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Original Article

Purification of grey water by electrocoagulation process using iron electrodes

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ABSTRACT

In this study electrocoagulation is proved to be a suitable technology to purify grey water to meet the standards of water for irrigation purposes. The efficiency of electrocoagulation to remove total hardness, calcium, magnesium, nitrate, chemical oxygen demand (COD) and total dissolved substances (TDS) from grey water, under the influence of operating parameters including initial pH, time, current density, electrode inter-distance and temperature, was investigated. Electrocoagulation was performed in batch reactors employing iron (Fe) electrodes. The optimal removal conditions were proposed to be at pH = 11, time 60 min, temperature 25 °C, current density 120 mA/cm^2 and electrode inter-distance 1 cm. The highest magnesium, calcium and total hardness removal efficiencies were about 92.3%, 87.5% and 89%, respectively, while the highest removal efficiency of nitrates was obtained at pH 7 and reached about 76%, and that for COD was 80.0% at pH 4.

KEYWORDS: electrocoagulation, removal, calcium, magnesium, grey water, nitrate, removal efficiency, current density, Fe-Fe electrode.

INTRODUCTION

The growing disparity between readily available sources of clean water and its growing demand associated with population growth and economic development forced the decision-makers to look for sustainable water management strategies, one of which is treating wasted water. An evidence of movement in this direction is the increasing attention given to the utilization of grey water (GW) in wastewater reclamation and reuse projects [1, 2].

Essentially, GW is defined as household wastewater made of all domestic wastewater with the exception of toilet flushes (e.g., wastewater produced in bathtubs, showers, and laundry machines) [3]. Grey water (GW) reuse can play a fundamental role in saving water by converting a significant fraction of wastewater (WW) from waste to valuable water. Reusing grey water serves two purposes: it reduces the amount of freshwater needed to supply a household, and reduces the amount of waste water entering sewer or septic systems [4, 5]. Electrocoagulation, due to some advantages over chemical coagulation, is becoming a popular process to be used for wastewater treatment [6]. Electrocoagulation has been proposed in recent years as an effective method to treat various wastewaters such as landfill leachate, restaurant wastewater, saline wastewater, tar sand and oil shale wastewater, urban wastewater, laundry wastewater, nitrate and arsenic-bearing wastewater, and chemical mechanical polishing wastewater [7-12].

The purpose of this study is using electrocoagulation for purification of grey water to meet water standards for irrigation purposes.

MATERIALS AND METHODS

Chemicals

Standard solutions of potassium dichromate ($K_2Cr_2O_7$), sulfuric acid (H_2SO_4) reagent with

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silver sulfate (Ag_2SO_4) and mercury sulfate ($HgSO_4$) were prepared to measure the COD. In addition, sodium hydroxide (NaOH), ethylene diaminetetraacetic acid (EDTA), eriochrome black T, and murexide indicator were used for determination of Ca^{+2} and total hardness, while ammonium chloride (NH_4Cl), dextrin $(C_6H_{10}O_5)_n$, yeast extract, starch, sodium carbonate (Na_2CO_3), sodium dihydrogen phosphate (NaH_2PO_4), potassium sulphate (K_2SO_4) and cooking oil were used for the preparation of synthetic grey water. All chemicals were of analytical grade and purchased from Merck.

Preparation of synthetic grey water

The synthetic grey water in this study was prepared by mixing the components listed in Table 1.

Equipment and procedures

Electrocoagulation (EC) was applied to grey water using a 4-L cylindrical tank and a power supply with variant current density; iron-iron electrodes of identical dimensions (2.0 cm × 2.0 cm × 0.2 cm) were used as anode and cathode. Electrodes were rinsed with acetone and a 0.01 N HCl solution to remove organic and inorganic deposits. For each run, the inter-electrode gap, electrolysis time (t), electrode type, pH, temperature and current density were changed. Experiments were carried out at room temperature and atmospheric pressure and each experiment was repeated twice for assessing reproducibility of data. Samples were taken out at different time intervals and filtered by 0.45 μm filters (Macherey-Nagel GmbH, Germany); the filtrates were then used for subsequent chemical analysis. The schematic diagram of the experimental set up is shown in Figure 1.

