

## Nickel (II) Removal from Aqueous Solutions by Adsorption on Fly-ash

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### ABSTRAK

Kemungkinan pengestraktan Ni(II) dari air melalui penyerapan ke atas "fly-ash" telah dikaji. Data keseimbangan bagi pengestraktan Ni(II) yang didapati itu mengikuti persamaan Langmuir dengan baik. Pengiraan muatan erapan ekalapisan memberikan nilai 0.293 mg g<sup>-1</sup> pada 30°C. Kinetik penyerapan kelompok mengikut tindak balas tertib pertama dan tindak balas penyerapan itu ialah terkawal pembauran. Nilai bagi koefisien pemindahan jisim dan pembauran liang adalah 1.14 × 10<sup>-5</sup> cm s<sup>-1</sup> dan 6.2 × 10<sup>-11</sup> cm<sup>2</sup> s<sup>-1</sup> pada 30°C. Kesan kepekatan awal nikel, jangka masa terendam suhu dan pH ke atas proses penyerapan telah dikaji. Kenaikan suhu dan pH serta kekurangan kepekatan menambahkan pengestraktan nikel oleh "fly ash". Penjerapan maksimum ion Ni (II) didapati pada pH 7.0. Parameter termodinamik telah dikenal pasti bagi sistem ini. Model empiris bagi kinetik pengestraktan Ni (ii) melalui penyerapan ke atas "fly ash" dan parameter bagi perjalanan berterusan proses pengestraktan telah ditentukan.

### ABSTRACT

The feasibility of Ni(II) removal from water was investigated by adsorption on fly-ash. The equilibrium data of Ni(II) removal thus obtained is well fitted to Langmuir equation. The monolayer adsorption capacity was calculated and found to be 0.293 mg g<sup>-1</sup> at 30°C. The batch adsorption kinetics follows first order reaction and appears to be diffusion controlled. The values of mass transfer and pore diffusion coefficients were 1.14 × 10<sup>-5</sup> cm s<sup>-1</sup> and 6.2 × 10<sup>-11</sup> cm<sup>2</sup> s<sup>-1</sup> respectively at 30°C. The influence of initial nickel concentration, residence time, temperature and pH on metal adsorption process was studied. An increase in the solution temperature, pH and decrease in concentration favour the removal of nickel by fly-ash. The maximum adsorption of Ni(II) ions was noted at pH 7.0. The various thermodynamic parameters were calculated for the present system. The empirical model has been tested for the kinetics of Ni(II) removal by adsorption on fly ash and the parameters for the continuous operation of the removal process were determined.

### INTRODUCTION

The presence of nickel ions in surface water is a problem of increasing importance. Elevated environmental levels of nickel may come from a variety of sources such as tableware plating (Nemerow 1963); metal finishing (Anderson and Lobst 1968); small parts fabrication (Mc-

Ethamey 1953); plating plants (Wisé 1948); silver refineries (Banerjee 1952) and automotive plating of zinc base casting (Lowe 1970). The permissible limit of nickel in drinking water is 1 mg l<sup>-1</sup> (IS 1963).

The ingestion of nickel above permissible limit acts on the living system through the li-

gand binding property, thereby, interacting with either simple molecules like vitamins-coenzymes, aminoacids and other metabolites or macromolecules like proteins, nucleic acids, etc. (Chatterjee 1988). In some cases it affects the air pockets of lungs resulting in respiratory symptoms and causing lung cancer (EPA 1976).

There are numerous reports in the technical literature of soluble metal removal through activated sludge (Ming *et al.* 1975; Stones 1959), biological treatment (Nieboer and Richardson 1980), precipitation (Nilson 1971) and adsorption process (Malcom and Maunir 1979; Jasenka and Janes 1978; Tom *et al.* 1987).

The present investigation deals with the study of Ni(II) removal from water by adsorption technique using fly-ash, an unconventional adsorbent. These studies were made at various concentrations, contact time, temperature and pH of the solution. In order to understand the clear mechanism involved in this process, the thermodynamic parameters were calculated. This paper is also concerned with the application of various models to enable a clearer understanding of the mechanism of the removal process and to formulate the operational parameters for a continuous process on the basis of batch adsorption studies.

