Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Open Channel In-Stream Drainage Water Treatment Using Electro-Coagulation Stainless Steel Electrodes

R. F. Hussein [1,*], A. M. Elmolla [2], A. A. Sayed [3], M. A. Abd Ellatif [4]

[1]*Strategic Research Unit, National Water Research Center, El Qanater, Cairo, Egypt.*
[2]*Head of Irrigation and Hydraulics Dept., Faculty of Engineering, Al Azhar University, Cairo, Egypt.*
[3]*Drainage Research Institute, National Water Research Center, P.O. Box13621/5, El Qanater, Cairo, Egypt.*
[4]*Mechanical and Electrical Research Institute, National Water Research Center, El Qanater, Cairo, Egypt*

Abstract

Egypt suffers from a water shortage and is expected to be scarcer. This shortage is rewarded by water reuse with different methods to solve this deficit. There are low-cost water treatment methods to mitigate water shortage compared to other expensive approaches. One of these methods is Electro-Coagulation were, the simultaneous removing of many pollutants, using electrical current and sacrificial metal plates (electrodes) without adding any chemicals. This research illustrates the use of Electro-coagulation depending on a scaled open channel physical model with installed in-stream stainless steel plates electrodes to reduce water pollution, the used electrodes were installed of the same spacing in parallel to the water flow direction, using four different values of volts used in the experiment. The effluent of the physical model focused in some water parameters such as COD, TSS, pH, salinity, and turbidity. The results showed, in case of discharge Q=10 l/hr, the treatment was optimal where the values of COD before and after Electro-Coagulation were 212 mg/l and 24 mg/l respectively. TSS has been reduced from 70mg/l to 6 mg/l. Which means, this method was effective and of low operating cost (0.31$/m^3) treating water and delivering it to the required specifications for reuse again.

Keywords: Electro-coagulation.; Water treatment; Stainless steel electrode

1. Introduction

Water is a vital component of human life because practically all human life's needs and actions depend on water. Wastewater can be created from. domestic and or manufacturing activities. Domestic wastewater is formed from houses like washing cooking, bathing. [1] .The characteristics of wastewater, such as greywater and black water, are dominated by water quality parameters such as Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Biochemical Oxygen Demand (BOD), Heavy metals, dyed, protein, smelly, fat and disinfectants [2]. Wastewater treatment is a process to reduce a load of pollutant in such non-conventional water sources by existing treatments involve biological and chemical approaches. The biological treatments are effective but require long treatment times, large treatment facilities and are expensive. The chemical approaches, which involve adding chemicals to extract or precipitate the pollutant, are very effective in removing the target pollutant, but the anion of the salt added can cause secondary pollution and large amounts of sludge. In this paper, we use one of the best treatment methods is Electrocoagulation is an electrochemical removal technique for water treatment, where an anode follows in the discharge of active coagulant in the form of metal ions like aluminum, Stainless steel, or iron into a solution. At the same time at the cathode, an electrolysis reaction happens in the form of hydrogen gas release [2]. On the other hand, a study was carried out using electrodes of Al and Fe by different values of power, current strength, and time confirmed to reduce COD by 65% - 76% and TSS by 85% [3].

*Corresponding author e-mail: reham_farouk_hussien@yahoo.com.; (Reham.F. Hussein)
Receive Date: 03 February 2022, **Revise Date:** 26 March 2022, **Accept Date:** 30 March 2022, **First Publish Date:** 30 March 2022
DOI: 10.21608/EJCHEM.2022.118228.5378

Objective

Producing Conventional water from non-conventional water using Electro-coagulation technology.

2. Electro-coagulation concept

The concept of Electro-coagulation depends on (electrolysis) which means destroying substances apart using electrical energy (separation). In the electrolysis method, oxidation and reduction reactions occur after electrical energy is applied to an electrolytic solution.

The process occurs in a mix of electrolyte, water, or salt-melting solution that improves the transmission of the ions among electrodes. When an electrical current is practical, the positive ions travel to the cathode, while the negative ions travel to the anode. At the electrodes, the cations are reduced and the anions are oxidized [4]

2.1 Electro-coagulation Mechanism

The Electro-coagulation treatment approach is the weakening suspended, emulsified, or dissolved contaminants in an aqueous medium by introducing an electric current into the medium. The electrodes used in this process are made of iron or aluminum and submerged in wastewater.

The metals and metal hydroxide cations take part in the EC process, in which the generation of coagulant in situ by the ending of metal from the anode with simultaneous formation of hydroxyl ions and hydrogen gas at the cathode.

