ELECTROCOAGULATION OF PALM OIL MILL EFFLUENT USING ALUMINIUM ELECTRODES

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ABSTRACT

Electrocoagulation is a treatment method that has the potential in removing various pollutants without generating secondary pollutants which only involves simple and compact equipment. In this study, the potential to treat palm oil mill effluent using an electrocoagulation process was studied. The objectives of the study are to determine the optimum current density, the optimum retention time, and the optimum initial pH of the sample for the electrocoagulation of palm oil mill effluent using aluminium in terms of removing chemical oxygen demand, suspended solids and colour of the palm oil mill effluent. The palm oil mill effluent samples were collected from Pertubuhan Peladang Negeri Johor palm oil mill. The range of current density, retention time and initial pH used to obtain the optimum value were 20-100 A/m2, 10-30 minutes, and 2-10, respectively. The distance between the electrodes and settling time were kept constant at 5 cm and 30 minutes, respectively. The sludge volume and the variability of pH changes throughout the electrocoagulation process were also studied. Results show that the optimum conditions for the electrocoagulation process using aluminium-aluminium electrode pair are current density of 80 A/m2, retention time of 15 minutes, and initial pH of 4. This optimum condition was able to reduce chemical oxygen demand, suspended solids, and colour up to 72.75%, 96.93%, and 92.79%, respectively. At the end of electrocoagulation, the sludge volume obtained was 27.27% and pH was increased from 4.00 to 4.38. It can be concluded that the electrocoagulation process has the potential to be utilized for effective removal of chemical oxygen demand, suspended solids and colour of the palm oil mill effluent.

KEYWORDS: aluminium electrodes, electrocoagulation, palm oil mill effluent, removal efficiency

1.0 INTRODUCTION

Over the last three decades, Malaysian palm oil industry has grown to become an important agriculture-based industry. Today, Malaysia and Indonesia accounted for more than 90% of global palm oil production as

they benefits in fulfilling the current and future demand as a source of edible oil (Lam *et. al.*, 2009).

In fact, Malaysian palm oil industry recorded an impressive performance in 2008 and 2009 where the total oil palm planted areas in 2006 were 4.69 million ha. The total exports of oil palm products were 20.13 million tons in year 2008 and year 2009. Unfortunately, this important economic activity generates an enormous amount of liquid effluent or palm oil mill effluent (POME) (Ahmad *et. al.*, 2005). It will be one of the greatest pollutant contributors in Malaysian river or lakes if releases without effective treatments.

POME contains high loads of chemicals. It has been reported that fresh POME is a colloidal suspension containing 95-96% water, 0.6-0.7%oil and 4-5% total solids including 2-4% suspended solids that are mainly debris from palm fruit mesocarp generated from three main sources, i.e. sterilizer condensate, separator sludge and hydrocyclone (Sumathi *et. al.*, 2008). It is acidic (pH 4-5), hot (80-90°C) and non-toxic since no chemicals are added during oil extraction (Ahmad *et. al.*, 2005).

POME generally is treated by anaerobic digestion which results in methane as a value-added product. POME also have been treated by pond system, upflow anaerobic sludge fixed film bioreactor, pretreatment using moringa oleira seeds as an environmental friendly coagulant, semi-commercial closed anaerobic digester and synthetics polyelectrolytes (Agustin *et. al.*, 2008). Commonly used physico-chemical treatment processes require chemical additions and a great quantity of sludge is generated. Therefore, there is an urgent need to develop innovative and more effective techniques for treatment of wastewaters (Mouedhen *et. al.*, 2008).

Several studies have reported that the electrocoagulation process has potential in treating various pollutants in wastewater including the removal of dyes, suspended solids, heavy metals, breaking up oil-on-water-emulsion, the removal of complex organics and bacteria, viruses and cysts (Phalakornkule *et. al.*, 2010). Thus, electrocoagulation method is yet another alternative treatment that is to be studied and findings are reported in this paper.

Electrocoagulation method is chosen to be studied since it has potential in the future POME industry that considers the economical and environmental-friendly aspects as claimed by several previous researches. In the previous literatures, it has been proven that the electrocoagulation method has potential in removal efficiency without generating secondary pollution by just using compact equipment (Moreno-Casillas *et. al.*, 2007).

