higher current densities was observed to be lower at pH levels up to 8 but after pH 8 efficiency at all current densities was close and above %80. Figure 4.38 shows that results for copper removal in relation to current density were similar. However, for pH levels above 6 for all current densities was %80 or higher.

4.3. Mining Industry

Tests have been carried out in this industry by changing the electrode materials at different pH and current values. Tests made are shown separately below. At all test pH balanced after E&E output.

Table 4.41. Studies with iron electrodes and pH balanced at E&E output.

Current (A)	pH	Manganese		Aluminum		Magnesium		Nickel	
		Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
200	9	308	0,732	197	<1	1015	495	465	0,318
	10	308	0,116	197	<1	1015	141	465	0,185
	11	308	1	197	<1	1015	5	465	1,121
250	9	308	4	197	<1	1015	177	465	4
	10	308	0,073	197	<1	1015	88	465	1,03
	11	308	0,019	197	<1	1015	<1	465	0,07
300	9	308	3	197	<<1	1015	189	465	4
	10	308	0,07	197	<1	1015	122	465	1,24
	11	308	0,017	197	<1	1015	4	465	0,082

Table 4.42. Efficiency of studies with iron electrodes and pH balanced at E&E output

		Efficiency %			
		Mn	Al	Mg	Ni
Current (A)	pH				
200	9	99,76234	99,74619	51,23153	99,93161
	10	99,96234	99,74619	86,10837	99,96022
	11	99,67532	99,74619	99,50739	99,75892
250	9	98,7013	99,74619	82,56158	99,13978
	10	99,9763	99,74619	91,33005	99,77849
	11	99,99383	99,74619	99,95074	99,98495
300	9	99,02597	99,74619	81,37931	99,13978
	10	99,97727	99,74619	87,9803	99,73333
	11	99,99448	99,74619	99,60591	99,98237

Efficiency graphs of the studies performed are presented in the following Figure 4.41 and 4.44 respectively

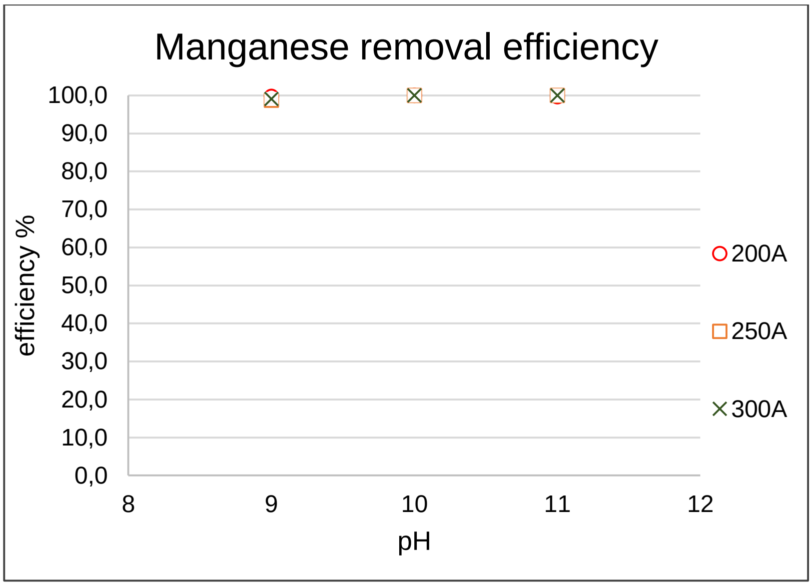


Figure 4.41. Manganese removal efficiency with iron electrodes, pH balanced at E&E output

Table 4.43. ANOVA Table for Manganese by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,0887898	2	0,0443949	0,15	0,8625
Within groups	1,7566	6	0,292767		
Total (Corr.)	1,84539	8			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the manganese removal.

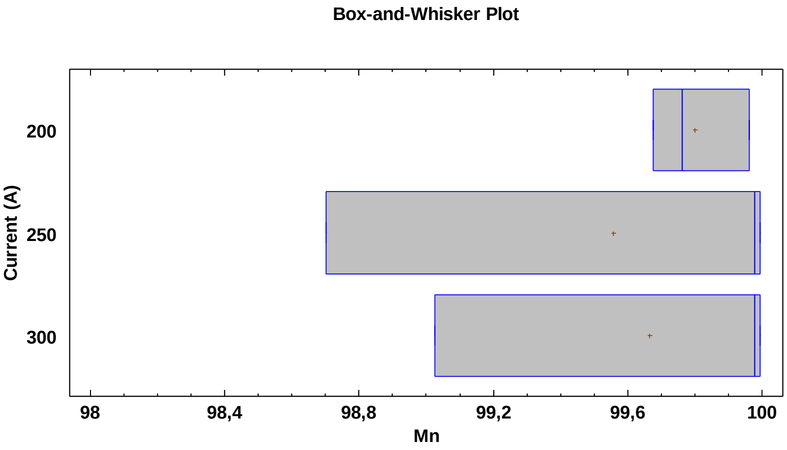


Figure 4.42. Box and Whisker Plot for Manganese by Current (A)

Table 4.44. ANOVA Table for Manganese by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1,18633	2	0,593163	5,40	0,0456
Within groups	0,659063	6	0,109844		
Total (Corr.)	1,84539	8			

Anova table shows us the pH level did make a statistically significant difference on the manganese removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the manganese.