In its simplest form, an Electro-coagulation reactor consists of an electrolytic cell with one anode and one cathode as shown in (Figure 1).

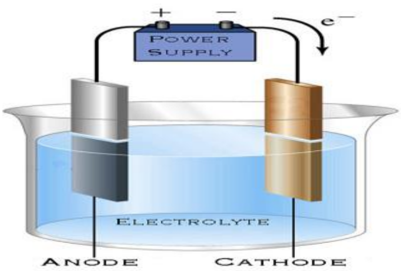


Figure.1. Diagram of Electro-coagulation cell

When the cell is linked to a power source, the anode is rusted due to oxidation. The released ions remove unwanted pollutants either by the chemical reaction by causing the colloidal materials to coalesce, to be removed after flotation and sedimentation.

As a result, contaminants will be released from the wastewater [4]. The contaminant type and bubble size, concentration and position, floc stability, and agglomerate size all influence the process of the E-C cell.

On the other hand, the complexity and number of potential interactions of an E-C process are shown in Figure 2. The general mechanism is a mixture of mechanisms functioning synergistically.

The main mechanism may vary in harmony with the dynamic process as the reaction develops and modification with changes in operating parameters and contaminant types [5]. The following reaction takes place during the E-C process [4]

At the anode:

$$M_{(s)} \rightarrow M^{n+}_{(aq)} + ne^- \quad \text{(Eq. 1)}$$

$$2H_{(2)}\ o_{(1)} \rightarrow 4H^+_{(aq)} + o_{2(g)} + 4e^- \quad \text{(Eq. 2)}$$

At the cathode:

$$M^{n+}_{(aq)} + ne^-\ M_{(s)} \quad \text{(Eq. 3)}$$

$$2H_{(2)}\ o_{(1)} + 2e^- \rightarrow H_2 + 2OH^-_{(aq)} \quad \text{(Eq. 4)}$$

Where:

S=solid aq= aquos e^- =electron n^+= nitron

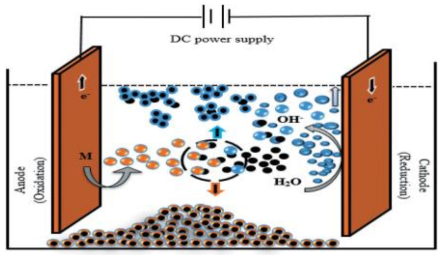


Figure. 2. Mechanism of Electrocoagulation process [6]

The anode produces cations as in (Eq. 1). Highly charged cations weaken colloidal units by the growth of polyvalent poly-hydroxide complexes. These complexes have high adsorption properties, forming masses with pollutants. The growth of hydrogen and oxygen gas helps in mixing and flocculation. The weakening mechanism of the pollutants, particulate suspension and breaking of mixtures taking place in an EC reactor may be brief as follows

1. Compression of the diffuse double layer nearby the charged types by the interfaces of ions generated by oxidation of the sacrificial anode.
2. Charge neutralization of the ionic types present in wastewater by counter ions produced by the electrochemical ending of the sacrificial anode. These counter ions reduce the electrostatic antiparticle dislike to the extent that the Van der Waals attraction predominates, thus producing

coagulation. A zero net charge results in the process.

3. The floc is formed, as an outcome of coagulation and makes a sludge blanket.

3. Methodology

In this research, the study of a newly designed Electro-coagulation (EC) reactor to domestic and sewage water in a stream of an open channel physical model (prototype)is tested. The reactor puts electrodes in parallel the direction of water flow and studies the effect of flow discharge of water on the quality of water in accord with different input electric power values of the reactor.

3.1. Electrodes parallel with water direction

3.1.1. Experimental component

The tools used in this study involved of Feed tank, Perspex channel, reactor, electrode, and power supply. Domestic wastewater is placed in the tank. Then the wastes were forced to the reactor, which has an electrode sheet. The electrode sheet is connected to the power according to the anode and cathode used. The Electro-coagulation reactor sizes are of spacing 3cm, width 10 cm, and length 57cm, and the thickness of the plate is 3mm. The reactor inlet is put after the starting of the channel by 30 cm, and the outlet at the end of the channel, In Perspex channel, put 4 parts with different shapes along the channel to help us to reduce the quantity of the Flocculation and sedimentation at the end when taking the samples. In this research paper, stainless steel (SS) plates electrodes are used, and the length is 57 cm and the width of 10 cm. The intended wastewater sample was collected from the wastewater effluents of the building National Water Research Center (Figure 3).