The main objective of this research is to investigate the effectiveness of electrocoagulation using aluminium (Al) in the removal of chemical oxygen demand (COD), suspended solid (SS), and colour from palm oil mill effluent. The optimum current density, the optimum retention time, and the optimum initial pH of the sample are determined to ensure that the best efficient pollutant removal by the electrocoagulation of POME using aluminium as electrodes is achieved.

2.0   MATERIALS AND METHODS

2.1   Preparation of Sample

POME is discharged with high oily texture, high organic contents, brownish in colour, and the heat of up to 80°C. POME samples are collected and stored in bottles and kept in a store room at 4°C prior to use to avoid degradation or changes to its characteristics (APHA, AWWA, WEF, 2005). All sampling procedures are carried out in accordance to Method 1060 (APHA, AWWA, WEF, 2005). To avoid excessive deterioration of the POME samples, stored samples were kept for not more than two weeks, after which they should be discarded (Ng *et. al.*, 1987).

The POME samples taken out from the storage room are left till it reaches room temperature. Then the initial conditions including the concentration of COD, SS, colour and pH of the POME samples were determined. The initial characteristics of the raw POME are shown in Table 1. This research only focused on four quality parameters, i.e. COD, SS, colour, and pH.

Table 1 Characteristics of raw POME collected from PPNJ palm oil mill in Kahang, Johor

Parameter	Initial Characteristics
Biochemical Oxygen Demand (BOD)	29,700 – 30,020
Chemical Oxygen Demand (COD)	72,821 – 72,890
Suspended Solids (SS)	12,116 – 13,580
Total Solids (TS)	33,460 – 33,580
Colour	11,330 – 11,918
pH	4.03 – 4.59

*All units are in mg/L except for pH and PtCo for colour

2.2   Experiment Set Up

The electrocoagulation experiment was carried out in batch mode using a 1000 ml glass beaker of diameter 11 cm, vertically positioned Al electrodes are spaced at 5 cm as shown in Figure 1. The dimensions of the electrode are 200 mm high × 50 mm wide × 1 mm thick. It is made of aluminium plates and connected to a digital direct current (DC) power supply (MPS 3030DD model). The total effective working area is 0.01 m^2 when immersed at a depth of 10 cm into the POME solution. The settling time was kept constant at 30 minutes. pH of the POME solutions before and after the electrocoagulation were measured by a HACH Sension3 pH meter. COD, SS, colour tests were carried out according to the standard methods (APHA, AWWA, WEF, 2005).
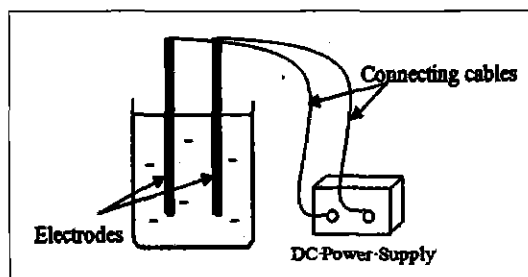
Figure 1 Electrocoagulation process set-up

2.3   Apparatus

2.3.1   Reactor (glass tank)

One liter glass beaker is used as the reactor tank in the experimental studies.

2.3.2 Electrodes

Aluminum electrodes are used in the electrocoagulation process as plates for the anodes and cathodes with the dimension of 200 mm high × 50 mm wide × 1 mm thick.

2.3.3 pH

HACH Sension3 pH meter is used to determine the pH of the POME samples. To obtain the optimum initial pH value, the pH of POME solution was adjusted by adding either sodium hydroxide (NaOH) or sulphuric acid (H_2SO_4).

2.3.4 Chemical Oxygen Demand, Suspended Solids and Colour Analyses

COD, suspended solid and colour analyses are performed in accordance to the standard methods described in (APHA, AWWA, WEF, 2005) with the use of DR 5000 spectrophotometer.

3.0 EXPERIMENTAL RESULTS AND DISCUSSIONS

The electrocoagulation process is quite complex and may be affected by several operating parameters such as the current density, retention time, and initial pH of the samples. In the electrocoagulation process, under the varied operating parameters, the removal efficiencies of COD, SS, and colour of the POME samples are determined. The sludge volume also is determined as well as the pH changes during electrocoagulation process.

