Influence of electrodes spacing on internal temperature of electrocoagulation (EC) cells during the removal (Fe II) from drinking water

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Abstract

The electrocoagulation (EC) method, which is in situ generation of coagulating ions by applying direct electrical current to metallic electrodes, has recently been applied to remove a wide spectrum of pollutants from waters and wastewaters. However, its efficiency is highly influenced by key operational parameters such as electrolysis time and current density. Therefore, the current investigation has been carried out to explore the influence of electrodes spacing on the performance of EC method in terms of internal temperature iron removal from drinking water.

To achieve the planned target, iron containing synthetic water samples were electrolysed, for 25 min, using a flow column electrocoagulation reactor (FCER), at three different distances between electrodes (5, 10, and 20 mm). The progression of temperature of water being treated was measured at 5 minutes intervals over a 25 minutes period. These batch experiments were commenced at a constant current density of 1.5 mA/cm^2 and initial pH of 6.

The results obtained showed that the amount of produced heat is directly proportional to the DBE, where it has been noticed that the water temperature increased by about 9% as the distance between electrodes increased from 5 to 20 mm, respectively.

Keywords — Iron removal, energy consumption, flow column, electrocoagulation.

1. Introduction

During the last few decades different methods have been practiced to treat drinking water, such as chemical precipitation (Toyoda and Taira, 2000), biological treatment (Alattabi *et al.*, 2016), membrane separation (Ndiaye *et al.*, 2005), and electrocoagulation (EC) (Tezcan Un *et al.*, 2013; Hashim *et al.*, 2017a). However, recent studies have demonstrated that the EC method is an attractive alternative for traditional treatment processes, as it does not require chemical handling, is easy to perform, produces fewer total dissolved solids, and remarkably reduces the sludge volume (Mollah *et al.*, 2001; Zhu *et al.*, 2007; Emamjomeh and Sivakumar, 2009; Hashim *et al.*, 2017c). This method has been practiced during the last century to treat different pollutants such as iron (Amrose *et al.*, 2013; Hashim *et al.*, 2017c), fluoride (Zhu *et al.*, 2007; Hashim *et al.*, 2017a), organic matter (Vepsäläinen *et al.*, 2012), dye (Amani-Ghadim *et al.*, 2013), crystal violet (Durango-Usuga *et al.*, 2010), nitrate (Yehya *et al.*, 2014; Hashim *et al.*, 2017b), arsenic (Kobya *et al.*, 2011), and water hardness (Malakootian *et al.*, 2010). However, the efficiency of this method is very sensitive to several operating parameters such as the initial pH of solution, current density, solution chemistry, and solution conductivity (Mollah *et al.*, 2001; Zhao *et al.*, 2009; Hashim *et al.*, 2016b; Hashim *et al.*, 2016a). Therefore, some researchers investigated the influence of some key parameters on the performance of the EC method. For instance, the effect of co-existing anions on fluoride removal in the EC method was investigated by Hu *et al.* (2003). Irdemez *et al.* (2006a) studied the influence of pH on both energy consumption and phosphate removal using iron electrodes. Similarly, the influence of current density on phosphate removal using either iron or aluminium electrodes was explored in another study by Irdemez *et al.* (2006b). Additionally, Wan *et al.* (2011) investigated the influence of water chemistry on the removal of arsenic from drinking water.

Thus, the present project has been devoted to investigate the effect of distance between electrodes (DBE) on the temperature of water being treated. The internal temperature of EC cells has been investigated as it plays an essential role in the electrocoagulation processes, where it not only significantly influences the solubility of the precipitates, but also influences the production rate of hydroxyl radicals, and dissolving of electrodes, and consequently the removal efficiency (Vepsäläinen *et al.*, 2009; Chou and Huang, 2009; Hashim *et al.*, 2015). A new electrocoagulation reactor (FCER), which reactor utilises the concept of flow columns to enhance the performance of EC reactors, has been used in current study to explore the influence of the DBE on water temperature in the EC method.

2. Materials and methods

The batch electrocoagulation experiments were commenced using a new bench-scale EC reactor (FCER) having a total volume of 2.16 L (Figure 1). FCER consists of a Perspex container with a radius of 5.25 cm that contains a flow column. The flow column consists of three PVC rods, spacers, and perforated discoid electrodes that made from aluminium. More details about the FCER are mentioned by Hashim *et al.* (2017b); Hashim *et al.* (2015). This reactor was supplied with a rectifier (HQ Power; Model: PS 3010, 0-10 A, 0–30 V) to generate the required electrical current.

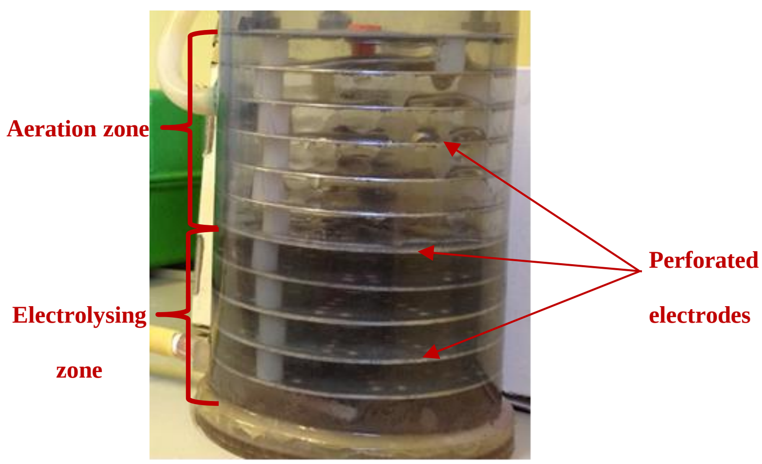

Figure 1: the new reactor FCER.