Analytical methods

Several parameters were measured to evaluate the electrochemical treatment's efficiency as shown in Table 2: total hardness, calcium, magnesium, conductivity and nitrates were analyzed according to the American Public Health Association standard methods [13].

After grey water treatment by electrocoagulation method, the removal efficiency was calculated using the following equation [14, 15]:

$$RE\% = \frac{C_0 - C_1}{C_0} \times 100 \quad (1)$$

where C_0 is initial concentration of grey water before electrocoagulation in $mg \cdot L^{-1}$, and C_1 is the final concentration of grey water after electrocoagulation in $mg \cdot L^{-1}$. Repeated experiments were performed to check the reproducibility of the experimental results and the reproducibility was found to be ±3%.

The COD was determined using a closed reflux colorimetric method at λ_{max} = 600 nm [16]. The calculation of COD removal efficiency after

Table 1. Components of synthetic grey water.

1	Dextrin	85 mg/l
2	Ammonium chloride	75 mg/l
3	Yeast extract	70 mg/l
4	Soluble starch	55 mg/l
5	Sodium carbonate	55 mg/l
6	Washing powder	30 mg/l
7	Sodium dihydrogen phosphate	11.5 mg/l
8	Potassium sulphate	4.5 mg/l
9	Shampoo	0.1 ml/l
10	Cooking oil	0.1 ml/l

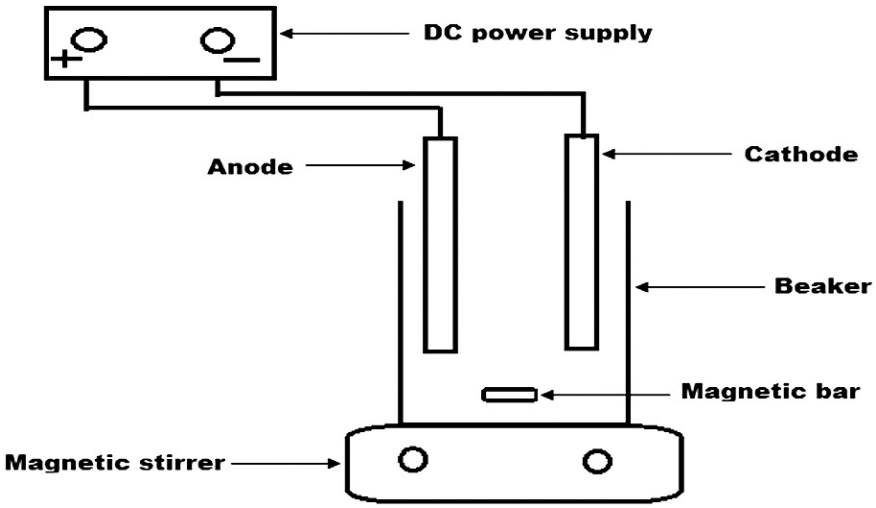

Figure 1. The schematic diagram of the experimental set-up.

Table 2. Analysis of various parameters.

Parameters	Unit	Method
EC	µS/cm	EC meter
Hardness	mg/l as $CaCO_3$	Titrametric method
Ca^{2+}	mg/l	Titrametric method
Mg^{2+}	mg/l	Calculation method
NO_3^-	mg/l	UV spectrophotometer
pH	-	pH meter
COD	mg/l	Closed reflux colorimetric method

EC treatment was performed using the formula in equation 1.

Mechanism of electrocoagulation process

Figure 2 represents the mechanism of electrocoagulation process. In the EC process the coagulants are generated *in situ* by dissolving electrically the consumable iron-iron (Fe/Fe) electrodes. The generation of the metal ions takes place at the anode, while hydrogen gas is released from the cathode [17].

