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ORIGINAL PAPER

Systematic assessment of electrocoagulation for the treatment of marble processing wastewater

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Abstract In this study, the treatability of marble processing wastewater by electrocoagulation using aluminum and iron electrodes was investigated. The sample used was from the marble-processing plant in Sivas and its turbidity, suspended solids, chemical oxygen demand and total solids concentrations were about 1,914 NTU, 2,904, 150 and 4,750 mg/L, respectively. The effects of various operating parameters such as initial pH, current density and electrolysis time on turbidity, suspended solids, chemical oxygen demand and total solids removal efficiencies were investigated. The settling characteristics of waste sludge produced and energy and electrode consumption were also determined. The optimum values of initial pH, current density and electrolysis time in electrocoagulation studies carried out using aluminum electrode were found to be 7.8, 30 A/m^2 and 5 min, respectively. Under these conditions, the removal efficiencies obtained for turbidity, suspended solids, chemical oxygen demand and total solids were 98.5, 99.2, 55.2 and 92.4 %, respectively. Corresponding energy and electrode consumptions were 0.143 kWh/kg SS and 0.010 kg Al/kg SS. For iron electrode, the optimum parameter values were found to be 7.8 pH, 20 A/m^2 and 5 min, respectively. Under these conditions, removal efficiencies for turbidity, suspended solids, chemical oxygen demand and total solids were determined as 94.3, 99.1, 54.2, and 96.1 %, respectively. Energy and electrode consumptions were 0.0571 kWh/kg SS and 0.0206 kg Fe/kg SS, respectively. Settling characteristics of sludge produced during experiments carried out using both aluminum and iron electrodes were fairly good. The results showed that electrocoagulation method can be used efficiently for the treatment of marble processing wastewater under proper operating conditions.

Keywords Electrocoagulation · Iron and aluminum electrode · Settling characteristic of waste sludge · Treatment of marble processing wastewater

Introduction

Marble is widely used for different purposes in different sectors including mainly the construction business (e.g. internal and external finishes, monument and cemeteries, sculpture for decoration purposes). Approximately 40 % of world marble reserves are in Turkey. Therefore, marble processing appears to be an important branch of the industry in Turkey. Especially the marble processing has a quick development in Turkey. This causes an increase in water consumption, one of the existing natural resources and the most important one. Great quantities of wastewater are produced in the marble processing because of high water consumption. Most of the wastewater appeared in marble processing is formed as a result of cutting, washing, cleaning and polishing processes. 50–150 m^3/day water is used for a medium sized facility. This wastewater should be recovered to be processed again (Ersoy 2003). It will be possible to obtain water with decreased amount of suspended solids (SS), purified from solids, and to reuse this water within the process only using a good treatment method. Especially when using water with high SS content in the facility this causes marble to be scratched during

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polishing and cleaning processes. This affects its usage by declining raw material, marble, quality (Acar 2001). Therefore, water to be used again should be treated through a good treatment method. Marble-processing wastewater (MPW) is characterized by high suspended solids (SS). The physical–chemical methods are typically employed in reuse and treatment of wastewaters in big workshops. Coagulation and flocculation is a widely used physical–chemical process in wastewater treatment. Ayoub et al. (2000) investigated the coagulation–flocculation of MPW, using seawater liquid bitterns as a coagulant and in another study by Arslan et al. (2005) treatment efficiency was investigated using various coagulant chemicals. In small workshops, the general application for reusing of wastewaters is currently proceeded with purifying the wastewater through gravitational settling methods in pools and then including it into the process pipeline by pumping the supernatant (Solak et al. 2009). The major disadvantages of physical–chemical treatment of wastewaters via coagulation and flocculation process can be costly and increase total dissolved solids of wastewater, and formation of high amounts of sludge. Especially high amount and stability of sludge from chemical treatment is relatively important for the storage. Various biotechnological methods are used to stabilize waste sludge with organic content. These treatment methods are not available for waste of inorganic origin, such as marble processing sludge. The treatment and reuse of these wastes by various methods are important from both environmental and waste management viewpoints (Arslan et al. 2005).

Therefore, minimizing sludge volume causes a longer landfill area usage. If the solid waste volume is not minimized, new landfill areas will be required, and this is relatively important in terms of environment and waste management.