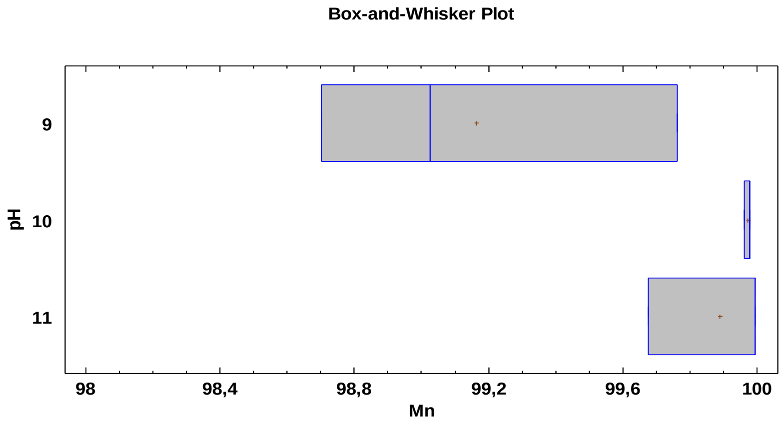


Figure 4.43. Box and Whisker Plot for Manganese by pH

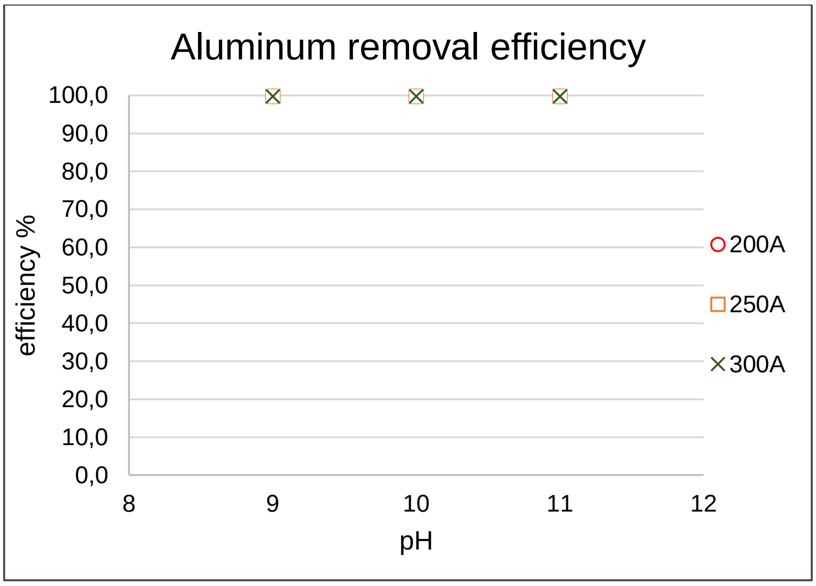


Figure 4.44. Aluminum removal efficiency with iron electrodes, pH balanced at E&E output

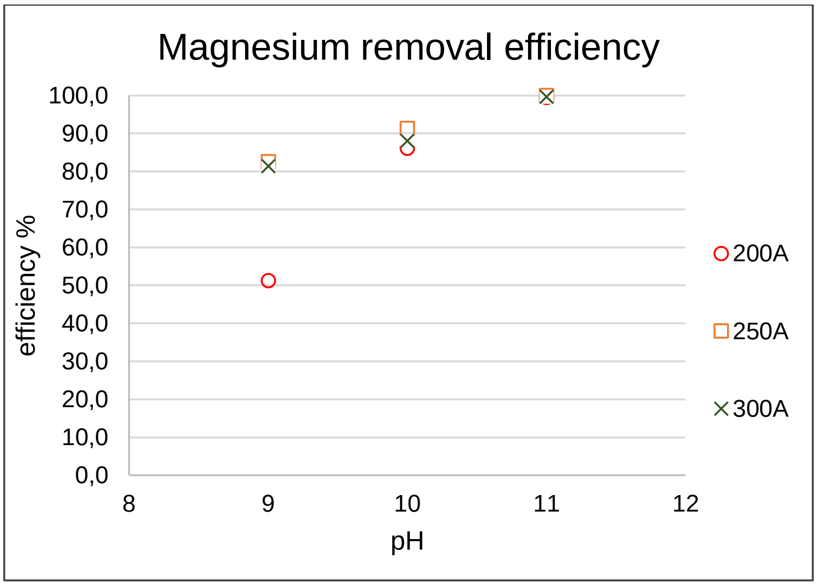


Figure 4.45. Magnesium removal efficiency with iron electrodes, pH balanced at E&E output

Table 4.45. ANOVA Table for Magnesium by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	269,333	2	134,667	0,52	0,6208
Within groups	1563,67	6	260,612		
Total (Corr.)	1833,0	8			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the magnesium removal.

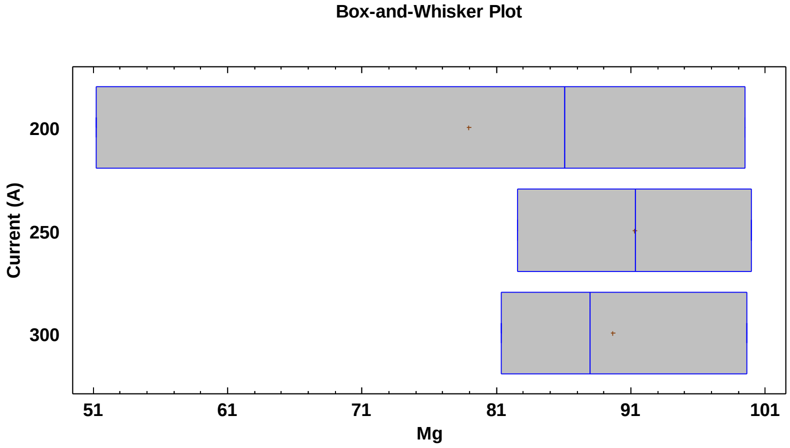


Figure 4.46. Box and Whisker Plot for Magnesium by Current (A)

Table 4.46. ANOVA Table for Magnesium by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1188,28	2	594,139	5,53	0,0435
Within groups	644,725	6	107,454		
Total (Corr.)	1833,0	8			

Anova table shows us the pH level did make a statistically significant difference on the magnesium removal because of the p was less than 0.05. Increasing pH value is a positive effect on removal efficiency of the magnesium.

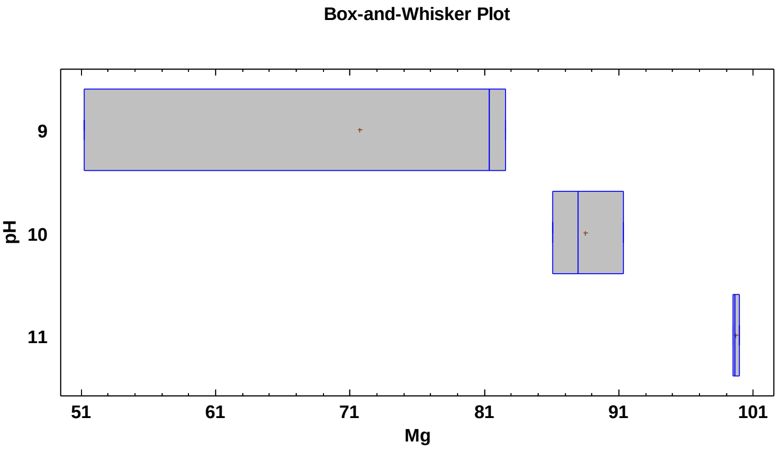


Figure 4.47. Box and Whisker Plot for Magnesium by pH

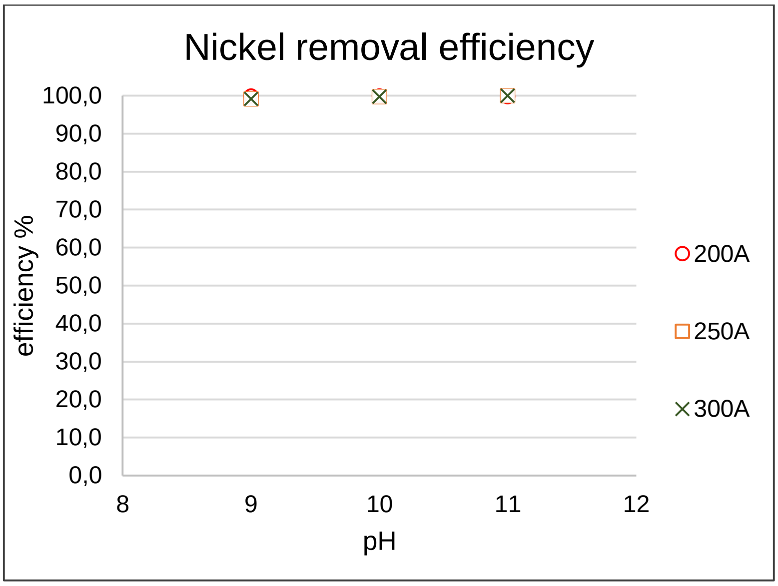


Figure 4.48.Nickel removal efficiency with iron electrodes, pH balanced at E&E output

