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Copper and nickel removal from plating wastewater in the electrodialysis process using a channeled stack

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Abstract. Electrodialysis (ED) is an advanced separation process used to treat industrial wastewater using potential differences. In this study, flow rates within the stack were increased by creating a flow channel to increase the limiting current density (LCD). Increasing the flow rate within the stack increases the diffusion flux, which leads to an increase in LCDs. Experiments show that the applied voltage of the flow-accelerated stack was improved by 12.2% compared to the stack without a flow channel, but the LCD decreased by 3.6%. The removal efficiency of both copper and nickel between the two stacks was greater than 95.6%, with no significant difference. However, the concentration rate of ions was superior in the stack without a flow channel. This may be attributed to the fact that the applied voltage increases when the channel is attached, resulting in differences in the separation rate and the resulting concentration polarization. In terms of the current efficiency, the channel-less stack was found to be 42.5% better than the channeled stack. It would be desirable to apply voltages below the LCDs as those exceeding LCDs at the same membrane flow rate would significantly reduce the economic feasibility.

Keywords: channeled stack; current efficiency; economic feasibility; electrodialysis; limiting current density

1. Introduction

Organic and inorganic ions are present in most industrial and urban wastewater along with natural freshwater. In some cases, these ions need to be concentrated and recovered or completely removed (Zhang *et al*. 2012). High concentrations of various metals present in industrial wastewater can cause serious environmental pollution if not properly treated (Fu *et al*. 2011, Malamis *et al*. 2012). The electroplating industry wastewater contains various types of toxic substances such as cleaning agents, heavy metals, and solvents. Among these, metallic substances such as copper and nickel are dangerous, especially when discharged without treatment (Akbal and Camcı 2011, Lee *et al*. 2017). Therefore, a variety of removal methods have been developed, including chemical precipitation/coagulation, membrane technology, electrolytic reduction, ion exchange, and adsorption (O'Connell *et al*. 2008).

Recently, ion exchange, reverse osmosis, nanofiltration, and electrodialysis (ED) have been proposed as technologies for the separation and concentration of ions (Strathmann 2010, Nakayama *et al*. 2017, La Cerva *et al*. 2018, Min *et al*. 2019, Oh *et al*. 2020). ED consists of electrodes, spacers, and ion exchange membranes arranged in a way that has more than one separate stream. In ED, ions are separated by the potential differences of the two electrodes at either end of the ion exchange membrane system (Koutso *et al*. 2007, Silva *et al*. 2013, Iváñez Mengual *et al*. 2015). The rate of separation of ions depends on the charge and mobility of each ion, conductivity of the ionic solution, relative concentration of ions, and applied potential difference. Additionally, the results of ED also depend on the design parameters such as the flow rate, configuration, and structure of the cells and spacers (Lee *et al*. 2006, Silva *et al*. 2013, Min *et al*. 2020).

These parameters affect the current utilization and concentration polarization (Lee *et al*. 2002). Concentration polarization in ED occurs at the surface of the ion-exchange membrane. In general, the transport number of counter-ions is one and the transport number of co-ions is zero in ion-exchange membranes (Strathmann 2010). As the ion concentration in the ion exchange membrane is lower than that in the diluate, the ion concentration in the diluate solution decreases. Eventually, the electrolyte concentration at the membrane surface decreases, resulting in a concentration gradient between the membrane surface and well-mixed bulk fluid, resulting in the diffusion of electrolyte transport. A steady-state is obtained when the additional ions needed to balance those removed from the ion-exchange membrane surface are supplied by the diffusion transport. However, when the ion concentration of the diluate on the surface of the ion exchange membrane becomes zero, the current density approaches its maximum value, which is thus defined as the limiting current density

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