Therefore, there is a need to look for alternative processes that could efficiently remove SS and produce low amount of sludge at relatively low operating costs. Moreover, high quality water in terms of suspended solids is desired to reuse it in MPW. Electrocoagulation (ECG) process has been preferred because of its various advantages over chemical coagulation process (Holt et al. 2002). The advantages of this process include basic equipment requirements; being easy to process, low retention time, no chemical material need, low amount of sludge formation, stable and easy sludge settling; as well as, flocs being large, resistance to acidic environment and easily filtered sludge formation. ECG process was applied for the treatment of various wastewaters including domestic wastewater treatment (Holt et al. 2002), restaurants wastewater treatment (Chen et al. 2000), pulp and paper mill wastewater treatment (Mahesh et al. 2006), fluoride-containing wastewater treatment (Mameri et al. 2001), textile dye solution treatment (Daneshvar et al. 2004, 2006; Kobya et al. 2006a; Kashefialasl et al. 2006), removal of nitrate and arsenic (Koparal and Ogutveren 2002; Kumar et al. 2004; Malakootian et al. 2011), tannery wastewater treatment (Jin-wei et al. 2007) and slaughterhouse wastewater treatment (Ozyonar 2007) and successful results with high removal efficiencies were obtained. Solak et al. (2009), in their study, have investigated the treatment of MPW by ECG process and obtained removal efficiencies of over 99 % in terms of both turbidity and SS. A literature survey has shown that the above mentioned studies, which investigated the treatment of MPW by ECG process, are the only ones and need further research. Thus, the treatability of wastewater from marble processing by ECG process method was investigated in this study. A reactor with monopolar aluminum and iron electrodes connected in parallel was designed for this purpose, and the effect of pH, current density and electrolysis time on turbidity, suspended solids (SS), chemical oxygen demand (COD) and total solids (TS) removal efficiencies have been analyzed. In addition, operation cost for each electrode material was calculated (energy and electrode consumption), and sludge settling characteristics were observed. This research was done at Cumhuriyet University, Sivas on 2010.

Description of ECG processes

ECG is a processes consisting of creating metallic hydroxide flocks within wastewater by electrodissolution of soluble anodes, usually made of iron or aluminum. The generation of metallic cations takes place at the anode, due to the electrochemical oxidation of the iron or aluminum, whereas at the cathode the production of H_2 typically occurs. ECG process involves many chemical and physical phenomena, such as discharge, anodic oxidation, cathodic reduction, coagulation, electrophoretic migration, and adsorption (Kobya et al. 2003). When aluminum or iron is used as electrode material, the reactions are as follows:

$$\text{Anode: } \mathrm{M} \rightarrow \mathrm{M}^{3+}_{(aq)} + 3e^- \tag{1}$$

$$\text{Cathode: } 3\mathrm{H_2O} + 3e^- \rightarrow \frac{3}{2}\mathrm{H_2} + 3\mathrm{OH}^- \tag{2}$$

$$\text{In the solution: } \mathrm{M}^{3+}_{(aq)} + 3\mathrm{H_2O} \rightarrow \mathrm{M(OH)}_{3(s)} + 3\mathrm{H}^+_{(aq)}, \tag{3}$$

Table 1 Characteristics of marble processing wastewater

Parameters	Value
pH	7.8
Electrical conductivity (μs cm^{-1})	1,340
Turbidity (NTU)	1,914
Total solids (mg/L)	4,750
Suspended solids (mg/L)	2,904
TDS (g/L)	0.91
Oil grease (mg/L)	40
Chemical oxygen demand (mg/L)	150

where M is Fe and Al. The generated Fe^{3+} or Al^{3+} ions will immediately undergo further spontaneous reactions to produce corresponding hydroxides and/or polyhydroxides (Mollah et al. 2001; Daneshvar et al. 2007). These insoluble aluminum and iron hydroxides react with the suspended and/or colloid solids and precipitate. Coagulation, adsorption, precipitation and flotation are removal mechanism of the ECG process.

Materials and methods

Test wastewater

The wastewater collected from a marble processing plant in Sivas was used for all experiments. The characterization of the wastewaters is given in Table 1.

Experimental setup

The ECG experiments were carried out in a batch mode using a 1,000-ml plexiglass reactor (100 × 100 × 130 mm in dimension) using vertically positioned iron and aluminum electrodes spaced by 20 mm and dipped in the MPW (Fig. 1). Two anodes and two cathodes with dimensions of 72 × 48 × 3 mm made iron and aluminum plate (Fe 99.53 % purity, Al 99.32 % purity), were connected to a digital DC power supply (GPC 6030D) in monopolar parallel connection mode and equipped with galvanostatic operational options. The total effective electrode area was 216 cm^2.

All of the experiments were carried out with 1,000 ml of wastewater at room temperature and 250 rpm mixing speed. Before each run, the wastewater was filtered through a filter paper having coarse pore sizes in order to get a homogenized particle size distribution in the sample. Electrodes were washed for 2 min with 0.1 N NaOH, H_2SO_4 solutions and distilled water after ECG experiments (Mordirshahla et al. 2008). Then again a filtration procedure was applied in order to eliminate a potential additional removal effect of filter paper and chemical analyses were carried out. At the end of each ECG experiment run, sludge volume index (SVI) analyses were conducted on the solution. The percentage removal efficiency of SS, turbidity, COD and TS was calculated using the following equation, Eq. (4).

$$\text{Percentage removal efficiency } (\%) = \left(\frac{(C_o - C)}{C_o}\right) \times 100, \tag{4}$$

where C_o is the initial concentration and C is the final concentration of the pollutant (mg/l and NTU).