Table 4.47. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,132615	2	0,0663075	0,51	0,6267
Within groups	0,786777	6	0,13113		
Total (Corr.)	0,919392	8			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

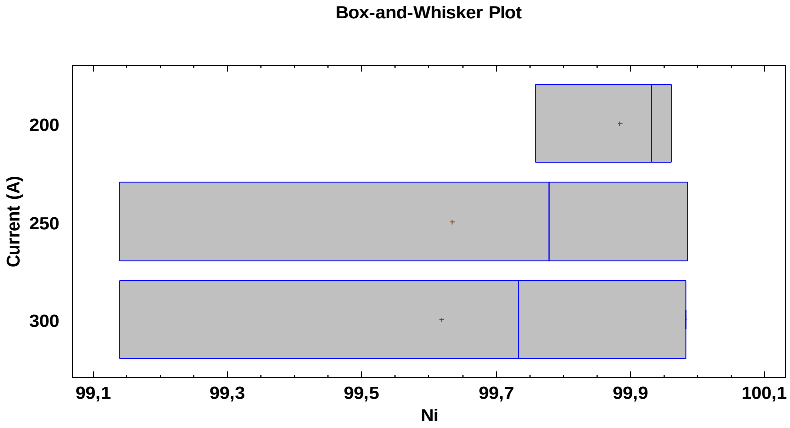


Figure 4.49. Box and Whisker Plot for Nickel by Current (A)

Table 4.48. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,438872	2	0,219436	2,74	0,1428
Within groups	0,48052	6	0,0800867		
Total (Corr.)	0,919392	8			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the nickel removal.

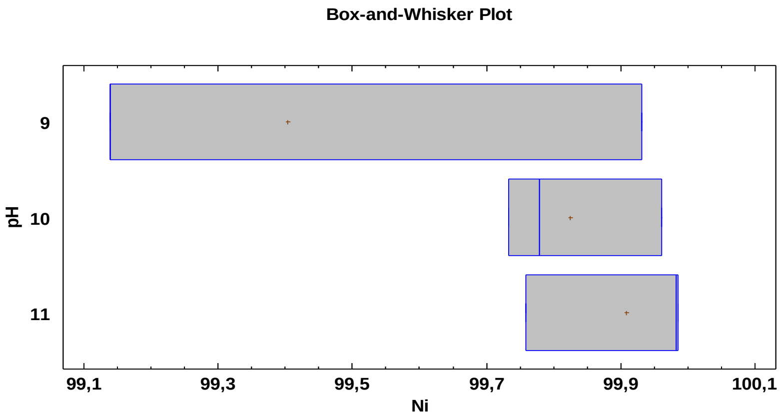


Figure 4.50. Box and Whisker Plot for Nickel by pH

Table 4.49. Studies with aluminum electrodes and pH balanced at E&E output.

		Manganese		Aluminum		Magnesium		Nickel	
Current (A)	pH	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)	Influent Conc (ppm)	Effluent Conc (ppm)
250	9	312	0,76	170	<1	1023	221	425	0,12
	11	312	0,087	170	<1	1023	<1	425	0,05
300	9	312	1,664	170	<1	1023	357	425	0,48
	11	312	0,001	170	<1	1023	40	425	0,05

In studies which were conducted with iron electrodes on mine waste water, at all tested current densities and pH values, %90 or higher efficiency was observed except for magnesium. On magnesium removal efficiency, at lower current density and pH 9 efficiency was around %50 and after pH10, efficiency reached %90 at lower current densities.

Studies show at mining industry high current density has got more efficiency than lower density. Because of that at next test with Al electrodes also applied with 250A and 300 A current density. And test made with 2 different pH range 9 and 11

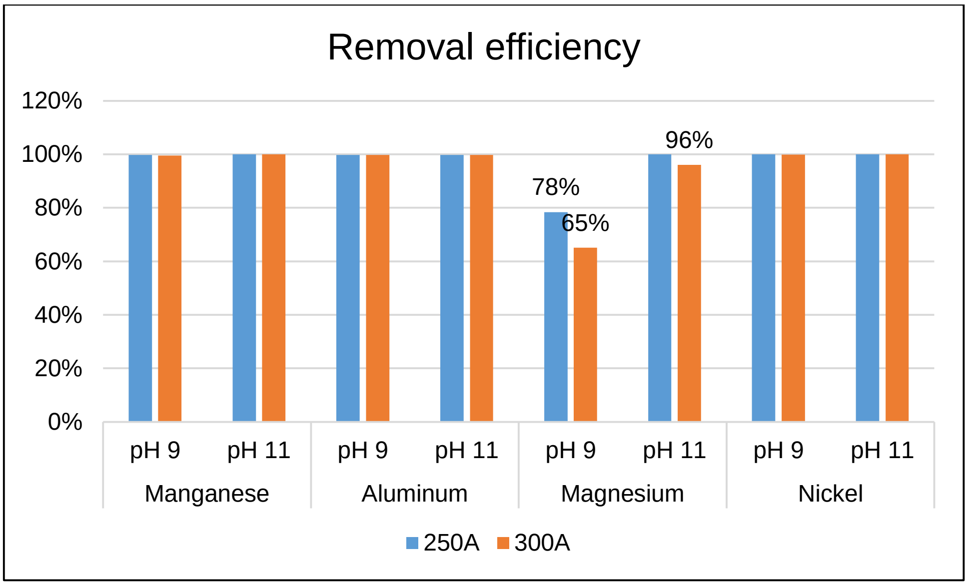


Figure 4.51. Removal efficiency with Aluminum electrodes, pH balanced at E&E output.

Table 4.50. ANOVA Table for Manganese by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,0171845	1	0,0171845	0,21	0,6931
Within groups	0,165316	2	0,0826578		
Total (Corr.)	0,1825	3			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the manganese removal.

