Electrochemical Treatment of Oily Wastewater using Three Dimensional Steel Wire Electrodes

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Abstract
Electrochemical technologies have been successfully applied for the removal of heavy metals, dyes, organics and oils from wastewater. In the present study, wastewater containing cutting oils was treated by applying electric field using stainless steel wire bed electrodes. The steel wires were 0.3 mm in diameter and 1 cm in length. In addition, three different polyurethane materials have been tested for the separation of steel wire electrodes in the coalescer cell. The experiments were performed under constant potential and the applied voltages were 5, 10 and 15 V. As the potential difference between the electrodes increases, the current passing through electrocoalescer cell increases. This improves electrolysis reaction rates at the stainless steel wire electrode surfaces. Then the transport of oil droplets to the water surface by gas bubbles is accelerated. In the experiments, the highest removal efficiency was 85% and obtained at 15 V. The experiments were also performed by varying the steel wire bed lengths. The studied bed lengths were 9 cm, 18 cm and 27 cm. Even though, higher oil yields were obtained at 27 cm bed length, similar oil yields were also obtained at 18 cm bed length, especially after 60 min, with less energy consumption. Therefore, the optimum electrode bed length was concluded to be 18 cm. The results also show that the electrical conductivity and porosity of the intermediate material are important parameters in the evaluation of oil removal efficiency.

Keywords: Electrocoalescer, steel wire electrodes, oily wastewater, electrochemical treatment

Introduction

Electrochemical technologies have made great progress in wastewater treatment recent years due to its high efficiency, environmental friendly and versatility (Chen, 2004; Zhang et al., 2012). The major electrochemical methods for the treatment of wastewater are electrocoagulation, electroflotation and electrooxidation. There are many successful applications of electrocoagulation process for the removal of dyes (Merzouk et al., 2009), metals (Hu et al., 2014), oils (Genc & Bakirci, 2015), and organics (Sakka et al., 2015) from wastewaters. In addition, electric field assisted coalescence is found to be one of the most efficient methods for the dehumidification of oil emulsions (Luo et al., 2016).

Coalescers are commonly used for the separation of unstable emulsions and are basically improved filtration processes using a medium which accelerate the coalescence of dispersed droplets (Sokolovic et al., 2010). In order to improve oil removal efficiency, polymeric materials, woven and non-woven fabrics, sponges and foams, carbon derived materials, metals, various particles and powders were tested as bed mediums in coalescers (Hu et al., 2017). During the treatment of oily wastewater, oil droplets move towards the bed medium, more and more oil droplets are accumulated on the surface with time. Then larger droplets form as a results of coalescing and these droplets can be separated easily by gravity settlers. The separation capacity can be improved by applying electric field (Kakhki et al., 2016). Dispersed oil droplets are reoriented in emulsion as a result of changes in the distribution of droplets surface charges in the presence of electric field. Therefore, emulsion becomes unstabilized and oil droplets coalescences are promoted.

Wastewater Characteristic

The synthetic oily wastewaters were produced from bor oil (Petrol Ofisi). It is one of the commonly used oils in metal cutting industry in Turkey. It is paraffin based mineral oil and contains surfactants and other chemicals such as biocides, lubricating agents, pressure additives, anti-foam agents and corrosion inhibitors. The synthetic wastewater samples which were used as in the experiments were prepared by adding bor oil to tap water (2%). Then the mixture was stirred mechanically (Heidolph R2R 2020) at a stirring speed of 2000 rpm for 30 minutes. The initial pH, conductivity, turbidity and COD of the wastewaters were measured before the experiments.
The characteristics of the synthetic wastewater used in the study were presented in Table 1.

Table 1: The characteristics of synthetic wastewaters

Parameters	Value
pH	7-8,5
Conductivity (µS/cm)	350-500
Color	White
Turbidity (NTU)	10500-13500
COD (mg/l)	50000-60000
Density (g/cm^3)	0.983

Experimental Set-up

The electrocoalescer cell was made of plexiglass and its dimension were 35 cm in length, 17 cm in width and 9.5 cm (Figure 1). The electrocoalescer cell was horizontally divided into two sections in order to form electrode beds. The electrode beds were packed by stainless steel wires which were in 1cm length and the top bed was the anode electrode. The electrode beds were separated by placing a porous polymer material which was made of polyurethane in the middle. The potential gradients at anode and cathode electrodes were supplied by using a DC power supply (18 V, 10 A) and water flow rate was adjusted by a peristaltic pump (Masterflex). In all experiments, the electrodes were only used once and they were submerged into water.