3.1 Determination of Optimum Current Density

The effect of current density in the range of 20 A/m² to 100 A/m² was investigated using aluminium electrodes at POME natural pH of 4.59, electrodes distance of 5 cm and retention time of 20 minutes. Different materials could be used as electrodes for electrocoagulation and the electrode material has been known to be an important factor influencing the performance of the electrocoagulation process (Lin *et. al.*, 2003). The optimum current density was determined based on the percentage removal efficiencies. The current density which gives the highest removal efficiencies in term of COD, SS, and colour as well as sludge volume percentage is the optimum current density.

Figure 2 shows the effects of current density on COD, SS and colour removal efficiencies as well as sludge volume percentage for Al-Al at pH 4.59, retention time of 20 minutes, distance between electrodes of 5 cm, and settling time of 30 minutes. COD removal efficiencies at current densities of 20 A/m², 40 A/m², 60 A/m², 80 A/m², and 100 A/m² were 67.39%, 68.83%, 69.37%, 71.99 and 69.69%, respectively. SS removal efficiencies at current densities of 20 A/m², 40 A/m², 60 A/m², 80 A/m², and 100 A/m² were 87.80%, 90.77%, 93.72%, 98.38%, and 96.49% respectively. Colour removal efficiencies at current densities of 20 A/m², 40 A/m², 60 A/m², 80 A/m², and 100 A/m² were 91.84%, 91.91%, 91.99%, 93.04 and 92.65%, respectively. Sludge volume percentages at current densities of 20 A/m², 40 A/m², 60 A/m², 80 A/m², and 100 A/m² were 22.73%. 22.73%, 22.27%, 36.36 %, and 18.18%.
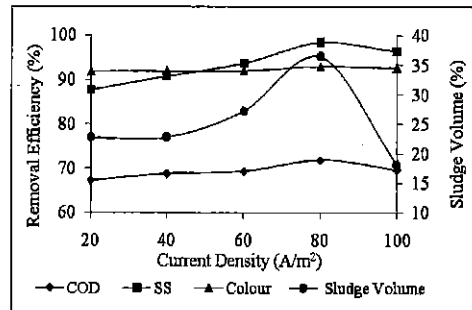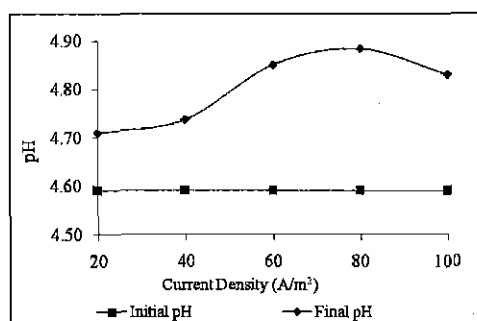

Figure 2 Effects of current density on COD, SS and colour removal efficiencies as well as sludge volume percentage for Al-Al at pH 4.59, retention time 20 minutes, distance between electrodes 5 cm, and settling time 30 minutes

The highest removal efficiencies obtained for the COD, SS, and colour as well as the sludge volume percentage occurred at current density of 80 A/m². At current density higher than 80 A/m², the removal efficiency was slightly decreased. Thus, the current density of 80 A/m² is the optimum current density for Al-Al electrocoagulation process since the best removal efficiency is achieved for all the tested pollutants.

Among the quality parameters tested as well as the sludge volume, SS removal efficiency showed the highest value which was 98.38% at current density of 80 A/m² followed by colour, and COD removal efficiencies which were at 93.04% and 71.99%, respectively. The highest sludge volume that occurred at current density of 80 A/m² was 36.36%.

Figure 3 shows the effect of electrocoagulation on the pH evolution. The final pH was higher than the initial pH. As for determination of optimum current density, the natural POME pH used was 4.59 for all tested current densities. At the end of electrocoagulation process, the measured pH at current densities of 20 A/m², 40 A/m², 60 A/m², 80 A/m², and 100 A/m² have increased to pH 4.71, 4.74, 4.85, 4.88, and 4.83, respectively. At current density of 80 A/m², natural POME of pH 4.59 increased up to 4.88 which is the highest pH evolution among other tested current densities. The initial pH of the POME sample is slightly acidic (4.59), and the pH value increases during electrocoagulation process (Mouedhen et al., 2008).