Analytical method

Turbidity, SS, COD and TS were determined according to standard methods (APHA 1992). In all experiments, chemicals with analytic grade were used. 0.45 μm filter paper (Whatman, 47 mm) was used for SS measurements. COD of samples were determined using closed reflux method. The pH, electrical conductivity and

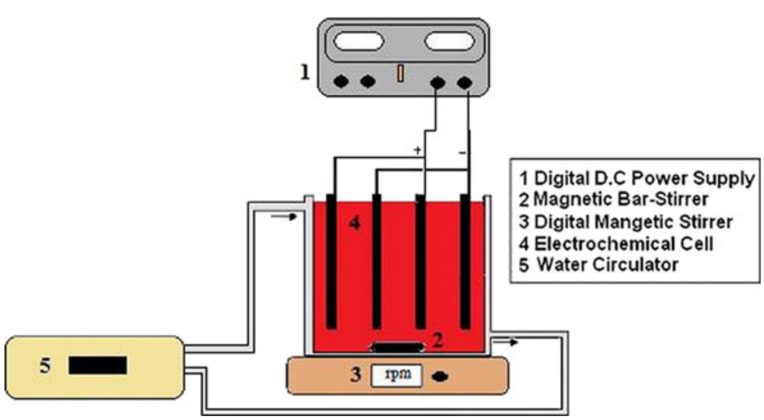

Fig. 1 Schematic diagram of experimental setup

turbidity were measured using a pH meter (consort model C931), a WTW Model 340i conductivity meter and a HF model Micro TPI turbidimeter respectively. Sludge volume index (SVI) measurements were conducted by the method given in standard methods. The pH was adjusted by adding sodium hydroxide (NaOH) or hydrochloric acid (HCl).

Results and discussion

This study is mainly focused on the ECG of MPW. The efficiency of pollutants removal from wastewaters by ECG process depends on several operating parameters, such as the type of electrode material, initial pH, current density and electrolysis time. Effect of initial pH, current density and electrolysis time on turbidity, SS, COD, and TS removal and electrodes and energy consumptions were investigated in order to determine the optimum operating conditions.

The operating cost is one of the most important parameters in the ECG process because it affects the application of any method of wastewater treatment. The operating cost includes material (mainly electrodes) cost, electrical energy cost, as well as labor, maintenance and other costs. The latter cost items are largely independent of the electrode material (Kobya et al. 2006b; Bayramoglu et al. 2004; Donini et al. 1994). Thus, in this study, the operating cost was calculated with electrodes and electrical energy costs. So both energy and electrode consumption costs are taken into account as major costs items. Calculation of operating cost is expressed as

$$\text{Operating cost} = X\text{Energy}_{\text{consumption}} + Y\text{Electrode}_{\text{consumption}}, \quad (5)$$

where $\text{energy}_{\text{consumption}}$ and $\text{electrode}_{\text{consumption}}$ are consumption quantities per m^3 of wastewater treated. Unit prices, X and Y, given for the Turkish Market, September 2009, are as follows; electrical energy price 0.06 US $/kWh, electrode material price 1.80 US $/kg for aluminum. Energy consumption is the consumed electric energy to remove 1 kg SS, and Electrode consumption is the amount of the sacrificed electrode to remove 1 kg SS. The total change in amount of anode and cathode electrode (MT) was calculated to the following equation:

$$M_T = M_A + M_C, \quad (6)$$

where M_T and M_C is the change in amount or the dissolved materials from the surface of anode and cathode electrode (g), respectively.The energy consumption (Wh) in the process was calculated according to the following equation:

$$E = V \times I \times t, \quad (7)$$

where E is the electric energy (Wh), V is the voltage, I is the current applied (A), and t is the time (h).The energy demand was calculated according to the faraday equation:

$$C_e = \frac{(I \times t \times M_w)}{(F \times v \times z)}, \quad (8)$$

where C_e is the energy demand (F/m^3), F is the Faraday constant (96,487 C/mol), M_w is the molecular weight of aluminium (26,98 g/mol) and iron (55,84 g/mol), and z is the electron transfer coefficient (z_{Al}: 3, z_{Fe}: 2).

