Journal of Water Process Engineering 8 (2015) 64–74

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

# Evaluations of operating parameters on treatment of can manufacturing wastewater by electrocoagulation

M. Kobya [a,*], E. Demirbas [b]

[a] Gebze Technical University, Department of Environmental Engineering, 41400, Gebz, Turkey
[b] Gebze Technical University, Department of Chemistry, 41400, Gebze, Turkey

ARTICLE INFO

*Article history:*
Received 22 May 2015
Received in revised form
12 September 2015
Accepted 13 September 2015
Available online 26 September 2015

*Keywords:*
Can manufacturing wastewater
Electrocoagulation
Al electrode
Electrode connection mode
Operating cost

ABSTRACT

In this study, treatment of can manufacturing wastewater (CMW) by electrocoagulation (EC) process using aluminium plate electrodes was investigated in a batch mode operation to obtain optimum operating conditions with minimum operating cost. Effects of operating parameters such as current density, operating time and electrode connection modes (monopolar series (MP-S), monopolar parallel (MP-P) and bipolar series (BP-S)) on removal efficiencies of aluminium (125.1 mg/L), zirconium (81.2 mg/L), and phosphate ($PO_4^{3-}$ – P, 32.1 mg/L), chemical oxygen demand (COD: 850 mg/L) and total organic carbon (TOC: 300 mg/L) from the CMW were evaluated. The results indicated that removal efficiencies of Al, Zr, and phosphate at the optimum conditions (20 A/m$^2$, 40 min and MP-P electrode connection mode) were determined to be 99.41% for Al, 99.38% for Zr and 99.80% for phosphate, 72% for COD, and 37% for TOC in the wastewater, respectively. In addition, charge density, electrode and energy consumptions, amount of sludge and operating cost at the optimum operating conditions were calculated as 13.196 F/m$^3$ or 1270.59 C/L, 0.1432 kg/m$^3$, 1.366 kWh/m$^3$, 1.674 kg/m$^3$ and 0.366 €/m$^3$. The results indicated that the EC process is very effective and efficient process for treatment of the CMW.



## 1. Introduction

Aluminium cans are one of the popular packaging solutions for beverages. Makers of beer and soft-drink containers in the world produce billions aluminium beverage cans everyday [1–3]. Can makers in American produce about 100 billion aluminium beverage cans a year, equivalent to one can per American per day. The aluminium beverage can is made with two pieces which are can body and the can top (or lid) in a continuous process [4–6]. There are two major aluminium products, body stock and end stock, for can manufacturers [7]. The can body and the tops (end and tab) of the can are manufactured separately. The can fillers are attached to the end to the can after it has been filled. The manufacturing process starts with coils of aluminium. There are some stages for making the body of the can which are lubrication-cupper-bodymaker-trimmer, washer-decoration-necker and flanger-quality test and packing. Different plants make can ends and tabs, and can bodies. There are four stages, blank and shell formation, curling, compounding and conversion, for making the end of a can. The finished end is then bagged, palletised and sent to the customer. Based on EPA's current information, wastewaters from a typical aluminium can manufacturing plant are source of rinse water, demineralised regenerant, lube oils and clean-up water [8].

The can manufacturing wastewater (CMW) contains oil and grease, suspended solids, phosphates, heavy metals (aluminium and zirconium), chemical oxygen demand (COD) and total organic carbon (TOC). The presence of these pollutants in the CMW leads to serious damage when discharged directly into the environment. Therefore, adequate treatment of these wastewaters is essential before it is discharged into water bodies. The potential treatment methods for pollutants in the CMW include dissolved air flotation [9], chemical treatment [10], membrane separation [11,12], adsorption [13] and ion exchange [14]. However, most of these treatment methods have some some disadvantages because these methods take considerable operating time, addition of treatment chemicals, require an extensive set-up, generate release of secondary pollutants (chloride, sulphate in the coagulation-precipitation), and generate large volumes of sludge or waste which have to be disposed of. In recent years, electrocoagulation (EC) has been receiving greater attention for removals of pollutants from wastewaters compared to the conventional methods. Electrocoagulation has the potential to extensively eliminate the disadvantages of the classical treatment techniques to achieve a sustainable and economic treatment of industrial wastewaters [15]. In recent

