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Treatment of Sewage by Electrocoagulation and the Effect of High Current Density

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Abstract
Treatment of sewage water by electrocoagulation with high cell current densities (605 A/m^2, 908 A/m^2, 1211 A/m^2, 1513 A/m^2 and 1816 A/m^2) using stainless steel, iron and aluminum electrodes were studied. High current densities applied were very effective for the removal of COD, BOD and SS in 30 minutes. In the electrocoagulation of sewage water, the effect of electrode material, current densities, electrocoagulation time, interelectrode distance and initial pH were examined. The optimum operating range for each operating variable was experimentally determined in order to provide an economical and effective treatment for the sewage water. Therefore, the optimum condition for this treatment is in 30 minutes, by using stainless steel electrode, at 1816 A/m^2, in pH7 and 10 mm electrode distances. The optimum treatment condition reduced COD by 98.07%, BOD by 98.07% and SS by 97.64% and the anode loss during the experiment is 9.2 x 10^2 g.

Keywords: *electrocoagulation; sewage water; COD; BOD; SS*

1 Introduction

Sewage is the main point-source pollutant on a global scale [1]. Sewage, on the one hand, normally contained of biological, chemical and physical composition which is usually high in Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Suspended Solid (SS). So, direct discharge of raw or improper treated sewage into the water body is one of the main sources of pollution on a global scale [1]. There are two main objectives of wastewater treatment, one is protecting the environment and the other one is conserving fresh water resources [2]. Nowadays, many of the treatment plants use the biological process in treating sewage water but there are also disadvantages for that process because as the concentration of BOD increases, the higher oxygen volume by the aeration is needed resulting of higher capital and energy cost to them. Besides, this conventional method also need to have huge treatment space, skilled technicians and required a long period to treat the sewage water.

Simple, affordable, and efficient sewage water treatment systems are urgently needed in developing countries because most of the conventional technologies currently in use in industrialized nations are too expensive and complex [3]. Electrocoagulation is one of a simple method to treat wastewater efficiently [4]. This electrochemical treatment seems to be a promising treatment method due to its high effectiveness, its lower maintenance cost, less need for labor and rapid achievement of results [5]. Research, in the past few decades, have shown that the electrocoagulation is a promising treatment method and effectively potential to treat verity type of wastewaters including dyes wastewater [6-8], tannery wastewater [9], restaurant wastewater [4], palm oil mill effluent [6], food wastewater [7], potato chip manufacturing wastewater [8], urban wastewater [9], and removing heavy metals [10–19] .

Electrocoagulation treatment methods offer an alternative to the use of chemical coagulant such as metal salts or polymers for breaking the pollutants because during the electrocoagulation process, the electrode can generate coagulated species and metal hydroxides that destabilize and aggregate the suspended particles and precipitate. The hydrogen gas released from cathode would also help to float the flocculated particles out of the water [20].

2 Materials and methods

2.1 Sewage water samples

Sewage water was obtained from the first untreated pond at Indah Water Konsortium (IWK) which located at Indera Mahkota, Kuantan, Pahang, Malaysia. The composition of wastewater then characterized to identify the pH, Suspended Solids (SS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD).

2.2 Experimental device

The batch experimental setup is schematically shown in Fig. 1. The electrochemical unit consists of an electrocoagulation cell, a D.C power supply and the electrodes (stainless steel, aluminum and iron). There are two monopolar electrodes having same dimension (120 mm x 100 mm x 2 mm) as an anode and a cathode which spacing of 10 mm, 20 mm, 30 mm and 40 mm (depending on experiment) between each other. The total effective electrode was 1.652×10^{-2} m^2. In order to maintain an unchanged composition and avoid the association of the flocs in the solution, the stirrer was turned on and set at 80rpm. All the electrodes were washed with dilute HCl before every experiments conducted. Every experiment was performed at the room temperature.