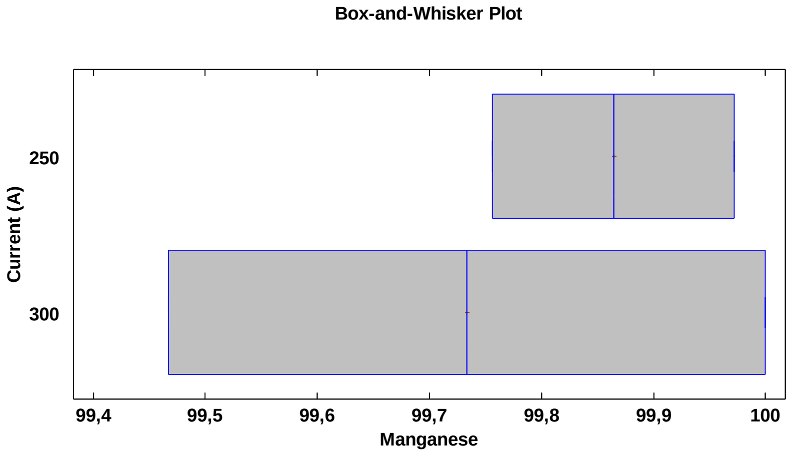


Figure 4.52. Box and Whisker Plot for Manganese by Current (A)

Table 4.51. ANOVA Table for Manganese by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,140145	1	0,140145	6,62	0,1237
Within groups	0,0423556	2	0,0211778		
Total (Corr.)	0,1825	3			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the manganese removal.

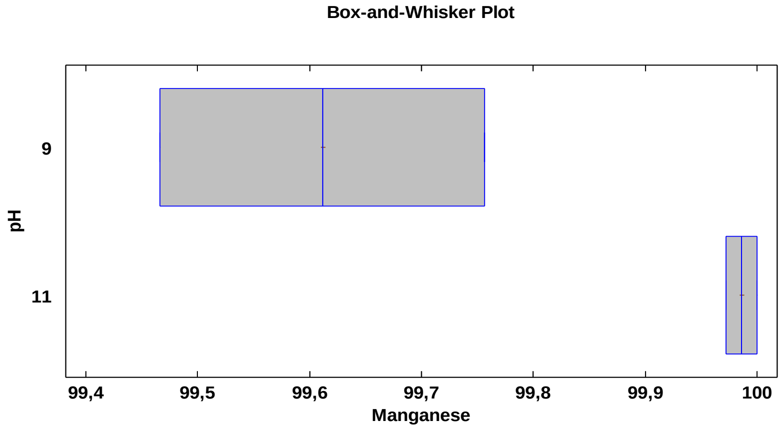


Figure 4.53. Box and Whisker Plot for Manganese by pH

Table 4.52. ANOVA Table for Magnesium by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	73,5772	1	73,5772	0,21	0,6940
Within groups	712,399	2	356,2		
Total (Corr.)	785,976	3			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the magnesium removal.

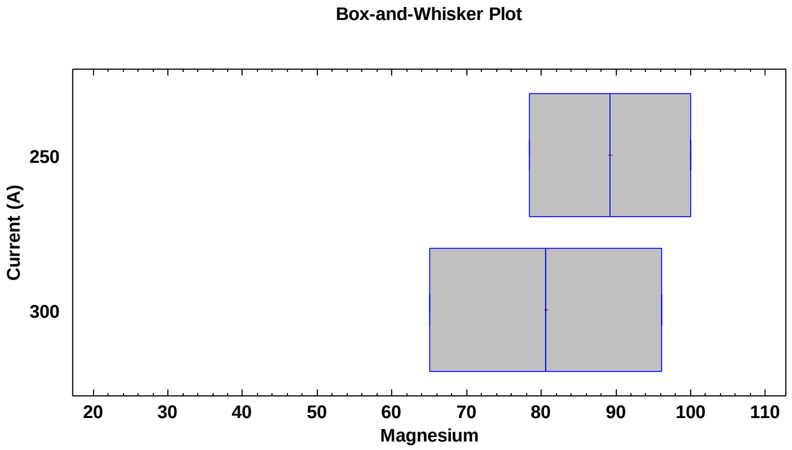


Figure 4.54. Box and Whisker Plot for Magnesium by Current (A)

Table 4.53. ANOVA Table for Magnesium by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	690,153	1	690,153	14,40	0,0629
Within groups	95,8227	2	47,9114		
Total (Corr.)	785,976	3			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the magnesium removal.

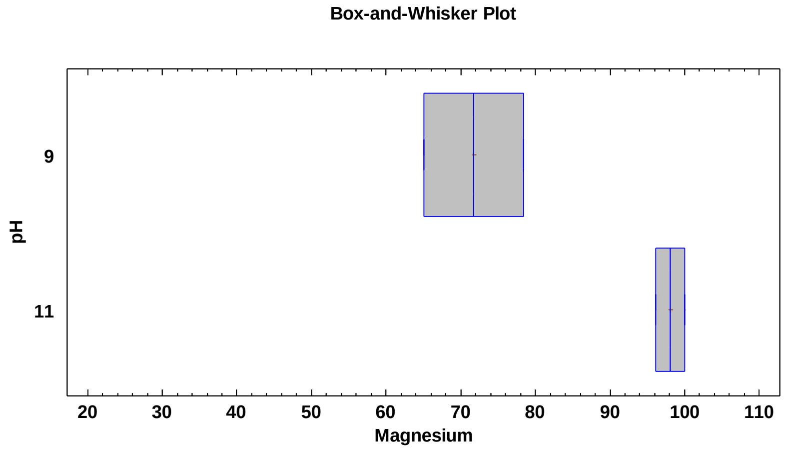


Figure 4.55. Box and Whisker Plot for Magnesium by pH

Table 4.54. ANOVA Table for Nickel by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,00179377	1	0,00179377	0,68	0,4955
Within groups	0,00525398	2	0,00262699		
Total (Corr.)	0,00704775	3			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the nickel removal.

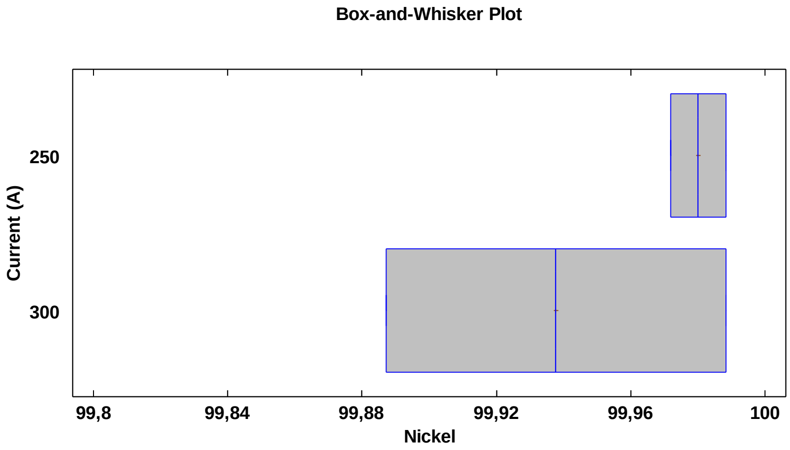


Figure 4.56. Box and Whisker Plot for Nickel by Current (A)

Table 4.55. ANOVA Table for Nickel by pH

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,00346021	1	0,00346021	1,93	0,2993
Within groups	0,00358754	2	0,00179377		
Total (Corr.)	0,00704775	3			

Because of the p value in the table was higher than 0.05 anova table shows us the pH level did not have any statistical significant link on the nickel removal.