## MATERIALS AND METHODS

### *The Adsorbent*

Fly-ash is a waste by-product of thermal power plants. It was obtained from Obera Thermal Power Plant, Mirzapur (U.P.), India. The adsorbent was sieved through 63  $\mu$  sieve and used as such without any pretreatment. The average particle size of adsorbent was measured by HIAC-320 Model 8002917 (ROYCO Inst. Div., USA) and the surface charge was characterised by electrophoretic measurements using Lazer-Z-meter, Model 500 (Penken Inc. New York, USA). The surface area of the adsorbent was determined by "three point"  $N_2$  gas adsorption method using model Q5-7 Quantasorb Surface Area Analyzer (Quanta Chrome Corp., USA). The porosity and density of the fly-ash particle was determined by mercury porosimeter and by specific gravity bottles, respectively. The chemical constituents of fly-ash sample were

determined by Indian Standard Methods of Chemical Analysis (1960) and are shown in Table 1 along with other characteristics.

TABLE 1  
Constituents and characteristics of fly-ash

Constituents	% by weight
SiO <sub>2</sub>	56.04
Al <sub>2</sub> O <sub>3</sub>	25.90
CaO	2.22
Fe <sub>2</sub> O <sub>3</sub>	1.26
MgO	0.94
Loss of ignition	13.64
Mean particle size	48 $\times$ 10 <sup>-4</sup> cm
Surface Area	5.77 m <sup>2</sup> g <sup>-1</sup>
Density	3.42 g cm <sup>-3</sup>
Porosity	0.38
pH <sub>ZPC</sub>	2.4

### *The Adsorbate*

A 0.448 gm of NiSO<sub>4</sub> 6H<sub>2</sub>O (AR grade) was dissolved in one liter of deionised-distilled water to prepare the stock solution (Nickel concentration 0.10 mg/ml). The appropriate volumes of stock solution of NiSO<sub>4</sub> 6H<sub>2</sub>O were added to obtain synthetic wastewater containing 2.5, 5.0, 7.5 and 10.0 mg l<sup>-1</sup> of Ni(II). The desired pH of the adsorbate solution was maintained using H<sub>2</sub>SO<sub>4</sub> or NaOH of appropriate strengths.

### *Adsorption Experiments*

Batch adsorption experiments were carried out in different polythene bottles by mixing 1.0 g fly ash with 50 ml of synthetic wastewater containing varying concentrations of Ni(II) at various temperatures and pH in a shaking incubator. The speed of mixing was kept constant for each run. At the end of predetermined time intervals, the adsorbate and adsorbent were separated by centrifugation at 10,000 rpm and the supernatant liquid was analysed for the remaining concentration of Ni(II) by dimethylglyoxime method (APHA 1975) using a Spectronic-20 spectrophotometer at 445 nm. Blanks were also prepared to test for adsorption onto the internal surface of the bottles and make corrections accordingly.

**RESULTS AND DISCUSSION**

It is clear from Table 1 that the main constituents of fly-ash is alumina and silica while other oxides are present in trace amounts. It is thus expected that most of the Ni(II) ions will be adsorbed either by alumina, silica or by a combined influence of these oxides.

*Adsorption Isotherm*

Adsorption equilibria was conducted with the help of Langmuir equation to determine the nature of adsorption using the equilibrium time of

$$\frac{C_e}{q_e} = \frac{1}{Q^\circ b} + \frac{C_e}{Q^\circ} \quad (1)$$

where,  $C_e$  is the equilibrium concentration ( $\text{mg l}^{-1}$ ),  $q_e$  is the amounts adsorbed at equilibrium ( $\text{mg g}^{-1}$ ) and  $Q^\circ$  and  $b$  are Langmuir constants. The straight line plot of  $C_e/q_e$  Vs  $C_e$  (Fig. 1) at  $30^\circ\text{C}$  and  $\text{pH } 6.5$  shows the applicability of Langmuir model to the present system. The values of  $Q^\circ$  (adsorption capacity) and  $b$  (adsorption energy) were calculated from the slope and intercept of the plot (Fig. 1) and found to be  $0.293 \text{ mg g}^{-1}$  and  $0.683 \text{ lmg}^{-1}$ , respectively at  $30^\circ\text{C}$ .

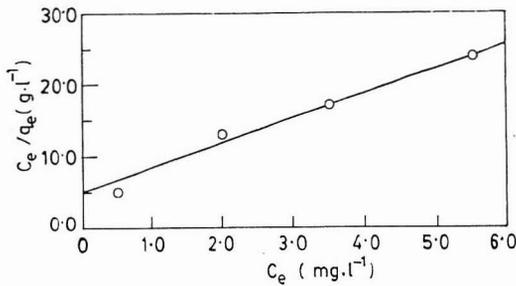


Fig. 1 Langmuir isotherm for the adsorption of Ni(II) of fly-ash,  $30^\circ\text{C}$  (o), Conditions :  $5.0 \text{ mg l}^{-1}$ , Ni(II) concentration,  $\text{pH } 6.5$ .

