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ORIGINAL ARTICLE

Improving the rate of Cu^{+2} recovery from industrial wastewater using a vertical array of reciprocating perforated zinc discs

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Abstract This work investigates the possibility of improving the rate of Cu^{+2} recovery and/or removal from industrial wastewater by cementation technique using an array of pulsating horizontal perforated zinc discs. The results show that the rate of cementation was found to increase by increasing frequency and amplitude of oscillation (vibrating velocity); disc diameter; copper ion concentration and solution temperature while decreasing by increasing the disc separation. Under certain conditions using pulsating array of perforated zinc discs was found to increase the rate of mass transfer by a factor of 17 times the stagnant discs. The activation energy of the reaction was found to be 8.948 kcal/mol which indicates that under the present conditions cementation takes place under mixed control, i.e. the reaction is partially diffusion control. As such no overall mass transfer correlation could be obtained.

1. Introduction

Cementation out of the conventional methods of recovery of metals such as, electro-winning from aqueous or fused salt baths, gaseous reduction chemical precipitation of metal compounds has been proved for its advantage of its suitability for recovery of value from very dilute solutions. Cementation relies on the theory that a more electropositive metal ion in solution, when brought into contact with positive metal, is displaced from the solution and cemented on the latter method to the following equation:

$$mN^{+n} + nM_{(s)} = nM^{+m} + mN$$

where N and M represent the noble metal the reductant one respectively; n and m are its valences respectively. It is importance in the recovery of metal values from metallurgical wastes and/or ores were discussed in many researches [1–5]. Copper ions, as a pollutant, do not accumulate in body in massive amounts, though copper can cause illness or even death. Many attempts have been made for improving the rate of cementation and reducing both time and power consumption, some

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Nomenclature

A_m	amplitude of oscillation (cm)	k	rate of mass transfer (cm/s)
A	active surface area of the perforated zinc disc (cm^2)	R	gas constant (J/mol K)
A_o	constant at Arrhenius equation	t	time (s)
C	$CuSO_4$ concentration at any time t (mol/l)	T	absolute temperature (K)
C_o	initial $CuSO_4$ concentration (mol/l)	Vi	vibrating velocity (cm/s)
D	Cu^{+2} diffusivity (cm^2/s)	V_s	solution volume in the reactor (cm^3)
f	frequency of oscillation (s^{-1})	μ	solution viscosity (g/cm s)

studied the effect of certain surfactants [1,2], gas sparging [3] and ultrasound [6] to reduce process time. This work investigates the possibility of enhancing the performance of a batch reactor used for the removal and/or recovery of copper ions from industrial effluents using an array of pulsating perforated zinc discs. Recently surface vibration (oscillation) has received a great attention as a tool for enhancing the rate of mass transfer in diffusion controlled processes. Tojo et al. [7] who studied the effect of vibratory agitation on the rate of mass transfer using a reciprocating perforated disc came to the conclusion that vibratory agitation needs less energy than rotary agitation for the same degree of mixing. Kalantary et al. [8] studied the effect of vibratory agitation on the rate of metal deposition during electroplating in a cylindrical cell using perforated disc, the authors reported that vibratory agitation increases the rate of metal deposition by a factor ranging from 3 to 20 depending on the operating conditions. Mubarak et al. [9] found that disc reciprocation has increased the rate of cementation of copper on reciprocating horizontal perforated zinc disc by a factor ranging from 2.8 to 5.5 compared to cementation on stagnant disc. Elshazly [10,11] in his investigations for the rate of copper recovery from industrial wastewater by cementation using pulsating zinc cylinders and pulsating vertical parallel plates, found that pulsation has increased the rate of cementation by a factor ranging from 2.5 to 5 and from 2.75 to 4.8, compared to stagnant cylinders and stagnant plates respectively. The present work seeks to test the performance of oscillating perforated zinc disc in removing copper ions by cementation from a synthetic solution which simulates industrial waste solutions such as electroplating rinsing solutions and printed circuits industries. The study covered a wide range of conditions which include the effect of initial copper ions concentration, frequency and amplitude of pulsation, disc separation, disc diameter and solution temperature.

2. Experimental part

Fig. 1 shows the experimental setup used in the present study. It consisted of the vibrating system and the reactor which consisted of a multilayer of reciprocating perforated zinc discs. Different disc diameters ranging from 6 to 12 cm and different disc separations ranging from 1 to 2.5 cm were used, and the amplitude of oscillation was changed from 1 to 4 cm. The oscillation intensity was expressed by the vibration intensity (Vi) where $Vi = 2A_mf$. The number of zinc discs, disc perforation diameter and its thickness were kept constant at 4, 0.5 mm and 1 mm respectively. For finding out the nature of cementation reaction under the above mentioned conditions the effect of solution temperature was investigated in the range from 25 to 40 °C and hence the activation energy was determined using Arrhenius equation. The multilayer perforated zinc discs were placed in a Plexiglas column of 20 cm diameter and 40 cm height. The layers were held inside the column by insulated stainless steel stem of 3 mm diameter which penetrated the discs at its centres. The stem was fixed to the top (vibrating system). The upper end of the stem was connected to the vibrator through a Teflon sleeve. Vertical oscillation was induced to the zinc layers by means of a mechanical vibrator connected to the upper end of the stem. The mechanical vibrator was described by the author in previous investigations [9–12]. The rate of cementation of copper on zinc was followed by measuring the change in concentration of Cu^{+2} with time. Before each run, 4 l of fresh $CuSO_4$ solution was placed in the column, in the mean time the solution was subjected to oscillation at the required vibration intensity. Samples of the solution (5 ml) were withdrawn at regular time intervals. The intervals ranged from 2 to 3 min at high and low vibration intensities respectively. The samples were analysed by spectrophotometric analysis. The mass transfer coefficient was calculated from the concentration time data as shown in Fig. 2. Four different $CuSO_4$ concentrations were used ranging from 0.02 to 0.3 M. All solutions were prepared using AR chemicals and distilled water. A digital portable pH meter was used to measure the

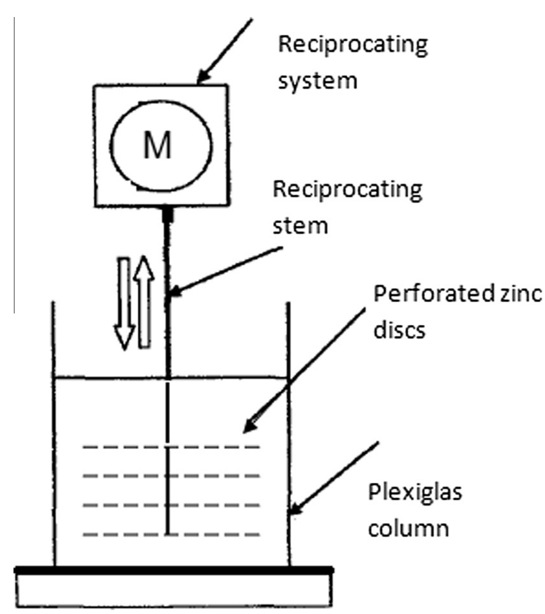

Figure 1 Experimental setup.