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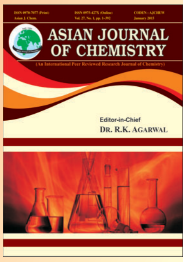

Effect of Magnetic Field on Rate of Production of Nickel Powder from Nickel Solution by Cementation of Zinc

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The effect of magnetic field on the rate of cementation of nickel from nickel sulphate on zinc was studied. Variables studied were nickel sulphate concentration and magnetic field intensity. It was found that the rate of nickel cementation increases significantly with increasing the intensity of magnetic field and percentage of increase in the rate of cementation ranges from 16.6 to 122 %. Results were explained on the basis that the application of magnetic field produces magneto hydrodynamic flow which enhances the rate of cementation.

Keywords: Cementation, Zinc, Nickel, Mass transfer, Magnetic field.

INTRODUCTION

Cementation is one of the most effective and economic techniques for recovering toxic and/or valuable metals from industrial waste solution[1]. Cementation is also used in purifying leach liquor prior to electrowinning of metals[2]. It consists in displacing the metal from its solution by a less noble metal which is usually low-cost and nontoxic. Some work[3-6] has been done on the factors affecting the rate of cementation such as geometry of the less noble metal surface, temperature, concentration of the metal ions and stirring. These studies have revealed that cementation is a diffusion controlled reaction. In industry magnetic fields exist as a result of using electrical machines such as motors, generators transformer *etc*. Previous studies have shown that magnetic field affects the rate of metal corrosion[7,8], the rate of the electrodeposition of metals[9-17] and the quality of the deposit[18,19].

There are several methods that can remove nickel ions from solutions such as chemical precipitation, ion exchange adsorption, reverse osmosis and electrodialysis. All of these methods have drawbacks, *e.g.* chemical precipitation requires extremely long settling times; both ion exchange and carbon adsorption are very expensive and may require frequent regenerations for adequate performance. Reverse osmosis and electrodialysis require expensive equipment and have high operating costs[20].

The advantages of the cementation process include: (i) high process efficiency and permitting practically complete removal or detoxification of heavy metals; (ii) high process rate; (iii) simplicity of treatment facilities; (iv) recovery of most metals in pure metallic form and (v) a relative absence of sludge. Since inexpensive scrap metals can be used, process operational costs can be kept low. Most of the industrial cementation processes use metal powder within stirred tank reactors. Their major interests a low-energy requirement, an easy control and a frequent removal of the metallic species under its metal form[21,22]. The aim of this work to study the effect of magnetic field on the rate of cementation of nickel on zinc metal.

EXPERIMENTAL

The apparatus showed in Fig. 1 consists of 250 mL glass beaker containing 200 mL nickel sulphate solution in which a zinc cylinder of 1 cm diameter and 7 cm height is immersed. The glass beaker was surrounded by a magnetic coil connected in series with 6 volt d.c. power supply, a rheostat and a multi-range ammeter. The strength of magnetic field was varied by changing the current passing through the circuit.

The magnetic flux density was calculated from the current passing through the circuit using the equation:

$$B = \mu_o n_o I \qquad (1)$$

where B is the magnetic flux density in tesla, μ_o is the magnetic permeability constant ($4\pi \times 10^{-7}$ Weber/amp. m), n_o is the number of turns per unit length and I is the current passing through the circuit in amperes.

The rate of cementation of nickel on zinc was determined by analyzing the residual nickel solution after 80 min of cementation. Nickel solution was analyzed by titration[23].

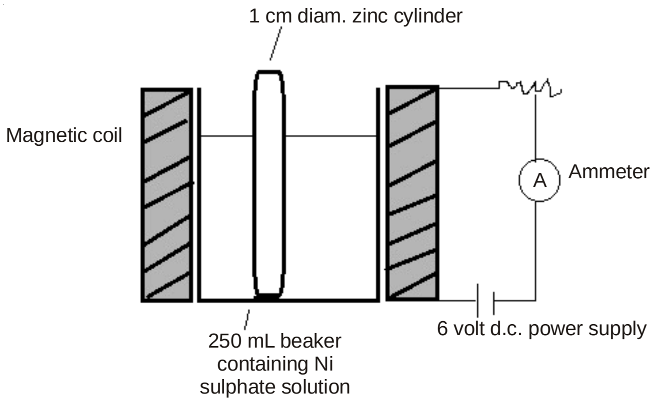

Fig. 1. Experimental apparatus

Each experiment was carried out twice using a fresh solution and a fresh zinc cylinder. All chemicals were of A.R. grade, all solution was prepared using distilled water. Temperature was 23 ± 1 °C during all experiments. Before each run the flat end of zinc cylinder was isolated with epoxy resin.