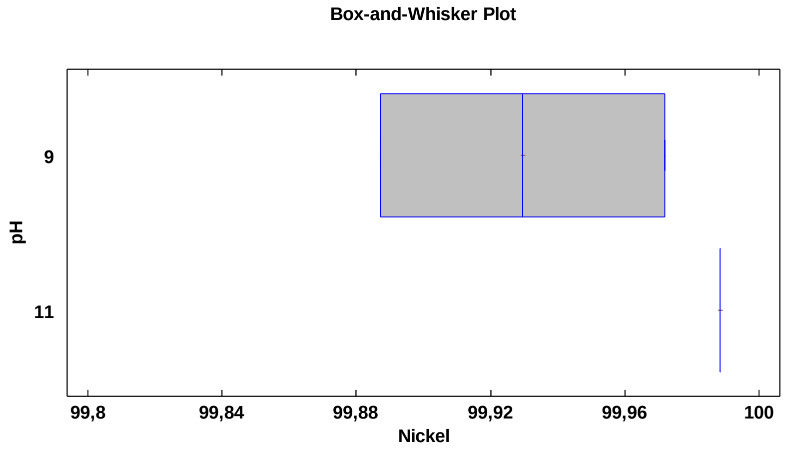


Figure 4.57. Box and Whisker Plot for Nickel by pH

In studies conducted with aluminum electrodes, the initial study conditions were kept, and studies were done at pH 9 to 11 and current density 250A-300A. Just like the first study, %95 or higher efficiency was reached at all conditions. Also similar to the results with iron electrodes, efficiency drop after pH 9 on magnesium removal was observed.

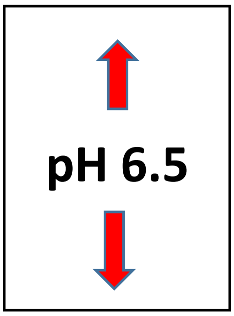
4.4. Textile Industry

At this industry studied with main 2 pollutants. These parameters are color which is an important parameter for textile and COD is the one of main parameter for environmental research. Studies applied with 2 different current densities and these values were chosen as 150 and 300 Amperes. During the study, the wastewater sample entered the only with Al electrodes and Al+Fe electrodes after this the analysis results were compared. It was determined that the following research colorant reacts in different shapes inside of the wastewater with the pH values. Equations of these different reactions are given below.

Adsorption

Dye + $Al(OH)_{3\,(S)}$ →→→→ Particles

[Dye + POLYMERIC Al]$_{(s)}$ + $Al(OH)_{3\,(s)}$→→→→ Particles



Sedimentation

Dye + Monomeric Al -→ [Dye – Monomeric Al] $_{(S)}$ pH: 4-5

BOYA + polymeric Al -→ [Dye – polymeric Al] $_{(S)}$ pH: 5-6 [31]

Result of the studies given the below between table 4.20 And 4.21.

Table 4.56. Color removal values and efficiency of E&E reactor.

pH	Current (A)	Volt (V)	Electrode Material	Color (input)	Color (output)	Efficiency %
7	150	12	Al+Fe	520	270	48
7	300	18	Al+Fe	500	180	64
7	150	12	Al	500	140	72
7	300	14	Al	520	90	82

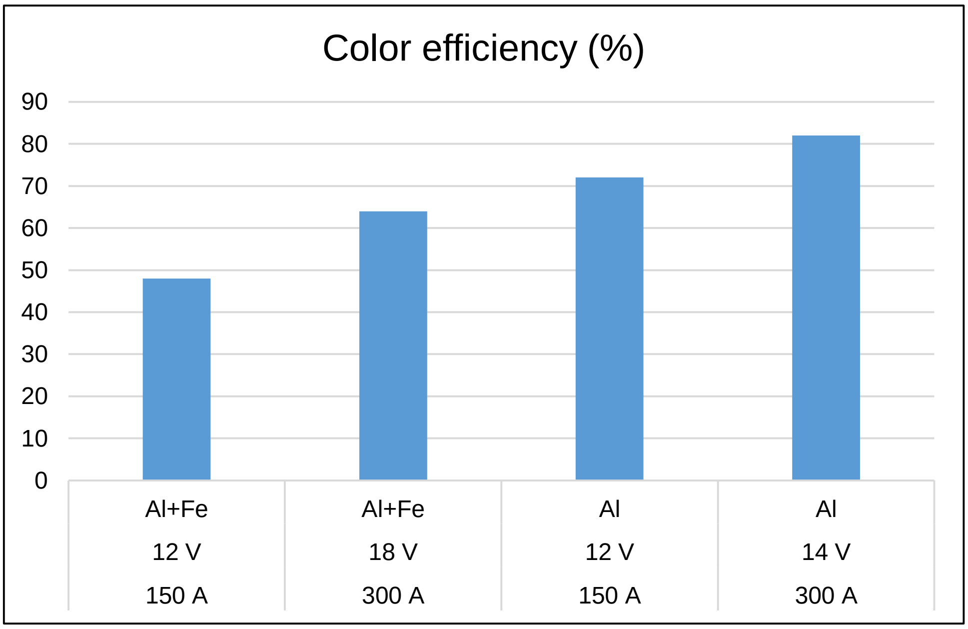


Figure 4.58. Color removal efficiency of E&E reactor.

Table 4.57. ANOVA Table for Color Efficiency by Current (A)

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	169,0	1	169,0	0,75	0,4775
Within groups	450,0	2	225,0		
Total (Corr.)	619,0	3			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the Color removal.

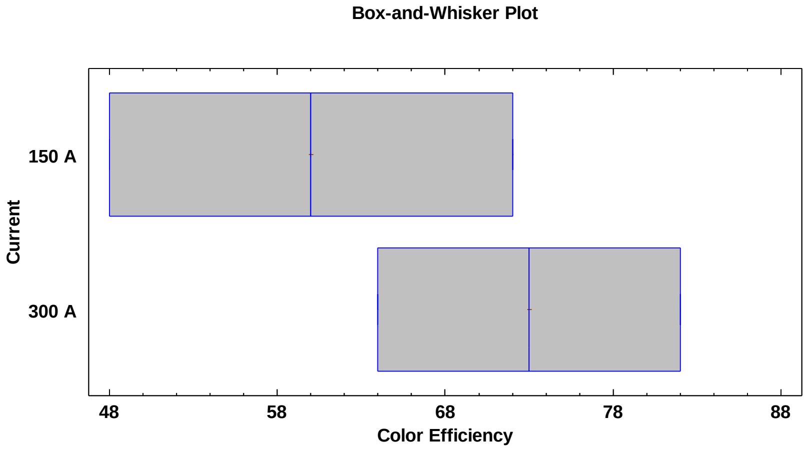


Figure 4.59. Box and Whisker Plot for Color Efficiency by Current (A)

Table 4.58. ANOVA Table for Color Efficiency by Electrode

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	441,0	1	441,0	4,96	0,1559
Within groups	178,0	2	89,0		
Total (Corr.)	619,0	3			

Because of the p value in the table was higher than 0.05 anova table shows us the electrode type did not have any statistical significant link on the color removal.

