

Removal of Nickel (II) Ions from Aqueous Solution Using Thermal Power Plant Fly Ash as a Low Cost Adsorbent

Adsorption Isotherm and Kinetics Study

Ajay K. Agarwal^{*1}, Mahendra S. Kadu², Chandrashekhar P. Pandhurnekar³, Ishwerdas L. Muthreja⁴

^{1,2}Department of Civil Engineering, Shri Ramdeobaba College of Engineering and Management, Nagpur, Maharashtra, 440 013, India

³Department of Applied Chemistry, Shri Ramdeobaba College of Engineering and Management, Nagpur, Maharashtra, 440 013, India

⁴Department of Mining Engineering, Visvesvaraya National Institute of Technology, Nagpur, Maharashtra, 440 011, India

¹agarwal_rkn@rediffmail.com; ²mahendra.kadu@rediffmail.com; ³chand2783@gmail.com; ⁴muthreja2158@rediffmail.com

Abstract-The objective of this study was to investigate removal characteristics of Nickel (Ni^{+2}) ions from aqueous solution using exhausted thermal power plant coal fly ash. The effects of various experimental conditions such as amount of adsorbent, contact time both in mixing condition and steady state condition; and initial metal concentration on the efficiency of Ni^{+2} ions removal from the aqueous solution were studied at room temperature. In this study, it was found that fly ash effectively adsorb Ni^{+2} ions from aqueous solution. When lime used as an admixture along with the fly ash, the removal tendency of Ni^{+2} ions from the solution was found to be increased. In the batch kinetics study, it was observed that adsorption process is pseudo-second order reaction. From the adsorption isotherm study, it reveals that the equilibrium adsorption data fit well in to the Freundlich adsorption isotherms model than Langmuir adsorption isotherms. The test results indicated that fly ash could be used as a cheap adsorbent for effective removal of Ni^{+2} ions in aqueous solutions.

Keywords- Removal of Ni^{+2} Ions Using Fly Ash; Low Cost Adsorbent; Admixture; Adsorption Isotherm; Reaction Kinetics

I. INTRODUCTION

Heavy metals are nowadays among the most important pollutants in source and treated water, and are becoming a severe public health problem. These are toxic to aquatic life and cause natural waters to be unsuitable as potable water sources^[1, 2]. Metal-bearing effluents generally generated from metallurgical industries, electroplating and metal finishing industries and hazardous waste sites. Ni^{+2} ions are toxic, especially to activated sludge bacteria^[3, 4]. The presence of Ni^{+2} is detrimental to the operation of anaerobic digesters used in wastewater treatment plants^[5, 6]. Heavy metal removal from aqueous solutions has been commonly carried out by several processes: chemical precipitation, solvent extraction, ion-exchange, reverse osmosis or adsorption^[7]. Among these processes, the adsorption with the selection of a suitable adsorbent can be an effective technique for the removal of heavy metals from wastewater. The suggested adsorbents having high metal adsorption capacity are activated carbon, alumina, silica and ferric oxide. These are expensive and difficult to be separated from the wastewater after use. Therefore, over the recent years, this has prompted a growing research interest into the development of low cost alternatives to these adsorbents from a range of carbonaceous and mineral precursors^[8].

At present, there is growing interest in use of low-cost, commercially available materials for the adsorption of heavy metals. A wide variety of materials such as modified cellulosic materials, modified bark, sawdust, tea-industry waste, newspaper pulp, orange peel, teak leaves powder, biomass and soybean straw,^[9] and fly ash are being used as low-cost alternatives to expensive adsorbents.

Fly ash is the most abundant waste materials from the combustion of powdered coal. The compounds which are generally present in the coal fly ash include alumina, silica, ferric oxide, calcium oxide, magnesium oxide and unburnt carbon. Its physical properties such as porosity, particle size distribution, surface area and moreover, the alkaline nature of fly ash make it a good neutralizing agent. Also, fly ash with a predominant negative charge has a good affinity to adsorb cations or polar substance or pollutants. This motivated the researchers to use it as a potential agent for the adsorption of heavy metal contaminants in water and wastewaters^[10-13].

With this point of view, the present study was undertaken to evaluate the effectiveness of exhausted thermal power plant coal (TPPC) fly ash in the removal of Ni^{+2} ions from aqueous solution. The effects of various experimental conditions such as amount of adsorbate, contact time both in mixing condition and steady state condition; and initial metal concentration on the efficiency of removal of Ni^{+2} ions from the aqueous solution were studied at room temperature. It is observed that addition of lime enhances the removal tendency of Ni^{+2} ions from the solution when used as an admixture along with the fly ash.

II. MATERIALS AND METHODS

A. Fly Ash Sample

Sample of the raw coal fly ash was collected from Unit 7 of Electrostatic Precipitator (ESP) hopper number 5 of a coal-burning thermal power plant situated at Koradi, Nagpur District, Maharashtra, India; it was used without pre-treatment. The fly ash powder was dried in the electric oven at 120°C for at least 24 hours and kept over fused calcium chloride in the desiccators, just prior to use. The major chemical constituents of fly ash used are silica and alumina as presented in the Table I.

TABLE I CONSTITUENT OF THE FLY ASH

Constituent	Percentage by weight
SiO ₂	65.01
Al ₂ O ₃	24.41
Fe ₂ O ₃	4.04
TiO ₂	0.69
CaO	0.35
MgO	0.55
Na ₂ O	0.22
K ₂ O	0.21
SO ₃	0.15
P ₂ O ₅	0.037
Mn	0.28
Loss on Ignition	2.04

The particle size distribution was done using standard method by passing the fly ash over the standard size sieves and the particle size distribution of the fly ash collected has been shown in Table II. It is observed that more than 90% fly ash particles have size below 75 µm.

