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## Comparing pretreatment by iron of electro-flocculation and chemical flocculation

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### Abstract

A comparison was made between two technologies: electro flocculation (EF) and chemical flocculation (CF), which may be used as pretreatment in wastewater treatment. Natural water reservoir or wastewater intended for reuse, that contains high concentrations of iron particulates, often requires particle destabilization and removal. These particles can be removed by flocculation process applying ferric chloride (CF) or by Fe<sup>3+</sup> ion (EF) that change to Fe<sup>2+</sup> in a short time. EF, a fairly new environmentally-friendly process has been developed with the aim of reducing, or even avoiding altogether, the amount of chemicals required during pretreatment. The behavior of iron oxide and hydroxide colloid in EF aims at solving the problem of contaminated water or industrial wastewater. In this paper EF with iron electrodes and chemical dosing with ferric chlorides were investigated for several types and different concentrations of iron suspension. The results show a gradual rise in absolute  $\zeta$ -potential and an increase in particle size with flocculation time. The results of both processes were compared through the efficiency of solid/liquid separations performed by sludge sedimentation and filtration. Preliminary testing identified the process conditions, pH of the water treated, dosage of the coagulant, mixing conditions, conductivity, and current density. The target was to find the method which provides optimum coagulation and avoids excessively high energy consumption in EF.

*Keywords:* Advanced wastewater treatment; Jar-test; Chemical treatment; Flocculation; Electro flocculation; Iron coagulation; Water reuse

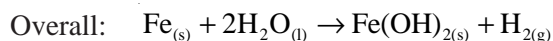
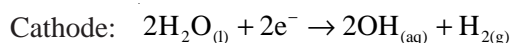
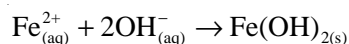
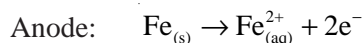
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## 1. Introduction

Dosing with metal salts is currently used in wastewater treatment for the removal of colloids. The electrolytic dosing is followed by colloid flocculation and floc sedimentation [1,2]. It can be applied on natural water reservoirs or industrial waste-water that has large and illegal quantity of iron particles. Practical removal of pollutants from wastewater, enabling it to be recycled, can decrease the use of quality water in industrial application, and additionally, afford the opportunity to use additional natural water reservoirs. Effective separation of those iron particle essentials with particle destabilization and flocculation is commonly used to improve subsequent solid–liquid separation processes such as sedimentation or flotation and filtration [3–5]. EF is achieved by the creation of an electric field between two, generally corroding, electrodes such as aluminum, iron, etc. When a DC electric field is applied, the following electrolysis reaction are expected in the vicinity of the iron electrodes:



Generation of iron hydroxides is followed by an electrophoretic concentration of colloids (usually negatively charged), which are swept by the electric field in the region close to the anode [6,7]. The particles subsequently interact with the iron hydroxides and can be removed by electrostatic attraction. In the region close to the anode, the high concentration of local iron hydroxide increases the probability of colloids coagulation. The iron hydroxides produced by EF or iron dosing depends highly on the iron concentration, pH and the nature of the colloidal suspension [8,9]. In an EF cell, however, surface charges can be neutralized without adding chemicals. By apply-

ing an electrical field, the charged particles are attracted and move to the electrodes. Particles are concentrated there and oriented so that coagulation becomes possible [10,11].

In this paper, EF with iron electrodes is compared to chemical dosing with iron salts following the determination of the optimum operating conditions for each of these processes [7,12].

## 2. Materials and methods

A large number of samples of wastewater from the steel industry served during the primary stage of this research. Thereafter, the research was carried out using calibrated water that was prepared in the laboratory. A conventional jar-test procedure (Fig. 1) was applied at various coagulant dosages (1–3 mg/l) and various pH conditions. The samples' initial pH values were varied by adding NaOH to the raw wastewater prior to coagulant addition. The coagulant was added to six cups, 800 ml each, with raw wastewater and mixed at 100 rpm for 1 min. Puddle speed was adjusted thereafter to 30 rpm to next 20 min. Observation of floc formation were carried out. The slow mixing was stopped and the suspension was allowed to settle for 30 min. Zeta potential was measured by Brookman Zetaplus analyzer on samples drawn from a depth of 4 cm below the water surface of the six cups in a jar-test device following either the EF or CF process. All the experiments were