Figure 3 Effects of current density on pH evolution for Al-Al during electrocoagulation at pH 4.59, retention time 20 mins, distance between electrodes 5 cm, and settling time 30 minutes

3.2 Determination of Optimum Retention Time

The influence of retention time was investigated when the current density was kept constant at 80 A/m², natural POME pH at 4.59, electrode distance of 5 cm and settling time of 30 minutes during the COD, SS, and colour removal process.

Figure 4 shows the effects of retention time on COD, SS and colour removal efficiencies as well as sludge volume percentage for Al-Al at pH 4.59, retention time of 20 minutes, distances between electrodes of 5 cm, and settling time of 30 minutes.

COD removal efficiencies at retention time of 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes were 67.55%, 78.37%, 73.30%, 71.02%, and 65.19%, respectively. SS removal efficiencies at retention time of 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes were 90.39%, 90.84%, 90.15%, 90.12%, and 89.93%, respectively. Colour removal

efficiencies at retention time of 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes were 91.76%, 95.06%, 92.30%, 92.06%, and 88.79%, respectively. Sludge volume percentages at retention time of 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes were 18.18%, 22.73%, 18.18%, 9.09%, and 9.09%.

Highest removal efficiencies of COD, SS, and colour as well as the sludge volume occurred at retention time of 15 minutes. The efficiency decreases when the retention time is greater than 15 minutes. Therefore, the optimal retention time is 15 minutes for Al-Al electrocoagulation process since it gives the highest removal efficiency for all the tested parameters (COD, SS, colour and sludge volume).
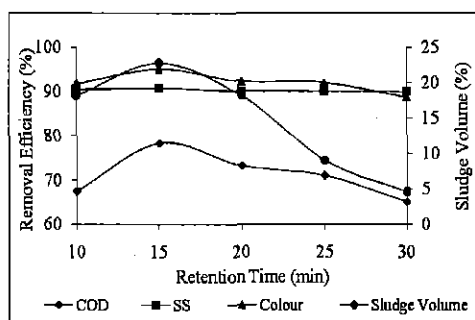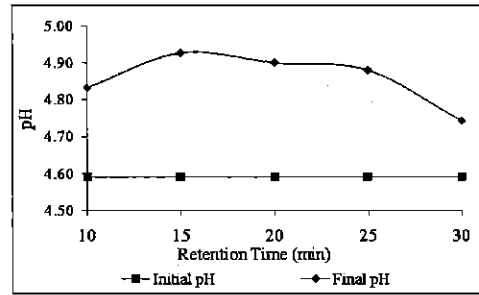

Figure 4 Effects of retention time on COD, SS, and colour removal efficiencies as well as sludge volume percentage for Al-Al at pH 4.59, current density 80 A/m², distance between electrodes 5 cm, and settling time of 30 minutes

Among the COD, SS, and colour removal efficiencies as well as sludge volume percentage for electrocoagulation of POME using Al-Al electrode pair, colour removal efficiency showed the highest value which was 95.06% at retention time of 15 minutes followed by SS and COD removal efficiencies which were 90.84% and 78.37%, respectively. The highest sludge volume that occurred at retention time of 15 minutes was 22.73%.

Figure 5 shows the effect of electrocoagulation on the pH evolution. Based on the result, the final pH was always higher than the initial pH. As for determination of optimum retention time, the natural POME pH used was 4.59 for all tested retention times. After the electrocoagulation process is completed, the measured pH at retention time of 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes were increases to 4.83, 4.93, 4.93, 4.89, and 4.74.
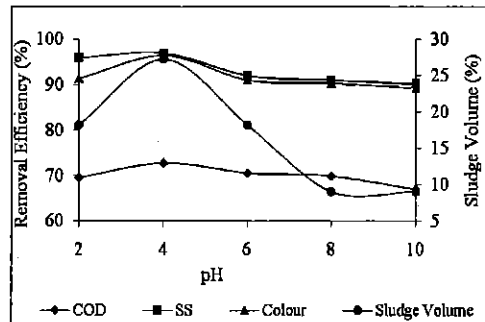
Figure 5 Effects of retention time on pH evolution for Al-Al at pH 4.59, current density 80 A/m², distance between electrodes 5 cm, and settling time of 30 minutes

At retention time of 15 minutes, natural POME pH of 4.59 increased up to 4.93 which is the highest pH increment among other tested retention times.