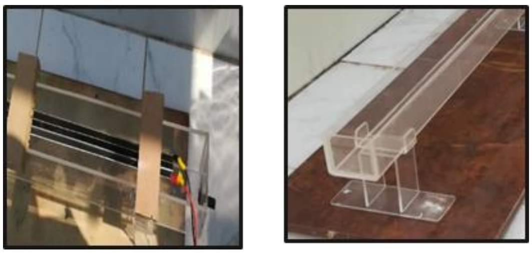


Figure. 3. The reactor is parallel with the water direction and Perspex channel.

3.1.2. Variables

The research consists of three types of variables, independent, dependent, and control variables. Independent variables represent current strength. Dependent variables include the concentration of physicochemical parameters (such as pH, EC, TDS, TSS Turbidity, BOD, and COD), and Microbiology parameters such as total and fecal coliform. On the other hand, control variables are Sewage wastewater discharge and reactor size as shown in (table 1).

In this study, changes in input power volts are 4V, 6V,12V, and 17V to be applied and, Stainless Steel (SS) plates as electrodes.

Table. 1. Types of variables

Dependent variables	Independent variables	Control variables
• pH-EC-TDS-TSS-COD-BOD…etc.	• Current Strength of Solution	• Sewage wastewater discharge • Reactor size.

3.1.3. Implementation phase

The Electro-coagulation was carried out continuously for 3.5 hours, the type of water used in this search is sewage wastewater and the discharge of water is equal to 10 L /hr. and 15 L/hr. In the Perspex channel, we put the reactor after the front of the Perspex channel at a distance of 30cm to allow the entering water easily before the reactor. In this time appear two important processes in the Electro-coagulation technology flocculation and sedimentation in (Fig 4), that's an indicator the oxidation process it is done. In the Perspex channel put 4 partitions with different shapes along the channel to help us to reduce the quantity of the Flocculation and sedimentation at the end when taking the samples, after the stage of the sampling process starts, we take samples from the water before and after the Electro-coagulation process, these samples are used to determine some variable as a physicochemical parameter like pH, EC, TDS, TSS Turbidity, BOD and COD, and Microbiology parameter as total and fecal coliform to explain the removal efficiency with this design of reactor and SS electrodes.

Flocculation after 2 hr Sedimentation after 2hr

Figure. 4. Flocculation and sedimentation in Electro-coagulation technology in situ.

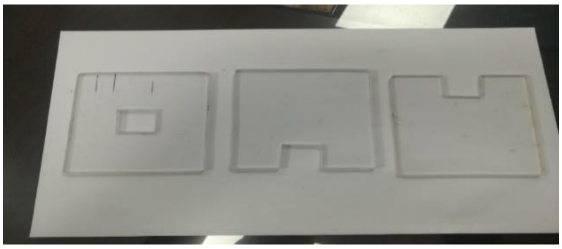


Figure.5. The Shapes of partions are put in Perspex Channel to create waving in an open channel.

3.1.4. Analysis of data

This research uses the Electro-coagulation technique to determine the result of electrical current on the deletion efficiency of these variables as physicochemical parameters like pH, EC, TDS, TSS Turbidity, BOD and COD, and Microbiology parameter as total and fecal coliform, And the depend on the data from the laboratory in the National water research center and it is certificated from ISO.

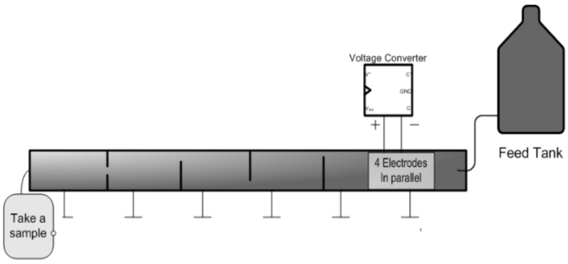


Figure. 6. Diagram of the Experiment

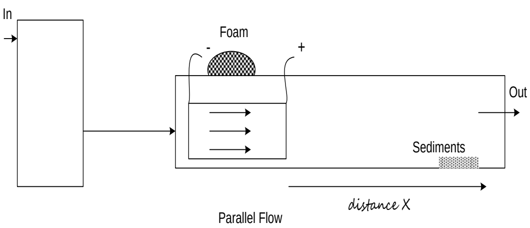


Figure.7. Cross-section of the Experiment

4. Results and discussion

4.1. Results:

4.1.1 Characteristics of domestic waste

The sewage wastewater under this research from the building of a central laboratory for environmental quality monitoring in the National water research center has physical properties that appear to be particles of suspended materials with a brown color. Further testing is shown on the raw sewage water to determine pH, EC, TDS, TSS, Turbidity, COD, BOD, total coliform, and fecal coliform. The results are in the following table (2)