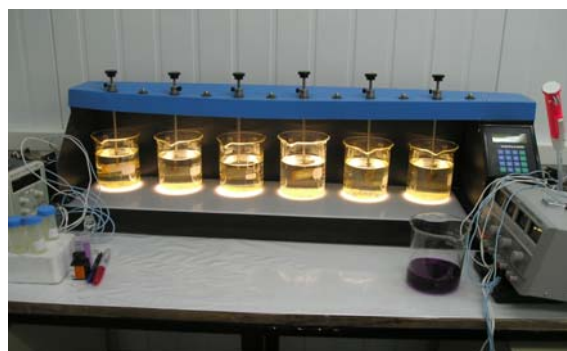


Fig. 1. Jar test used in the experiment.

run under the same conditions: kaolin 20 mg/l as colloid, sodium nitrate for conductivity 0.5 ms, sodium carbonate as buffer and a standard jar-test device. The pH was adjusted to either 4, 6, 7.5 or 9.

After settling, the samples were drawn from 4 cm below the water surface and checked for turbidity, iron particle concentration, zeta potential and particle size.

The flocculants used:

- 1) in raw wastewater — polyacrylamide (anionic) 0.1% concentration;
- 2) in calibrated water — ferric chloride  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  that was added in the first 3 min only;
- 3) in EF —  $\text{Fe}^{3+}$  ions that are generated by electrolytic oxidation that was applied in the first 3 min only.

Particle size and zeta potential were measured by using ZetaPlus and Particle seizer (Brookman Ltd.), in the range of 10–1000 nm.

The jar-test device was fitted to EF by adding two electrodes to each cup (Fig. 2). These electrodes were fitted in a way that allowed the paddle to rotate freely and were connected to a DC power generator. The DC power supply provided current and voltage between the ranges 0–5 A and 0–30 V. In EF, sodium nitrate was used to adjust the suspension conductivity. pH was adjusted to 4, 6, 7.5 and 9 by addition of hydrochloric acid (HCl) or sodium hydroxide (NaOH) and buffer for stability of the pH. The calibrated water used in this research contained 20 mg/l kaolin. All the conditions

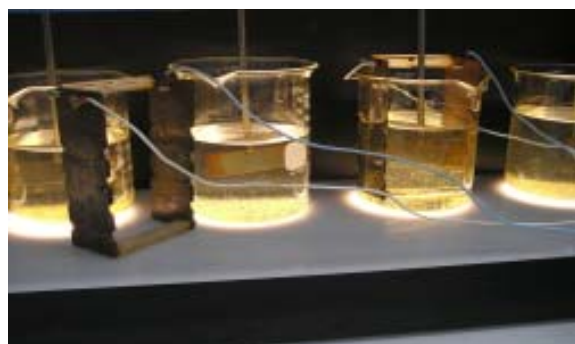


Fig. 2. Jar test device fitted to EF.

of the experiments were the same for CF and EF.

### 2.1. Electrical power and energy consumption

An investigation of energy requirements for EC was performed to avoid excessive energy losses. Apart from EC time, the energy consumption is mainly controlled by the current or voltage, the distance between the electrodes and the resistance in the electrolyte. The main source of energy consumption in EC is generated by the  $RI$ -drop which is expressed through Ohm's law by:

$$U\Omega = RI(d/YA)T \quad (1)$$

where  $R$  is the electrolyte electrical resistance,  $Y$  is the suspension conductivity,  $d$  is the distance between electrodes and  $A$  is the electrolysis surface area of the electrodes. The results confirm that the conductivity increase led to reduced  $RI$ -drop and the interest in adjusting the salinity in EC to avoid excessive energy consumption by the  $RI$ -drop. Some authors have previously highlighted how excessively high suspension conductivity can lead to secondary parasite reactions that replace the main reaction of electrolytic decomposition of the iron electrodes. For conductivity adjusted by sodium nitrate, sedimentation and filterability were effective. Electricity consumption and Faraday's iron concentration in EF were also taken into account. Energy consumption in EF was expressed in kWh/m<sup>3</sup> for each suspension treated. The voltage ( $U$ ), the current ( $I$ ) and EF time ( $t_{\text{EF}}$ ) were registered. A constant current intensity was applied in the tests whilst the voltage remained almost constant during EF. The electrical energy consumed ( $E$ ) was calculated by:

$$E = U \cdot I \cdot t_{\text{EF}} \quad (2)$$

## 3. Results and discussion

### 3.1. Comparison of turbidity and iron removal using CF and EF

Wastewater from the steel industry was the

water that had been used for cleaning iron wire in a production line. Raw wastewater turbidity was 2–3 NTU; pH, 1.6–1.7 and 700–800 mg/l dissolved iron at mixed solubility. The results of iron removal TSS and turbidity, after adding concentrated NaOH to increase the pH and high speed mixing, appear in Figs. 3–5. The changes of the emulsion appeared 10 min after the mixing stopped and after a few minutes, the separation of the iron from the emulsion was very clearly observed. As expected, the iron concentration and suspended solids were very high. The turbidity was low at low pH, but at pH between 5–7.5 the

turbidity became higher and declined again at very high pH. The results show that at pH 1.6–1.8 the iron mixed very well in the suspension so the turbidity was very low, even though its concentration was 600–700 mg/l (very high). At pH 5–8, the iron concentration became close to 100–300 mg/l but the turbidity was the highest. This is a very special behavior.

To examine the effect of pH, the wastewater was adjusted to the desired pH for each experiment by using sodium nitrate or caloric acid (HCl). The results from these preliminary tests of industrial wastewater were used as a base for the tests that were carried out thereafter with calibrated water under similar conditions. The goal was to find the explanation of this behavior and then to find the best conditions for removing the iron and TSS from industrial wastewater in an environmentally-friendly and cost-effective process like EF. The first check was carried out to find the best current density and the results appear in Figs. 6 and 7. Changing of the current density was achieved by

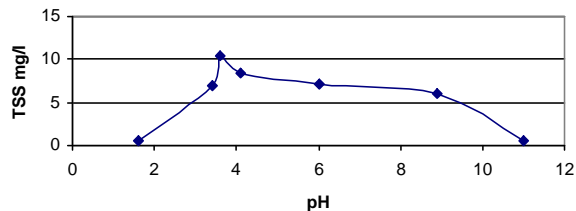


Fig. 3. Change of TSS of industrial wastewater after pH change.

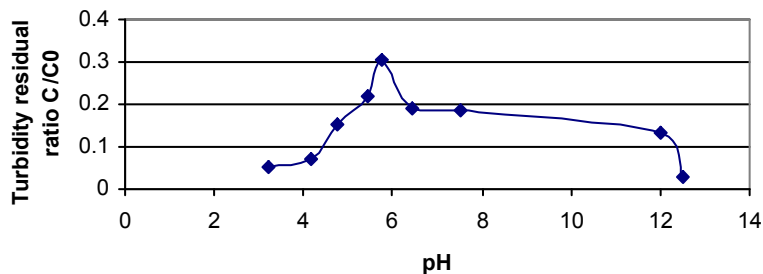


Fig. 4. Change of turbidity of industrial wastewater after pH change.

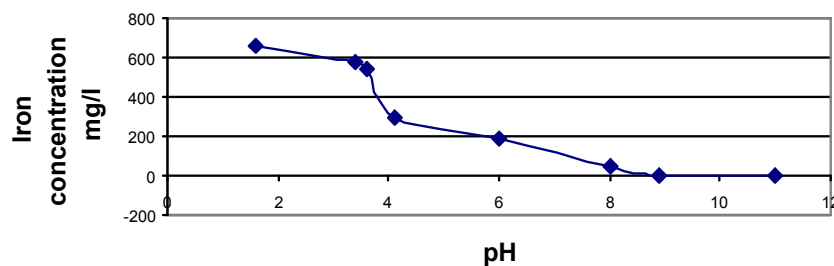


Fig. 5. Change of iron concentration of industrial wastewater after pH change.