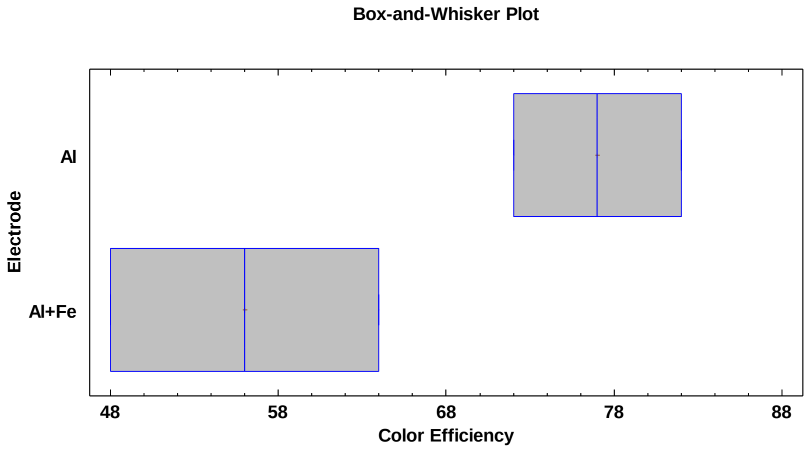


Figure 4.60. Box and Whisker Plot for Color Efficiency by Electrode

Table 4.59. COD removal values and efficiency of E&E reactor.

pH	Current (A)	Volt (V)	Electrode Material	COD (input)	COD (output)	Efficiency %
7	150	12	Al+Fe	779	599	23
7	300	18	Al+Fe	606	432	29
7	150	12	Al	660	481	27
7	300	14	Al	694	478	31

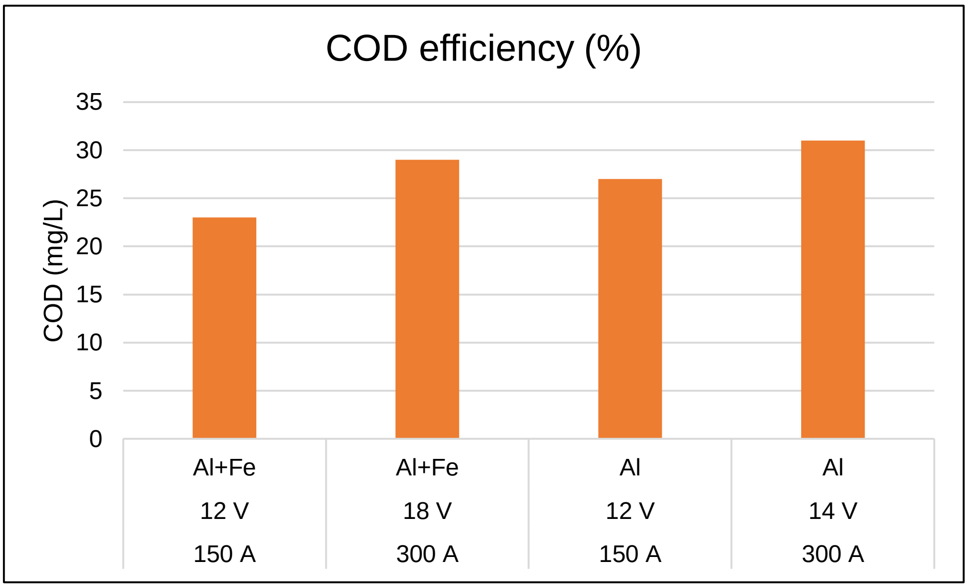


Figure 4.61. COD removal efficiency of E&E reactor.

Table 4.60. ANOVA Table for COD Efficiency (%) by Current Density

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	25,0	1	25,0	5,00	0,1548
Within groups	10,0	2	5,0		
Total (Corr.)	35,0	3			

Because of the p value in the table was higher than 0.05 anova table shows us the current density (A) did not have any statistical significant link on the COD removal.

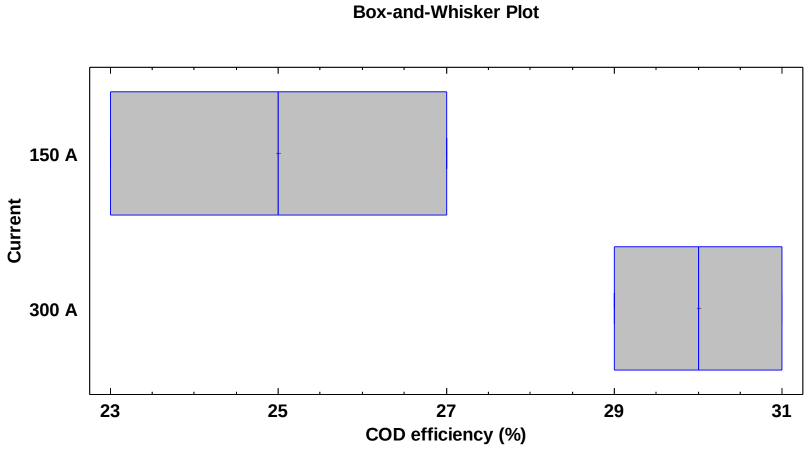


Figure 4.62. Box and Whisker Plot for COD Efficiency by Current (A)

Table 4.61. ANOVA Table for COD efficiency (%) by Electrode

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	9,0	1	9,0	0,69	0,4929
Within groups	26,0	2	13,0		
Total (Corr.)	35,0	3			

Because of the p value in the table was higher than 0.05 anova table shows us the electrode type did not have any statistical significant link on the COD removal.

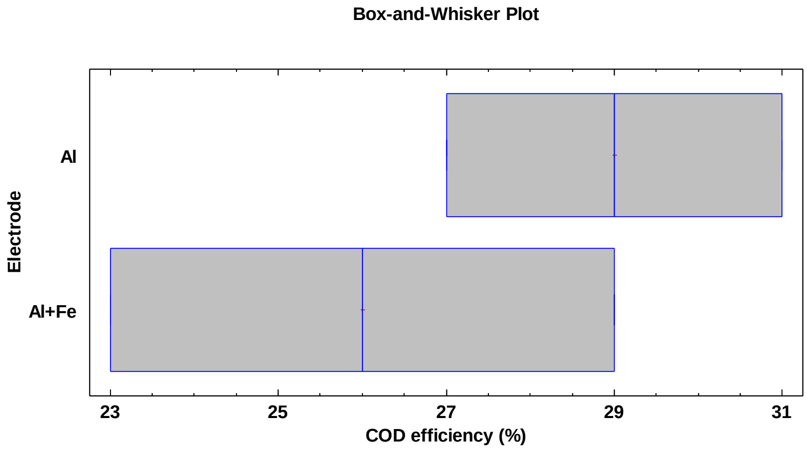


Figure 4.63. Box and Whisker Plot for COD Efficiency by Electrode

Because of the low efficiency at COD removal the reaction time was doubled as in the previous tests and the test results were obtained.