RESULTS AND DISCUSSION

The cementation reaction is diffusion controlled reaction whose rate in a bath reactor can be represented by equation[2,4]:

$$Ni^{2+} + Zn = Ni + Zn^{2+} \quad (2)$$

$$-V(dc/dt) = KAC \quad (3)$$

which integrated to

$$V \ln (C_o/C) = KAt \quad (4)$$

where V is the volume of solution containing Ni^{2+}, C_o is the initial concentration Ni^{2+}; C is the concentration of Ni^{2+} at a time t; K is the mass transfer coefficient; t is the time of cementation.

Eqn. 4 was used to calculate the mass transfer coefficient of nickel cementation on zinc under different conditions. Fig. 2 and Table-1 give the relation between log C_o/C and time for different concentration of Ni^{2+} at 25 °C before used magnetic field intensity. Table-1 gives the values of mass transfer coefficient in presence of magnetic field intensity.

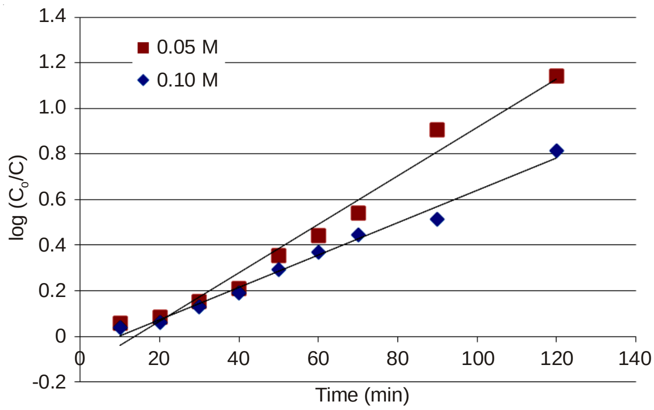

Fig. 2. Relation between log C_o/C against time (min) at 25 °C using different concentration of Ni^{2+}

TABLE-1
RELATION BETWEEN log C_o/C AND TIME AT DIFFERENT CONCENTRATIONS OF Ni^{2+}

Time	0.05 M	log (C_o/C)	0.1 M	log (C_o/C)
0	0.097	–	0.098	–
10	0.085	0.057	0.090	0.037
20	0.080	0.084	0.085	0.062
30	0.068	0.154	0.073	0.128
40	0.060	0.209	0.063	0.192
50	0.043	0.353	0.050	0.292
60	0.035	0.443	0.042	0.368
70	0.028	0.540	0.035	0.447
90	0.012	0.908	0.030	0.514
120	0.007	1.142	0.015	0.815

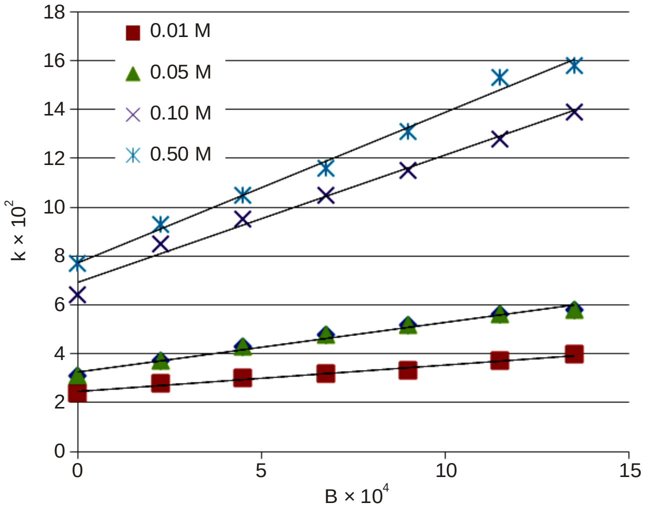

Fig. 3. Effect of magnetic field intensity on rate of Ni removal at 25 °C

TABLE-2
EFFECT OF MAGNETIC FIELD INTENSITY ON RATE OF Ni REMOVAL AT 25 °C

Magnetic field intensity Tesla. 10^4 (B)	Values of rate constant at 25 °C and different $NiSO_4$ concentration			
	0.01 M	0.05 M	0.10 M	0. 50 M
	K × 10^3			
0.00	2.4	3.1	6.4	7.7
2.25	2.8	3.7	8.5	9.3
4.50	3.0	4.3	9.5	10.5
6.75	3.2	4.8	10.5	11.6
9.00	3.3	5.2	11.5	13.1
11.50	3.7	5.6	12.8	15.3
13.50	4.0	5.8	13.9	15.8

Fig. 3 and Table-2 show the effect of magnetic field intensity on the mass transfer coefficient of nickel cementation on zinc. For all nickel concentrations the mass transfer coefficient increases linearly with the magnetic field intensity, the data can be represented by equation:

$$K = a + bB \quad (5)$$

where a, b are constants depending on Ni^{2+} concentration. Table-3 and Fig. 4 show that the % increase in the rate of cementation in presence of magnetic field ranges from 16.6 to 122.5 %.

