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Thickening of Biological Sludge by Electro-Coagulation-Flotation Process

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The present study is to investigate the thickening of hospital wastewater biological sludge by the Electro-Coagulation-Flotation (ECF) process. The electrochemical thickening of biological sludge has been studied by batch electrolysis experiments under different conditions. The various parameters like effect of pH (2-11), current density (0.5-3 mA cm^{-2}), and reaction time (2 to 60 min) on increase of sludge suspended solids concentration and also the removal efficiencies of Chemical Oxygen Demand (COD) and turbidity from the biological sludge were studied. The results indicated that the maximum COD and turbidity removals were achieved in acidic pH level and electrolysis time of 30 minutes. With increasing current density from 0.5 to 3 mA cm^{-2} at the optimum conditions of operation, the removal efficiencies of COD and turbidity reached from 65.1 to 75.6% and 56 to 96.4% respectively during the ECF. In addition, in the above-mentioned conditions, suspended solids concentration increased to 2.1 percent. Mean energy consumption and current efficiency were figured at about 0.03 kWh m^{-3} and 200%, respectively.

Keywords: Biological sludge; Electro-Coagulation-Flotation process; COD; Suspended solids concentration; Turbidity

1. INTRODUCTION

Activated sludge, is also called biological sludge, is produced by secondary treatment processes with suspended growth. Biological sludge has light brown color and suspended solids concentration of 0.4 to 1.5%. The density of primary sludge is 1gr cm^{-3}. Dewatering secondary sludge, because of biological flocs in secondary sludge is more difficult than primary sludge. Thickening of the activated

sludge is most important process in wastewater treatment due to the high volume and low suspended solids concentration of the biological sludge. Thickening is a procedure used to decrease of sludge volume and increase of its solids concentration by removing a portion of the liquid fraction. Sludge pumping condensed is easily possible. The important purpose of thickening of sludge and decrease of its volume is included increase the efficiency and decrease of costs related to sludge processing. [1]. Thickening is generally accomplished by methods including: gravity (co-settling in clarifier), gravity (thickening in separate tank), dissolved air flotation, solid-bowl centrifuge, gravity-belt thickener and rotary-drum thickener. These methods have disadvantages that are included: occasional use can be odorous, the high operating cost, poor suspended solids concentration, high energy required and high area required. Recently the applications of the ECF process as electrochemical method to remove a large number of pollutants has reported [2-5]. ECF is a coagulation process in which coagulant agent is produced with dissolution of a sacrificial anode using the current between the two electrodes, the cathode and anode. The suitable electrodes in ECF process for the treatment of pollutants are aluminum and iron [6-9]. In this method, metal hydroxide is generated by chemical reactions created by electrical forces due to electrical current between electrodes. The metal hydroxides act as coagulant / flocculant for removal of undesirable contaminants either by chemical reaction and precipitation or by causing colloidal materials to coalesce [10-13]. The ECF process has many advantages, that make it is suitable for the treatment of various pollutants. These advantages including: requires small area and simple equipment, high capability to remove a variety of pollutants such as (azo and reactive dyes, phosphate, pulp wastewater, zinc, nitrate and ect), easy operation, low sludge production and no need for chemicals [14- 18]. Based on our review, there is no research concerning the thickening biological sludge using ECF. Therefore, in this work, the possibility of thickening of biological sludge, reduction of COD and turbidity of biological sludge by ECF investigated and the process examined under different values of current density, pH and time, in order to determine optimum operating conditions. In addition, the amount of energy consumed in the process was determined.

2. EXPERIMENTAL SECTION

2.1. Biological sludge sample

Table 1. The basic characteristics of sludge biological samples from hospital wastewater treatment plant

Parameter	Unit	Value
Color	-	Light brown
pH	-	7.0
TSS	(mg/L)	12750
Turbidity of supernatant effluent after settling 30min	(NTU)	175
Soluble COD	(mg/L)	780
Total COD	(mg/L)	8600
Electrical Conductivity	(ms/cm)	3.02
Volatile Total Solids	(mg/L)	12250

In this study, samples collected from HAFTHEHTIR hospital wastewater treatment plant located in Tehran, Iran. Polyethylene containers used to collect samples of the sludge. Samples were stored at 4 ° C before use. Sludge samples analyzed for their basic characteristics. Table.1 summarizes the characteristics of the produced sludge. The experiments performed at room temperature.