TABLE II PARTICLE SIZE DISTRIBUTION OF FLY ASH

Particle size in µm	Left over Fly ash in g (Total quantity= 500 g)	%
> 1000	0.14	0.028
1000 - 600	0.24	0.048
600 - 425	0.26	0.052
425 - 300	0.42	0.084
300 - 212	0.88	0.176
212 - 150	5.62	1.124
150 - 75	36.82	7.364
< 75	455.62	91.124

B. Equipments

Atomic absorption spectra were recorded on an atomic absorption spectrophotometer (Model – GBC 932 AA). Different batch experiments were carried out by measuring atomic absorption spectra at wavelength of 341.5 nm (slit width = 0.2 nm) using Air-acetylene (oxidizing) flame type. For the weighing purpose, digital balance (Make: Metler Toledo, Switzerland) was used having uncertainty to weigh up to ± 0.1 mg. Solution pH was measured by using digital pH meter (Model EQ 621, Make - Equip-tronics, India).

C. Preparation of Solution of Ni⁺² Ions Solutions

The analytical reagent grade Nickel sulphate hexahydrate (E-Merck, India, mass fraction purity – 99.9 %) was used for the batch adsorption study. The stock solution of Ni⁺² (500 mg/l) was prepared by dissolving 4.4783 g NiSO₄.6H₂O in 2 liters fresh doubly distilled water. Standard stock solution of Ni⁺² of 1000 mg/l were procured from Merck, India (mass fraction purity - 99.98%) and were used for the calibration of spectrophotometer.

D. Adsorption and Kinetics Study of Removal of Ni⁺² Ions From Aqueous Solution

The effect of amount of fly ash on the percentage efficiency of removal of Ni⁺² from the aqueous solution has been studied. For this purpose, aqueous solutions containing of Ni⁺² (concentration = 20 mg/l to 100 mg/l) were prepared from the stock

solution of 500 mg/l. Aqueous solutions of Ni^{+2} ions (100 ml) were taken in the different conical flask, and fly ash ranging in the amount of 1g to 48 g were added in to these conical flasks. The mixtures were stirred using magnetic stirrer for 3 hours and then keeping this solution unstirred for 21 hours. The adsorbent were separated from the solution by centrifuge at a speed of 3000 rpm for 5 minutes and the Ni^{+2} solution was used to undertake measurements of final pH of the solution and atomic adsorption spectra.

To investigate the effect of contact time under the mixing condition and unstirred condition, two sets of experiment were carried out using aqueous solution of Ni^{+2} (concentration = 20 mg/l). Amount of fly ash were maintained constant equal to 10 g in 100 ml solution in each of the batch experiments. Eleven samples in different conical flasks were kept unstirred while remaining eight samples in different conical flasks were mixed continuously at 150 rpm speed over the magnetic stirrer for different time intervals. In both the conditions, the adsorbent were separated from the solution by centrifuge at a speed of 3000 rpm for 5 minutes and the supernant Ni^{+2} solution was used to measure atomic adsorption spectra.

Effects of addition of lime as admixture under constant mixing condition and unstirred condition have also been investigated in the present study. For this purpose, batch experiments were carried with 100 ml aqueous solution of Ni^{+2} (20 mg/l) were taken in the conical flask. In each sample, 1.0 g fly ash as adsorbent was added, whereas, the amount of lime was varied as 4 mg/l (pH = 7.3), 20 mg/l (pH = 8.5) and 24 mg/l (pH = 9.0). The studies of addition of higher amount of lime were not undertaken as pH of the solution with higher amount of lime was rising above 9.0. As per the norms of Central Pollution Control Board of India (CPCB, India) for the industrial waste effluent, the pH should be within 5.5 to 9.0.

The aqueous solutions containing 5 mg/l, 10 mg/l, 20 mg/l, 40 mg/l, 60 mg/l, 100 mg/l and 200 mg/l Ni^{+2} , were prepared from the stock solution (500 mg/l). In the 100 ml of these samples, 1.0 g fly ash was added. These samples were stirred constantly at 150 rpm for 3 hours to attain the equilibrium time. The adsorbent were separated from the solution by centrifuge at a speed of 3000 rpm for 5 minutes and the supernant Ni^{+2} solution were used to measure atomic adsorption spectra. The Ni^{+2} adsorption isotherm in aqueous solutions were obtained from the study.

III. RESULTS AND DISCUSSION

A. Effect of Amount of Fly Ash

The effects of dose of adsorbent on the removal efficiency of Ni^{+2} from the aqueous solution have been depicted in Fig. 1. A perusal of Fig. 1 indicates that percentage efficiency increases from 16.2 % for 1 g adsorbent up to 91.1 % for 22 g of adsorbent per 100 ml of solution. It was further observed that the addition of adsorbent, do not increase the removal efficiency of Ni^{+2} ions from the aqueous solution. It can be interpreted that when mass of adsorbent in the solution is less, due to greater affinity of attachment of metal ion on the surface of fly ash, the magnitude of percentage efficiency varies very sharply. But at very high dose of adsorbent, active binding surfaces of fresh fly ash molecules for the adsorption of metal ions are hindered. It was noticed that when 22 g or more amount of adsorbent was mixed in 100 ml batch sample, thick slurry was formed and hence it was decided to restrict the dose of fly ash to a maximum of 10 g per 100 ml of solution in the further study.