The water contaminants are treated either using chemical reactions and precipitation or by physical and chemical attachment to colloidal materials being generated by the electrode erosion. They are then removed by electroflotation, sedimentation, or filtration. A current is passed through the metal electrode, oxidizing the metal (M) to its cation (M^{n+}). Simultaneously, water is reduced to hydrogen gas and the hydroxyl ion (OH^-). Electrocoagulation thus introduces metal cations *in situ*, electrochemically, using sacrificial anodes [18].

Reaction mechanism of EC

At the anode:

$$4Fe_{(s)} \rightarrow 4Fe^{2+}_{(aq)} + 8e^- \quad (2)$$

$$4Fe^{2+}_{(aq)} + 10H_2O_{(l)} + O_{2(aq)} \rightarrow 4Fe(OH)_{3(s)} + 8H^+_{(aq)} \quad (3)$$

At the cathode:

$$8H^+_{(aq)} + 8e^- \rightarrow 4H_{2(g)} \quad (4)$$

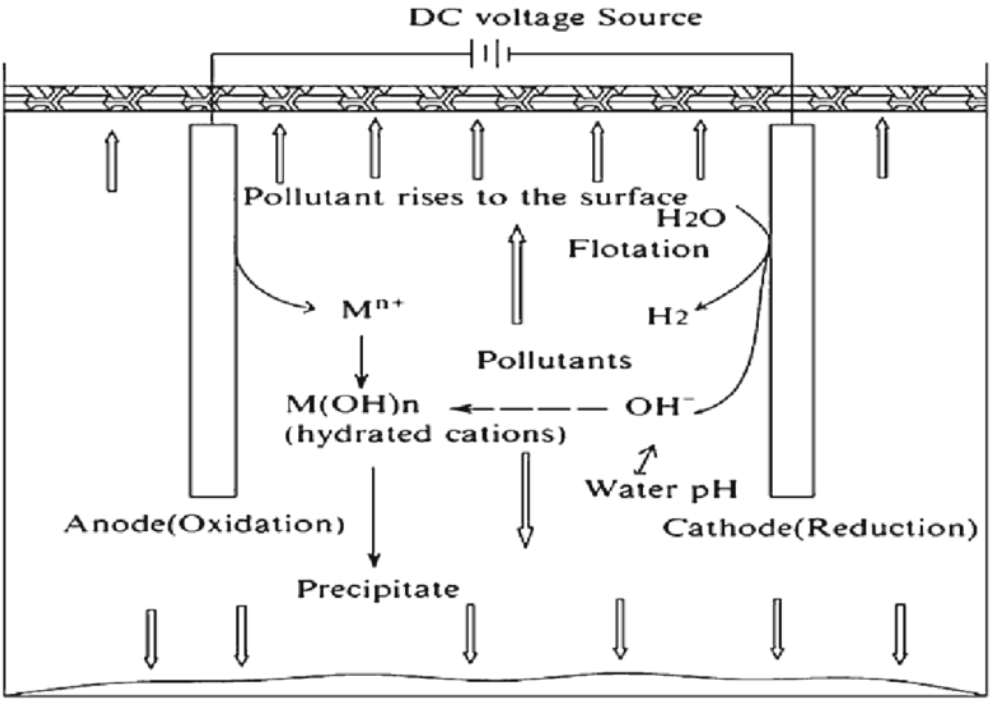

Figure 2. Mechanism of electrocoagulation process.

Overall:

$$4Fe_{(s)} + 10H_2O_{(l)} + O_{2(aq)} \rightarrow 4Fe(OH)_{3(s)} + 4H_{2(g)} \quad (5)$$

RESULTS AND DISCUSSION

The effect of pH

It has been established from previous studies that pH is one of the most important factors which affect the performance of electrocoagulation process [8, 19]. To evaluate this effect, a series of experiments were performed using solutions containing a sample with an initial pH varying in the range of 4-11 in an attempt to study the influence of this parameter on the removal of pollutants. The effect of pH on total hardness, calcium and magnesium removal efficiencies were found to be the best when pH = 11. As shown in Figure 3 the magnesium, calcium and total hardness removal efficiencies were about 92.3%, 87.5% and 89%, respectively.