2.2. ECF reactor setup and procedure

The ECF experiments carried out in a cylindrical glasses cell with 2000 ml useful volume, which were 24 cm in height and 8 cm in internal diameter. Reactor equipped with six blades made of aluminum that installed in monopollar parallel, a DC power supply, a magnetic stirrer using a constant speed of 400 rpm, and required accessories. The dimensions of electrodes were (0.2 ×10 ×10 cm) in thickness, length and width, which placed in parallel with each other and distance between electrodes was 1 cm. Electrode weights were recorded after each test. The batch experimental setup is schematically shown in Fig. 1. In every stage of the experiment 2000 ml biological sludge poured in the reactor, turn on DC power and ECF process with special current density (0.5-3 mA cm^{-2}) was down. After the elapse of time (2 - 60 min) turn off DC power and sampling 50 ml sludge of surface reactor to determine total suspended solids and total volatile suspended solids. Also measured pH, turbidity and COD effluent samples after 30 minutes settling, were taken of under floating sludge (the sludge was isolated using Whatman filter paper with pore size 11 μm). To eliminate the influence of mass transport rate of pollutants to the electrodes (this causes an increase of 50% in the treatment time and power requirements), high mixing was carried out by a magnetic stirrer. The aluminum electrodes were polished after each experiment using grinding papers, and then were washed with deionized water and soap water.

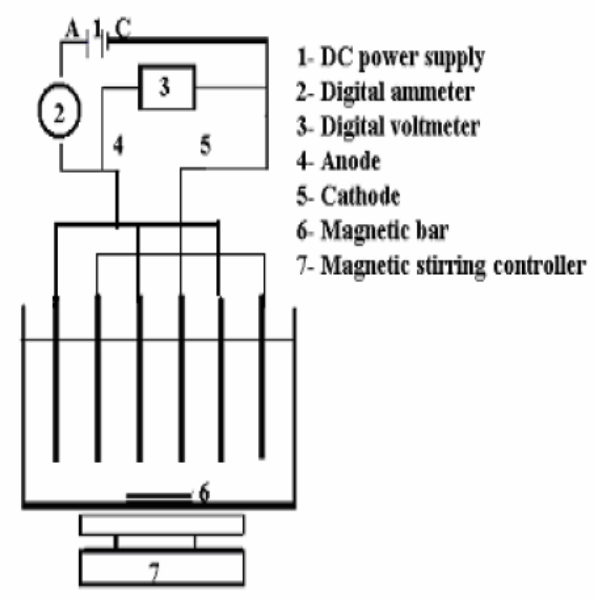


Figure 1. A schematic diagram of the electrochemical reactor

2.3. Analysis

The sludge and liquid under floating sludge samples were analyzed for color, pH, TSS, turbidity, COD, EC and volatile total solids, both before and after ECF. The performance of ECF in thickening of biological sludge was evaluated in terms of the suspended solids concentration percentage. For monitoring of the solution pH and temperature used the ultrameter II (Myron L Company) in the electrolysis. The spectrophotometer (DR 5000) used for measuring of COD index. The electrical conductivity and turbidity were determined using Hack instruments. The concentration of soluble electrode materials, sludge and liquid under floating sludge analysis were measured according to Standard Methods [19].

3. RESULTS AND DISCUSION

Initial experiments showed that sludge characteristics are included, light brown in color, relatively high total chemical oxygen demand, pH neutral and suspended solids 1.3 percentage. According to the results by taking the index of COD, pollution load of sludge wastewater treatment plant is 20 times rather than municipal wastewater (Table 1). The conditions and runs relating to the ECF experiments are mentioned in Table 2.