*Adsorption Kinetics*

The kinetics of Ni(II) adsorption on fly-ash follows the following first order rate expression (Lagergren 1898)

$$\text{Log}(q_e - q) = \text{log } q_e - \frac{K}{2.303} \cdot t \quad (2)$$

where,  $q$  is the amount of Ni(II) adsorbed ( $\text{mg g}^{-1}$ ) at time  $t$  and  $q_e$  is the amount adsorbed ( $\text{mg g}^{-1}$ ) at equilibrium.

The value of rate constant of adsorption  $K$  was calculated from the slope of the linear plot of  $\text{log}(q_e - q) / V_s t$  (Fig. 2a) and found to be  $2.303 \times 10^{-2} \text{ min}^{-1}$  at  $30^\circ\text{C}$  and  $\text{pH } 6.5$ . The adsorption of Ni(II) on fly-ash is supposed to be a three-step process (McKay *et al.* 1981).

Step 1 – Mass transfer of Ni(II) from bulk solution to the solid phase, Step 2 – intra-particle diffusion, and Step 3 – adsorption at interior sites.

The surface transfer coefficient was determined from the following mathematical diffusion model (McKay *et al.* 1981)

$$\ln\left(\frac{C_t}{C_o} - \frac{1}{1 + mk}\right) = \ln\left(\frac{mk}{1 + mk} - \frac{1 + mk}{mk} \cdot \beta_L \cdot S_s \cdot t\right) \quad (3)$$

where,  $C_t$  is the Ni(II) concentration in the bulk liquid at time  $t$  ( $\text{mg l}^{-1}$ ),  $C_o$  is the initial concentration in bulk liquid ( $\text{mg l}^{-1}$ )  $m$  the mass of adsorbent particle per unit volume of particle free Ni(II) solution ( $\text{g l}^{-1}$ ),  $k$  the Langmuir constant ( $\text{l g}^{-1}$ ),  $\beta_L$  the surface mass transfer coefficient ( $\text{cm s}^{-1}$ ), and  $S_s$  the outer surface of adsorbent per unit volume of particle free slurry ( $\text{cm}^{-1}$ ).

The value of  $m$  and  $S_s$  were obtained from the following relation:

$$m = \frac{W}{V} \quad (4)$$

$$S_s = \frac{6m}{d_p \rho_p (1 - \epsilon_p)} \quad (5)$$

where,  $W$  is the weight of adsorbent ( $\text{g}$ ),  $V$  is the volume of particle free solution ( $\text{L}$ ),  $d_p$  is the particle diameter ( $\text{cm}$ ),  $\rho_p$  is the density of fly-ash particle ( $\text{g l}^{-1}$ ), and  $\epsilon_p$  is the porosity of fly-ash particles ( $\text{cm cm}^{-1}$ ).

This value of mass transfer coefficient was calculated from the slope and intercept of the straight line plot of  $\ln(C_t/C_o - 1/1+mk) / V_s t$  (Fig. 2a) and found to be  $1.14 \times 10^{-5} \text{ cm s}^{-1}$  at  $30^\circ\text{C}$  and  $\text{pH } 6.5$ . This value suggests that the velocity of adsorbate transport is quite rapid to use such adsorbent for the treatment of wastewaters enriched in Ni(II) (Panday *et al.* 1985). The product  $\beta_L \cdot S_s$  has the unit of the first order adsorption kinetics ( $\text{time}^{-1}$ ) and is equal to  $0.811 \times 10^{-2} \text{ min}^{-1}$  indicating that the rate of adsorp-

tion is sufficient to transport the adsorbate species on the adsorbent.

The rate of intraparticle diffusion  $K_{id}$  for the adsorption of Ni(II) ions was determined from the slope of the linear plot of amount adsorbed  $V_s$  square root of time  $t$  (Fig. 2b) and found to be  $1.73 \times 10^{-2} \text{ mg g}^{-1} \text{ min}^{-\frac{1}{2}}$  at  $30^\circ\text{C}$  and pH 6.5. The plot which is linear for a wide range of contact period does not pass through the origin indicating the presence of other modes of adsorption within the extent of intercept on X-axis (Poots *et al.* 1978).