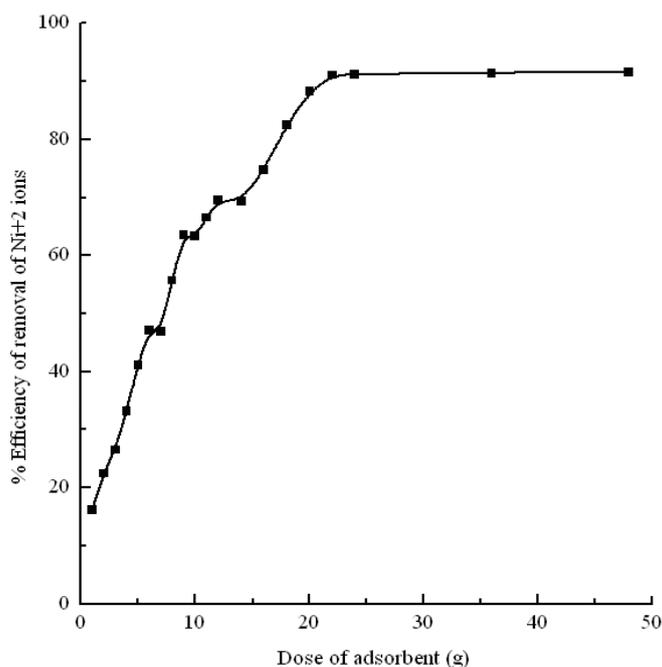


Fig. 1 The plot of variation in % efficiency of removal of Ni^{+2} ions in aqueous solution against amount of fly ash (Experimental Condition: Initial concentration of Ni^{+2} ions = 20 mg/l, contact time = 3 hour stirring and 21 hours under unstirred condition)

B. Effect of Contact Time

Preliminary kinetic experiments were conducted to assess the time taken for attaining equilibrium under mixing condition and steady condition without stirring. The results of these two conditions are presented in Fig. 2 and Fig. 3. The equilibrium time was observed to be 3 hours under continuous mixing condition whereas the equilibrium time was increased up to 24 hours under steady state condition.

Thus, it was concluded that the greater efficiency can be achieved in a short duration, by through mixing of fly ash in the aqueous solution. The longer time required to reach equilibrium using fly ash also indicated that the removal of Ni⁺² ions was mainly attributed to the effective adsorption reaction and not a precipitation reaction^[14, 15].

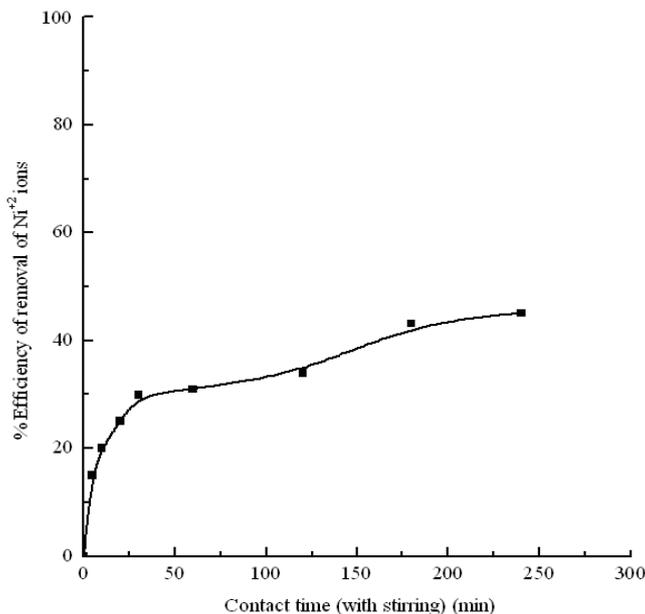


Fig. 2 The plot of variation in % efficiency of removal of Ni⁺² ions in aqueous solution against contact time (with stirring) (Experimental Condition: Initial concentration of Ni⁺² ions = 20 mg/l; amount of fly ash = 10 g per 100 ml sample)

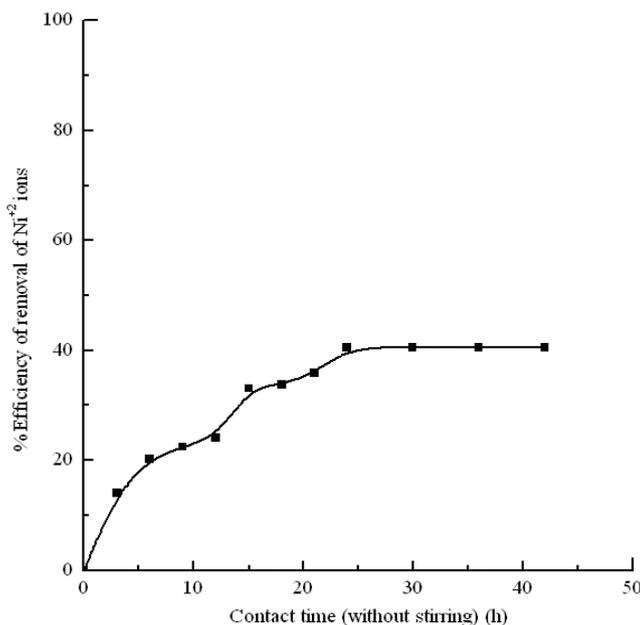


Fig. 3 The plot of variation in % efficiency of removal of Ni⁺² ions in aqueous solution against contact time (without stirring) (Experimental Condition: Initial concentration of Ni⁺² ions = 20 mg/l; amount of fly ash = 10 g per 100 ml sample)

C. Effect of Addition of Lime as an Admixture

To understand the effect of lime added as an admixture along with the fly ash, the graphs have been plotted showing the variation in percentage efficiency of removal of Ni⁺² ions against contact time, under constant mixing condition in Fig. 4 whereas the results of batch experiments under unstirred condition have been plotted Fig. 5.