Table. 2. Characteristics of raw sewage water

Physicochemical Parameters	Units	Parameters of wastewater used in Experimental
pH	-------	7.95
Electrical Conductivity (EC)	mmhos/cm	0.925
Total Dissolved Solids (TDS)	mg/l	600
Total Suspended Solids (TSS)	mg/l	70
Turbidity	NTU	60
Biological Oxygen Demand (BOD)	mg/l	10
Chemical Oxygen Demand (COD)	mg/l	212
Microbiological Parameters		
Total Coliform	CFU/100ml	1100000
Fecal Coliform	CFU/100ml	300000

The Experimental have included treatment of Q= 10 L/hr. with different values of volts 4,6,12, 17 volts and another treatment of Q=15 L/hr with the same values of the volts. The produced treated sewage water was collected and samples were filtered for analysis purposes.

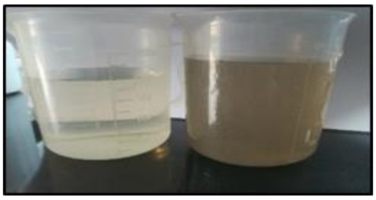
4.1.2. Treatment of Q=10 l/h. with different Volts

a. Analysis of Data:

In this case, collected the data before and after the experimental and analyses these data calculate the removal efficiency of all parameters and show it in the table (3): -

Table .3. Removal Efficiency when Q=10 L/hr with different volts

Parameters	Removal Efficiency%			
	v=4	v=6	v=12	v=17
pH	1.14	1.14	1.13	1.9
Electrical Conductivity (EC)	0.31	18	23	39
Total Dissolved Solids (TDS)	0.98	19	24	40
Total Suspended Solids (TSS)	48.84	86	91	86
Turbidity	57.14	92	95	85
Biological Oxygen Demand (BOD)	69.00	70	80	90
Chemical Oxygen Demand (COD)	40.00	81	89	94
Total Coliform	5.00	10	100	100
Fecal Coliform	20.00	33	100	100



Difference between Before and after treatment

Figure. 8. Treatment Stages with the different volts after 3.5 h

b. Water Quality after Electro-coagulation technology

This part includes applying the analysis of the selected parameters to show the removal efficiency data when the discharge is equal to 10 L/hr

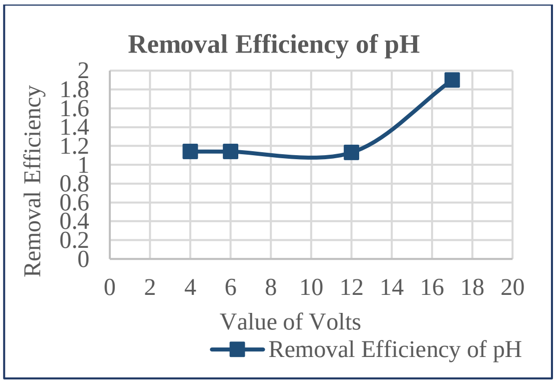


Figure.9. Relation between Removal Efficiency of pH with different volts.

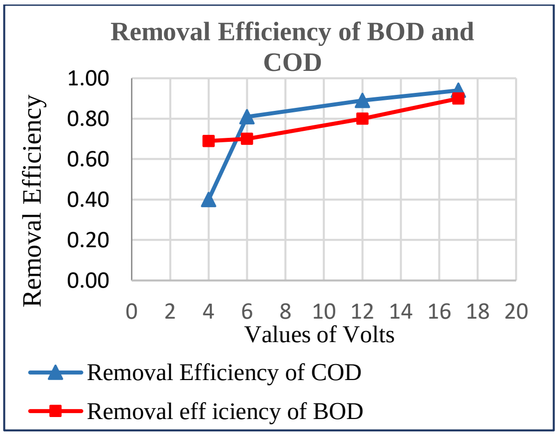


Figure.10. Relation between Removal Efficiency of COD and BOD with different volts

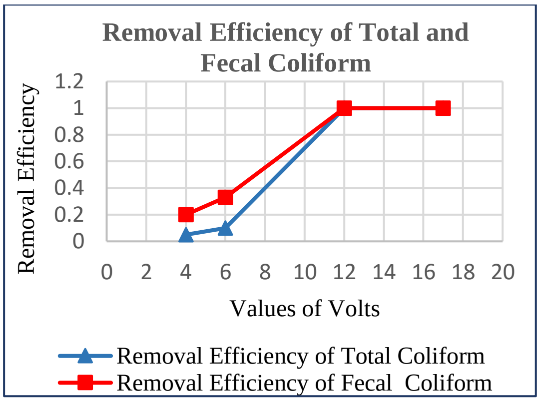


Figure.11. Relation between Removal Efficiency of Total and Fecal coliform with different volts.