Figure 4 showed that the highest removal efficiency for nitrate was obtained at pH 7 and reached about 76%, while the highest removal efficiency for COD was 80.0% at pH 4.

Effect of current density

The current applied in the electrocoagulation reactor is the most important parameter affecting the number of coagulant ions released from the anode. Thus, increasing the current density will increase the number of coagulant ions and consequently increase the removal of pollutants. Another effect of high current density is the increase in rate of generation of the hydrogen bubbles and the decrease in their size. Both factors will, to a certain extent, increase the efficiency of removal of pollutants from wastewater [20].

The influence of current density (70-163 $mA.cm^{-2}$) has been examined on the removal efficiency for the total hardness, calcium and magnesium, at pH = 11, time 60 min., and temperature 25 °C. Figure 5 indicates that the maximum total hardness, calcium and magnesium removal efficiencies using Fe electrodes were 81%, 78.6% and 95%, respectively, at 120 $mA.cm^{-2}$. The higher the current density, the faster the metal ion generation which obviously speeds up the anode dissolution rate. This causes an enhancement in the number of

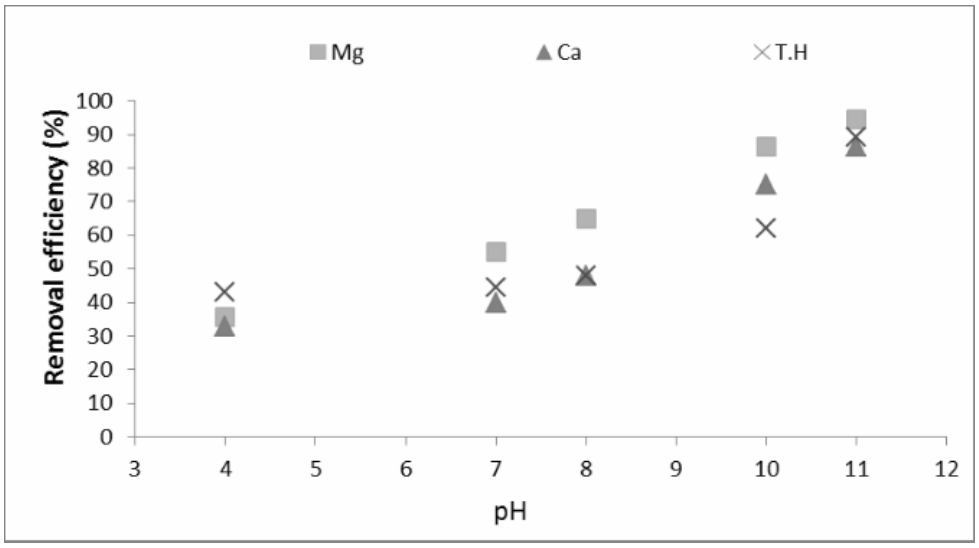

Figure 3. Effect of initial pH on total hardness, calcium and magnesium removal efficiencies using Fe-electrode (current density 120 mA/cm^2, operational time 60 min., and temperature 25 °C).