Table 4.62. COD removal values and efficiency of E&E reactor with double reaction time.

pH	Current (A)	Volt (V)	Electrode Material	COD (input)	COD (output)	Efficiency %
7.29	300	18	Al	1965	752	61

Studies on textile waste water were done with both Al and Al+ Fe mixed electrodes. In both studies an efficiency rise at color removal was observed as the current density was risen. In both studies it was observed that even though COD removal efficiency was extremely low, a rise was seen with rising current density. And at all test results show us color and COD removal of Al electrode is effective than hybrid electrode. When we change the electrode type and increase of the Al^{+3} ions inside the water removal efficiency results increase then the hybrid electrode.

4.5. Vegetable Oil Production Industry

This study aims to examine optimum operating conditions and efficiencies for the treatment of wastewaters of mixed vegetable oil plant effluents with high organic pollution load.

The pH effect, conductivity, current density and operating time on the removal efficiency of COD, TN, TP have been explored

Raw water was fed to E&E reactors with its original pH and 200 A current was applied. The pH adjustments were made with sulfuric acid and sodium hydroxide. The pH adjustments were made up to the point where the best precipitation was observed. The COD value of the wastewater used in the tests carried out was measured as 14200 mg / l and the pH value varied from 1 to 3.

Table 4.63. Effluent of COD removal at optimization test.

	COD	Influent pH	Effluent adjusted pH	Conductivity	Energy	Reaction Time
Influent	14200	<3		5560		
200A effluent	7100	<3	10	5800	4 Volt	1 min
300A effluent	6950	<3	10	5720	3,8 Volt	1 min

In order to determine the optimum current value, the current between 100A and 300A and the 1 minute of reaction time were applied and effluent COD concentrations were measured. Lime was used for pH adjustment.

Table 4.64. Effluent of COD with various current values.

	COD	Influent pH	Effluent adjusted pH	Conductivity	Energy	Reaction Time
Influent	14200	<3		5560		
100A effluent	7050	<3	10	5300	3 Volt	1 min
200A effluent	7100	<3	10	5800	4 Volt	1 min
250A effluent	6550	<3	10	5450	4,7 Volt	1 min
300A effluent	6950	<3	10	5500	5,5 Volt	1 min

After these results same test also applied with 250-300 A current for 7 effluent adjusted pH

Table 4.65. Effluent of COD removal at pH 7.

	COD	Influent pH	Effluent adjusted pH	Conductivity	Energy	Reaction Time
Influent	14200	<3		5560		
250A effluent	6100	<3	7	5610	6,3 Volt	1 min
300A effluent	No measurement	<3	7	5650	7 Volt	1 min

In this study, it was observed that 250 amperes gave the highest yield at pH 7-8 and the reaction times were tested according to these values. 300A tests were observed to cause burning and deterioration in the water structure.

Table 4.66. Efficiency of COD removal with different reaction time.

Reaction Time	COD (mg/L)	Efficiency (%)
2. Minute	2200	84,45
3. Minute	1800	87,32
4. Minute	1900	86,66
5. Minute	2700	80,99
6. Minute	2400	83,31

After the calculate optimum conditions test results Show us;

optimum reaction time: 3 minutes

optimum energy: 250 A

pH 7-8 range.

Under optimum conditions result of TN and TP removal is also calculated and result Show us

COD removal efficiency 87.32 %

TN removal efficiency: 62,3 %

TP removal efficiency: 88 %

Table 4.67. Efficiency of TN removal at different reaction time.

Reaction Time	Total Nitrogen (mg/L)	Efficiency (%)
Influent	239,2	
1. minute	117,6	50,83
2. minute	105,2	56,2
3. minute	90,8	62,3

Table 4.68. Efficiency of TN removal at different reaction time.

Reaction Time	Total phosphorus (mg/L)	Efficiency (%)
Influent	186	
1.minute	119	36
2. minute	103	45
3. minute	21,8	88

4.6. Landfill Leachate Wastewater

Initially, two studies were conducted on 150 A and 250 A with the aim of observing the effects of E&E application on high and low ampere values. All the test applied with Al+Fe electrodes. The analysis results of these studies are the following Table 4.69.

Table 4.69. Results of studies with low and high current density.

	COD	Nitrite	Nitrate	Ammonium	Phosphate	Total Suspended Solids (TSS)
Influent	4640	0,02	0,3	848	33,2	213,3
150A	3416	0,14	12	535	10,75	666,7
250A	4360	0,24	8	808	21,3	1100

After first experiment low current density results has been found to be more appropriate for next tests.

At next experiment 150 A current density also applied with double reaction time and results of reaction given the below table 4.30.

Table 4.70. Test results with double reaction time.

	COD	Nitrite	Nitrate	Ammonium	Phosphate	Total Suspended Solids (TSS)
Influent	4328	0,08	24	824	14,4	85
150A	3416	0,001	16	736,8	44	1130
150A (Double Reaction Time)	3448	0,04	24	736,8	18,4	1210

Same test condition also applied to leachate wastewater with only Al electrodes and all test results of Al electrodes reactions given the below table 4.31.

Table 4.71. Test results with double reaction time with all Al electrodes.

	COD	Nitrite	Nitrate	Ammonium	Phosphate	Total Suspended Solids (TSS)
Influent	4480	0,04	32	832	178,4	440
150A	3808	0,04	24	782,4	32	786,66
150A (Double Reaction Time)	3368	0,04	24	792	47,2	784

5. CONCLUSION

Rising consumption needs, production methods and industrial waste water which is a product of industrial development are important causes of environmental pollution. For this reason, many studies on waste water which needs to be treated are being conducted. Purpose of this thesis study is to see the potential of the E&E process and examine its efficiency as an alternative treating method for refining waste water to the preferred five industrial waste water type.

E&E reactor that was used in the study was designed to handle high current densities and as opposed to previous studies, efficiency evaluation was done with high current densities and low reaction times. Especially at high pH levels, the efficiency that was reached at all current densities are much higher than expected. When the literature is browsed, studies where low current density was used for thirty minutes or higher reaction times at heavy metal removal can be seen. In this study where, current density of 100A or higher was used for short reaction times such as three minutes and similar results were achieved. Also, in studies on pH leveling processes, it was determined that when doing pH leveling after the reaction has positive effect on removal efficiency. Thanks to the high efficiency values that were obtained in these studies industries which have high levels of heavy metal in their waste water like metal coating and mining has seen that E&E technology can be used as an alternative.