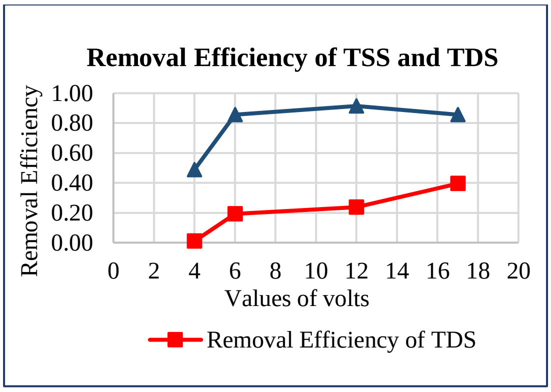


Figure.12. Relation between Removal Efficiency of TSS and TDS with different volts.

4.1.3 Treatment of Q=15 l/h. with different Volts

a. Analysis of Data:

In this case, collected the data before and after the experimental, the source of sewage wastewater is the same as shown in table (1) but change the discharge to 15 L/hr., analyses these data and calculate the removal efficiency of all parameters and shows in the table (3):

Table.3. Removal Efficiency when Q=15 L/hr with different volts.

When the electrodes parallel with the direction of water and Q=15 l/hr with different Volts				
Parameters	Removal Efficiency%			
	V=4	V=6	V=12	V=17
pH	1.05	1.15	1.1	1.05
Electrical Conductivity (EC)	19	22	24	26
Total Dissolved Solids (TDS)	19	22	24	27
Total Suspended Solids (TSS)	57	66	92	92
Turbidity	47	74	94	92
Biological Oxygen Demand (BOD)	80	93	98	98
Chemical Oxygen Demand (COD)	66	70	77	78
Total Coliform	98	99	99.7	100
Fecal Coliform	99	99	99.9	100

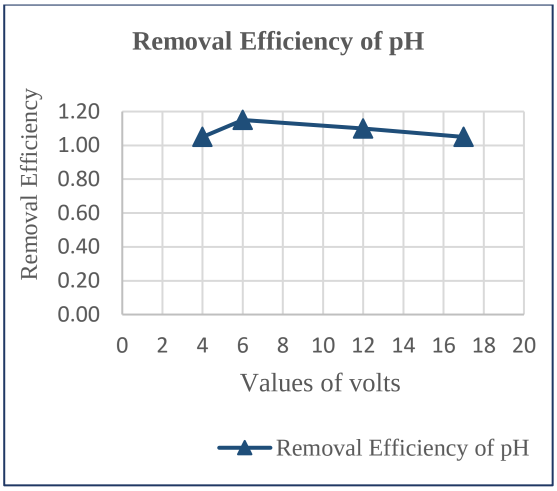


Figure.13. Relation between Removal Efficiency of pH with different volts.