Effect of Initial pH

pH of the medium changes generally during the ECG process which depends on type of the electrode material and initial pH. Types of metal hydroxides formed in ECG process changes depending on the initial pH. The effect of pH on the process performance is explained as follows: the dominant aluminum species are different according to the solution pH: Al^{3+} and $Al(OH)^{2+}$ are dominant in pH 2–3, and with pH between 4 and 9, various polymeric species such as $Al_{13}O_4(OH)_{24}^{7+}$ are formed and precipitated $Al(OH)_3(s)$ leading to a more effective treatment. As seen in Figs. 2 and 3, the pH of medium changes during ECG depending on, to some extent, the initial pH. And above pH 9 the soluble species $Al(OH)_4^-$ is the predominant and only species present above pH 10 (Gomes et al. 2007). Similarly, ferric ions generated by electrochemical oxidation of iron electrode may form monomeric ions, $Fe(OH)_3$ and hydroxil complexes namely; $Fe(H_2O)_6^{2+}$, $Fe(H_2O)^{2+}$, $Fe(H_2O)_4(OH)^{2+}$, $Fe_2(H_2O)_8(OH)_2^{4+}$ and $Fe_2(H_2O)_6(OH)_4^{4+}$, depending on the pH of the aqueous medium in the ECG process. The complexes (i.e. hydrolysis

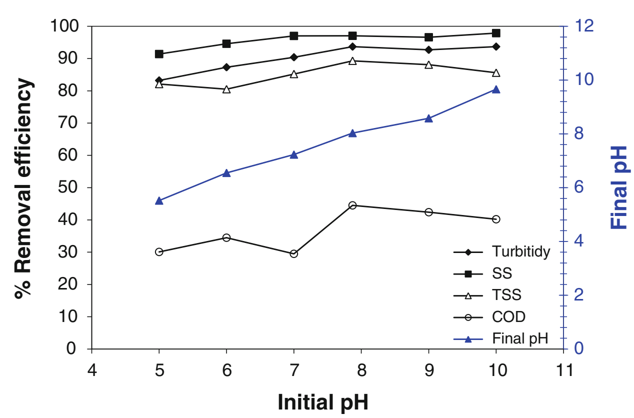

Fig. 2 Effect of initial pH on turbidity, SS, TS and COD removal by aluminum electrode (electrolysis time 3 min, current density 15 A/m^2, mixed speed 250 rpm)

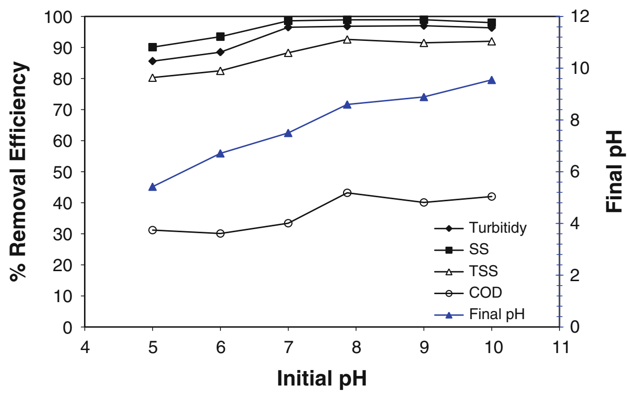

Fig. 3 Effect of initial pH on Turbidity, SS, TS and COD removal by iron electrode (electrolysis time 3 min, current density 15 A/m^2, mixed speed 250 rpm)

products) have a pronounced tendency to polymerize at pH 3.5–7.0. Under very acidic condition at pH <2.0, but as the pH and the coagulant concentration rises, hydrolysis occurs to form $Fe(OH)_3(s)$ (Kobya et al. 2008). The flocs of $M(OH)_3(s)$ have large surface areas, which are useful for a rapid adsorption and soluble organic compounds and trapping of colloidal particles. Finally, these flocs are removed easily from aqueous medium by sedimentation or flotation (Aoudj et al. 2010). ECG process is effective in the range of pH 5–8. To examine effect of pH, the MPW were adjusted to range of 5–10 by adding sodium hydroxide and hydro caloric acid solution. Moreover, at natural pH of the wastewater (pH 7.8) was also carried out. In experiments, current density, electrolysis time and mixing speed were kept constant at 15 A/m^2, 3 min and 250 rpm, respectively, for both aluminum and iron electrodes. In ECG experiments performed using aluminum electrodes, initial pH effect on turbidity, SS, COD and TSo removal efficiencies are shown in Fig. 2. It can be seen that, when the initial pH increases, the pollutions removal efficiencies increases. At $5 \geq pH \leq 7.8$, SS and TS removal efficiencies are at slight increase. At pH 7.8≥, the pollutions removal efficiencies do not change significantly. Removal efficiencies obtained at natural pH of the wastewater (pH 7.8) were 93.7, 97, 44.5 and 89.3 % for turbidity, SS, COD and TS, respectively. As seen as Fig. 2, at pH 7.8 value high removal efficiencies for all parameters were obtained.