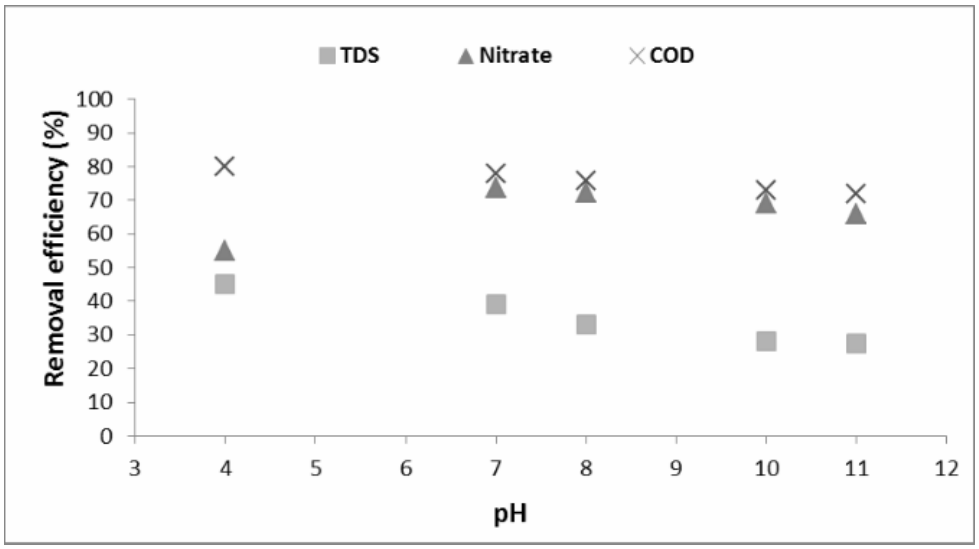

Figure 4. Effect of initial pH on nitrate, COD and TDS removal efficiencies using Fe-electrode (current density 120 mA/cm^2, operational time 60 min., and temperature 25 °C).

metal hydroxide flocs and overall, the efficiency of pollutant removal becomes greater. An increase in current density above the optimum current density value does not result in a corresponding increase in pollutant removal efficiency because sufficient numbers of metal hydroxide flocs are already available for the sedimentation of the pollutant [21].

From the results obtained in the experiments, as shown in Figure 6 the COD and nitrate removal efficiencies are approximately 76.5% and 78.4%, respectively at 120 mA·cm^{-2} using Fe electrodes.

Effect of operating time

Electrolysis time determines the rate of production of metal ions from electrodes. In the current study

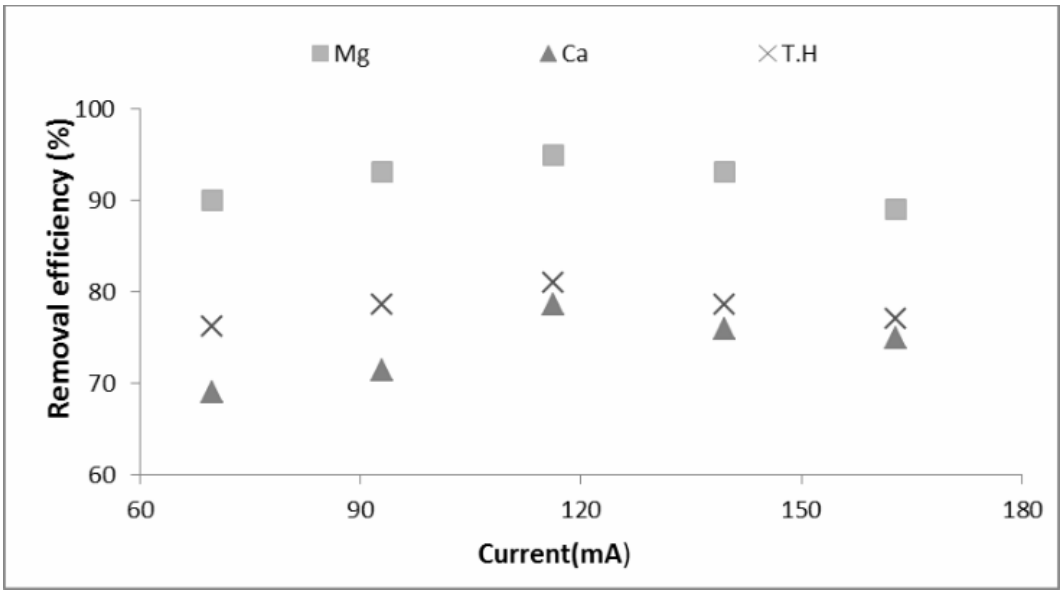

Figure 5. Effect of current density on total hardness, calcium and magnesium removal efficiencies using Fe-electrode (pH = 11, operational time 60 min., and temperature 25 °C).