Table 2. The conditions and runs relating to the ECF experiments

Run	Operation mode	Experiment	Operational conditions			
			Material (anode-cathode)	pH	Current density (mA cm^{-2})	Reaction time (min)
1	Batch	Effect of pH	Al-Al	2-11	3	30
2	Batch	Effect of current density	Al-Al	6	0.5-3	30
3	Batch	Effect of reaction time	Al-Al	6	0.5-3	2-60

3.1. Factors affecting in efficiency of ECF process

3.1.1. Effect of initial pH

The pH has a significant role in the performance of ECF process. To explain this effect, pH was altered within a range of 2 to 11 and optimum value of pH was determined. Effect of initial pH on ECF process in the removal of COD and turbidity (Fig. 2a) and increase of suspended solids (Fig. 2b) is shown in Fig. 2. As seen in Fig. 2, the removal rates sharply increased from 50.6% to 79% for COD and from 65 to 94% for turbidity when the pH was increased from 2 to 5. Also suspended solids

concentration increased to 2.1% after the reaction time 30 min in pH 6.0 with 3 mA current. The COD and turbidity removal percentage and suspended solids concentration percentage remained constant for a pH "between" 6 to 9 and increasing the pH to 12 led to a reduction in removal efficiency ($P<0.05$). These results are consistent with results obtained by other researchers [20-22]. The reaction occurring in the ECF cell with the Al electrode can be written as follows: in acidic conditions, the oxidation of anode led to the release of Al^{3+} into the solution, as shown in Eq. (1). Due to the presence of oxygen, Al^{3+} reacts with hydroxide ions to produce $Al(OH)_3$ according to Eq. (2). In the cathode, H^+ is reduced to hydrogen gas Eq. (3). The overall reaction in acidic condition can be written as Eq. (4).

Acidic condition:

Anode:

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

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

Cathode:

$$2H^+{}_{(aq)} + 2e^- \rightarrow H_{2(g)} \quad (3)$$

Overall:

$$2Al_{(s)} + 4H_2O_{(l)} + O_{2(aq)} \rightarrow 2Al(OH)_{3(s)} + 2H_{2(g)} \quad (4)$$

In alkaline condition, the anode oxidized, and Al^{3+} formed in the water can in absence of oxygen, reacts with hydroxide ions which results in produce gelatinous hydroxide precipitates, as shown in Eqs. (5) and (6). The hydrolysis of water molecules at the cathode (according to Eq. (7)), leds to generating hydrogen gas and hydroxyl ion. The overall reaction in alkaline condition can be written as Eq. (8) [23, 24].

Alkaline condition:

Anode:

$$Al_{(s)} \rightarrow Al^{3+}{}_{(aq)} + 3e^- \quad (5)$$

$$Al^{3+}{}_{(aq)} + 3OH^-{}_{(aq)} \rightarrow Al(OH)_{3(s)} \quad (6)$$

Cathode:

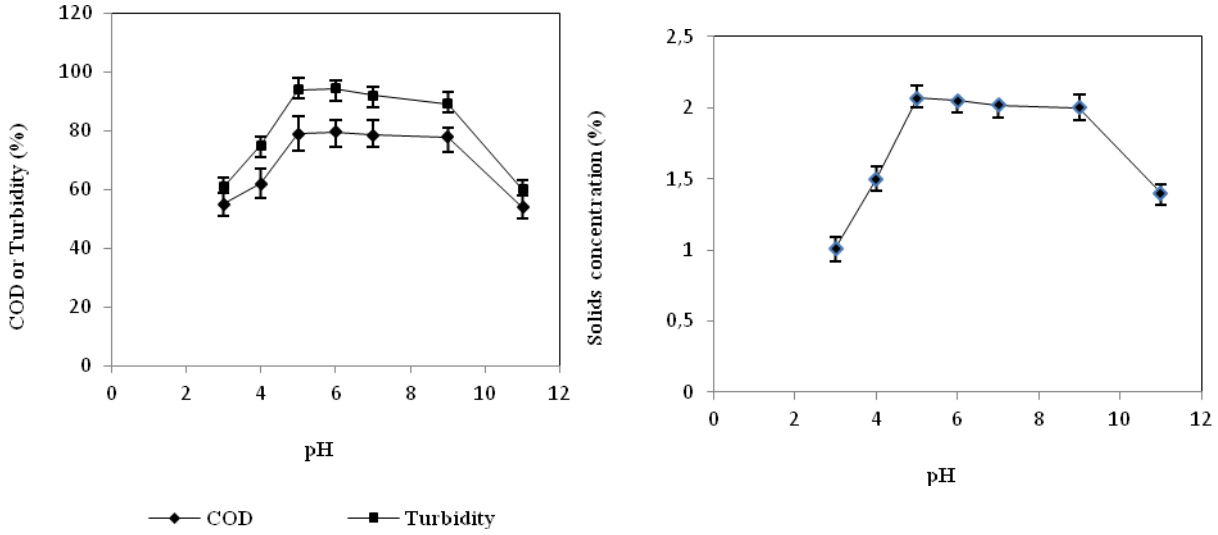
$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-{}_{(aq)} \quad (7)$$