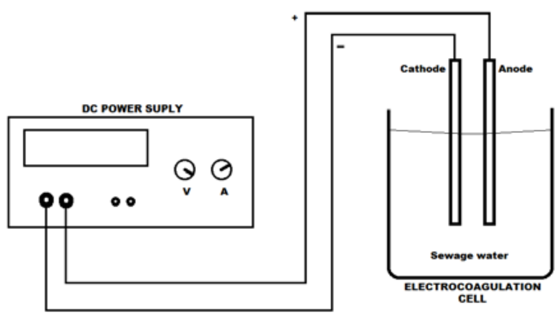


Figure 1 Schematic diagram of experimental setup

2.3 Experiment procedure

The experiments were carried out in a batch mode. For each experiment, a sewage water sample of 1 liter was collected in the electrochemical cell with two electrodes dipped into the sample. Six different of high current densities; 605 A/m^2, 908 A/m^2, 1211 A/m^2, 1513 A/m^2 and 1816 A/m^2 were applied. In each current density applied, contact time of 5, 10, 15, 20, 25, 30 were used. Therefore, a total of 17 experiments were carried out to determine the effect of electrode material, current densities, electrocoagulation time, interelectrode distance and initial pH. After the experiment, the treated sample was then kept undisturbed for 20 min in order to allow the flocs to settle. Subsequently, after settling the sample of supernatant was collected to perform the analysis of SS, COD, and BOD.

3 Result and discussion

3.1 Characteristic of sewage water

Table 1 shows the characteristic of the sewage water sample used before the treatment. As observed, the average COD, BOD and SS concentration is in medium concentration which is 466 mg/l, 259 mg/l, and 297 mg/l respectively and the value of pH is 7.6.

Table 1 Characteristic of raw sewage water

Parameter	Value
COD (mg/l)	466
BOD (mg/l)	259
SS (mg/l)	297
pH	7.6

3.2 Effect of electrode material

Electrode assembles as the heart of the electrocoagulation process. Therefore, the appropriate selection of its materials is very concerned. In this experiment, the stainless steel, iron and aluminum electrode were used as these types of electrode are proven effective to treat wastewater. The experiment was first running in 30 minutes at 1816 A/m^2 current density by using different types of electrode to obtain the best electrode in sewage water treatment. Figure 2 compares the treatment efficiency for these three kinds of electrodes under the same current density.

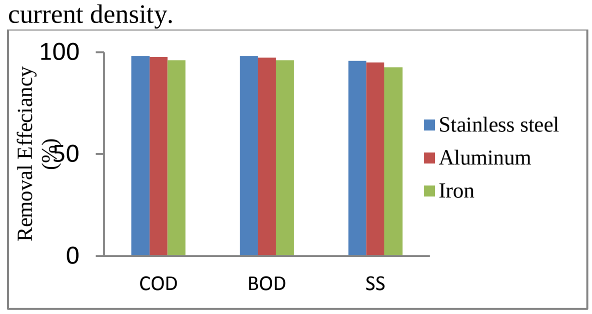


Figure 2 Effect of electrode material with current density 1816 A/m2, time 30 minutes, pH 7, interelectrode distance 10 mm

The results indicated that for sewage water, the stainless steel electrode was more effective than the iron and aluminum electrode, which can reduce COD, BOD, and SS by 98.07%, 98.07%, and 95.69% 30 minutes of treatment. While, by using iron as the electrode, percentage of COD, BOD, and SS removal is 96.14%, 96.14%, and 92.55%, which a little bit lower than stainless steel. Besides, by using iron electrodes, the treating solution begins to change into greenish color after 5 minutes and then switch into brownish color a few minutes later during treatment. The green color must be due to Fe^{2+} and the brown color is Fe^{3+}. Fe^{2+} can be easily oxidized into Fe^{3+}.

Fe^{3+} usually exist in the form of $Fe(OH)_3$ which is fine particles and hard to precipitate. So iron electrode is not suitable to be used in this process. By using aluminum as electrode, the percentage of COD, BOD, and SS removal is 97.64%, 96.14%, and 94.9% respectively. Although the treatment by aluminum electrode is almost about the same as the stainless steel electrode, it also not suitable in this experiments because aluminum electrode leave a thick turbidly sludge in the solution. Therefore, all subsequent experiments were carried out with stainless steel electrode.