In experimental studies in which iron electrode has been used in ECG, similar results with aluminum electrode studies were obtained (Fig. 3). Here, removal efficiencies of pollutants at original pH value of the wastewater were found as 96.83 % for turbidity, 98.9 % for SS, 43.2 % for COD and %92.6 for TSo. Muruganathan et al. (2004) have investigated SS removal from tannery wastewater by electroflotation process using aluminum and iron electrodes and obtained high removal efficiency at an initial pH of 8. In another study, Bukhari (2008) have investigated the removal of total suspended solids and turbidity from municipal wastewater by electrocoagulation process and this wastewater pH is 7. Moreover, Kobya et al. (2006b) examined treatment of potato chips manufacturing wastewater by electrocoagulation and obtained high removal efficiencies of 99 % for turbidity at pH > 6. According to these studies, pH value of the medium increased during experimental studies when the initial pH was low, and it decreased when the initial pH value was higher than 9. Consequently the original pH value of wastewater increased to 8 with aluminum electrode and to 8.6 with iron electrode for the initial pH of 7.8.

Figure 4 shows the effect of initial pH on energy and electrode consumption, respectively. In terms of energy consumption it appears that aluminum electrode consumes more energy than iron electrode. At natural pH, the energy required for aluminum and iron electrodes was calculated to be 0.039 kWh/kg SS and 0.0318 kWh/kg SS, respectively. Considering electrode consumption, it is clear that at natural pH value, the iron electrode was consumed more than the aluminum electrode (0.0105 kg Fe electrode/kg SS, 0.0034 Al electrode/kg SS).

Effect of current density

To investigate the effect of current density on turbidity, SS, COD and TS removal, current density was changed between 5 and 40 A/m^2. Figure 5 shows the effect of current density on turbidity, SS, COD and TS removal efficiencies in ECG process in which the aluminum electrode has been used, whereas Fig. 7 is for iron electrode. When the current density was increased, turbidity, SS,

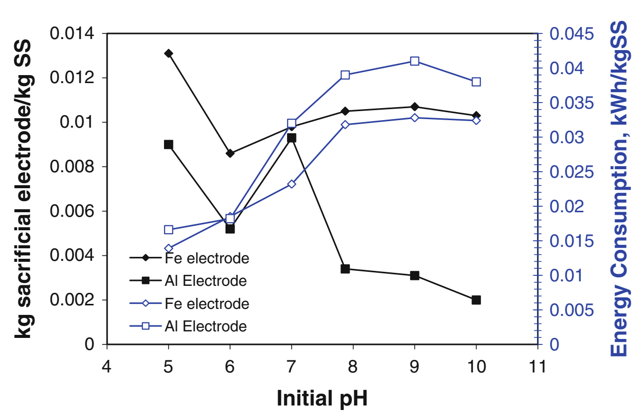

Fig. 4 Effect of initial pH on energy and electrode consumptions

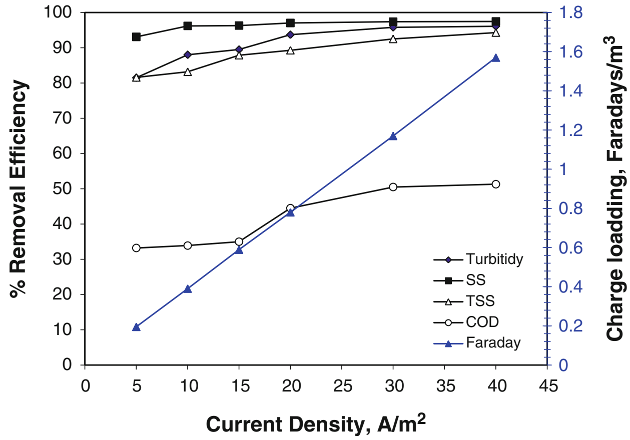

Fig. 5 Effect of current density on turbidity, SS, TS and COD removal by aluminum electrode (pH 7.8, electrolysis time 3 min, mixed speed 250 rpm)

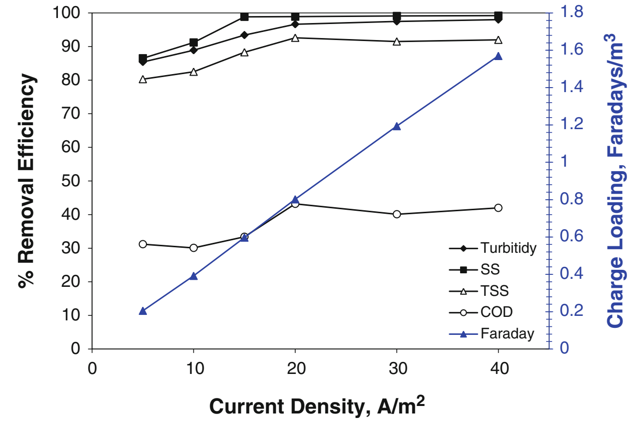

Fig. 6 Effect of current density on turbidity, SS, TS and COD removal by iron electrode (pH 7.8, Electrolysis time 3 min, mixed speed 250 rpm)