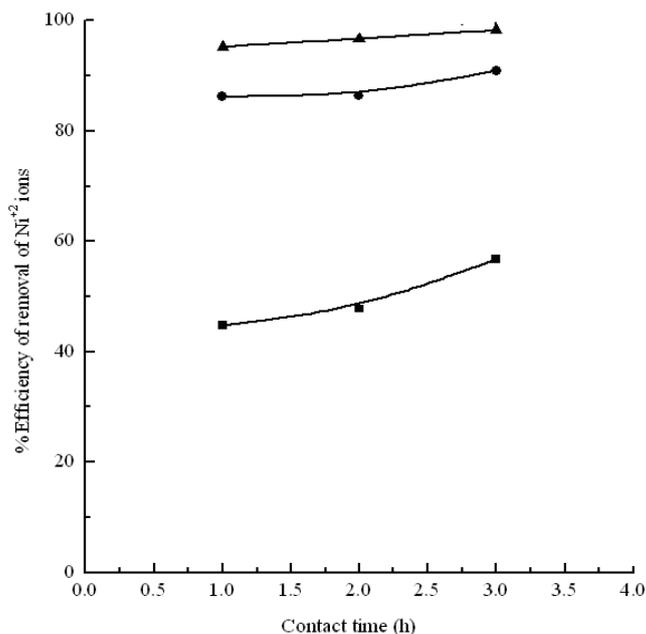


Fig. 4 The plot of variation in percentage efficiency of removal of Ni²⁺ ions in aqueous solution against contact time (with stirring condition) Experimental Condition: 100 ml aqueous solution of 20 mg/l Ni²⁺ ions + 10 g/l fly ash + Lime (▲ – ▲, 24 mg/l; ● – ●, 20 mg/l; ■ – ■, 4 mg/l)

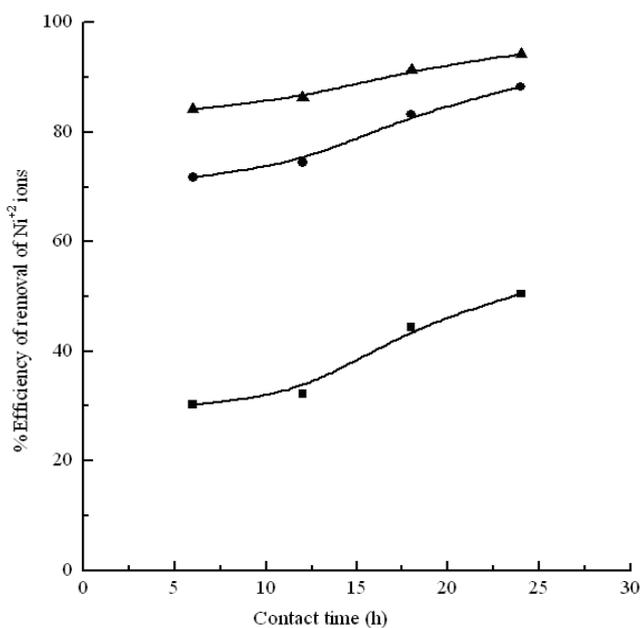


Fig. 5 The plot of variation in percentage efficiency of removal of Ni²⁺ ions in aqueous solution against contact time (under unstirred condition) Experimental Condition: 100 ml aqueous solution of 20 mg/l Ni²⁺ ions + 10 g/l fly ash + Lime (▲ – ▲, 24 mg/l; ● – ●, 20 mg/l; ■ – ■, 4 mg/l)

It can be seen from these figures that with rise in contact time, uptake of metal also increases slowly and also it can be seen that amount of lime plays a significant role on the adsorption process. The magnitude of percentage efficiency rises from 44.71 % as in case of mixture of 4 mg/l lime along with 1.0 g fly ash to the 95.25 % in the case of 24 mg/l lime and 1.0 g fly ash for 1 hour under constant stirring condition. While under steady state condition, the magnitude of percentage efficiency rises from 30.35 % as in case of addition of 4 mg/l lime to the 84.14 % in the case of 24 mg/l lime for 6 hours. In the presence of lime, the increase in removal efficiency is due to the increase in pH of solution which increased from 7.3 at 4 mg/l of lime to 9.0 for 24 mg/l of lime. Interpretation can be drawn from the above results that pH of the solution also plays a pivotal role in the removal of Ni²⁺ ions from the solution.

D. Effect of Initial Concentration of Ni²⁺ Ions

In the present study, investigations were carried to study effect of initial concentration of Ni²⁺ ions on the adsorption behaviour by allowing the solution to attain the equilibrium adsorption by mixing fly ash and solution for 3 hours.

The results of variation in amount of Ni²⁺ ions adsorbed against initial concentration of Ni²⁺ ions have been plotted in Fig. 6.

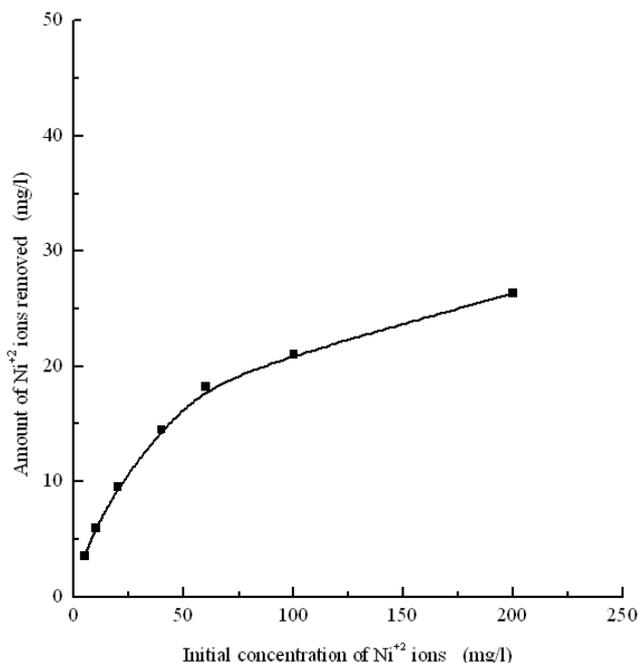


Fig. 6 The plot of variation in amount of Ni²⁺ ions adsorbed against initial concentration of Ni²⁺ ions (Experimental Condition: Contact time – 2 hrs; amount of fly ash = 10 g per 100 ml sample)