The impact of DBE on the internal temperature of the EC unit was explored using 20 mg/L iron containing synthetic water samples. These samples were prepared by dissolving the required amount of $FeSO_4 \cdot 7H_2O$ in deionised water. The initial pH of these synthetic samples was adjusted at 6 using a proper amount of 1 M HCl or 1 M NaOH solutions, while the conductivity of these samples was adjusted to 320 µS/cm using the required amount of NaCl. All experiments were commenced at an initial temperature of 20 ^{0}C, which controlled using water bath (Nickel-Electro: Clifton).

It is noteworthy to highlight that all chemicals were supplied by Sigma Aldrich and used as supplied.

The prepared samples were electrolysed for 25 min at different DBEs (5, 10, and 20 mm) at a constant current density of 1.5 mA/cm^2, and initial pH of 6. The progress of water temperature removal was monitored by collecting 10 mL samples periodically from the reactor over the course of the treatment process. Then, the temperature of the collected samples was using a Hanna device (Model: HI 98130). After each run, the electrodes were washed with HCl and then rinsed with deionised water.

The percentage of the increase in water temperature (T %) was calculated as follows:

$$T\ \% = \frac{T_0 - T_t}{T_o} \times 100\% \qquad \textbf{(1)}$$

Where, T_0 is the initial water temperature, and T_t is temperature of water at any time during the course of the treatment process, in ^{0}C, respectively.

2. Results and discussion

Ohmic heating, which is known as Joule heating, is the phenomenon of heat generation in a conductor due to the flow of current, and the amount of the produced heat is in proportion to the magnitude of both current and electrical resistance (Alwis and Fryer, 1990). The amount of generated heat can be determined according to the flowing equation (Castro, 2007):

$$Q = R \cdot I^2 \qquad \textbf{(2)}$$

where Q is the generated heat (J/sec), R is the electrical resistance (ohm), and I is the applied current (Amber).

Therefore, the DBE plays a key role in temperature generation within solution being treated as it significantly influences the electrical resistance (Eq.3) (Ghosh *et al.*, 2008), and consequently the water temperature. Where, the relation between the ohmic potential drop and the DBE could be explained by the following equation (Ghosh *et al.*, 2008):

$$IR = I.\frac{d}{A.k} \qquad \textbf{(3)}$$

Where IR is the ohmic potential drop, I is the applied current (A), d is the DBE (m), A is the active surface area of the anode (m^2), and k is specific conductivity (μS/m).

In order to investigate the influence of DBE on heat generation inside FCER, water samples with an iron concentration of 20 mg/L were electrolysed for 25 min at different DBEs (5, 10, and 20 mm). The applied current density was kept constant at 1.5 mA/cm^2 during the course of experiments.

As seen in Figure 4, the amount of produced heat is directly proportional to the DBE. Where it has been noticed that the water temperature increased from 20.2 ^{0}C at DBE of 5mm to 22 ^{0}C at

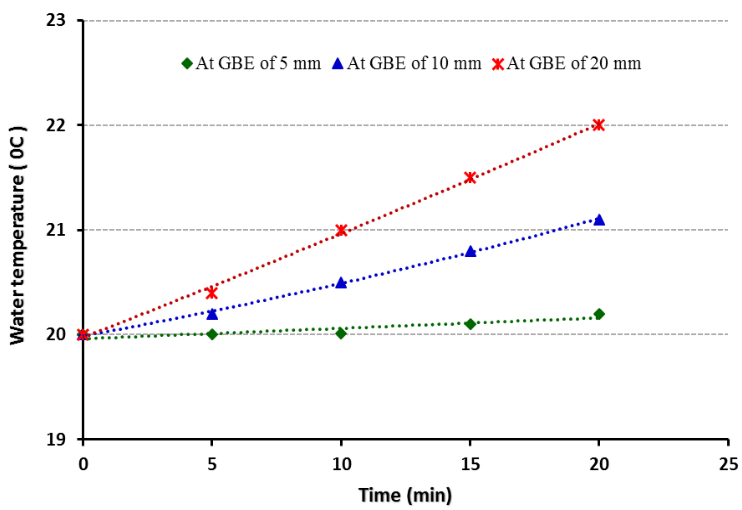

Figure 4: Influence of DBE on water temperature.

DBE of 20 mm after 25 min of electrolysing. Hence, the lowest value of the studied DBEs can ensure a virtually stable temperature level during the course of the electrolysing process.

3. Conclusion

The results obtained from the current projects highlights that the performance of the EC method could be significantly enhanced by optimising the distance between electrodes, as the latter caverns both the electrodes dissolving rate and water temperature. Additionally, optimising the distance between electrodes can significantly minimising the energy consumption of the EC units, which in turn minimising the operating cost of this method.

Therefore, in the current investigation, DBE of 5 mm was found to be very effective for the removal of iron from water.

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