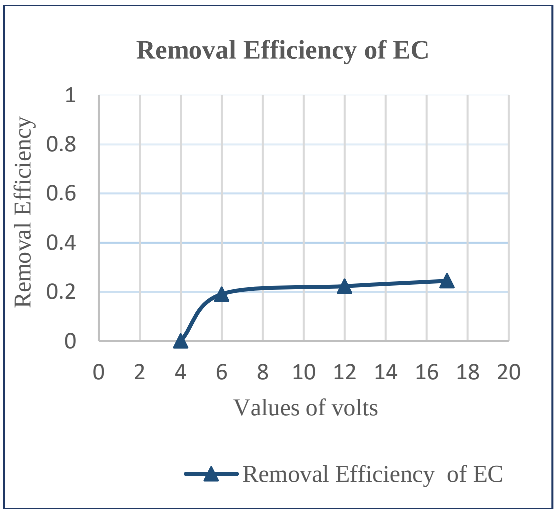


Figure.14. Relation between Removal Efficiency of EC with different volts

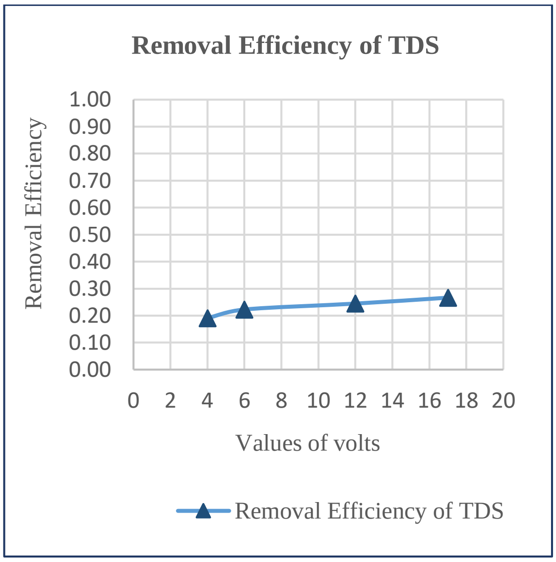


Figure.15. Relation between Removal Efficiency of TDS with different volts.

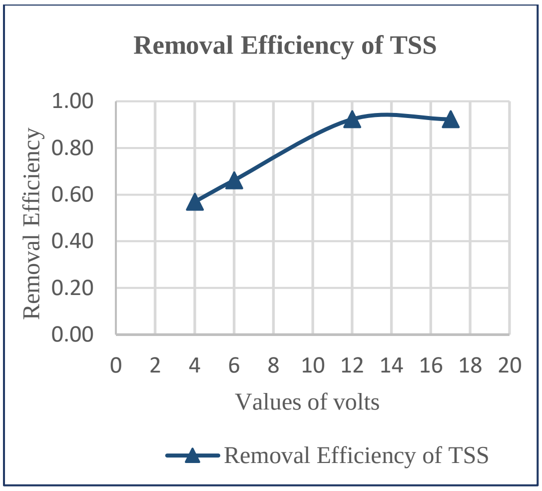


Figure.16. Relation between Removal Efficiency of TSS with different volts.

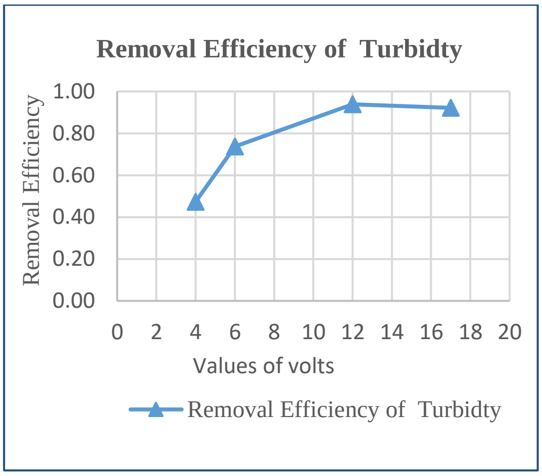


Figure.17. Relation between Removal Efficiency of Turbidity with different volts.

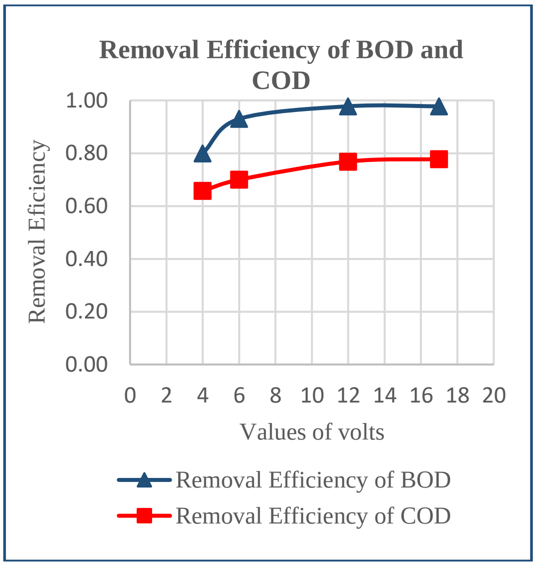


Figure.18. Relation between Removal Efficiency of BOD and COD with different volts

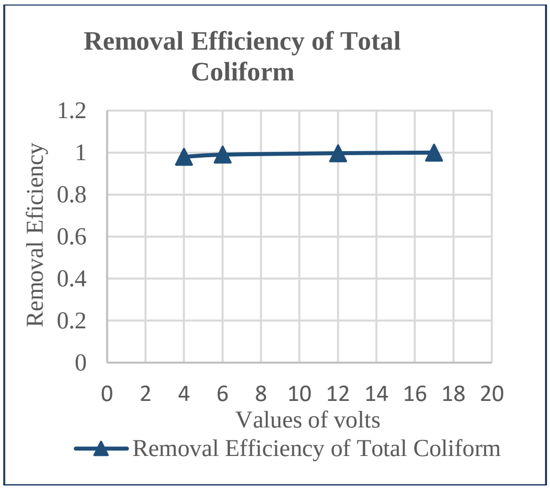


Figure.19. Relation between Removal Efficiency of Total coliform with different volts