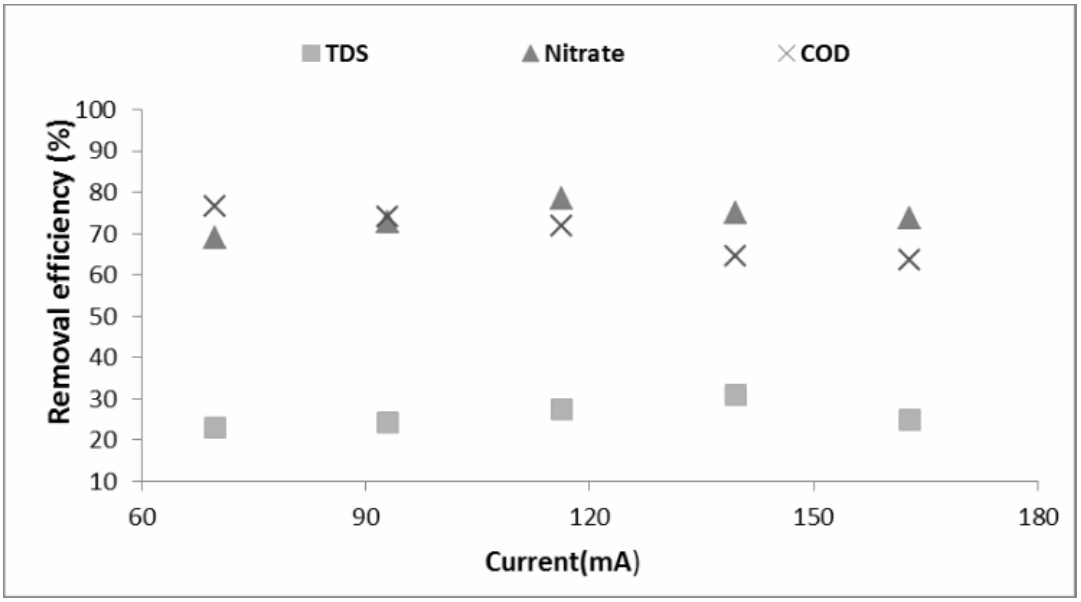

Figure 6. Effect of current density on nitrate, COD and TDS removal efficiencies using Fe-electrode (pH = 11, operational time 60 min., and temperature 25 °C).

the effect of operating time on total hardness, calcium and magnesium removal efficiencies was studied by changing the operating time from 20 to 80 min at current density 120 mA/cm^2, pH = 11, and temperature 25 °C. As shown in Figure 7 the total hardness, calcium and magnesium removal efficiencies increase from 76.2% to 89%, 73.6% to 86.4%, and 82% to 95%, respectively, whereas the maximum nitrate and COD removal efficiencies using Fe-electrode were 73.7% and 81.8%,

respectively at the same conditions. Figures 7 and 8 indicate that the best results given were at the operating time 60 min.

Effect of temperature

Figure 9 shows the effect of temperature on total hardness, calcium and magnesium removal efficiencies at current density 120 mA/cm^2, pH = 11, and operating time 60 min. The results from the above figures indicate that increasing temperature above 30 °C has a negative effect on removal efficiencies. In this case, the volume of colloid M(OH)n and production of pores on the metal anode decreased [22].