It can be seen from the above figure that amount of Ni²⁺ ions removed from the solution upon adsorption of fly ash increases with increase in the initial concentration of Ni²⁺ ions. The variation in percentage efficiency of removal of Ni²⁺ ions in aqueous solution against initial concentration of Ni²⁺ ions have been plotted in Fig. 7. It can be observed that percentage efficiency decreases with increase in the initial concentration of Ni²⁺ ions.

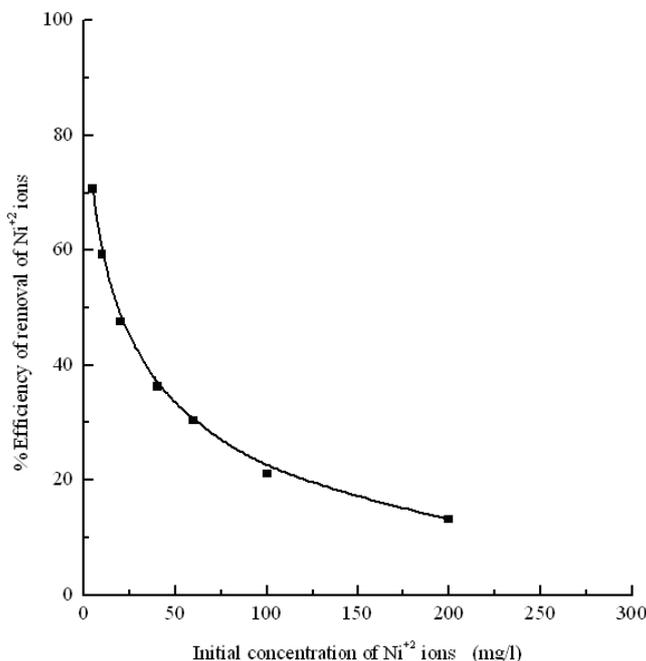


Fig. 7 The plot of percentage efficiency of removal of Ni²⁺ ions in aqueous solution against initial concentration of Ni²⁺ ions (Experimental Condition: Contact time – 2 hrs; amount of fly ash = 10 g per 100 ml sample)

E. Reaction Kinetics Study

A number of experimental parameters are usually considered in kinetics studies for one adsorption process. Two well-known kinetic models, pseudo-first-order and pseudo-second-order model, were employed to describe the adsorption process. The pseudo-first order, proposed by Lagergren^[16] for adsorption analysis, is expressed in the form:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \tag{1}$$

where q_e and q_t are the sorption capacity (mg/g) of Ni^{+2} ions at equilibrium and at a time t , respectively, and k_1 is the rate constant for pseudo first-order sorption (1/min). After integration and applying boundary conditions, viz. that the initial conditions are $q_e - q_t = 0$ at $t = 0$, Eq. (1) becomes:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \tag{2}$$

Equation (2) can be transformed to nonlinear form as

$$q_t = q_e(1 - e^{-k_1 t}) \tag{3}$$

The pseudo second-order equation^[14] can be written as:

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2 \tag{4}$$

where q_e and q_t are the sorption capacity (mg/g) of Ni^{+2} ions at equilibrium and at a time t , respectively, and k_2 is the rate constant for pseudo second-order sorption (g/(mg.min)). For the boundary conditions $t = 0$ to $t = t$ and $q_t = 0$ to $q_t = q_t$, the integrated form of Eq. (4) becomes:

$$\frac{1}{(q_e - q_t)} = \frac{1}{q_e} + k_2 t \tag{5}$$

which is the integrated rate law for a pseudo second-order reaction^[17]. This has a linear form:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \tag{6}$$

Fig. 8 and Fig. 9 show the first-order kinetic model and pseudo second-order model fitting to the experimental data. It is seen from the figure that the first order rate expression could not fit quite well to the experiment data. In contrast, the pseudo second-order kinetics has shown much better correlation coefficients ($R^2 = 0.999$), suggesting it is applicable to the adsorption kinetics. The experimental values were fitted in equation of pseudo second-order kinetics by using least square fit method and the values of q_e i. e. the sorption capacity (mol/g) of Ni^{+2} ions at equilibrium were calculated to be 0.7199 mg/g and k_2 i. e. the rate constant for pseudo second-order sorption was calculated to be equal to 0.1789 g/(mg.min).