COD and TS removal efficiencies also increased for both electrodes. When the current density was increased from 5 to 30 A/m^2, the turbidity, SS, COD and TS removal efficiencies increased from 81.5, 93.1, 33.2 and 81.6 % to 95.8, 97.4, 50.5 and 92.7 %, respectively, for the aluminum electrode. A significant change in removal efficiencies was not observed for current densities over 30 A/m^2 for the aluminum electrode.

The optimum current density at which the removal efficiency reached the maximum value for all parameters was found to be 20 A/m^2 for the iron electrode (Fig. 6). For this current density, turbidity, SS, COD and TS removal efficiencies were 96.63, 98.9, 43.2 and 92,6 %, respectively. The increase in removal efficiencies as a result of an increase in current density can be explained by an increase in anodic dissolution of metal electrodes and thus in floc formation at high current densities. According to Faraday's law (Eq. 8), when current density increases, the amount of ion generated on the electrodes increases. Thus it causes an increase in floc formation and pollutants removed get increased (Mollah et al. 2004). In addition, It was established that the rate of bubble-generation increases and the bubble size decreases with increasing current density. Both of these trends are beneficial in terms of high pollutant removal efficiency by H_2 flotation (Un et al. 2009).

Figure 7 shows the effect of current density on electrode and energy consumption. It has been observed that increasing current density causes an increase in electrode and energy consumption. When the current density was increased from 5 to 40 A/m^2, energy consumption for iron and aluminum electrodes was observed to increase from 0.0039 to 0.26 kWh/kg SS and from 0.0041 to 0.148 kWh/kg

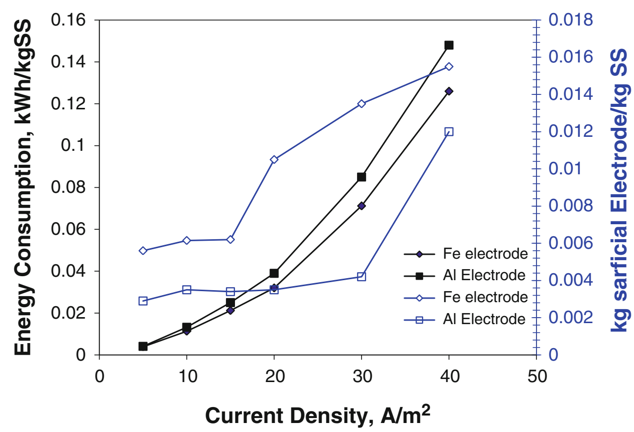

Fig. 7 Effect of current density on energy and electrode consumptions

SS, respectively. Considering electrode consumption, the iron electrode appeared to be consumed more than the aluminum (Fig. 7). Corresponding increases in electrode consumptions for iron and aluminum electrodes were from 0.0056 to 0.0155 kg Fe/kg SS and from 0.0029 to 0.012 kg Al/kg SS, respectively.

Effect of electrolysis time

To investigate the effect of electrolysis time on ECG process, experiments were carried out at natural pH of wastewater. The current densities were kept constant at 30 and 20 A/m^2 for aluminum and iron electrodes, respectively. The electrolysis time was varied from 0.5 to 15 min. The effect of electrolysis time on turbidity, SS, COD and TS removal efficiencies for aluminum and iron electrodes

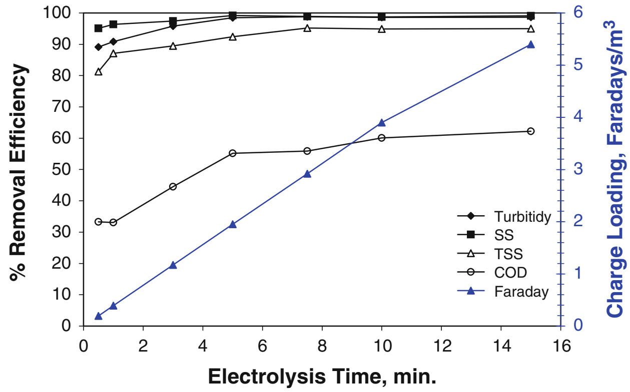

Fig. 8 Effect of electrolysis time on turbidity, SS, TS and COD removal by aluminum electrode (pH 7.8, current density 30 A/m^2, mixed speed 250 rpm)