Overall:

$$2Al_{(s)} + 3H_2O_{(l)} \rightarrow Al(OH)_{3(s)} + 1.5H_{2(g)} \quad (8)$$

With regard to the mechanisms described above, the predominant form of aluminum at pHs between 5 and 9, is the $Al(OH)_3$ gelatinous precipitate. Therefore, TSS, COD and turbidity have likely

been removed from the sludge through complex with the active sites present on Al $(OH)_3$ gelatinous precipitate and adsorption onto the aluminum hydroxide flocs by Van der Waals forces. Decreasing COD, turbidity removals from liquid and increasing of suspended solids concentration from sludge at pHs below 5 or above 9 can be attributed to increasing solubility of Al^{3+} at these pHs which this result leads to reduced formation of aluminum hydroxide [25]. Removal of COD and turbidity and thickening of sludge at natural pH can be beneficial from both engineering and economic points of view because of both simple and cost effective.



(a) (b)

Figure 2. The effect of initial pH (2–11) on the removal of COD and turbidity (a) suspended solids concentration (b)in the ECF process

3.1.2. Effect of current density

In the ECF process flocs size, production rate of bubbles and coagulant dosage depends on the current density in the reactor. So the current density is very important in the process of electrochemical. According to Faraday's law (Eq. 9), with increasing current density and electrolysis time, the dissolution of the anode increases, this increases the release of Al^{3+} from anode:

$$C_{Al}=\frac{M_w I t_{EC}}{ZFV} \quad (9)$$

Where C_{Al}, Z, F, V, and M_w are the theoretical concentration of Al^{3+} (g m^{-3}), the chemical equivalence, Faraday's constant (96,487 C/mol), volume of reactor (m^3), and molecular weight of aluminum (g mol^{-1}), respectively. To investigate the effect of current density on ECF process, experiments conducted by varying the current density from 0.5 to 3 mA cm^{-2}, at pH 6.0. The results of the influence of the current density on the COD and turbidity removals (Fig. 3a) and suspended solids concentration (Fig. 3b) are presented in (Fig. 3). The removal rates sharply increased from 50.6% to

79% for COD and from 65 to 94% for turbidity when the pH was increased from 2 to 5. Also suspended solids concentration increased to 2.1% after the reaction time 30 min in pH 5.0 with 3 mA current. Fig. 3 shows effect of current density on ECF process efficiency. The ECF produced a considerable COD, turbidity removals of 70 and 78% respectively at the low current density of 0.5 mA cm^{-2}. Also suspended solids concentration reached 1.4% after the reaction time 30 min in pH 6.0 and 0.5 mA current. It observed removal efficiencies 80.45 and 94.51% for COD and turbidity respectively, as current density reached to 3 mA cm^{-2}. In applied current density 3 mA cm^{-2}, suspended solids concentration increased to 2.1%. The improvement in COD and turbidity removals and increasing concentration percentage of solids due to current density applied in the ECF cell can be related to:

1-The extent of anodic dissolution of aluminum increases, so this leads to an increase in the production of metal hydroxides based on the mechanisms given in Eqs. (6) and (10).

$$Al(OH)_{3(s)} + \text{ pollutant} \rightarrow (Al(OH)_3 \text{ - pollutant) floc} \quad (10)$$

2- Decrease of bubble size and increase of bubble generation that can increase the removal efficiency of pollutants by H_2 floatation.

3- Increase of coagulant generation with increasing of the current density that it is expressed by measuring the loss in anode (Al) weight as a function of the applied current density at a given reaction time (Fig. 4).