3.3 Effect of current density

In all the electrocoagulation process, current density is the most important parameter in controlling the reaction rate. Rising current density resulted to an increase in the removal efficiency of COD, BOD, SS. Figure 3 shows the removal efficiency of COD, BOD and SS against current density applied to the stainless steel electrodes in the electrocoagulation process. When the current density increases, the efficiency of ion production in anode and cathode also increase, leading to the floc production increment. So that, 96%, 98.3% and 97.6% of COD, BOD and SS percentage of removal was obtained by using 1816 A/m^2 during 30 minutes of electrocoagulation process compared to the 92.2%, 94.6% and 94% of COD, BOD and SS respectively by using only 605 A/m^2. The optimum of current density of 1816 A/m^2 was used for this treatment in 30 minutes.

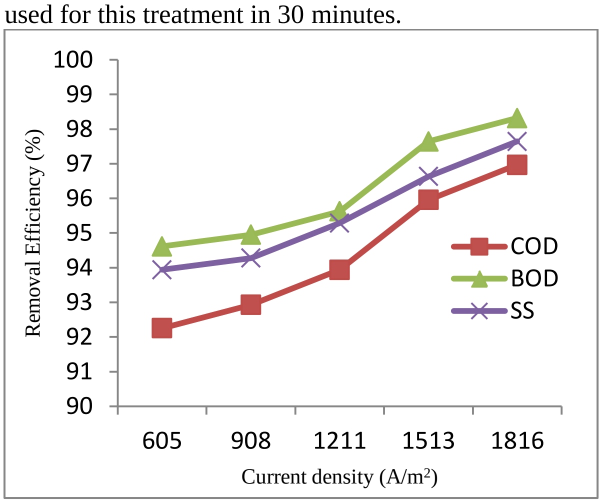


Figure 3 Effect of current density on removal efficiency of COD, BOD and SS using stainless steel electrode, time 30 minutes, pH 7, and interelectrode distance 10mm

3.4 Effect of electrolysis time

As shown in Fig. 4, as the time of electrolysis increase comparable changes in the removal efficiency of COD, BOD and SS are observed. Reactive time also influence the treatment efficiency of electrocoagulation process because the more time consume, the more production rate of hydroxyl and metal ion are produced on the electrodes.

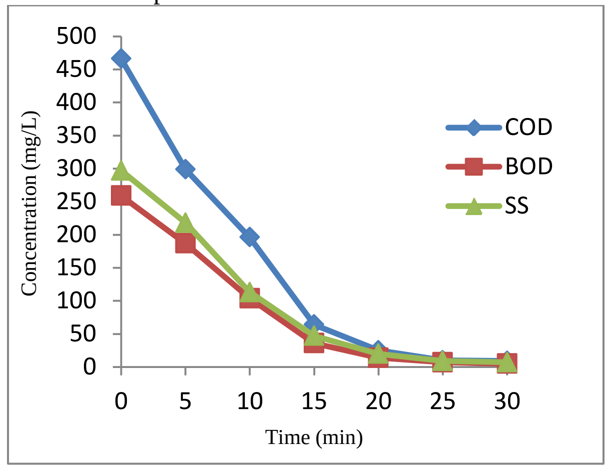


Figure 4 Effect of time on COD, BOD and SS removal using stainless steel electrode, current density 1816 A/m2, pH 7, and interelectrode distance 10 mm

The effect of time was studied at constant current density of 1816 A/m^2. In this experiment, two stages have been going trough by electrocoagulation process. The first stage is usually short, whereas the second one is taking relatively long time consumed. According to the result showed in Fig. 4, 15 minutes of operating time is sufficient for nearly complete treatment efficiency of COD, BOD, and SS. Treatment efficiency remains almost constant and has insignificant improvement above 20 minutes. Therefore, the optimum electrolysis time was 15 minutes.