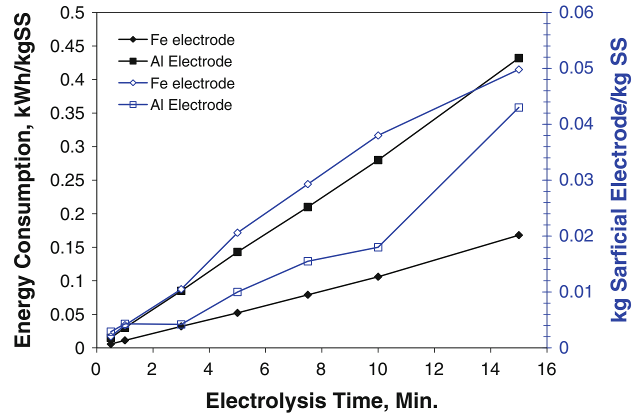

Fig. 10 Effect of electrolysis time on energy and electrode consumptions

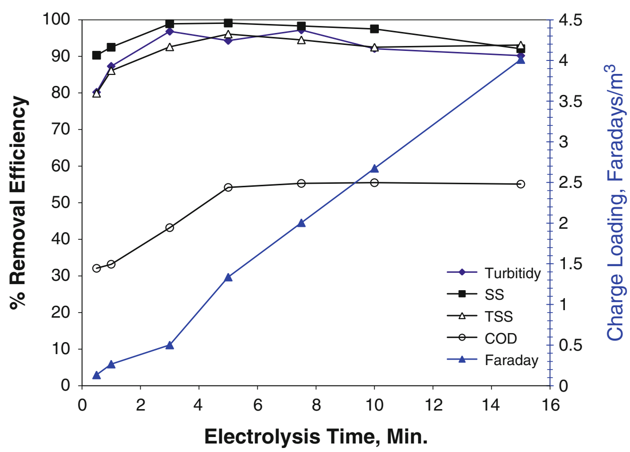

Fig. 9 Effect of electrolysis time on turbidity, SS, TS and COD removal by iron electrode (pH 7.8, current density 20 A/m^2, mixed speed 250 rpm)

is presented in Figs. 8 and 9, respectively. In ECG process the initial anodic dissolution provides coagulation. Ions concentration produced by the electrodes is important in removal of pollutants from the solution. Ions concentration and their hydroxide flocs increase when the electrolysis time increases. Namely, the suitable and sufficient floc formation in EC process is time dependent. It is clearly seen from Figs. 10 and 11 that suitable electrolysis time appears to be the same (5 min) for both electrode materials. Turbidity, SS, COD and TS removal efficiencies were 98.5, 99.2, 55.2 and 92.4 %, respectively, for the aluminum electrode. Corresponding removal efficiencies for the iron electrode were found to be 94.3, 99.1, 54.2 and 96.1 %, respectively.

The effect of electrolysis time on energy and electrode consumptions is shown in Fig. 10. Both energy and electrode consumptions increased with increasing electrolysis time. Increasing electrolysis time from 0.5 to 15 min increased the energy consumption from 0.015 to 0.432 kWh/kg SS and electrode consumption from 0.029 to 0.043 kg Al/kg SS for aluminium electrode. For the iron electrode, it increased energy consumption from 0.0057 to 0.168 kWh/kg SS and electrode consumption from 0.0206 to 0.0498 kg Al/kg SS. As a result, both the electrode and energy consumptions are two important parameters in terms of operating costs, and they should be taken into account when determining an optimum electrolysis time due to affecting the economic applicability of ECG process in treatment of MPW.

Settling properties of waste sludge

One of the most important advantages of electrochemical methods is the formation of lower amounts of sludge with better settling properties when compared to conventional chemical treatment methods (Mollah et al. 2001; Atmaca 2009). In general, settling properties of waste sludge are determined by sludge volume index parameter (SVI). According to Tchobanoglous et al. (2003), sludge with a SVI value of lower than 100 is considered to have good settling characteristics. SVI values estimated in different operating conditions for aluminum and iron electrodes are shown in Figs. 11 and 12 respectively. As seen in Fig. 11, when using aluminum electrodes; SVI values were determined to be above 100 in the range pH 7–10. Nevertheless, it was observed that SVI values were decreased