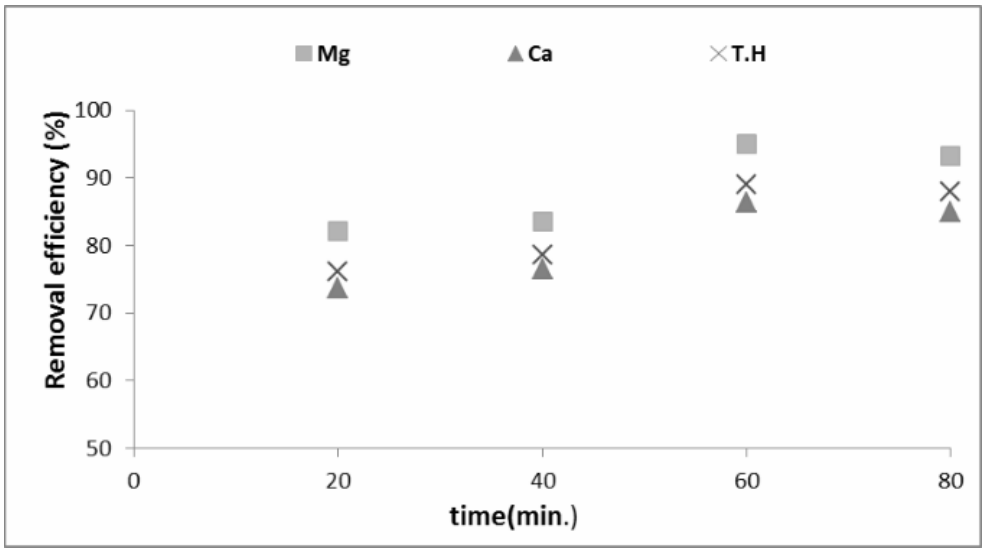

Figure 7. Effect of operating time on total hardness, calcium and magnesium removal efficiencies using Fe-electrode (current density 120 mA/cm^2, pH = 11, and temperature 25 °C).

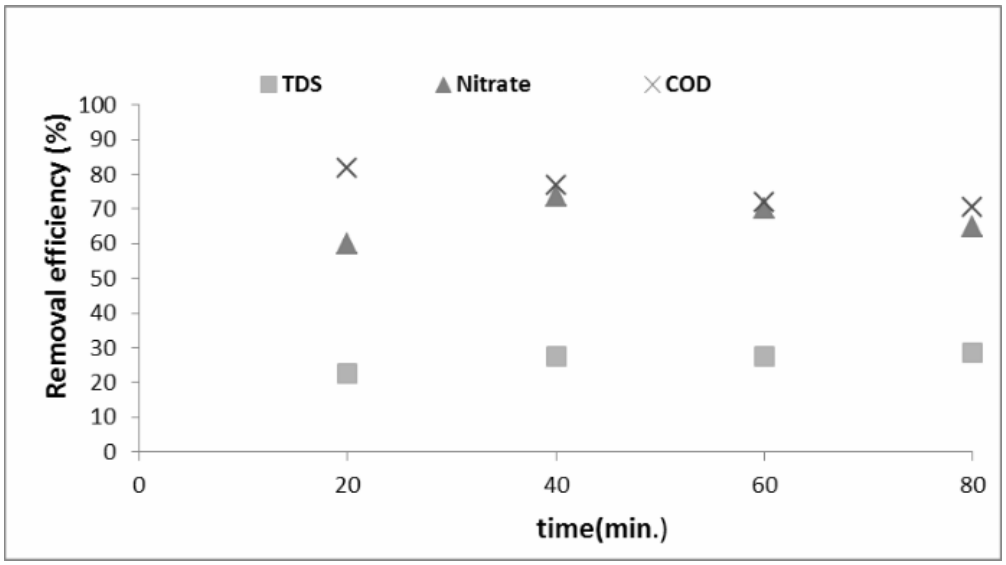

Figure 8. Effect of operating time on nitrate, COD and TDS removal efficiencies using Fe-electrode (current density 120 mA/cm^2, pH = 11, and temperature 25 °C).