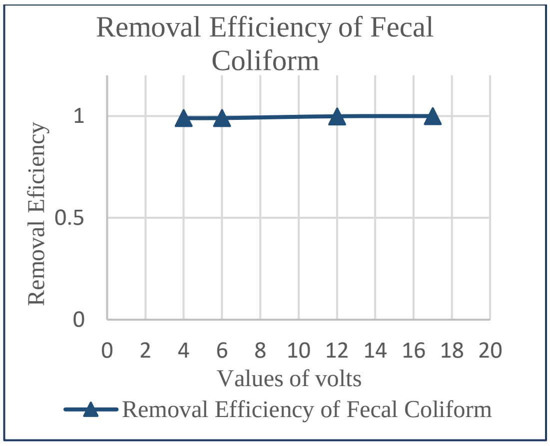


Figure.20. Relation between Removal Efficiency of Fecal coliform with different volts.

4.1.4 Operating cost analysis

In the electrocoagulation process, calculating an operating cost is important which consists of material (stainless steel electrodes and electrical energy) as well as other essential expenses consisting of sludge dewatering and disposal, but low operating costs could be calculated and no chemicals used for the reaction [7].

$$\text{Operating Cost} = a\, C_{energy} + b\, C_{electrode} \qquad \text{(Eq.5)}$$

Where, **a** is electrical energy price in $/kWh (0.04$/kWh)

b is electrode material price in $/kg (3.6$/kg)

C_{energy} is energy consumption (Eq. 6)

$C_{electrode}$ is electrode material consumption (5gm), The amount of material dissolved from the anode is calculated by measuring electrode mass before and after electrocoagulation [8].

The energy consumption can be calculated by the following equation:

$$C_{energy} = V*I*t / V_R \qquad \text{(Eq.6)}$$

Where,

V is the average voltage of the EC system which equals 12 volts

I is electrical current intensity (5.5 A)

t is a time of the process (3.5hr)

V_R is the volume of wastewater (32 liters)

From equation no.6, the energy consumption is 7.22 kWh/m3 and by applying equation no.5, the operating cost is 0.31$/m3 compering with other methods it is best in quality and price [9]

4.2. Discussion:

4.2.1. Sludge composition

In the E-C process, sacrificial anodes like iron, aluminium, copper, etc., destroy to release active coagulants. This paper used the sacrificial anode Stainless steel (SS) electrodes are used as coagulants to produce insoluble metal hydroxide flocs, which remove the contaminants by electrostatic attraction and/or surface complexation.

The iron coagulants from both Fe(OH)3 and Fe(OH)2 monomeric hydroxide species have charged composite polymeric hydroxide ion species.

These shapeless solid charged species nullify the charge of the colloidal particles present in the wastewater and agglomerates resulting in the creation of solid sludge. The EC sludge contains metallic composite along with organic and inorganic matter, bacteria, virus, nitrogen, phosphate, toxic heavy metals, trace metals.

The E-C process produces at least 60% less volume of sludge compared to chemical coagulation. EC-produced sludge is readily settable and easy to dewater when compared to chemical coagulation sludge, as it is collected of mainly metallic oxides/hydroxides. Reaction duration and electrical current density are the two important E-C factors that affect the sludge volume, to be analyzed.

The study revealed that the inorganic fraction of the sludge increased with the current density and reaction time. The color of the sludge produced decides the oxide of metallic compounds present in the sludge, for example, green-colored sludge displays the presence of Fe(OH)2 and brownish sludge shows the presence of Fe(OH)3.

4.2.2 Effect of current strength on parameters

The Electro-coagulation process using SS electrodes showed its effect on different parameters When changing the flow rate of water to 10, 15 L/hr.

The pH parameter increased with time, respectively with volts (4,6,12,17) from (7.95) to (9.06, 9.08, 9.02, 8.7)) in the case of Q=10 L/hr and the Second case changing from (7.95) to (8,8.9,8.5,8.14). The pH increase results from the reduction of H3O+ ions into H2(g) and OH^{-}ions at the cathode, which is not stoichiometrically balanced by Fe2+/3+ ions created at the anode; the charge is balanced, but some iron reacts with pollutant and other anionic species, so there is continuous production of excessOH^{-} that drives up the pH. Empirically, the growth of H2(g) gas bubbles at the cathode was much higher at the high volt. [6]

When record the values of BOD find increasing in the values of the removal efficiency with different volts (4,6,12,17) respectively (69,70,80,90) % in case of Q=10 L/hr and in case of Q=15L/hr (80,93,93,98) as shown in table (2,3).