The electrochemical experiments were performed at batch operating mode and were carried out by recirculating the effluent to the inlet. At the start of each experiment, the electrocoalescer cell was first filled by newly prepared wastewater and then the inlet and effluent flow rates were adjusted by keeping the water height in the cell at a constant level. After the adjustment of water flow rates, the potential difference was applied to the electrodes. In this study, the oil removal efficiencies were evaluated in terms of turbidity because a strong linear correlation was observed in between turbidity and oil percentage of wastewater. The evaluated regression coefficient was very close to 1 (R^2= 0.9976). 10 mL of water samples were taken from the effluent at every 5 min in order to evaluate turbidity variations with time. The turbidities of samples were measured by using Aqualytic AL450T-IR after dilution of the water samples 20 times. Three samples were prepared for the same operating conditions and the arithmetic average of these readings was used in the evaluation of removal efficiency.

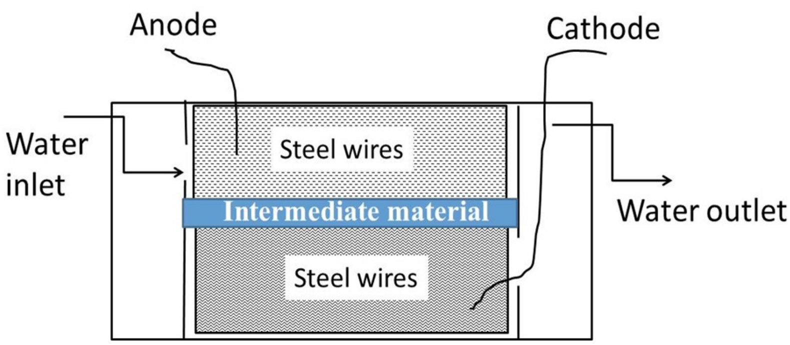

Figure 1: Electrocoalescer cell

The Effects of Operating Parameters on Removal Efficiency

a) The Potential Difference Applied to the Electrodes

The potential difference of 5 V, 10 V and 15 V was applied to the stainless steel wire bed anode and cathode electrodes in the electrocoalescer experiments. The evaluated turbidity removal efficiencies were shown in Figure 2. Also, when the potential difference is not applied on the electrodes, the turbidity removal percentages were presented in the same graph. These results clearly show that the oil droplets are not adsorbed on the steel wires or the intermediate material, which was a material made of polyurethane. In addition, as the potential difference applied to the electrodes is increased, an increase in removal efficiency is observed. When 15 V potential difference was created between the electrodes, the highest oil removal efficiency was around 85%. On the other hand, the attained removal efficiency was stayed around 30% when the applied potential difference was 5 V. When the potential difference between the electrodes was 10 V, 85% removal efficiency was only achieved after 180 minutes. When the applied potential difference is increased, the rate of gas bubbles formed on the electrode surfaces is also increasing as a result of electrolysis of water. The oil droplets are carried to the surface by gas bubbles. It has also been observed that the oil droplets moved toward the steel wire electrodes located in the anode zone and attached on the surface. Then larger oil droplets were generated on the steel wires as a result of coalescence of droplets.

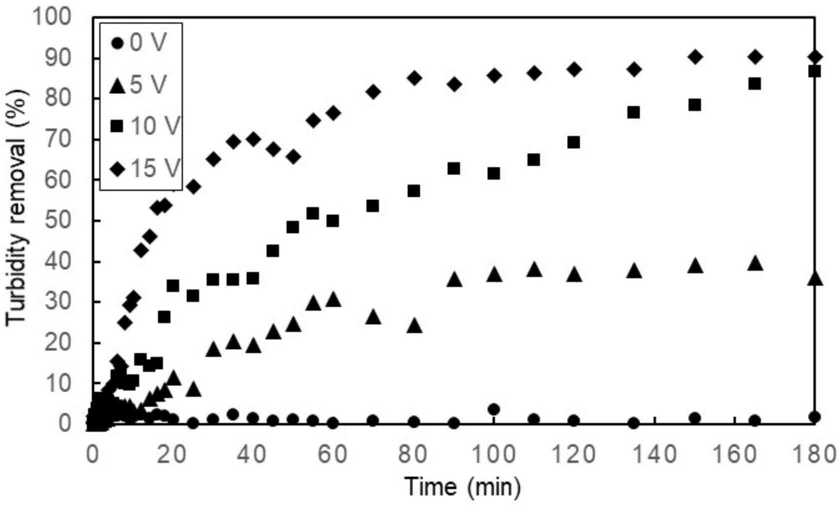

Figure 2: Turbidity removals depending on the potential difference applied to the electrodes