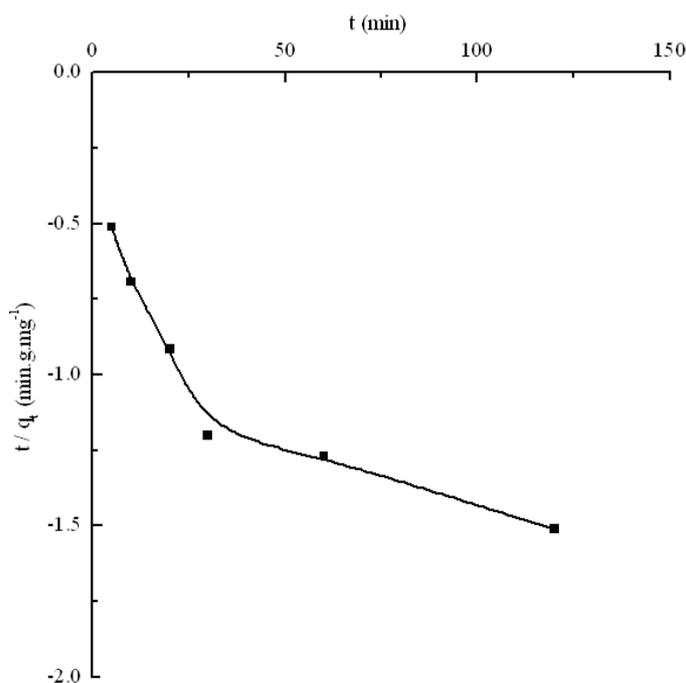


Fig. 8 The plot of pseudo first order kinetics for adsorption of Ni^{+2} ions in aqueous solution

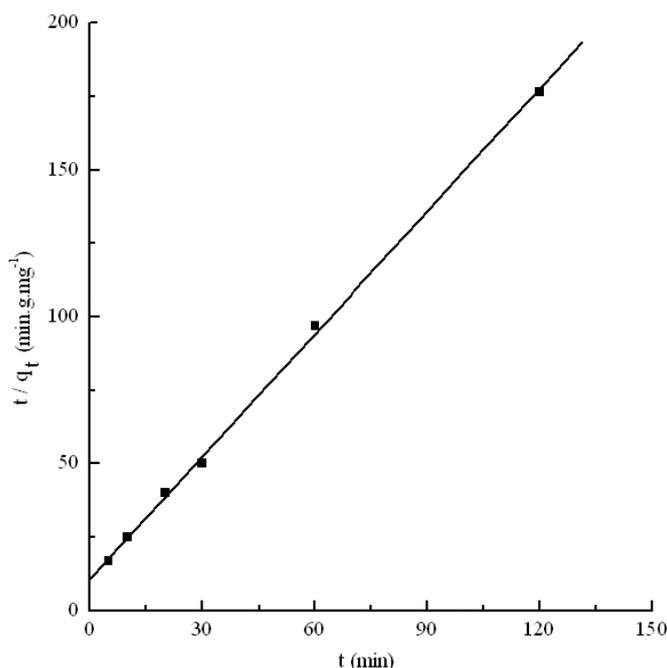


Fig. 9 The plot of pseudo second order kinetics for adsorption of Ni²⁺ ions in aqueous solution

F. Adsorption Isotherm Study

The isotherm plays a practical role in predictive modeling procedure for analysis and to design the sorption systems. The data obtained from batch sorption studies were analyzed according to Langmuir and Freundlich adsorption isotherms equations. To optimize the design of a sorption system for the sorption of Ni²⁺ ions from the aqueous solution, it is important to establish the most appropriate correlation for the equilibrium curves.

According to, Langmuir^[18] theory, the sorption takes place at specific homogeneous sites within the sorbent. Freundlich^[19] isotherm is derived by assuming a heterogeneous surface with a non-uniform distribution of heat of sorption over the surface.

The standard models of Langmuir (Equation (7)) and Freundlich (Equation (8)) used are represented below:

$$\frac{C_e}{q_e} = \frac{1}{q_m} C_e + \frac{1}{K_a \cdot q_m} \tag{7}$$

Where, C_e is equilibrium concentration of Ni²⁺ ions (mg.L⁻¹), q_e is solid phase concentration of Ni²⁺ ions (mg.g⁻¹), q_m (mg.g⁻¹), and K_a (L.mg⁻¹) are empirical constants denoting mono layer capacity or limiting sorption, signifies the solid phase concentration, corresponding to the complete coverage of available sorption sites and energy of sorption respectively, can be evaluated from the slope and intercept of the linear plot of C_e / q_e against C_e.

$$\ln q_e = \ln K_f + \frac{1}{n} \ln C_e \tag{8}$$

Where, K_f is the Freundlich characteristic constant [(mg.g⁻¹)(L.g⁻¹)^{1/n}] and 1/n is the heterogeneity factor of sorption, obtained from intercept and slope of ln q_e versus ln C_e linear plot respectively.

The results obtained batch adsorption experiment in the present work were fitted to Langmuir adsorption isotherm using least square fit method as shown in Fig. 10 and the coefficient of regression (R²) were found to be 0.982. The values of q_m was estimated to be equal to 0.249 mg.g⁻¹ whereas magnitude of K_a was found to be 0.0684 L.mg⁻¹.

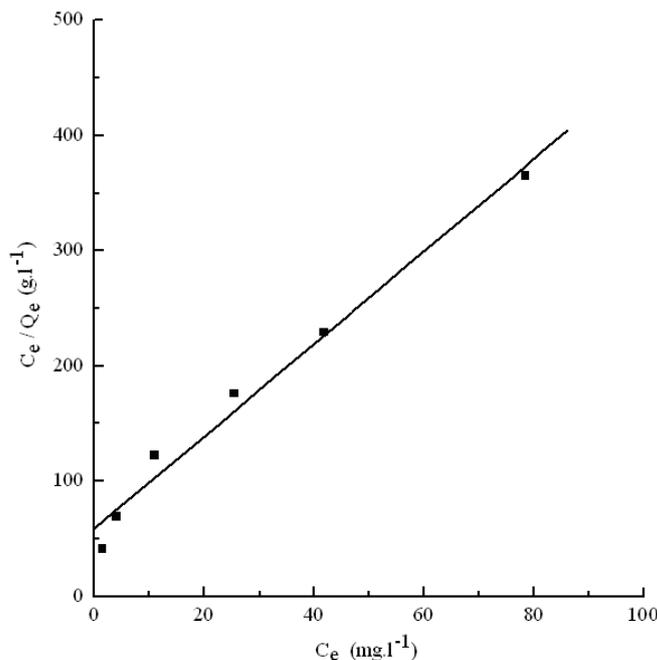


Fig. 10 Langmuir adsorption isotherm of Ni⁺² ions from aqueous solution using fly ash adsorbent

