Scale-up of Electrochemical Units for Mining Waters Treatment

Maria A. Mamelkina[1], Ritva Tuunila[1], Antti Häkkinen[1]

[1]*LUT School of Engineering Science, LUT University, P.O.Box 20 FI-53851, Lappeenranta, Finland*

Abstract

The mining industry is getting more attracted to developing water treatment technologies. The ease with which technology is brought from lab to industrial scale, along with minimizing the time consumption and costs, is influenced by several factors. Some of these depends on the reactor, removal mechanisms, volumes and operating conditions. While others are affected by external factors such as maximum size of the equipment, treatment costs of established or alternative technologies. Scale-up is mainly employed to see if the technology meets the market requirements and expectations. This study focuses on transferring an electrocoagulation process from lab scale to pilot plant.

Keywords: electrocoagulation, scale-up parameters, process development, mining waters

Introduction

Electrocoagulation background

Electrocoagulation, with aluminum and iron electrodes, has been first patented in the US in 1906, while drinking water treatment by electrocoagulation was conducted extensively in the US by 1946 (Chen 2004). However, still nowadays, electrocoagulation of mining waters may belong to TRL 5 to TRL 7, meaning that technology has been already validated, demonstrated and system prototypes already exists. Depending on the mining water content and source, application of electrocoagulation is still hindered and is at the early developing stages (TRL 3 to TRL 5). TRL here refers to the Technology Readiness Level as one of the indicators of a technology maturity level. TRL indicator levels vary from 1 (when basic principles of a process are observed) to 9 (when a technology is proven in an industrial environment). Regarding the mining waters, initially, the suitability of electrocoagulation to remove toxic metals was assessed (Florence 2015,). Later, removal of nitrate and other nitric compounds by electrocoagulation was studied (Lacasa et al. 2011c). One of the latest steps was to develop electrocoagulation for sulfate and cyanide removal by electrocoagulation from mining water (Mamelkina 2020).

Overview of the commercialized electrocoagulation units

While the full-scale industrial application of electrocoagulation for the treatment of mining waters is limited, some pilot units have already been commercialized. One of the latest industrial scale EC-treatment plants was installed in Severnyi Mine, JSC Kola MMC. Iron electrodes were used to remove N-compounds, suspended solids, color and metals (Fe, Cu and Ni). Pilot plants that utilize different electrochemical methods have been designed and tested to remove nitrogen compounds, neutralize water streams and remove toxic metals. Thus, there are several commercialized electrochemical technologies to treat nitrate (NitrEL) and ammonia (AmmEL) rich waters, for example, provided by Current Water Technologies Inc. Also, a solution (AmdEL) to prevent the formation of acid mine drainage using magnesium anodes is also available. The Outotec EWT process is another commercially available technology that is based on electro-oxidation and electrocoagulation for the removal of toxic metals, arsenic, antimony, selenium and other oxyanions. One module's treatment capacity is from 5 to 40 m^3/h, so that the need for the treatment of larger amounts of water can be met by adding more modules. Modular system benefits from the ease of scale-up and reduced

quantity of residues formed, when compared to conventional processes, however, the low conductivity and high solid content of treated water may hinder the process significantly. The Hydro 400 is an electrochemical water treatment unit that is available to treat mining and mineral processing water. One unit is capable of treating 40 m^3/h, and the treatment capacity can be increased by adding more units. When testing the Hydro 400 unit, case studies that were performed proved the suitability of EC-treatment to the removal of phosphorous, suspended solids, lead, iron and aluminum from contaminated water. The application of a Hydro 400 unit to treat mining waters resulted in a 15% cost reduction, compared to chemical coagulation and other conventional treatment methods. The Soneco® water treatment system by Power & Waters is based on the combination of ultrasound and electrolysis for the efficient removal of phosphorous and toxic metals, as well as for the neutralization of the acid mine drainage. Soneco® units benefit from a cleaning-in-place tool that provides electrode cleaning by ultrasonic cavitation, prolonging the lifetime of the equipment and affecting dramatically the operation costs. FCC Aqualia has been recently working on the application of electrocoagulation and bio-electrochemical processes to coprecipitate phosphorus and nitrogen. The main distinction of this process, when compared to the others mentioned, is that it produces biogas as a potential power source and benefits from the possible valorization of generated sludge containing aluminum, phosphorous and nitrogen as a fertilized.

Scale-up and design issues

Electrocoagulation process is classified as difficult but quantifiable or very difficult and rarely quantifiable. On one hand, the reactor geometry makes the process easy to scale-up. On the other hand, the electrochemical principles involved and especially the contaminant removal mechanisms hinder the scale-up of electrochemical water treatment processes crucially.