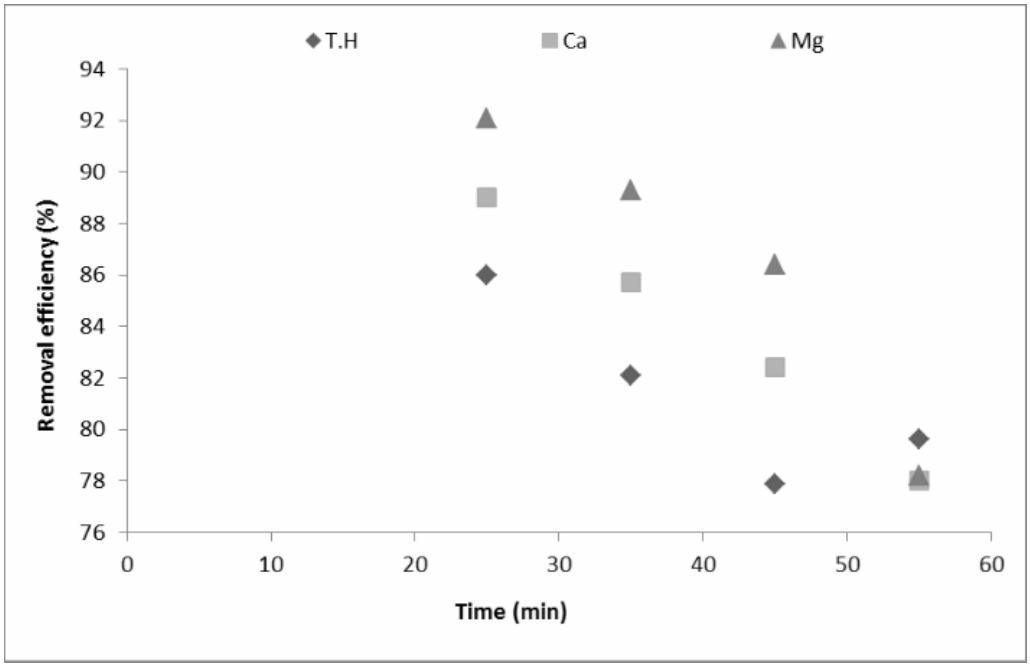

Figure 9. Effect of operating temperature on total hardness, calcium and magnesium removal efficiencies using Fe-electrode (current density 120 mA/cm^2, operational time 60 min., and pH = 11).

The results indicated in Figure 9 show that the optimal removal efficiency temperature for pollutants using Fe electrodes was 25 °C and as the temperature increases the removal efficiency decreases.

Effect of inter-electrode distance

The distance between the electrodes is an important variable to optimize operating costs. The greater the inter-electrode distance, the greater should be the difference in applied potential, because the solution presents higher resistivity to electrical current. A shorter inter-electrode distance is desirable, because the electrical resistance increases with inter-electrode distance [23]. In accordance with that, when the inter-electrode distance increased from 1 to 3 cm the turbidity removal efficiency decreased. The optimum total hardness, calcium and magnesium removal efficiencies were 86%, 88% and 93%, respectively, at current density 120 mA/cm^2, pH = 11, temperature 25 °C and optimal inter-electrode distance of 0.5 cm. The highest nitrate and COD removal efficiencies were 77% and 74%, respectively.

CONCLUSION

The total hardness, calcium, magnesium, nitrate, COD and TDS removal efficiencies from grey water by electrocoagulation using Fe-Fe electrodes were studied. The effects of current-density, temperature, pH, electrolysis-time, and inter-electrode-gap on removal were investigated.

The highest magnesium, calcium and total hardness removal efficiencies were obtained at pH 11, current density 120 mA/cm^2, operational time 60 min., and temperature 25 °C when using Fe-Fe electrode. The highest nitrate and COD removal efficiencies were obtained at pH 7 and 4, respectively, and reached about 76% and 80.0% under the above-mentioned operating conditions.

CONFLICT OF INTEREST STATEMENT

No conflicts of interest.

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