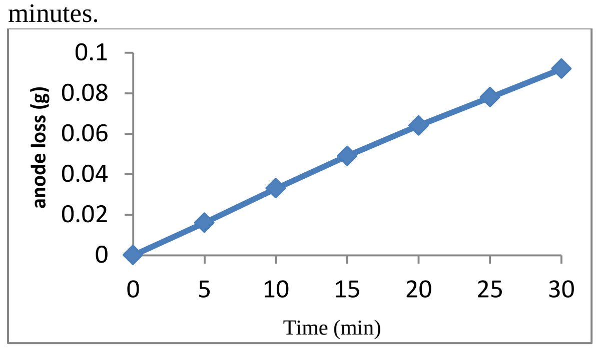


Figure 5 Wight of stainless steel anode loss during electrocoagulation, at current density 1816 A/m2, pH 7, interelectrode distance 10 mm, in 1Liter sewage water

Electrode consumptions are proportional to the operating time. Fig. 5 showed the electrode consumption increased almost steadily every minute. Increasing in time from 5 to 30 minutes resulted to a decreasing weight of cathode from 88.432 g to 88.356 g stainless steel anode which is increment average of anode consumption is about 15mg/L sewage water every 5 minutes. Therefore, this result indicates that retention time is very important parameter because it affects the economic applicability of electrocoagulation process in treatment of sewage water.

3.5 Effect of inter electrode distance

The effect of inter electrode distance does not show a significant result in this experiment. However, as shown in figure 6, when inter electrode distance increases, the efficiency of COD, BOD and SS removal decrease slightly because the rate of electron transfer is become slower. Variations of the percentage removal with inter electrode distance is shown in figure below.

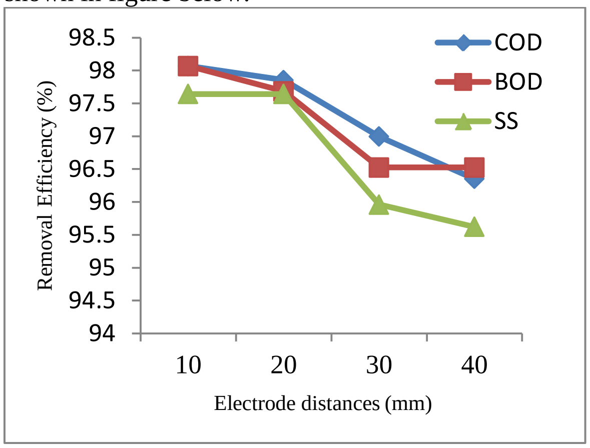


Figure 6 Effect of electrode distance on removal efficiency, using stainless steel electrode, at current density 1816 A/m2, pH 7, 30 minutes

From Fig. 6, the removal efficiency slightly decrease when electrode distance increase. For COD, removal efficiency decrease from 98.07% at 10mm electrode distances to 96.35% at 40mm electrode distances. For BOD, the removal efficiency is almost the same as COD which is from 98.07% at 10mm to 96.53% at 40mm electrode distance. For SS, the removal efficiency decrease from 97.64% at 10mm to 95.62% at 40mm electrode distances. The increase of inter electrode distance will make the cell potential (V) increases which also increases the resistance and adversely affect the sewage water treatment. According to Ohm's law, the amount of electric current through a metal conductor in a circuit is directly proportional to the voltage impressed across it, for any given temperature. This relationship can be expressed as:

$$V = IR \quad (1)$$

Ohmic potential drop or IR drop can have a significant influence on electrochemical measurements. Ohmic potential drop is potential drop due to solution resistance. The difference in potential required to move ions through the solution. The variation in IR drop is governed by equation below:

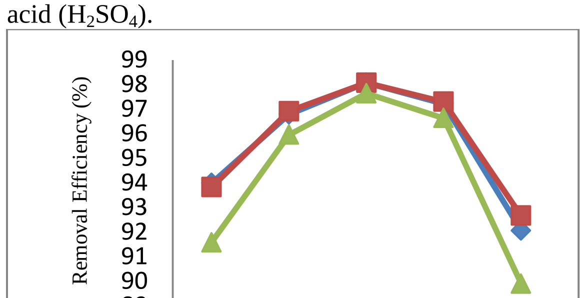
$$\eta IR = I.\frac{d}{A.\kappa} \quad (2)$$