The value of pore diffusion coefficient was calculated and found to be  $6.20 \times 10^{-11} \text{ cm}^2 \text{ s}^{-1}$ , assuming spherical geometry for the adsorbent (Helfferch 1962) with the help of the following equation (Bhattacharya 1984)

$$\bar{D} = \frac{0.03 r_0^2}{t_{\frac{1}{2}}} \quad (6)$$

where,  $r_0$  is the radius of adsorbent,  $t_{\frac{1}{2}}$  is the time for half adsorption and  $\bar{D}$  is the pore diffusion coefficient. According to Michelsen *et al.* (1975) pore diffusion was found to be rate limiting if the value of pore diffusion lies between  $10^{-11}$  to  $10^{-13}$ .

*Effect of Contact Time and Concentrations*

The removal of Ni(II) by adsorption on fly ash increases with time until the equilibrium is attained in 120 min. The equilibrium time is independent of the initial concentration of Ni(II). The extent of Nickel(II) removal by adsorption on fly-ash decreases from 0.225 to 0.100  $\text{mg g}^{-1}$  (Fig. 3) while the percentage removal increases from 45 to 80% by decreasing the initial Ni(II) concentrations in aqueous phase from 10.0 to 2.5  $\text{mg l}^{-1}$  at  $30^\circ\text{C}$  and pH 6.5.

*Effect of Temperature*

With an increase in temperature from  $30^\circ$  to  $50^\circ\text{C}$ , using  $5.0 \text{ mg l}^{-1}$  of Ni(II) solution, the

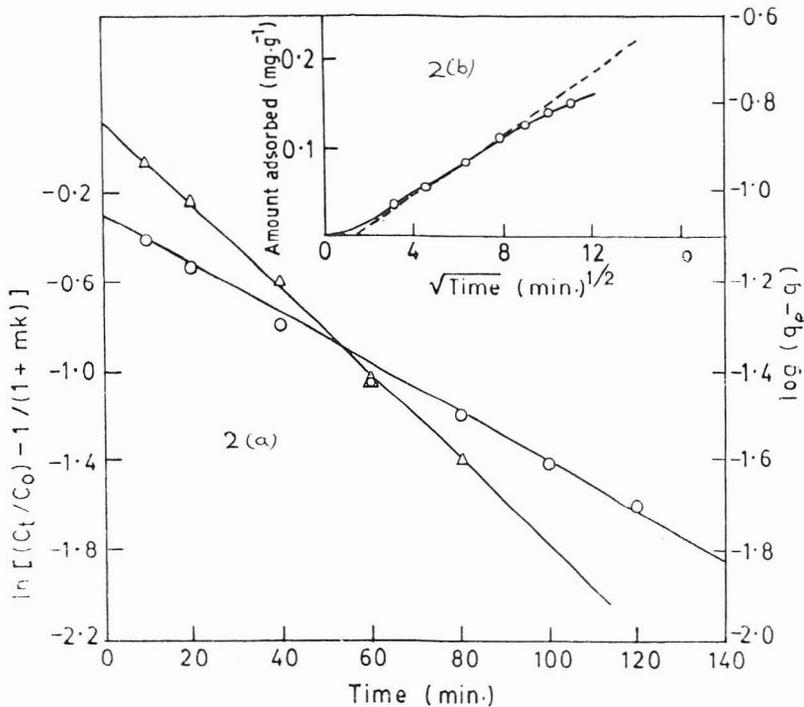


Fig. 2 Kinetics of Ni(II) adsorption, (a) mass transfer (o) and rate of adsorption ( $\Delta$ ). (b) rate of pore diffusion. Conditions :  $5.0 \text{ mg l}^{-1}$  concentration, pH 6.5,  $30^\circ\text{C}$ .

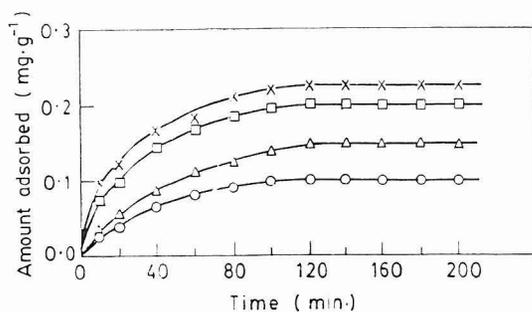


Fig. 3 Effect of concentrations on removal of Ni(II) by fly-ash :  $2.5 \text{ mg l}^{-1}$  (o);  $5.0 \text{ mg l}^{-1}$  ( $\Delta$ );  $7.5 \text{ mg l}^{-1}$  ( $\square$ );  $10 \text{ mg l}^{-1}$  (x); Conditions :  $30^\circ\text{C}$  and  $\text{pH } 6.5$ .