There are two main rules to consider in the design and scale-up of electrochemical reactors. The first concerns the optimal design of the cell and the other is devoted to the reaction mechanisms involved in the process. Among the most reported and significant scale-up parameters for electrocoagulation process is the relation of the surface area to volume ratio (S/V). The S/V ratio is mainly related to the current density, rate of coagulant dosing and bubble production; however, the flow regime and reactor configuration are not considered.

The cell design used for electrocoagulation processes varies greatly from applying open tanks, parallel plate cells or complex designs with moving electrodes. The choice of electrode material and shape, reactor configuration, operation mode and electrode arrangement are the key parameters, especially at the initial stage of process development. Electrode material affects the amount, and type, of metal ions in the solution, coagulation efficiency and process costs, while the reactor configuration influences the fluid flow regime, bubble paths, mixing/settling characteristics and mass transfer (Chopra 2001). The operation mode influences process performance, energy consumption, while electrode arrangement allows the minimization of energy consumption and improvement in the removal of contaminants (Zhou 2018).

Most of the research to date was performed using a monopolar connection of electrodes, very few studies have been performed using a bipolar connection arrangement. In the latter condition, it is possible to have better performance and lower energy consumption, however, bypassing of electrodes and loss of charge may occur.

The major distinctions between different the electrocoagulation reactors are their configuration and operation mode. A design may be presented as a batch or a continuous system. On one hand, the latter mentioned system has, as advantages, a continuous feed of wastewater and operation under (pseudo) steady-state conditions. One of the key advantages of continuous systems is that the coagulant demands are substantially fixed. On the other hand, a batch system maintains a fixed wastewater volume per treatment cycle. However, the main disadvantage is the change with time of operating conditions within the reactor (Holt 1999). The operation

mode mostly affects the performance, reliability and chemical interaction within the EC-process.

In all cases, the cell design should provide uniform current and potential distributions that promote the optimization of parameters such as energy consumption, coagulant production and process performance. In addition, it is desirable that the equipment should meet the requirements of low cost material for manufacturing, ease of maintanance, installation and operation as well as the possibility for scale-up.

In this paper process development and scale-up stage for electrocoagulation treatment of mining waters are decribed. Different operation modes, various cell designs and process conditions were assessed during the work. This paper contains data on sulfate andcyanide removal, however, the removal of other nitric compounds as well as toxic metals has been evaluated elswhere (Mamelkina 2020).

Methods

Current work focus was on switching from batch operation to continuous, process design and treatment of over 200 L of water. In this work both tank (1 L and 70 L) and parallel-plate flow electrochemical cells were utilized to treat mining waters. With the application of parallel-plate flow cell, both batch-recycle (3 L) and continuous (200 L) single pass modes were tested. The dimensions of electrodes for tank cells were 60×70×2 mm (resulting in total anode area of 168 cm^2) for 1 L reactor and 300×300×5 mm (resulting in total anode area of 3600 cm^2) for 70 L reactor. The dimensions of electrodes for parallel-plate flow cell were 100×100×2 mm (resulting in total anode area of 100 cm^2).

During tests both synthetic and real mining water samples were used. More details about the experimental procedure, operating parameters, contaminants concentrations and analytical procedure can be found (Mamelkina 2020).

Results and discussion

When developing an electrocoagulation process to treat mining waters, firstly, chemical coagulation tests were performed using sulfate and cyanide rich waters. At that stage, the coagulation mechanisms, required amount of coagulant and chemical coagulation performance have been studied. The highest sulfate removal of 81% was observed at pH 2 and iron coagulant , when cyanide removal did not exceed 15% with both iron and aluminum coagulants. Second step devoted to the batch lab scale electrocoagulation using tank (1 L) and parallel-plate flow (3 L) cell. At that stage performances of chemical coagulation and electrocoagulation were compared. Removal mechanisms and kinetics were studied, operation parameters and cell's configurations were evaluated. The highest sulfate removal was 54% when using tank cell at final pH 11, 3 A and iron electrodes. Operation with parallel-plate cell at batch conditions resulted in the highest sulfate of 18% at pH 2. Almost complete cyanide removal was observed using both tank and parallel-plate cells equipped with iron electrodes. The third step in scale-up of electrocoagulation process was performed using 70 L batch tank reactor and parallel-plate cell treating 200 L of real mining