b) The Bed Length of Stainless Steel Wire Electrodes

In this study, the bed length of stainless steel wires (L) was changed by keeping the bed height and porosity constant. 15 V potential difference was applied during the experiments. Figure 3 shows the variations in turbidity removal efficiency with time for three different bed lengths (L= 9 cm, 18 cm and 27 cm). The currents passing through the cells were also depicted in the same figure. At the beginning, the highest removal efficiencies were attained at L = 27 cm, while the oil yields at L = 18 cm and L = 27 cm were almost coincide after 60 min.

As the bed length of stainless steel wires increases, the current passing through the medium should also increase under constant applied potential difference to the electrodes. The highest currents passing through the cell was at L= 27 cm. Since the energy consumed is equal to the potential difference multiplied by the current, the energy consumption was the highest at L= 27 cm. For this reason, the optimum bed length can only be obtained by evaluating both yield and energy consumption.

c) Properties of Intermediate Materials

Three polyurethane materials (A, B, and C) were located between the anode and cathode stainless steel wire electrode beds in the electrocoalescer experiments in order to analyze the effect of intermediate material on removal efficiency. The material A and B were in the form of fabric whereas the material C was in the form of sponge. Moreover, their porosities were different: the porosity of material A was the highest while the porosity of material C was the lowest. The removal efficiencies and corresponding currents passing through the electrocoalescer cell were shown in Figure 4. The use of material A results in higher removal efficiencies and higher currents. According Faraday law, the formation of gases at the electrodes is the highest for the material A. The results show that the electrical conductivity of the material C is very low and, therefore, electrolysis reaction rates at the steel wire electrodes are very low. This causes almost no oil removal, i.e., the turbidity removal efficiencies were almost stayed constant around 8%.