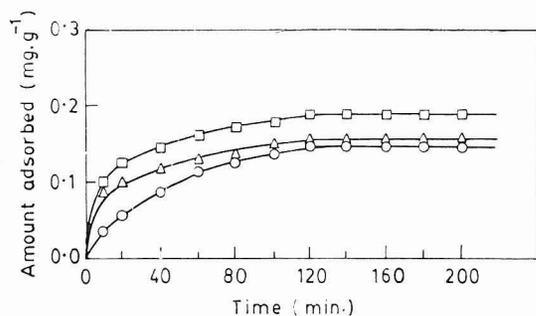


Fig. 4 Adsorption of Ni(II) on fly-ash at different temperatures,  $30^\circ\text{C}$  (o)  $40^\circ\text{C}$  ( $\Delta$ ) and  $50^\circ\text{C}$  ( $\square$ ). Conditions :  $5.0 \text{ mg l}^{-1}$  Ni(II) concentration,  $\text{pH } 6.5$ .

adsorption of Ni(II) increases from  $0.150 \text{ mg g}^{-1}$  (60%) to  $0.188 \text{ mg g}^{-1}$  (75%) at  $\text{pH } 6.5$  (Fig. 4). This shows the endothermic nature of the process (Malcom and Maunir 1979; Panday *et al.* 1985). The change in thermodynamic parameters (Table 2) such as standard free energy ( $\Delta F^\circ$ ), enthalpy ( $\Delta H^\circ$ ) and entropy ( $\Delta S^\circ$ ) have been calculated using the following relationship

$$\Delta F^\circ = -RT \ln K_o \quad (7)$$

$$\Delta H^\circ = R \left( \frac{T_2 \cdot T_1}{T_2 - T_1} \right) \ln \frac{K_o}{K_o'} \quad (8)$$

and

$$\Delta S^\circ = \frac{\Delta H^\circ - \Delta F^\circ}{T} \quad (9)$$

where,  $K_o'$  and  $K_o$  are the equilibrium constants at temperature  $T_1$  and  $T_2$  respectively and other terms have their usual significance. The values of equilibrium constants at each temperature were obtained from limiting slopes of adsorption isotherms at zero concentration (Kipling 1965). The negative values of  $\Delta F^\circ$  indicate the spontaneous nature of the process with high preferences of fly-ash for Ni(II) ions. The average change in  $\Delta H^\circ$  value indicates that the binding forces are of the order of activated adsorption (between  $5 - 20 \text{ Kcal mol}^{-1}$ ) i.e. physical adsorption gradually changes into chemisorption with the rise of temperature. The positive value of  $\Delta S^\circ$  suggests the increased randomness at the solid-solution interface during the adsorption of Ni(II) ions on fly-ash. On the adsorption of Ni(II), the adsorbed solvent molecules, which are displaced by the adsorbate species, gain more translational entropy than is lost by the adsorbate ions, thus allowing for the prevalence of randomness in the system.

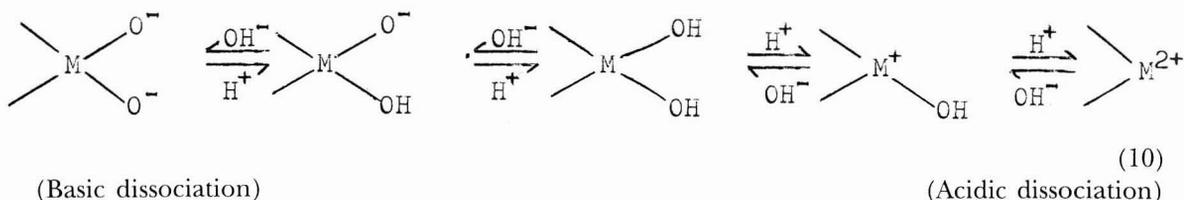
#### Effect of pH

With the change in pH of the solution from 3.0 to 7.0, the extent of Ni(II) removal by adsorption increases from  $0.08 \text{ mg g}^{-1}$  (32%) to  $0.22 \text{ mg g}^{-1}$  (88%) and thereafter starts decreasing at  $5.0 \text{ mg l}^{-1}$  of adsorbate solution and

TABLE 2  
Thermodynamic parameters at different temperatures

Temperature	Thermodynamic Parameters		
	$\Delta F^\circ$ (Kcal mol <sup>-1</sup> )	$\Delta H^\circ$ (Kcal mol <sup>-1</sup> )	$\Delta S^\circ$ (e.u.)
$30^\circ\text{C}$	-0.2441	1.5660	5.97
$40^\circ\text{C}$	-0.3038	12.2570	-
$50^\circ\text{C}$	-0.7051	-	-

temperature 30°C (Fig. 6). The variation in the removal of Ni(II) with pH of the solution may be explained on the basis of ion exchange mechanism. The metal oxides present in the adsorbent from aquacomplexes in the presence of water dipoles and develop positively or negatively charged surfaces through amphoteric dissociation (Panday *et al.* 1984) at varying pH values in the following manner:



where, M stands for Si, Al, etc.