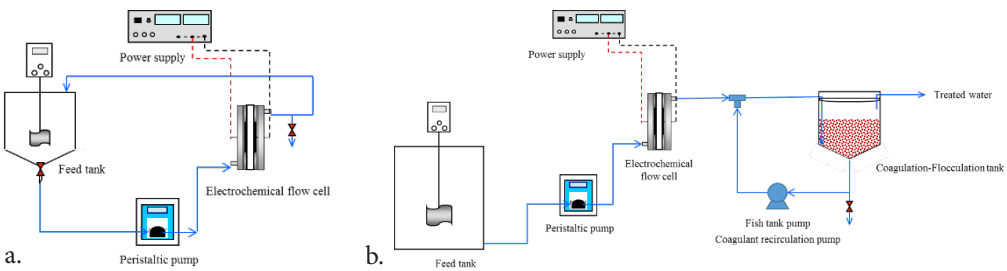

Figure 1 Schematic diagram of electrocoagulation process operating in a. batch and b. continuous modes using parallel-plate cell.

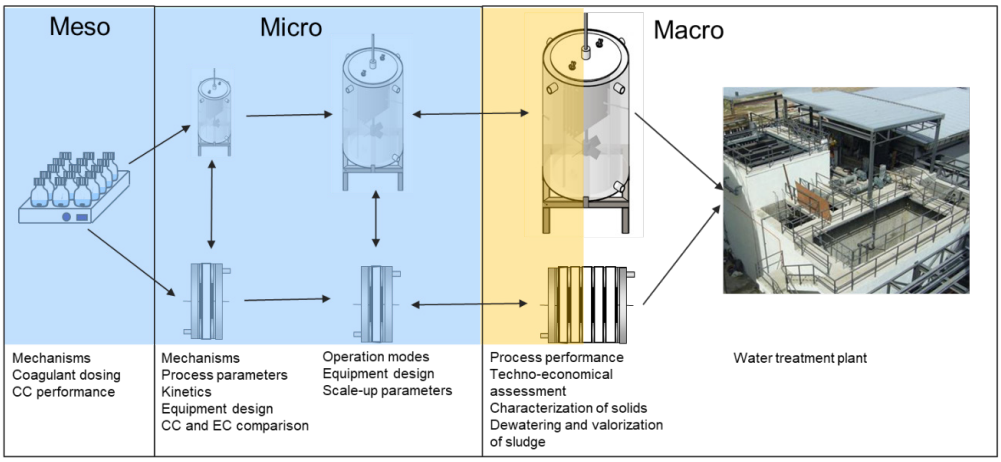

Figure 2 *Stages of process development and scale-up for the electrocoagulation of mining waters at meso. micro and macro levels, blue color – completed stages, yellow color – present stage.*

water. Scale-up parameters were determined, and operation modes were compared at this step. Sulfate was removed up to 50% in 1 L tank cell and up to 30% in 70 L tank cell with aluminum electrodes, using current density as a scale-up parameter. The highest removal of sulfate during continuous operation with parallel-plate cell was 70% at pH 2. The process development and scale-up stages are summarized in Fig. 2.

$$j = \frac{I}{S} \quad (1)$$

$$Q = \frac{j}{q} \cdot S \quad (2)$$

During scale-up of a tank cell, current density was chosen as a scale-up- parameter, however, later it was found that the amount of solids generated was the most reliable scale-up parameter. When developing a novel process design based on continuous operation and solids recirculation, the electric charge passing through the system was switched from batch operation to continuous, and this is proposed as one of the scale-up parameters. It should be highlighted that in this arrangement, electric charge depends on the intensity and flowrate, q, but not on time. The electric charge, Q, has been calculated using Eq. 2 based on the current density, j, (Eq. 1) that was similar for both batch and continuous operations. Where, I – current, S – anode area.

Conclusions

There are several reasons why understanding of scale-up might be needed at different stages of process development, such as studying the economic feasibility (pilot plant, demonstration plant), determination of bottlenecks of the technology (miniplant, pilot plant) and commercializing a new process. All in all, scale-up is mainly employed to see if the technology meets the market requirements and expectations. Even though the electrocoagulation treatment of mining waters has not been yet assessed from techno-economical point of view, the most suitable reactor configuration as well as process operation and scale-up parameters are proposed. Thus, based on the results parallel-plate electrode configuration and operation at continuous mode are recommended. The ease in scale-up of parallel-plate cells makes the utilization of those appealing for industrial application. Electric charge is suggested as one of the main scale-up parameters when switching to different operation modes and when increasing the scale-up level.

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