The results of adsorption were also fitted to the Freundlich Adsorption isotherm using least square fit method which is as shown in Fig. 11 and the coefficient of regression (R^2) was found to be 0.994. Therefore, the equilibrium adsorption data of Ni⁺² ions can be represented more appropriately by the Freundlich models in the studied concentration range. The magnitude of n i. e. reciprocal of heterogeneity factor of sorption was calculated to be equal to 2.1459 whereas K_f i. e. the Freundlich characteristic constant was estimated to be equal to 0.03025.

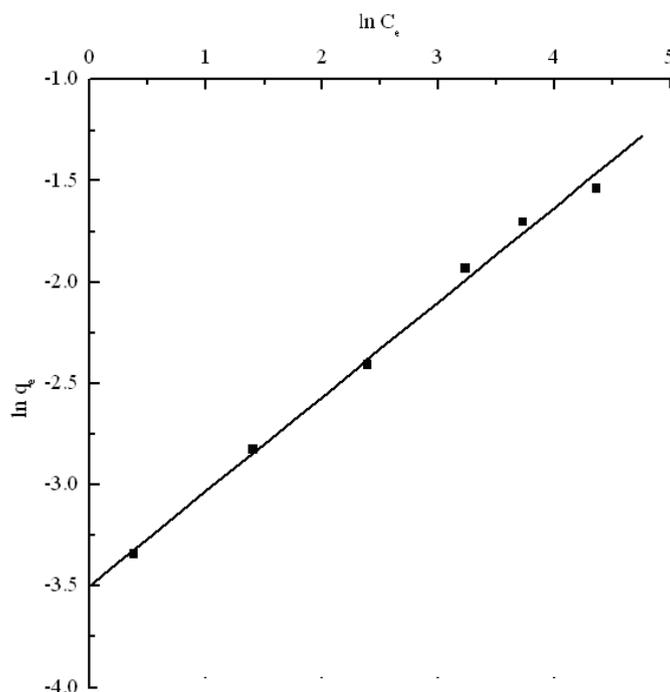


Fig. 11 Freundlich adsorption isotherm of Ni⁺² ions from aqueous solution using fly ash adsorbent

IV. CONCLUSION

The results obtained in this study clearly demonstrated the potential use of fly ash from coal-fired power plant for the removal of Ni⁺² ions from aqueous solutions. The following conclusions can be drawn based on the investigation:

- (i) The percentage efficiency of removal of Ni⁺² ions from aqueous solutions increases with increase in amount of

adsorbent up to 22 g per 100 ml sample, after which percentage removal almost remains constant.

(ii) The higher percentage efficiency was reached in a short duration by through mixing of fly ash in the aqueous solution than the unstirred condition which also enables us to conclude that removal of metal ion takes place via adsorption process rather than precipitation reaction.

(iii) Efficiency of removal of Ni^{+2} ions from the solution increases significantly by addition of small quantity of low cost admixture i. e. lime along with fly ash adsorbent.

(iv) The kinetics studies indicated that equilibrium in the adsorption of Ni^{+2} ions on the fly ash was reached in 3 h of contact between the fly ash and the aqueous solution.

(v) The adsorption of Ni^{+2} ions the aqueous solution over the surface of fly ash follows the second order reaction mechanism.

(vi) The absolute amount of Ni^{+2} ions adsorbed by the fly ash increased with the increase in concentration, while the percentage of adsorption decreased with an increase in concentration.

(vii) Langmuir isotherm better fitted the experimental data since the average percent deviation was lower than Freundlich isotherm; and also the correlation coefficient for Langmuir isotherm was higher than the Freundlich isotherm for metal. Although the amount of fly ash required to adsorb 20 mg/l Ni^{+2} ions completely was found to be higher, but it can be reduced up to 1g / 100 ml sample i.e. 10 g fly ash per liter sample by adding a small amount of lime in to it.