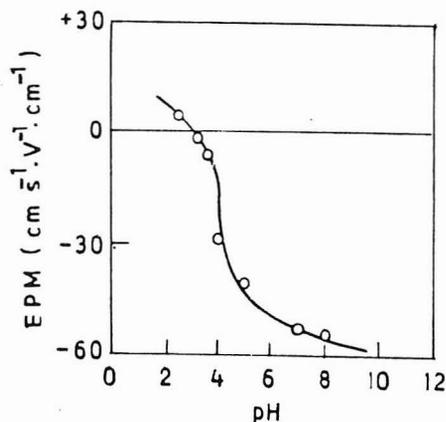
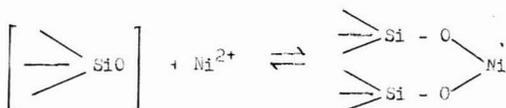
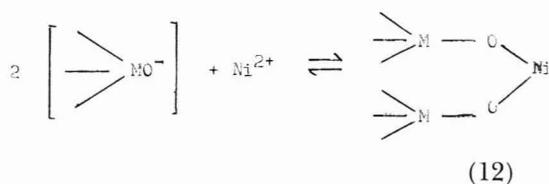
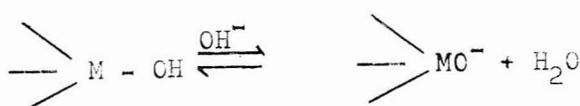


Fig. 5 Electroknetic behaviour of fly-ash; Conditions : 1 g l<sup>-1</sup> fly ash, 0.05 M NaClO<sub>4</sub>, temperature 30°C.

The zero point charge thus developed in acidic medium (below pH 2.4) (Fig. 5) does not favour the association of cationic adsorbate species. However, beyond pH 2.4 the adsorbent surface gradually starts to become negatively charged offering suitable sites for the adsorption of Ni(II) as follows



The pH<sub>ZPC</sub> for alumina and silica is reported to be 8.2 and 2.3 respectively (Yadava *et al.* 1987). The change in solubility of alumina

with pH (Fig. 7) shows a maximum near the neutral pH region, whereas, in the case of silica the change is not pronounced (Panday *et al.* 1984). This suggests that a relatively small number of alumina sites will be available for the adsorption of Ni(II) at pH 7.0. Thus, the major scheme for the adsorption of Ni(II) may be written as

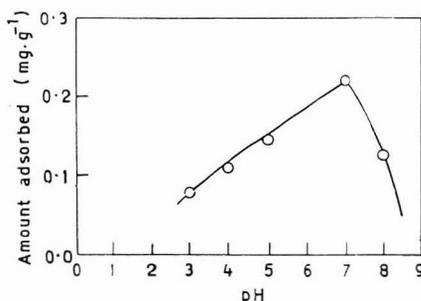
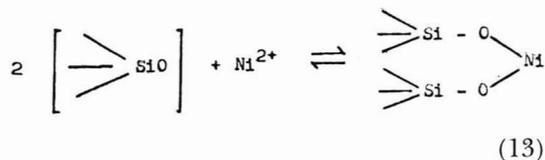
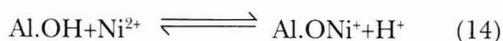


Fig. 6 Effect of pH on removal of Ni(II) by fly ash. Conditions : 5.0 mg l<sup>-1</sup> Ni(II) concentration, pH 6.5 temperature, 30°C.

However, at a lower pH, the interaction of Ni(II) ions with alumina sites are also likely to occur as follows



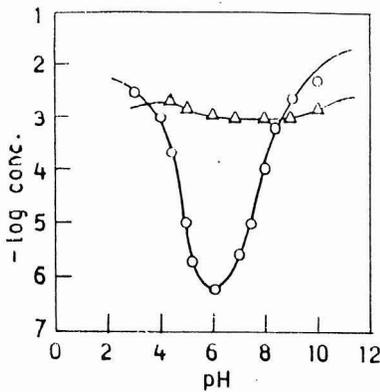


Fig. 7 Effect of pH on solubility of alumina (o), silica (Δ); Conditions: 5.0 g l<sup>-1</sup> solid, 0.05 M NaClO<sub>4</sub>, temperature 30°C.