Where:
I = current (A)
d = distance between cathode and anode (m)
A = active anode surface (m^2)
κ = specific conductivity (10^3 mS/m)
[21]

From the equation above infers that IR drop will increase by increasing the distance of the electrodes. During the experiment, the current suddenly drop after some time, so applied voltage has been increase in order to maintain the constant current. This situation occurs maybe due to the rising of Ohmic loss (IR drop) which lead to the rate of anodic oxidation inhibited. Therefore, the increase of IR drop by increase the distance between anode and cathode is not recommended in electrocoagulation process.

3.6 Effect of pH

It has been established from the previous studies that pH is an important variable influencing the treatment performance of the electrocoagulation process [4, 8, 20, 22, 23]. In order to examine its effect, the sewage water was adjusted to the desired pH by using potassium hydroxide (KOH) and sulfuric acid (H_2SO_4).



	3	5	7	9	11
COD	93.99	96.78	98.07	97.21	92.06
BOD	93.82	96.91	98.07	97.3	92.66
SS	91.58	95.96	97.64	96.63	89.9

Figure 7 Effect of pH on removal efficiency, using stainless steel electrode, at current density 1816 A/m2, 30 minutes, 10 mm electrode distances

Fig. 7 showed the effect of pH on COD, BOD, and SS removal efficiency. From the figure, the removal efficiency is very low in acidic electrolyte which is can only remove 93.82%, 91.58% and 93.99% for COD, BOD and SS at pH 3. Meanwhile, in alkaline solution, the removal efficiency is also very low which is for COD, BOD and SS is 92.06%, 92.66 and 89.9% respectively at pH 11. However, in neutral electrolyte solution, COD, BOD and SS removal efficiency is 98.07%, 98.07% and 97.64%. So, from the Fig. 7, it can be concluded that the optimum pH values appeared between 7 and 9 which will provide an economical and effective treatment for the sewage water in practical.

4 Conclusions

Electocoagulation was approved as an effective method for the reduction of COD, BOD and SS in sewage water. In this treatment, the effect of electrocoagulation on the removal efficiency of COD, BOD and SS point out to be dependent on the amount of ion release by electrode for the higher current densities of 605 A/m^2, 908 A/m^2, 1211 A/m^2, 1513 A/m^2 and 1816 A/m^2, meaning that, as the higher current density been given, the higher amount of metal ion been generated, leading to higher treatment efficiency. The influence of various operational variables such as current density, type of electrode material, electrocoagulation time, pH and inter electrode distance on removal of COD, BOD and SS was investigated. The result showed that the removal of COD, BOD and SS increase with the increase of every operational parameter stated except for pH and inter electrode distance. The highest removal efficiency of COD by 98.07%, BOD by 98.07%, and SS by 97.64% occurred at 1816 A/m^2 current density, 10 mm inter electrode distances and pH 7 in 30minutes of operating time by using stainless steel electrode.