Studies on color which is one of the basic polluting factors in textile waste water, it was observed that increase in efficiency of color removal is directly proportional to the rising current density levels. Also choosing Al electrodes was proved to have a positive effect on efficiency. In studies on vegetable oil industry, which were conducted with similar conditions on the same reactor, polluting factors exclusive to the industry such as COD, TN and TP were examined. Like in all studies, rising current density levels and optimal three minutes pH time had a positive effect on efficiency. However, in an industry with high level of organic pollution such as vegetable oil industry, when the current density level was too high burning and decaying reactions in waste water occurred and analysis results could not be obtained. In these studies, on color removal, the high efficiency levels obtained with E&E process have shown that it can be usable for color removal. The reason why it could not reach the desired performances on COD removal is that rather than being a solo removal method it is more of a step in in systems that were designed for textile industry.

Finally, E&E system that was ventilated and tested on leachate yielded very low efficiency levels with short reaction times and high current density levels for all parameters. In this study it was seen that E&E is not a technology that can be used as a stand- alone process with this type of waste water and it is not considered as an alternative.

As a result of these studies it is suggested that using different electrode materials for the future studies will be important for the development and completion of this technology. Additionally, it can be effective to produce a new hybrid technology to combine the system’s efficiency to other methods. Also, in future studies a more sensitive waste water type can be selected for the studies on E&E process and this way the study can be done on more parameters and study conditions and chemicals that can affect reaction can be used to see their effect on E&E performance.

When the data from past studies and this one examined E&E process is open to further studies and development. It is considered that with future studies, effects of the technology and its usability will be further explored, and it will affect new study fields.

6. REFERENCES

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CURRICULUM VITAE

Credentials

Name, Surname : Selçuk BULUT
Place of Birth : Kayseri/Turkey
Marital Status : Single
E-mail : selcukblt@gmail.com
Address :

Education

BSc. : BSC. In Environmental Engineering, Ataturk University, Erzurum, Turkey, 2013.
MSc. : Master degree in environmental engineer, Hacettepe University, Ankara, Turkey, 2018.

Foreign Languages

Turkish “The Native Language”, English “the second language, have good skills in spoken, reading and writing”.

Work Experience

- Environmental Engineer at water treatment and supply, ABC water treatmentment systems in Istanbul.
- Environmental Engineer at wastewater treatment prject and field production, Multiclair wastewater treatment systems in Ankara.

Areas of Experiences

- Electrochemical wastewater treatment systems
- Project and design of a wastewater treatment plant

Projects and Budgets

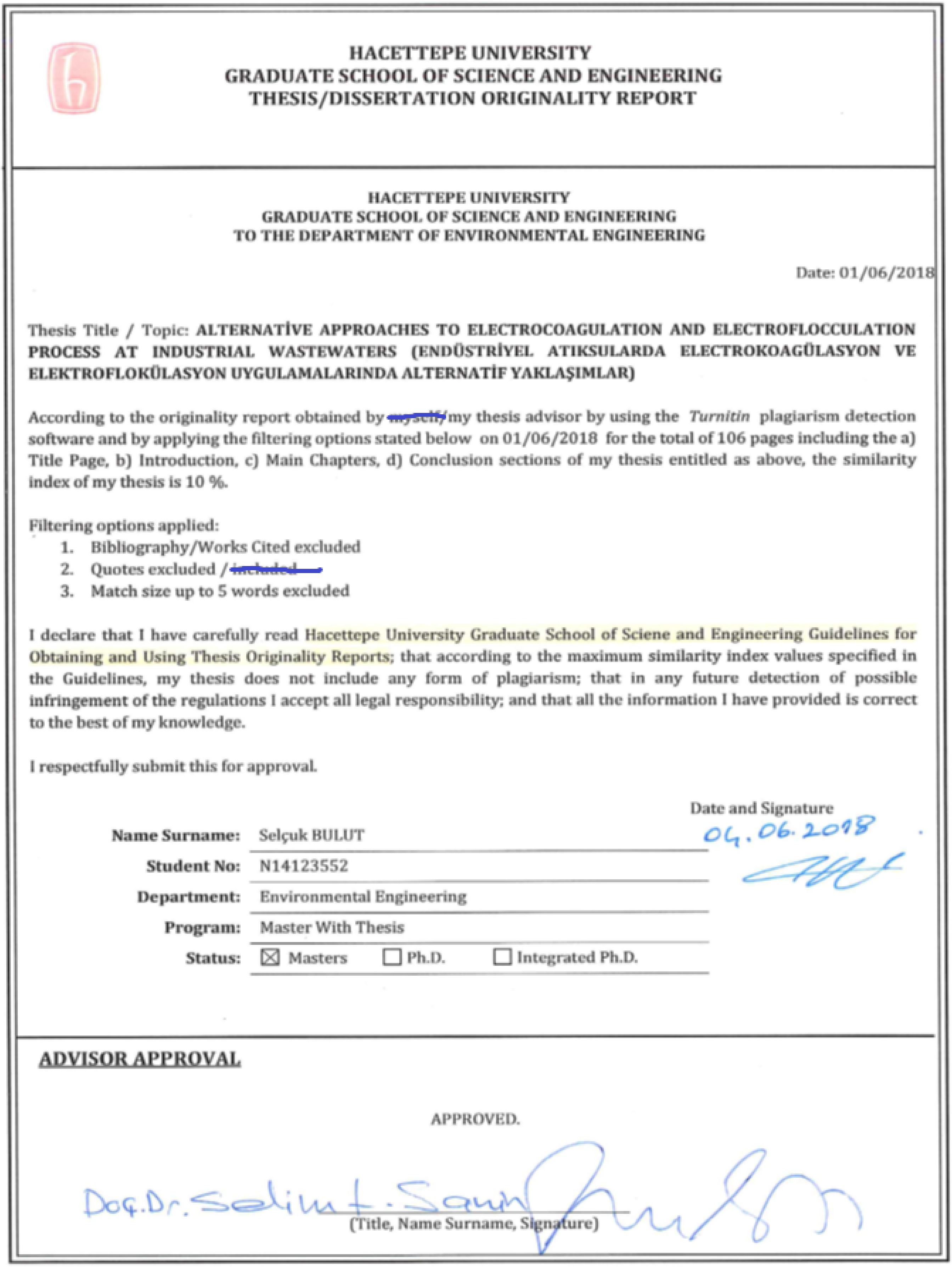
-

Publications

-

Oral and Poster Presentations

- Oral presentation with “Treatment of Mixed Herbal Oil Processing Factory Wastewaters by Pilot-Scale Electrocogaulation Unit: Technical and Economical Aspects” in the Pollution Control & Sustainable Environment conference in London.



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THESIS/DISSERTATION ORIGINALITY REPORT

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Name Surname: Selçuk BULUT
Student No: N14123552
Department: Environmental Engineering
Program: Master With Thesis
Status: ☒ Masters ☐ Ph.D. ☐ Integrated Ph.D.

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