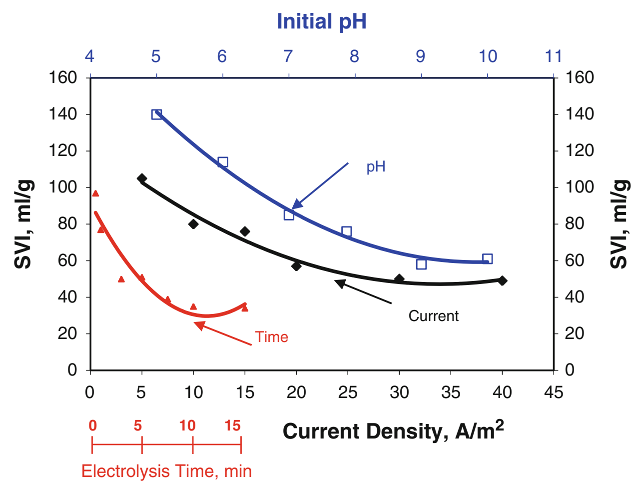

Fig. 11 SVI values of the sludge for different test conditions by aluminum electrode

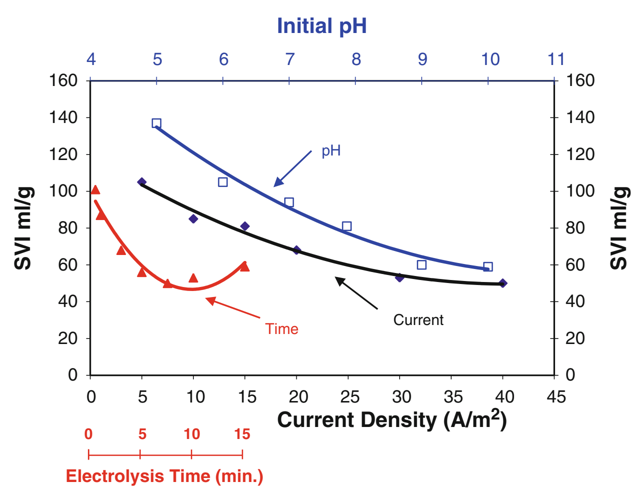

Fig. 12 SVI values of the sludge for different test conditions by iron electrode

proportionally by the increasing initial pH. It may be explained as such that Al(OH)n complexes form larger and more stabilized flocks under slight alkali conditions. Besides, in case of a current density over 20 A/m^2 and electrolysis time over 5 min, no increase was observed in the SVI values.

The SVI values obtained by ECG experiments using iron electrode under different operating conditions were shown Fig. 12. As seen Fig. 12, similar to the aluminum, the SVI values were determined to be below 100 under alkali and light basic conditions. This may be explained by metal hydroxide types formed under different pH values; $Fe(OH)_n$ complexes are larger and more stable under alkali and slight basic conditions. However, it is also observed that the SVI values were decreased when the current density and electrolysis time were increased, and that they increase again following a particular decline. It may be explained by these reasons including (a) flocks scattered by H2 gas which has been released in cathode similar to the aluminum electrode and (b) extra iron hydroxide flocks, hard to settle and yellowish, formed by the iron electrode (Chen et al. 2000; Bukhari 2008). Consequently, under optimum conditions, the sludge formed using aluminum electrodes was with better settling characteristics when compared to iron.

Conclusion

In this study, the treatability of MPW by ECG process using different metal electrodes (Al and Fe) was investigated and removed in removal pollutants parameters of MPW (turbidity, SS, COD and TS). The effects initial pH, current density and electrolysis time were investigated on turbidity, SS, COD, and TS removal efficiencies. In the ECG process using the aluminum electrode, the optimum conditions were determined as follows as a result of the experimental studies performed; pH 7.8 (original), current density 30 A/m^2, and electrolysis time 5 min and for the iron electrode, pH 7.8 (original), current density 20 A/m^2 and electrolysis time 5 min. Both aluminum and iron electrodes were obtained at the same in terms of SS removal efficiency. But turbidity parameter it is seen that iron electrodes are lower removal efficiency than aluminum. This is because the effluent treated with iron electrode as sacrificial anode appeared greenish first and then turned yellow and turbid. This green and yellow color must have resulted from Fe^{2+} and Fe^{3+} ions generated during the ECG. Fe^{2+} has relatively high solubility under acidic or neutral conditions and can be oxidized into Fe^{3+} by dissolved oxygen in water. Moreover, Fe^{3+} exists in formation of yellow $Fe(OH)_3$ particles hard to settle. Moreover, energy and electrode consumption under optimum conditions were determined as 0.143 kWh/kg SS, 001 kg Al/kg SS for the aluminum and as 0.0521 kWh/kg SS, 0.0206 kg Fe/kg SS for the iron. By the examination of results it is appeared that iron electrode usage would be more suitable in terms of energy, and aluminum electrode would be more suitable for electrode consumption. However, it has been revealed, by sludge settling tests under different operating conditions, that ECG process using iron electrode causes a reduction in efficiency resulting in an extra color in water, and in a sludge that is hard to settle which limits its usage.

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