Also, when record the values of COD find increasing in the removal efficiency with different volts (4,6,12,17) respectively (40,81,89,94) % in case of Q=10 L/hr and in case of Q=15L/hr. (66,70,77,78) as shown in table (2,3).

But in case of Turbidity, when the Q=10L/hr and Q = 15L/hr the value of the removal efficiency increased until the volt =12 after that decrease (57,92,95,85) % and (47,92,95,85) % respectively.

Also, when record the values of Total Suspended Solids(TSS) in case of Q=10L/hr and Q = 15L/hr the value of the removal efficiency increased until the volt =12 after that decrease (49,86,91,86) % and (57,66,92,92) % respectively.

Total coliform and Fecal coliform with Electro-coagulation achieve good results from volt=12 the removal efficiency up to 100 % in two cases.

Based on the data above, the Electro-coagulation effect on Electrical Conductivity (EC) in the previous two cases, but in the case of Q=10 L/hr is the best with the different volts. As the same with TDS related to the relation between them, as shown in Table (2,3).

5. Conclusion

The electro-coagulation process (EC) is a workable tool for the treatment of Sewage wastewater. EC can act as a pre-treatment and treatment process in wastewater treatment systems.EC process is effective to remove a wide range of pollutants and is suitable in operation. The cost-effectiveness, Additional benefits are gained from using EC as less cost, less sludge generation, environmental compatibility, and safe process. This is in agreement with the results obtained by [6]

The action duration found in most previous studies differs from 10 to 60 min and in some cases, it takes hours and applied electrical current was between 30 to 150 A/m2.

When the electrical current increases, the amount of coagulant also increases.

Results of the study revealed that: The flow rate of water Q=10 l/hr is the best under this design of this study therefore it is recommended that when the area of the section increases the flow rate must increase and the area of the electrodes also increase to get the best result of removal efficiency for the contaminants in sewage water.

The best volt understudy is 12 volts, where the removal efficiency is the best and this is in agreement with water properties in law 92 art 52.

6. Recommendation

1. Electro-coagulation is a new method for wastewater treatment.
2. The cost of this method is considered cheap while using solar cells to generate the electricity used in the treatment.
3. When using the electrodes and placing them in the drain, farmers must be made aware of their importance and preserve them to reuse them again in treatment.
4. It is preferable to use 10 L/hr with 12 volts to get the best and fastest treatment results.
5. It is necessary to research in this field to find an easy way to apply this research in a simple way on the ground.

References

[1] “" Asadiya A and Karnaningroem N 2018 Jurnal Teknik ITS 7(18)–22".”.

[2] “" Mubin F, Bintang A and Halim F 2016 Jurnal Sipil Statik 4(3) pp 211 – 223.".”.

[3] “"Holt P K 2012 Physicochem. Eng. Aspects. 211 pp 233-248".”.

[4] “"Ni’am A C, Caroline J, Afandi M H 2017 Jurnal Teknik Lingkungan 3(1)".”.

[5] “Sahu O, Mazumdar B, Chaudhari PK (2014) Treatment of wastewater".”.

[6] “Chopra A. K., Sharma A. K., and Kumar V., (2011)," Overview of Electrolytic treatment: An alternative technology for purification of wastewater", Archives of Applied Science Research, Vol. 3, No.5, pp 191- 206.".”.

[7] ““"Bouguerra, W., Barhoumi, A., Ibrahim, N., Brahmi, K., Aloui, L., & Hamrouni, B. (2015). Optimization of the electrocoagulation process for the removal of lead from water using

aluminum as electrode material. Desalination and Water Treatment, 56(10), 267”.

[8] “"Fayad, N. (2017). The application of electrocoagulation process for wastewater treatment and for the separation and purification of biological media (Doctoral dissertation, Université Clermont Auvergne).".”.

[9] “El-Awady, M. H., El-Ghetany, H. H., Aboelghait, K. M., & Dahaba, A. A. (2019). Zero liquid discharge and recycling of paper mill industrial wastewater via chemical treatment and solar energy in Egypt. Egyptian Journal of Chemistry, 62(Special Issue (Part”.

[10] “D. Syam Babu, T. S. Anantha Singh, P. V. Nidheesh & M. Suresh Kumar (2019): Industrial wastewater treatment by electrocoagulation process, Separation Science and Technology".