



# Comparison of conventional coagulation and electrocoagulation methods for dewatering of coal preparation plant

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## ABSTRACT

This study compares the results of the dewatering of coal preparation plants tailings by conventional coagulation processes using different types of coagulants and by electrocoagulation methods carried out by two different electrodes. When the results of electrocoagulation and conventional coagulation experiments were compared (aluminium electrode vs. ferric chloride), it was found that the coagulation efficiencies for both methods were similar, in the case that the aluminium electrode was used, there was a 22.2% decrease in the process cost compared to the use of ferric chloride.

## 1. Introduction

Depending on the processes applied in coal processing plants, wastewater containing fine sized solids (coal, clay etc.) is released. In order to prevent wastewater produced in the plant from polluting the environment, it is necessary to remove solids by sedimentation in the wastewater. Solids in suspensions may be removed employing sedimentation methods as in thickeners through flocculation or coagulation. In both cases, it is necessary to use additional chemicals in order to accelerate the sedimentation of particles (Alam et al., 2011; Holt et al., 2002; Burat et al., 2015; Ayyala et al., 1993).

Because of excessive slurry formation, excessive consumption of chemicals and increased water conductivity in the treatment of wastewater with classic dewatering methods particularly after increased environmental concerns and economic considerations, electrochemical methods such as electro-oxidation and electrocoagulation (EC) have been developed (Mollah et al., 2004; Chen, 2004; Kılıç et al., 2009; Özyonar and Karagözoğlu, 2012; Pouet and Grasmick, 1995).

EC system is an electrolytic cell made up of an anode and cathode. As in coagulation, adsorption, sedimentation, and flocculation, the working principle of the EC process depends on anodic dissolution and hydrolysis of metal anodes such as aluminium and iron, and formation of metal hydroxides such as  $\text{Al}(\text{OH})_3$ ,  $\text{Fe}(\text{OH})_2$ , and  $\text{Fe}(\text{OH})_3$  in the environment (Canizares et al., 2005; Mollah et al., 2001).

This study presents the results of an investigation into the purification of wastewater from coal washing plants by conventional coagulation and the EC methods. Furthermore, economic efficiencies of these methods were compared. In order to obtain the best results using EC processes, the parameters such as types of electrodes, pH of the

environment, current density, and treatment duration time were tested while the connection types for electrodes were kept fixed.

## 2. Materials and method

### 2.1. Materials

The sample of coal wastewater was obtained from a private mining company operating in the province of Tekirdağ, Turkey. The sample was taken in the form of slurry from the inlet of the thickener where wastewater of the coal preparation plant was settled out. The solid ratio of the slurry was determined as 3% (w/v), and the representative suspensions were prepared at 3% for the EC experiments. Solid ratio was kept constant in all experiments. The sample contains 69.74% ash, 18.83% carbon and 0.69 total S. In conventional coagulation experiments, aluminium sulphate, iron sulphate and ferric chloride (analytic grades) were used as they are commonly available, while aluminium and iron electrodes were used for the EC experiments. The tap water was used in all experiments.

The chemical analyses for the plants and tap water were performed to determine the cations and anions present in the process and tap water. The results of analyses are presented in Table 1.

The particle size distribution of the sample measured with Malvern Master size 2000 model device (Brookhaven Instruments, Holtsville, NY) showed that  $d_{50}$  was 45  $\mu\text{m}$ .

The results of chemical analyses of the sample are shown in Table 2.

The mineralogical analysis of the waste sample was carried out employing a Rigaku D/Max-2200/PC XRD device. The results revealed that the sample mostly contained lignite, quartz, muscovite,

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**Table 1**  
Chemical analysis results of the process water and tap water.

Ion type	Anions		Cations			
	Cl	SO <sub>4</sub>	Na	K	Mg	Ca
Process water (ppm)	93.5	1537.8	291	17.6	209.4	111.9
Tap water (ppm)	29.1	41.7	19.8	2.5	6.4	45.2

**Table 2**  
Chemical analysis of the sample.

Compounds	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	K <sub>2</sub> O	TiO <sub>2</sub>	Na <sub>2</sub> O	LOI
%	38.07	13.23	7.63	3.02	2.85	2.11	0.53	0.20	30

montmorillonite, chlorite, serpentine, calcite, and dolomite.

## 2.2. Methods

### 2.2.1. Zeta potential experiments

The zeta potential tests were carried out in single distilled water, the process water, and tap water using a ZetaPlus instrument (Brookhaven Instruments, Holtsville, NY) to determine the electrophoretic mobility of charged suspensions. First, about 5 g of the sample was dry ground for 15 min using a mortar and pestle. Then, the ground sample was screened through a 38 μm sieve, and the undersize fraction was conditioned in the water samples (solid ratio 1%w/v) using a magnetic stirrer at 500 rpm for 15 min. Before each experiment, the suspensions were kept for 5 min to allow the coarse particles to settle down. Then, a small amount of suspension was taken from the top of the suspension, and transferred to the measurement cell. Finally, ten measurements were performed, and the average value of the measurements was obtained for the coal particles. An average error of these measurements was about 3%. The experiments were carried out at room temperature (23 °C).