The decreasing trend of adsorption above pH 7.0 may be due to the formation of soluble hydroxy complexes. This type of behaviour has also been observed for other hydrolyzable metals (James and Healy 1972; Mac-Nanghton and James 1974).

*Empirical Kinetic Model*

An empirical mathematic relationship between time and the concentration of nickel adsorbed on fly-ash has also been tested. The empirical relationship is represented as (Prakash *et al.* 1987)

$$\text{Log}_{10} (t + 1) = B q_t^A \quad (15)$$

The value of empirical constants B and A depend on the initial concentration, the density and porosity of adsorbent and other influencing factors.

For different initial concentrations of nickel, the values of B and A were determined graphically by plotting Log<sub>10</sub> [Log<sub>10</sub> (t+1)] Vs Log<sub>10</sub> q<sub>t</sub> and the following relations were obtained

For C<sub>0</sub> = 2.5 mg l<sup>-1</sup>  

$$\text{Log}_{10} (t + 1) = 1.75 q_t^{0.375} \quad (16)$$

For C<sub>0</sub> = 5.0 mg l<sup>-1</sup>  

$$\text{Log}_{10} (t + 1) = 1.27 q_t^{0.425} \quad (17)$$

For C<sub>0</sub> = 7.5 mg l<sup>-1</sup>  

$$\text{Log}_{10} (t + 1) = 0.968 q_t^{0.481} \quad (18)$$

For C<sub>0</sub> = 10 mg l<sup>-1</sup>

$$\text{Log}_{10} (t + 1) = 0.738 q_t^{0.659} \quad (19)$$

The variation of q<sub>t</sub><sup>A</sup> with respect to Log<sub>10</sub> (t+1) at each concentration is shown in Fig. 8. The straight lines thus obtained indicate the applicability of the model to the present system.

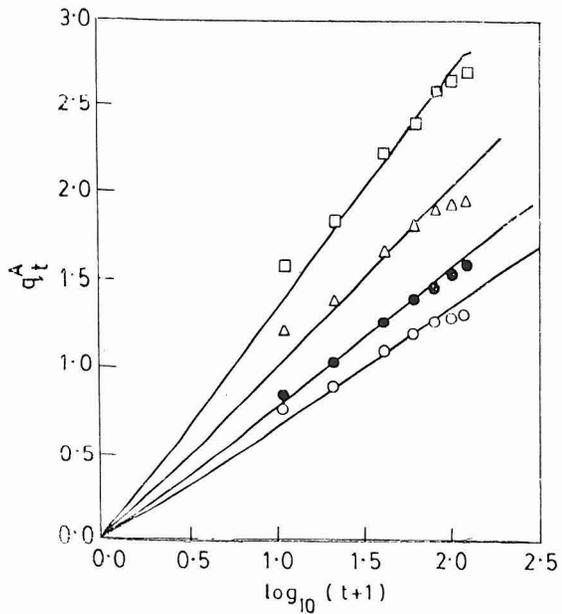


Fig. 8 Kinetics of Ni(II) removal for 2.5 mg l<sup>-1</sup> (o); 5.0 mg l<sup>-1</sup> (•); 7.5 mg l<sup>-1</sup> (Δ) and 10 mg l<sup>-1</sup> (□); Conditions : temperature 30°C and pH 6.5.

The values of empirical constants B and A vary with change in concentration. The variation of B with respect to C<sub>0</sub> shows a linear relationship (Fig. 9) and is expressed by

$$B = 3.0125 C_0^{-0.3750} \quad (20)$$

The behaviour of A is somewhat different with respect to the concentration range studied (Fig. 10) and the variation of A with C<sub>0</sub> can be expressed as:

$$A = 0.036 C_0 + 0.258 \text{ for } C_0 = 5.0 \text{ mg l}^{-1} \quad (21)$$

The validity of the above empirical model was further confirmed by plotting the computed values of q<sub>t</sub> at different times using Eqns. (16-19) against their corresponding empirical values (Fig. 11) which shows the linear relationship

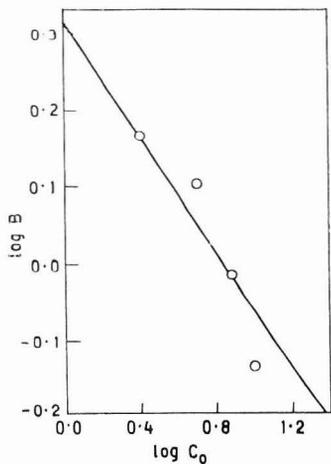


Fig. 9 Variation of  $B$  with initial concentration on log-log scale. Conditions : temperature  $30^{\circ}\text{C}$  and  $\text{pH } 6.5$ .