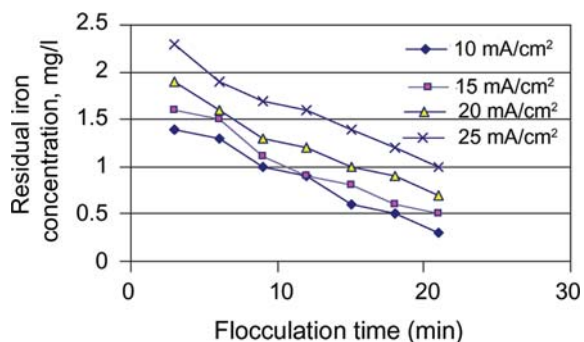


Fig. 6. Change of residual iron concentration at different current densities of calibrated water.

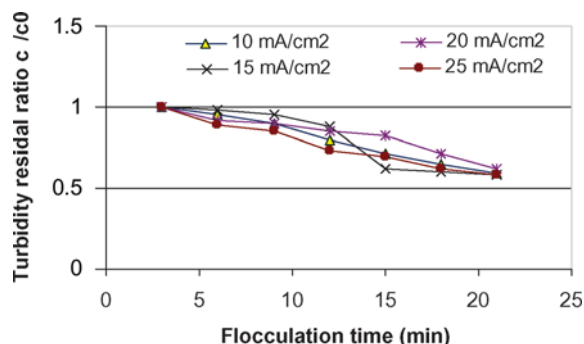


Fig. 7. Change of turbidity residual ratio at different current densities of calibrated water.

increasing or decreasing the voltage on the electrodes. According to these results, the best current density is 25 mA/cm<sup>2</sup>. However, if we take into account the cost of this high current, it seems that the difference, for iron concentration and turbidity, is not so large and therefore, using lower current density is more cost-effective.

The second test was carried out to find the efficiency of the EF under various concentrations of iron. In each of six cups, in the jar-test device, different quantities of FeCl<sub>3</sub> were added to obtain different iron concentrations, and CF processes were applied to find the most effective quantity of iron for the flocculation. The results appear in Figs. 8 and 9.

From these figures it can be seen that the best iron concentration is 1.9 mg/l, the highest that was checked. Applying this concentration in the EF process requires very high current density which means higher costs for the process. After checking the results the most economical yet efficient dose of 0.8 mg/l iron concentration was found to be the best.

### 3.2. Comparison of zeta potential using CF and EF

Figs. 10 and 11 show the variation of zeta potential of calibrated water after EF and CF as a factor of time of the process in the jar test. One

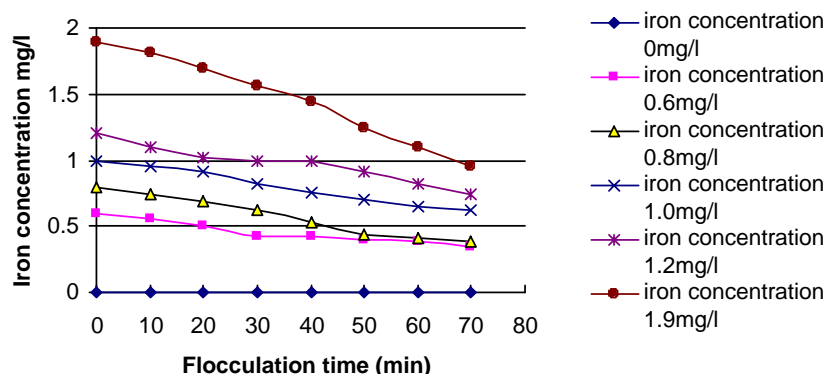


Fig. 8. Change of residual iron concentration after EF of calibrated water.