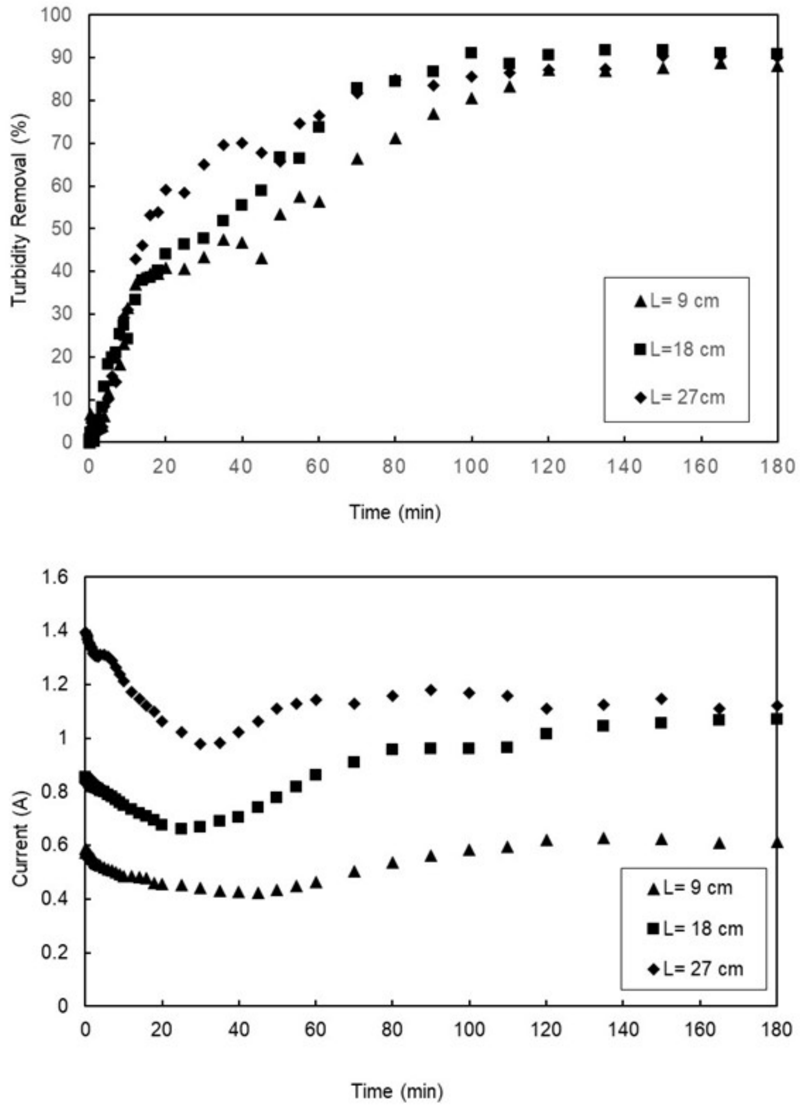

Figure 3: Removal efficiencies and current variations depending on bed length

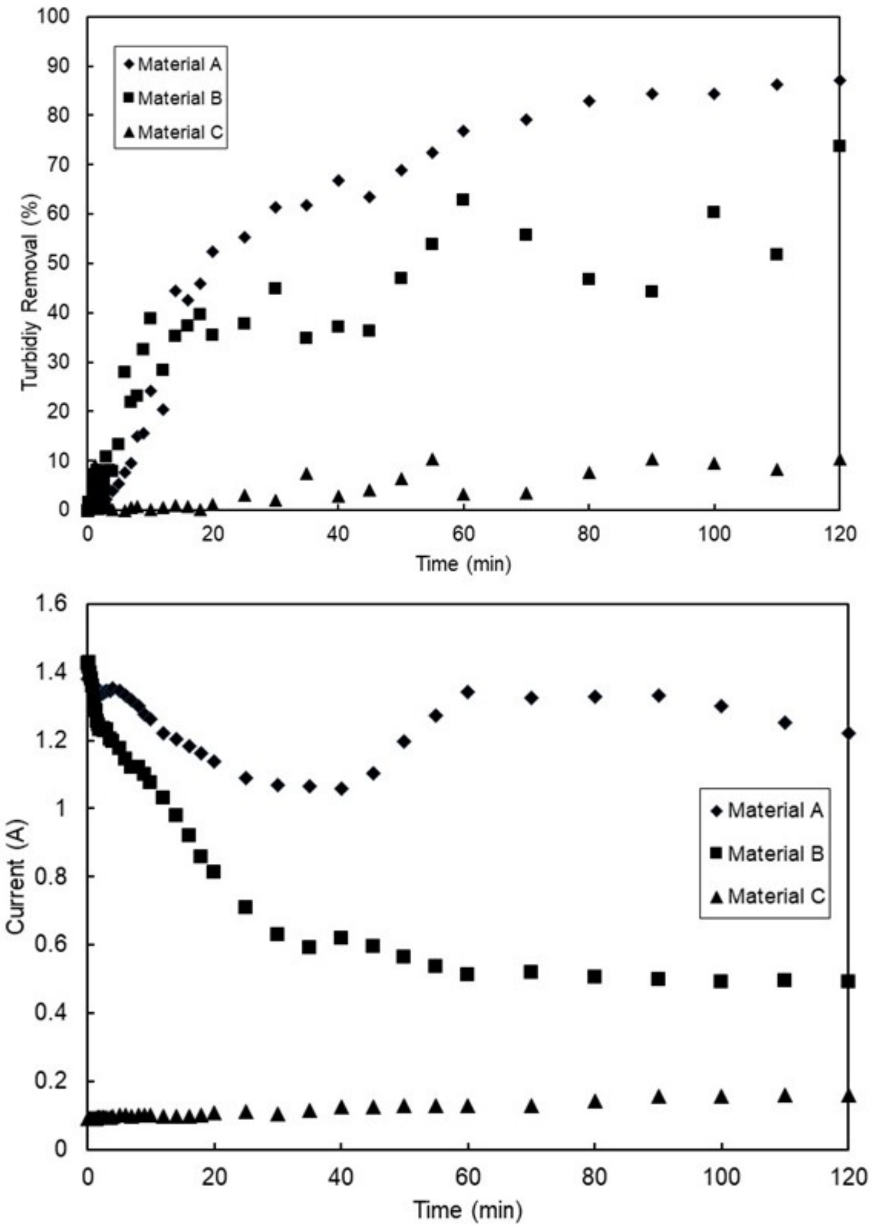

Figure 4: Removal efficiencies and current variations depending on intermediate material

Conclusions

Based on the experiments performed by using oily wastewaters, the following conclusions are drawn:

- 85% oil removal efficiency was obtained by applying 15 V potential difference to the stainless steel wire bed electrodes.
- The optimum bed length was found to 18 cm depending on the evaluations of removal efficiency and power consumption.
- The removal efficiency was strongly affected by the porosity and conductivity of polyurethane materials used in the separation of the stainless steel wire electrode beds.

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