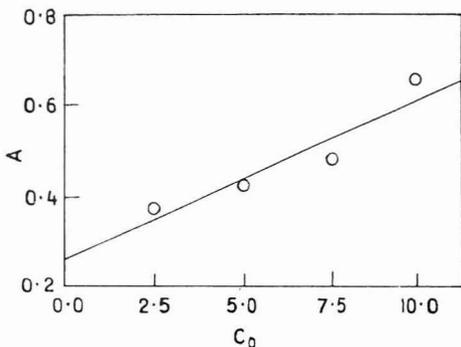


Fig. 10 Variation of  $A$  with initial concentration. Conditions : temperature  $30^{\circ}\text{C}$ ,  $\text{pH } 6.5$ .

between the computed and the experimental values of amount of Ni(II) adsorbed on fly ash for  $5.0 \text{ mg l}^{-1}$  nickel ion concentration.

*Design Parameters for Continuous Process*

In order to have an idea of the period of contact between the adsorbent and polluted water for the maximum removal of Ni(II), it is desirable to determine the approximate detention period by using the following relationship (Ramalho 1983)

$$t_D = \frac{q_e}{k \cdot C_e} \quad (22)$$

The rate constant has been determined from the slope of the straight line plot  $q_e/T$  Vs

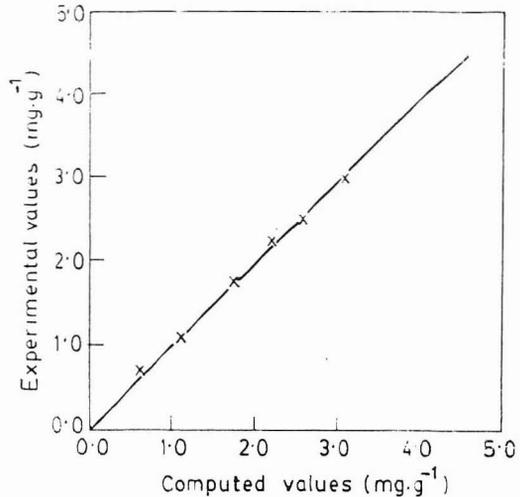


Fig. 11 Verification of kinetic model for nickel removal plot of experimental values Vs computed values. Conditions : temperature  $30^{\circ}\text{C}$ ,  $\text{pH } 6.5$ ,  $5.0 \text{ mg l}^{-1}$ .

$C_e$  (Fig. 12) and also from the regression analysis and were found to be  $0.600\text{h}^{-1}$  and  $0.580\text{h}^{-1}$  respectively for the removal of Ni(II) by adsorption. The approximate detention periods were 6.67, 2.50, 1.67 and 1.36 hours by graph and 6.89, 2.59, 1.72 and 1.41 hours by regression at Ni(II) concentrations 2.5, 5.0, 7.5 and  $10.0 \text{ mg l}^{-1}$  respectively. The values of  $t_D$  thus obtained for different concentration ranges studied, provide an idea about the maximum period of contact between the given quantities of adsorbent and polluted water, after which fresh adsorbent is necessary for the recharge.

**CONCLUSION**

The study concludes that fly-ash appears to be a suitable adsorbent for the removal of Ni(II). The data thus obtained may be helpful for

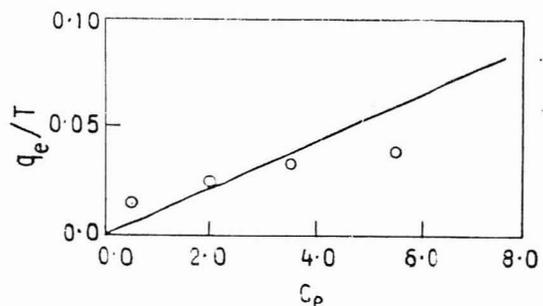


Fig. 12 Variation of  $q_e/T$  with equilibrium concentration. Conditions : temperature  $30^{\circ}\text{C}$ ,  $\text{pH } 6.5$ .

designing and fabricating a treatment plant for the removal of nickel present in wastewaters.

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