### 2.2.2. Chemical coagulation experiments

Since most of the colloidal substances have negative surface load, coagulation tests were carried out using salts of Al<sup>3+</sup> and Fe<sup>3+</sup> as coagulant. When sulphate and chloride compounds of these elements are added to water they form metal hydroxides. Emerging hydroxides are less soluble and readily precipitate at normal pH values. In the chemical coagulation experiments, the effects of different operational parameters such as type and quantity of reagent, pH of the slurry, mixing time and speed on the sedimentation of the particles were investigated.

The coagulation experiments were carried out in a reactor made of plexiglas with a volume of 1150 cm<sup>3</sup> with dimensions of 150 × 90 × 85 mm. Prior to experiments, the suspension was agitated with a magnetic mixer at a speed of 500 rpm for 30 min.

In order to determine the turbidity of the samples during the coagulation process, the samples were taken below 2 cm of the surface of the suspension at 10th, 20th, 30th, and 60th minutes of the coagulation experiment, and the turbidity values were measured with a turbidimeter in terms of NTU.

### 2.2.3. Electro coagulation (EC) experiments

In the EC experiments, in addition to Plexiglas experimental cell, Echinni-C Model 0–20 A, 0–30 V adjustable DC was used as a power supply. Laser cut aluminium and iron electrodes with dimensions of 50 × 60 × 1 mm were also used. The suspension within the cell was agitated with a magnetic mixer. The electrical measurements within the cell were made with the help of an amperemeter and a voltmeter. In all experiments, the electrode connection types (monopolar electrodes parallel connected), distances between electrodes (2 cm) and

temperature (room temperature) were kept constant. The electrodes were weighed before and after each experiment, the weight differences were noted, and these values were used for cost analysis. The results from the experiments were evaluated along with the turbidity measurements. Turbidity removal efficiency was also calculated using Eq. (1);

$$R(\%) = \frac{T_0 - T_t}{T_0} \times 100 \quad (1)$$

where  $T_0$  is the initial turbidity before the EC and coagulation processes;  $T_t$  is the final turbidity after the sedimentation process.

In the EC experiments, the quantities of dissolved aluminium and iron were calculated by Faraday's law; Faraday's law explains the relationship in terms of current density and quantity of dissolved metal. Faraday's law can be written simply between current density and the amount of substance dissolved as seen in Eq. (2).

$$w = \frac{i \cdot t \cdot M}{n \cdot F} \quad (2)$$

where  $w$  is metal (aluminium or iron) dissolved (g (Al/Fe)/cm<sup>2</sup>);  $i$  is current density (A/cm<sup>2</sup>);  $t$  is time (s);  $M$  is molecular weight of Al/Fe;  $n$  is the number of electrons involved in the oxidation reaction;  $F$ , Faraday's constant, 96,500 C/mol.

In the EC experiments, firstly, the effect of current density was assessed. Current density is a measure of electron density in current circuit. In other words, it is the amount of ions produced in line with average quantity of charged electrons. The current densities of 13.4; 26.8; 40; 53.6; 80.4, and 107.2 A/m<sup>2</sup>, which were generated in connection with current intensities of 0.5; 1; 1.5; 2; 3, and 4 A, respectively, were tested. During these experiments, the electrolysis period was constant as 5 mins; pH (natural pH) at 7.8; mixing rate at 360 rpm, and mixing time for 2 min. The changes in temperature and pH values were continuously recorded during the experiments. The quantities of the electrodes consumed during each experiment were measured, and these values were used for cost analysis.

## 3. Results and discussion

### 3.1. Zeta potential experiments

The results for the zeta potential experiments in deionized water, the process water, and tap water are presented in Table 3.

As seen from Table 3, the samples have negative surface charge in all three types of water. When the conductivity values of the suspension were examined, more conductivity was measured in the process water compared to the others. These results showed that the ionic strength of the process water was much higher compared to others. The negative charge of the particles obtained in the process water explains the effects of especially ionic sulphate species on the zeta potentials of the particles.

### 3.2. Chemical coagulation

#### 3.2.1. Aluminium sulphate [Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>·16H<sub>2</sub>O]

Fig. 1 shows the results of coagulation experiments made with aluminium sulphate.

As can be seen from Fig. 1(a) that as the mixing time of the suspension increased, the turbidity values also increased; and the lowest

**Table 3**  
Zeta potential of the sample in the deionized (DI), tap and process water.

Water type	pH (natural)	Zeta potential (mV)	Conductivity (mS/cm)
DI	6.09	−17.53	0.5
Tap water	7.8	−22.12	1.3
Process water	7.66	−24.17	6.4

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