* Corresponding author. Fax: +90 262 6053005.
*E-mail address:* kobya@gtu.edu.tr (M. Kobya).

http://dx.doi.org/10.1016/j.jwpe.2015.09.006
2214-7144/

years, EC has been successfully used to treat a variety of industrial wastewaters such as liquid organic fertilizer plant wastewater [16], baker's yeast wastewater [17], laundry wastewater [18], dairy industry wastewater [19], electroplating rinse water [20,21], textile wastewater [22–24], metal cutting wastewater [25] and poultry slaughterhouse wastewater [26]. EC has also been applied to remove metals (Cd, Cr, Cu, Mn, Pb, Zn, etc.) [27–30], anions (arsenate, boron, fluoride, nitrate and phosphate, etc.) [31–36], colloidal and suspended particles (clay minerals, virus, bacteria, and other microbial indicators) [37,38], oil and greases [39]. This process is characterized by a fast rate of pollutant removal, compact size of the equipment, simplicity in operation, decreased amount of sludge, and low operating costs [15–26].

Despite an intensive amount of scientific researches on treatment of industrial wastewaters by EC process, there are no reported publications yet on treatment of the CMW with this process. Therefore, the main objective of the present study was to determine the optimum operating conditions for the removal efficiency of the CMW in the EC process using Al sacrificial electrodes. Energy and electrode consumptions, operating costs and amount of sludge produced were also calculated.

## 2. A brief description of EC technique

EC technique uses a direct current source between metal electrodes, which is usually made of iron or aluminium immersed in wastewater. The EC process features electrochemical dissolution of a sacrificial anode and simultaneous hydrogen gas evolution at the cathode according to Faraday's law. In this study, aluminium electrodes are used in the EC process. This is caused by electrodissolution of the anode and the reduction of water at the cathode which generates aluminium and hydroxide ions according to the following reactions [40,41]:

$$Al_{(s)} \rightarrow Al^{3+} + 3e^- \quad (1)$$

$$3H_2O + 3e^- \rightarrow 3/2H_2 + 3OH^- \quad (2)$$

The speciation of the aluminium hydroxides formed during EC is highly variable and is strongly influenced by pH [41,42]:

$$xAl^{3+} + yOH^- \rightarrow Al_x(OH)_y^{3x-y} \quad (3)$$

The $Al^{3+}$ and hydroxide ions ($OH^-$) produced at the electrodes react to form monomeric species such as $Al(OH)^{2+}$, $Al(OH)_2^+$, $Al_2(OH)_2^{4+}$, $Al(OH)_4^-$ at low pH values and polymeric species such as $Al_6(OH)_{15}^{3+}$, $Al_7(OH)_{17}^{4+}$, $Al_8(OH)_{20}^{4+}$, $Al_{13}O_4(OH)_{12}^{7+}$, and $Al_{13}(OH)_{34}^{5+}$ (Fig. 1), transformed initially into $Al(OH)_{3(s)}$ in the solution according to Eq. (4) and finally polymerized [42–45]:

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_{3(s)} + 3H^+ \quad (4)$$

At pH values below 3.5, the aluminium ion is the predominant species. The predominant aluminium chemical species at pH values of 4.0–9.5 was $Al(OH)_{3(s)}$. The pH of minimum solubility of solid $Al(OH)_{3(s)}$ is about 6.5, and total soluble $Al^{3+}$ concentration is $3 \times 10^{-6}$–$3 \times 10^{-4}$ M (or 0.025–2.5 mg/L) between pH 6 and 9. However, it is interesting to note that a new aluminium complex forms as $Al(OH)_4^-$ at pH values greater than 10.0. This ion is soluble and directly affects the pollutant removal. On the other hand, the cathode may be chemically attacked by hydroxyl ions generated during $H_{2(g)}$ evolution at high pH values [46]:

$$2Al + 6H_2O + 2OH^- \rightarrow 2Al(OH)_4^- + 3H_2 \quad (5)$$

The positively charged polyhydroxo-complexes such as $Al_8(OH)_{20}^{4+}$ are the effective flocculants in the pH range 4–7. Freshly formed amorphous $Al(OH)_{3(s)}$ "sweep flocs" have large surface areas, which are beneficial for a rapid adsorption of soluble organic and inorganic compounds and trapping of colloidal particles. Simultaneously, the hydroxyl ions produced at the cathode increase the pH in the electrolyte and may induce precipitation and co-precipitation of metal ions in wastewater in the form of their corresponding hydroxides. Moreover, there is a possibility of oxidation and reduction of polluting substances in the wastewater at the anode and cathode, respectively. This acts synergistically to remove pollutants from water. The sweep flocs are removed easily from aqueous medium by sedimentation or $H_2$ flotation [40].

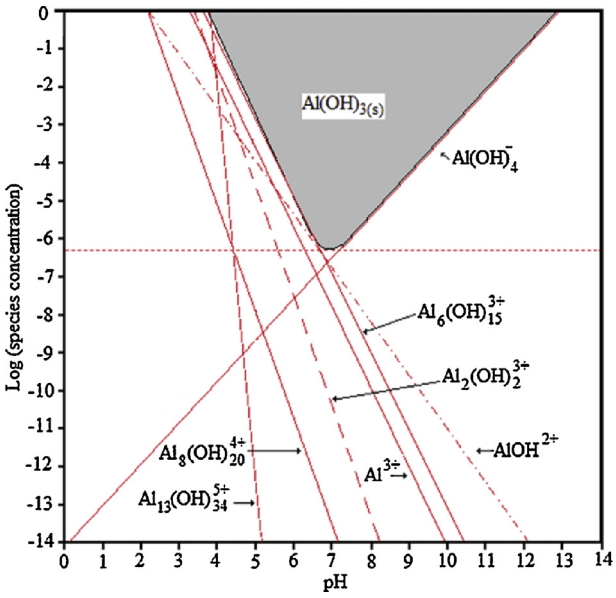


**Fig. 1.** Solubility of Al species as a function of Al concentration and pH.

## 3. Material and methods

### 3.1. Wastewater characteristics

The can manufacturing wastewater was obtained from a can manufacturing plant located in Kocaeli, Turkey. The CMW from aluminium beverage can manufacturing process lines was obtained in the equalisation tank. Characteristics of the CMW were pH 3.04, total suspended solids (TSS) of 110 mg/L, conductivity of 6.40 mS/cm (25 °C), total Al of 125.1 mg/L, total Zr of 11.9 mg/L, phosphorus ($PO_4^{3-}$ – P) of 32.1 mg/L, COD of 850 mg/L, and TOC of 300 mg/L, respectively.

### 3.2. Apparatus and instruments

The EC experiments were carried out in a batch mode using about 1.0 L Plexiglas reactor (12 cm × 9.5 cm × 8.5 cm in dimension). Aluminium electrodes spaced by 13 mm were placed vertically in the reactor (Fig. 2). Four aluminium plate electrodes (2 anodes and 2 cathodes) with dimensions of 5.0 cm × 7.5 cm × 0.3 cm (purity > 99.5%) were connected to a digital dc power supply (Agilent 6675A model; 120 V, 18 A) and equipped with galvanostatic operational options. The constant current was adjusted according to a desirable value. The total effective electrode surface area was 225 $cm^2$ and a gap of 2 cm was maintained between the bottom of the electrodes and the bottom of the cell to facilitate easy stirring. The solution in the reactor was constantly stirred at 200 rpm (Heidolp MR 3000D) to reduce the mass transport over potential.