3.3   Determination of Optimum Initial pH

The initial pH has a considerable influence on the performance of an electrocogulation process (Song *et. al.*, 2007), (Wang *et. al.*, 2009). The effect of the initial pH of POME on COD, SS, and colour removal was investigated in the range of pH 2 to pH 10 at a current density of 80 A/m² for Al-Al electrode pair, electrodes distance of 5 cm and retention time of 15 minutes.

Figure 6 Effects of initial pH on COD, SS, colour removal and sludge volume percentage for Al-Al at current density 80 A/m², retention time of 15 minutes, distance between electrodes 5 cm, and settling time of 30 minutes
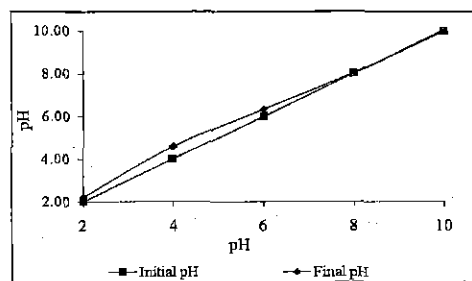
Figure 6 shows the effects of initial pH on COD, SS and colour removal efficiencies as well as sludge volume percentage for Al-Al at current density 80 A/m², retention time of 15 minutes, distance between electrodes of 5 cm, and settling time of 30 minutes.

COD removal efficiencies at initial pH of 2, 4, 6, 8, and 10 were 69.52%, 72.75%, 70.52%, 69.95%, and 66.95%, respectively. SS removal efficiencies at initial pH of 2, 4, 6, 8, and 10 were 95.86%, 96.93%, 92.02%, 91.02%, and 90.08%, respectively. Colour removal efficiencies at initial pH of 2, 4, 6, 8, and 10 were 91.31%, 92.79%, 91.37%, 90.67%, and 90.51%, respectively. Sludge volume percentages at initial pH of 2, 4, 6, 8, and 10 were 18.18%, 27.27%, 18.18%, 9.09%, and 9.09%.

All highest removal efficiencies of COD, SS, and colour as well as the sludge volume percentage occurred at initial pH of 4. For the initial pH more than 4, the removal efficiencies were decreased. Thus, pH 4 was determined as the optimum initial pH for Al-Al electrocoagulation process since it showed the highest values for all the tested parameters.

Among the COD, SS, and colour removal efficiencies as well as sludge volume percentage for electrocoagulation of POME using Al-Al electrode pairs, SS removal efficiency showed the highest value which was 96.93% at initial pH of 4 followed by colour, and COD removal efficiencies which were 92.79% and 72.75%, respectively. The highest sludge volume that occurred at initial pH of 4 was 27.27%.

Figure 7 shows the effect of electrocoagulation on the pH evolution. The final pH was always higher than the initial pH. As for determination of optimum initial pH, the pH of POME was modified to the desired initial pH values which are pH of 2, 4, 6, 8, and 10 by adding the appropriate amounts of NaOH or H₂SO₄. When the electrocoagulation process ends, the measured pH at initial pH of 2, 4, 6, 8, and 10 were increased up to 2.23, 4.38, 6.35, 8.03, and 10.06, respectively. At modified initial POME pH of 4.00, the pH increased up to 4.38 which is the highest pH evolution among other tested initial pH.

Figure 7 Effects of initial pH on pH evolution for Al-Al at current density 80 A/m², retention time of 15 minutes, distance between electrodes 5 cm, and settling time of 30 minutes.

Therefore, a pH of 4.0 was chosen as the optimum condition for the subsequent experiments. This finding is quite meaningful in electrocoagulation application to POME treatment which can eliminate further pH adjustment of the effluent.

4.0 CONCLUSION

This study has showed that electrocoagulation is a useful method in the treatment of palm oil mill effluent. Electrocoagulation is very effective in the suspended solids and colour removal and moderately effective in the COD removal of the POME. In order to achieve better percentage removal for COD, suspended solids, and colour, further study on settling time optimization is encouraged. Effectiveness from this study will be able to reduce POME strength before being discharge into the watercourse. As such, it is hoped that this method of treatment can become one of the alternatives to Malaysia POME treatment process in future.

5.0 ACKNOWLEDGEMENT

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