REFERENCES

1. Gijzen, H. *Anaerobic digestion for sustainable development: a natural approach.* Water Science and Technology, (2002), 45 : 321-28.
2. Bukhari, A. A. *Investigation of the electro-coagulation treatment process for the removal of total suspended solids and turbidity from municipal wastewater.* Bioresource Technology, (2008), 99 : 914-21.
3. Grau, P. *Integrated water and waste management.* Water Science and Technology, (1996), 33 : 39-46.
4. Chen, X., Chen, G., &Yue., P. L. *Separation of pollutants from restaurant wastewater by electrocoagulation.* Separation and Purification Technology, (2000), 19 : 65-76.
5. Feng, C., Sugiura, N., Shimada, S., &Maekawa, T. *Development of a high performance electrochemical wastewater treatment system.* Journal of Hazardous Materials, (2003) 103: 65-78.
6. Phalakornkule, C., Mangmeemak, J., &Intrachod, K. *Pretreatment of palm oil mill effluent by electrocoagulation and coagulation*. Scienceasia, (2010) 36 :142-49.
7. Zheng, Y. M.,&Chen, J. P. *Handbook of advanced industrial and hazardous wastes treatment.* Water, (2010).
8. Kobya, M., Hiz, H., Senturk, E., Aydiner, C., &Demirbas, E. *Treatment of potato chips manufacturing wastewater by electrocoagulation.* Desalination, (2006), 190 : 901-211.
9. Pouet, M. F., &Grasmick, A. *Urban wastewater treatment by electrocoagulation and flotation.* Water Science and Technology, (1995), 31 : 275-283.
10. Kabdaşli, I., Arslan, T., Olmez-Hanci, T., Arslan-Alaton, I., &Tünay, O., *Complexing agent and heavy metal removals from metal plating effluent by electrocoagulation with stainless steel electrodes.* Journal of hazardous materials, (2009), 165 : 838-45.
11. Akbal, F. &Camcı, S. *Copper, chromium and nickel removal from metal plating wastewater by electrocoagulation.* Desalination, (2011), 269 : 214-22.
12. Hanay, Ö. & Hasar, H. *Effect of anions on removing Cu2+, Mn2+ and Zn2+ in electrocoagulation process using aluminum electrodes.* Journal of hazardous materials, (2011), 189 : 572-6.
13. Shafaei, A., Pajootan, E., Nikazar, M. &Arami, M. *Removal of Co (II) from aqueous solution by electrocoagulation process using aluminum electrodes.* Desalination, (2011), 279, no. 1–3, pp. 121-6.
14. Shafaei, A., Rezayee, M., Arami, M., &Nikazar, M. *Removal of Mn^{2+} ions from synthetic wastewater by electrocoagulation process.* Desalination, (2010), 260 : 23-8.
15. Al Aji, B., Yavuz, Y. &Koparal, A. S. *Electrocoagulation of heavy metals containing model wastewater using monopolar iron electrodes.* Separation and Purification Technology, (2012), 86 : 248-54.
16. Shafaei, A., Rezaie, M., &Nikazar, M. *Evaluation of Mn^{2+} and Co^{2+} removal by electrocoagulation: A case study.* Chemical Engineering and Processing: Process Intensification, (2011), 50 : 1115-21.
17. Heidmann, I. &Calmano, M. *Removal of Zn(II), Cu(II), Ni(II), Ag(I) and Cr(VI) present in aqueous solutions by aluminium electrocoagulation.* Journal of hazardous materials, (2008), 152 :. 934-41.
18. Meunier, N., Drogui, P., Mercier, G. &Blais, J.-F. T*reatment of metal-loaded soil leachates by electrocoagulation.* Separation and Purification Technology, (2009), 67 : 110-6.
19. Merzouk, B., Gourich, B., Sekki, A., Madani, K. &Chibane, M., *Removal turbidity and separation of heavy metals using electrocoagulation-electroflotation technique A case study.* Journal of hazardous materials, (2009) 164 : 215-22.
20. Kobya, M., Demirbas, E., Can, O. T., &Bayramoglu, M. *Treatment of levafix orange textile dye solution by electrocoagulation.* Journal of hazardous materials, (2006), 132 : 183-8.
21. Eilen, E. T. G., Vik, A., Dale, Carlson, A., Arild, &Eikum, S. *Electrocoagulation of potable water.* Water Research, (1984), 18 : 1355-60.
22. Daneshvar, N., Oladegaragoze, A., &Djafarzadeh, N., *Decolorization of basic dye solutions by electrocoagulation: an investigation of the effect of operational parameters*. Journal of hazardous materials, (2006), 129 : 116-22.
23. Jing-wei, F., Ya-bing, S. U. N., Zheng, Z. Ji-biao, Z., Shu, L. I., & Yuan-chun, T. *Treatment of tannery wastewater by electrocoagulation.* (2007), 19 : 1409-15.