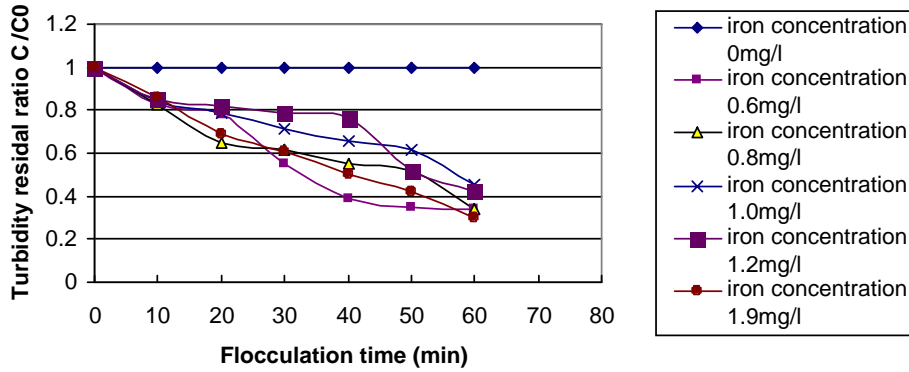


Fig. 9. Change of residual turbidity ratio after EF of calibrated water.

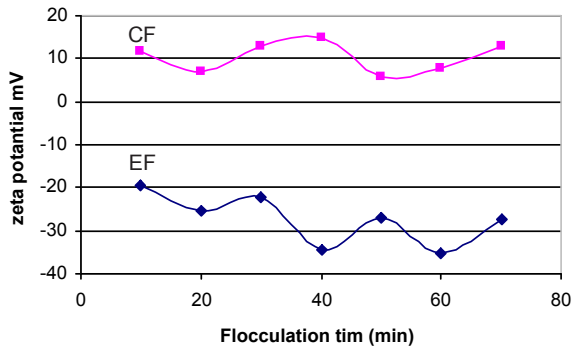


Fig. 10. Change of  $\zeta$ -potential between EF and CF (at pH 5).

can see that the results of zeta potential at pH 4 are different from those at pH 9.

Colloidal iron flocs cause a positive change in the zeta potential at any pH. However, initially a large change in the zeta potential was seen even after a relatively short time of flocculation in EF. While comparing Figs. 10 and 11, it seems that the zeta potential is more negative in EF. The zeta potential of iron colloids decreases with increasing the pH. That phenomenon may be explained by interparticle repulsion of iron colloids in the deposit on the big floc that is produced in

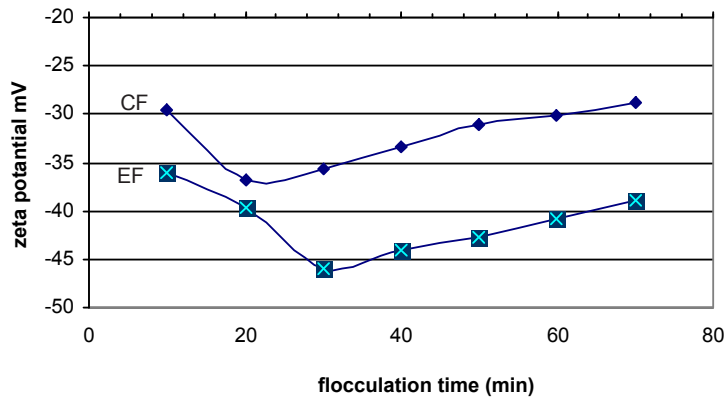


Fig. 11. Change of  $\zeta$ -potential between EF and CF (at pH 9).

flocculation and iron release with increasing pH when breakup occurs. Iron is more soluble at acidic pH so the iron concentration in the solution is larger.

#### 4. Conclusion

Having confirmed the potential of the EF process, the study concentrated on the optimization of the dissolution of ferric ions. The process variables — water pH, current density and duration of reaction. This study emphasizes the interest in EF as an alternative to chemicals to remove colloids from wastewater and water that contains high concentration of iron particles. The results from the comparison of turbidity between CF and EF show better separation at a high current density, but it is more efficient to work at a medium current density ( $0.8 \text{ mA/cm}^2$ ) which also gives good results while being more economical. Zeta potential can be used as an indicator for choosing which process — EF or CF — should be used and the conditions for running the process. The relationship between zeta potential and particle size is recommended for a different study, in order to find the way to get the biggest floc in EF and the ideal conditions for running the process.

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