The increase in the rate of cementation in the presence of magnetic field can be explained as follows:

As a result of deposition of nickel on the zinc surface the solution in the immediate vicinity of the zinc surface becomes less concentrated in nickel ions than the bulk solution[24-26]. This difference in concentration gives rise to the formation of a

TABLE-3
EFFECT OF MAGNETIC FIELD INTENSITY ARE % INCREASE IN THE RATE OF CEMENTATION AT DIFFERENT NiSO$_4$ CONCENTRATION AT 25 °C

Magnetic field intensity Tesla. 10^4 (B)	% Increase in the rate of cementation at different NiSO$_4$ concentration at 25 °C			
	0.01 M	0.05 M	0.10 M	0. 50 M
	Acceleration (%)			
2.25	16.6	19.3	32.8	31.0
4.50	25.0	38.7	48.4	48.0
6.75	33.3	58.1	64.0	63.3
9.00	48.8	67.7	79.6	84.5
11.50	54.2	77.5	100.0	118.4
13.50	67.0	87.1	117.1	122.5

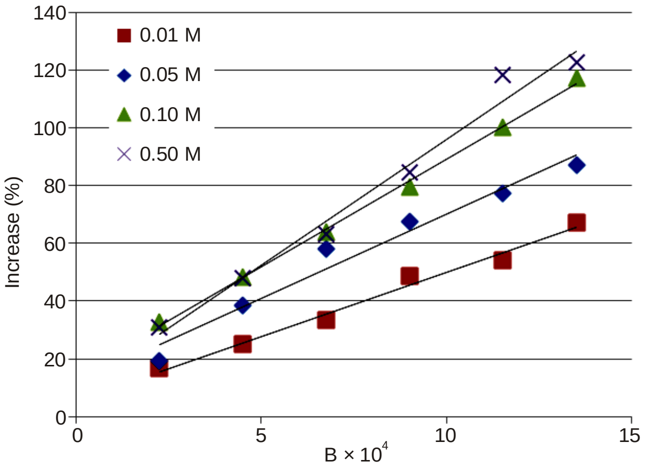

Fig. 4. Effect of magnetic field intensity on the % increase in the rate of cementation at different NiSO$_4$ concentrations at 25 °C

diffusion layer at the zinc cylinder across which nickel ions diffuse from the bulk solution to the zinc surface to sustain the cementation reaction.

In the presence of magnetic field, solution flow takes place at the zinc surface by virtue of Lorentz's force[27-29].

This force exists as a result of the interaction between the magnetic field and the electrical field which is established at the zinc surface due to the formation of the following galvanic cell through which cementation takes place:

$$Zn \mid Zn^{2+} \vdots Ni^{2+} \mid Ni$$

Solution flow at the zinc surface induced by Lorentz's force increases the rate of transfer of nickel ions to the zinc surface and enhances the rate of cementation. Solution flow may further enhance the rate of cementation if the nickel deposit is highly rough. According to Levich when a fluid flows past a roughness element, eddy formation takes place in the wake of the roughness element[30,31] with a consequent increase in degree of stirring and rate of cementation. The interaction between surface roughness resulting from the deposition of nickel powder on the zinc surface and the induced flow is likely to take place when the particle size grows sufficiently and extends beyond the diffusion layer[32] *i.e.* this effect does not exist in the early stages of cementation.

The present finding that magnetic field application enhances the rate of cementation is consistent with the finding of other authors who studied the effect of magnetic field on the rate of electrodeposition of metals. Fahidy *et al.*[27,33] found that the limiting current of copper electrodeposition increases with increasing the intensity of magnetic field. Cousins *et al.*[30] found that magnetic field application increases the current efficiency of chromium electrodeposition. In area of corrosion, Terlain and Dufrenoy[34] reported an increase in the rate of corrosion under the influence of magnetic field.

Conclusion

The increase in the rate of cementation causes by magnetic field effects as revealed by the present work underline the importance of magnetic field as a competitive tool for enhancing the rate of diffusion controlled processes. However, before recommending the use of magnetic field in practice, a study should be conducted on a pilot plant scale to assess the economic feasibility of using magnetic field as a tool for enhancing the rate of diffusion controlled processes in comparison to other methods such as mechanical stirring.

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