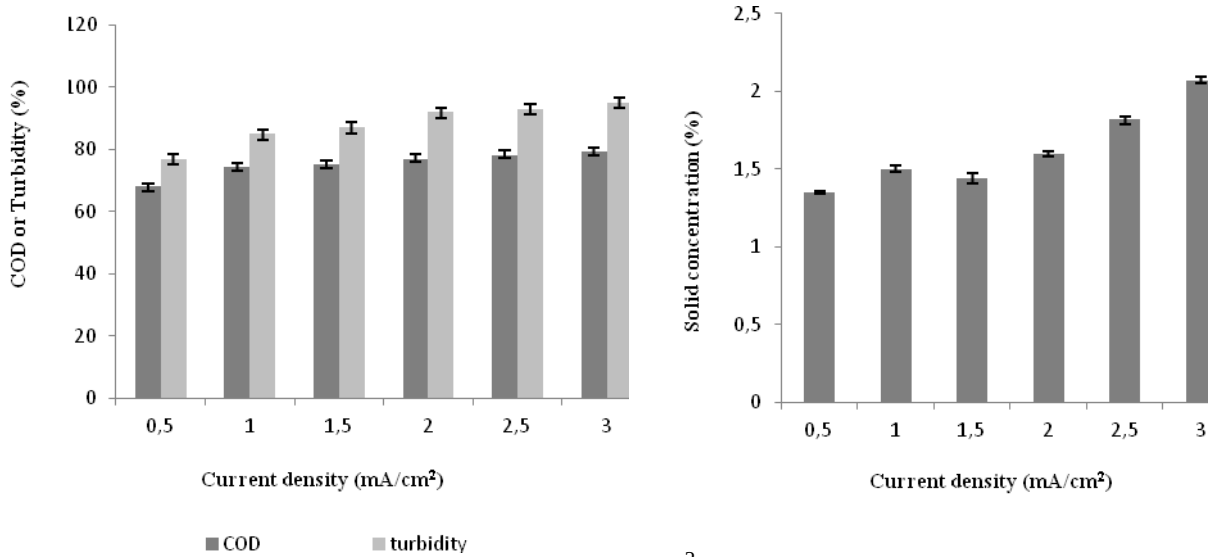


Figure 3. The effect of current density (0.5-3mA/cm^2) on the removal of COD and turbidity (a) and suspended solids concentration (b) in the ECF process

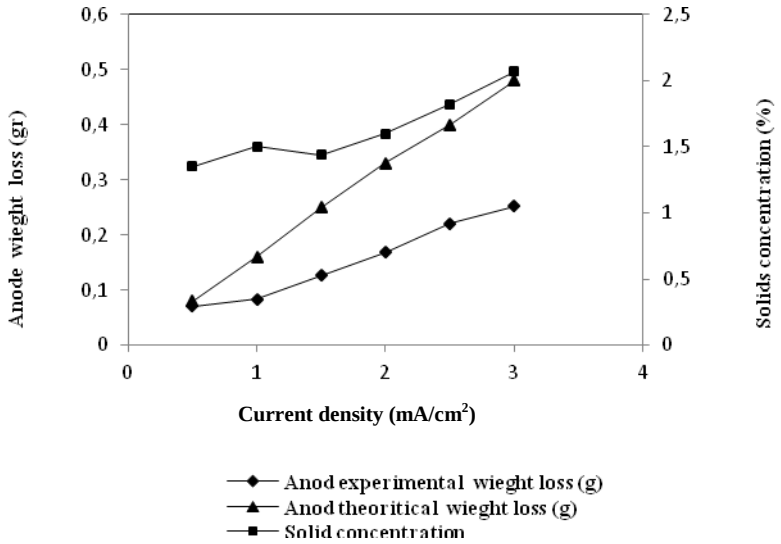


Figure 4. Suspended solids concentration and anode (Fe) weight loss as a function of current densities applied in the ECF

From the results Fig. 4, it is found that the anode weight loss increases with increasing current density between the electrodes. This finding is in agreement with most other researchers [e.g., 11, 22, 23, 26- 29].The theoretical amount of loss in anode (Al) weight was calculated by Eq. (11).

$$\Delta m_{theo} = \frac{MIt_{EC}}{nF} \quad (11)$$

Where M is the molar mass of the aluminum, (g mol^{-1}), t_{EC} the electrolysis time (s), n the number of electron moles and F is the Faraday constant (F=96487C mol^{-1}).

3.1.3. Influence of electrolysis time

The influence of current density between 0.5 and 3 mA cm^{-2} on suspended solids concentration by ECF versus reaction time was investigated. The results are depicted in Fig. 5. The experiment condition was accordance to Table 2. As mentioned above, with increasing current density and electrolysis time, the dissolution of the anode increases, this increases the release of Al^{3+} from anode (Eq. (9)). Therefore as presented Fig. 5, solids concentration increase with increasing electrolysis time and current density. The effect of electrolysis time was more pronounced when the reaction time was elevated from 5 to 30 min, as suspended solids concentration increased from 0.5 to 2.2% at current density of 3 mA cm^{-2} respectively. Trends in this study were consistent with those obtained by some researchers [30, 31].

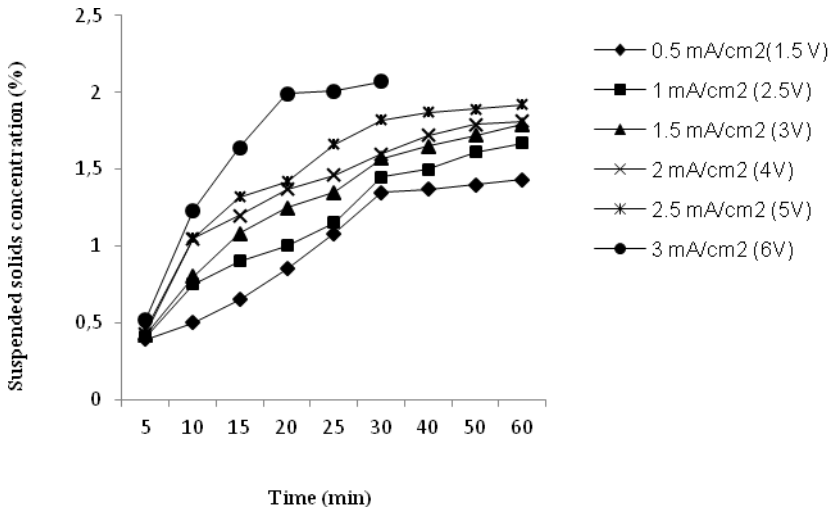


Figure 5. Effect of reaction time on suspended solids concentration in the ECF process (current density=0.5-3 mA cm^{-2}; Al-Al electrode; pH= 6.0; reaction time = 5-60 min).

3.2. Electric energy consumption, Current efficiency and Specific electrical energy consumption

The current efficiency and electrical energy consumption are important economical parameters in ECF process that the major operating cost of electrochemical process is associated with them. The current efficiency (ϕ), electrical energy consumption (E) and specific electrical energy consumption (SEEC) of ECF process were calculated by Eqs. (12) to (14) respectively.

$$\varphi = \frac{\Delta m_{exp}}{\Delta m_{theo}} \times 100 \quad (12)$$

$$E = UIt_{EC} \quad (13)$$

$$SEEC = \frac{nFU}{3.6\times 103 M\phi} \quad (14)$$

Where U is the cell voltage in volt (V), I the current density (A), t_{EC} is the time of EC process in per hour, n the number of electron moles and M is the molar mass of the Al, (g mol^{-1}) [32]. The calculated values are shown in Table 3.

Table 3. Characteristics' parameters calculated for ECF process in optimized condition

Sludge	E (kWh(kg sludge)$^{-1}$)	ϕ (%)	SEEC (kWh(kgAl)$^{-1}$)
Suspended solids concentration	0.03	200	0.2

4. CONCLUSIONS

The ECF process was investigated on the treatment and thickening of biological sludge. The effects of operational parameters such as pH, current density and electrolysis time on removal efficiencies of COD and turbidity and suspended solids concentration were investigated. The COD and turbidity removal efficiencies and suspended solids concentration that were achieved using ECF process were 75.6%, 96.4% and 2.1% after 30 min.The aluminum hydroxide generated in the cell can be decreased the suspended solids concentration present in the biological sludge. The optimal conditions for the process were determined to be [current density] = 3 mA cm^{-2}, [electrolysis time]= 30 min, [mean energy consumption] = 0.03 kWh (kg sludge)$^{-1}$, [current efficiency]= 200%, [specific electrical energy consumption] = 0.2 (kWh(kg Al)$^{-1}$) and [pH] = 6.0. Increase of approximately 2 percent of suspended solids (21000mg higher than of raw biological sludge) and conveying suspended solids of biological sludge equal to concentration of primary sludge can promise efficiency of this process for thickening biological sludge by ECF process.

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