REFERENCES

- [1] M. Rafatullah, O. Sulaiman, R. Hashim and A. Ahmad, "Adsorption of copper (II) onto different adsorbents," *J. Disp. Sci. Technol.*, vol. 31, pp. 918-930, 2010.
- [2] L. M. Ottosen, I. V. Kristensen, A. J. Pedersen, H. K. Hansen, A. Villumsen and A. B. Ribeiro, "Electrodialytic Removal of Heavy Metals from Different Solid Waste Products," *Separ. Sci. Technol.*, vol. 38, pp. 1269-1289, 2003.
- [3] A. I. Zouboulis and K. A. Kydros, "Use of red mud for toxic metals removal: the case of nickel," *J. Chem. Tech. Biot.*, vol. 58, pp. 95-101, 1993.
- [4] P. Mavros, A. I. Zouboulis and N. K. Lazaridis, "Removal of metal ions from wastewaters. The case of nickel," *Environ. Technol.*, vol. 14, pp. 83-91, 1993.
- [5] G. N. McDermott, M. A. Post, B. N. Jackson and M. B. Ettinger, "Nickel in Relation to Activated Sludge and Anaerobic Digestion Processes," *Water Poll. Control Fed. J.*, vol. 37, pp. 163-177, 1965.
- [6] S. McAnally, L. Benefield and R. B. Reed, "Nickel Removal from a Synthetic Nickel-Plating Wastewater Using Sulfide and Carbonate for Precipitation and Coprecipitation," *Separ. Sci. Technol.*, vol. 19, pp. 191-217, 1984.
- [7] Y. H. Wang, S. H. Lin and R. S. Juang, "Removal of heavy metal ions from aqueous solutions using various low-cost adsorbents," *J. Hazard. Mater.*, vol. 102, pp. 291-302, 2003.
- [8] D. A. Grassi, M. Galicio and A. F. Cirelli, "A homogeneous and low-cost biosorbent for Cd, Pb and Cu removal from aqueous effluents," *Chem. Ecol.*, vol. 27, pp. 297-309, 2011.
- [9] B. Volesky and Z. R. Holant, "Biosorption of heavy metals," *Biotechnol. Prog.*, Vo. 11, pp. 235-250, 1995.
- [10] M. Šmelcerović, D. Đorđević, M. Novaković and M. Mizdraković, "Decolorization of a textile vat dye by adsorption on waste ash," *J. Serb. Chem. Soc.*, Vol. 75, pp. 855-872, 2010.
- [11] X. Querol, N. Moreno, J. C. Umaña, A. Alastuey, E. Hernández, A. López-Soler and F. Plana, "Synthesis of Zeolites from coal flyash: an overview," *Int. J. Coal Geol.*, vol. 50, pp. 413-423, 2002.
- [12] R. S. Iyer and J. A. Scott, "Power station fly ash - A review of value-added utilization outside of the construction industry," *Resour. Conserv. Recy.*, vol. 31, pp. 217-228, 2001.
- [13] A. Mishra and B. D. Tripathi, "Utilization of fly ash in adsorption of heavy metals from wastewater," *Toxicol. Environ. Chem.*, vol. 90, pp. 1091-1097, 2008.
- [14] S. Lu, S. Bai, L. Zhu and H. Shan, "Removal mechanism of phosphate from aqueous solution by fly ash," *J. Hazard. Mater.*, vol. 161, pp. 95-101, 2009.
- [15] S. Lu, S. Bai and H. Shan, "Mechanisms of phosphate removal from aqueous solution by blast furnace slag and steel furnace slag," *J. Zhejiang Univer. Sci.*, vol. A 9, pp. 125-132, 2008.
- [16] S. Lagergren, "About the theory of so-called adsorption of soluble substances," *Kungliga Svenska Vetenskapsakademiens, Handlingar. Band.*, vol. 24, pp. 1-39, 1898.
- [17] G. McKay and Y. Ho, "Pseudo-second order model for sorption processes," *Process Biochem.*, vol. 34, pp. 451-65, 1999.
- [18] I. Langmuir, "Adsorption of gases on plane surfaces of glass, mica and platinum," *J. Am. Chem. Soc.*, vol. 40, pp. 1361-1403, 1918.
- [19] H. Freundlich, "Adsorption in solution," *Phys. Chem.*, vol. 57, pp. 384-410, 1906.



Ajay K. Agarwal did his B.E. in Mining from V.R.C.E. (Now VNIT), Nagpur (India) in the year 1986 & M.Tech. (Mine Planning & Design) from Indian School of Mines, Dhanbad. He also did AMIE in Civil Engineering in the year 2004 and Masters Degree in Civil engineering in 2010. Presently he is perusing his Ph. D. in Civil Engineering.

He joined Shri Ramdeobaba Kamla Nehru Engineering College, Nagpur, India in 1987. Presently he is working as an Assistant Professor in Civil Engineering Department and Foreign Universities Collaboration Coordinator. Since then he has published 68 technical papers in International/National seminars and journals. He has organized many National and International Seminars as Convener, Co-convener and Organizing Secretary. He has also worked as an editor for the proceedings of International and National Seminars/conferences.

He is associated as member with various professional institutes such as International Economics Development Research Center (IEDRC), Asia-Pacific Chemical, Biological & Environmental Engineering Society (APCBEES), Institution of Engineers (India), (IE(I)), Indian Society for Technical Education (ISTE) and Institution of Public Health Engineers, India. He has visited Kuwait, Dubai, Muscat and Bhutan.



Mahendra S. Kadu is working as Professor and Head in Civil Engineering Department of Shri Ramdeobaba College of Engineering and Management Nagpur India. He has completed his graduation in Civil Engineering in 1987. He has earned post graduate degree M. Tech. in Hydraulic Engineering and Doctoral degree in Engineering and Technology from VNIT Nagpur (India).

He has two ASCE publications in the field of Water Resources and Management. He has published five research papers in International journals, six research papers in international conferences and many others in national conferences. He has recently published six research papers in the area of Geo-polymer concrete in International and National conferences. Dr. Kadu is closely associated with many professional bodies like Institution of Water Works Association, Institution of Engineers and Indian Society of Technical Education.

Presently he is working as chairman of board of studies (Civil Engineering) and member of Academic Council of faculty of Engineering and Technology; RTM university of Nagpur (India). He is guiding Ph. D. scholars in the area of Optimization of Engineering system and Geo-polymer concrete.



Chandrashekhar P. Pandhurnekar did his M. Sc. and Ph. D. from Department of Chemistry, Rashtrasnt T. M. Nagpur University, Nagpur, India. He joined Shri Ramdeobaba Kamla Nehru Engineering College, Nagpur, India in 2008 as an Assistant Professor in the department of Chemistry. His main research areas are solution thermodynamics of aqueous systems and environmental studies. He has published 6 papers in reputed International journals of Elsevier Publications and American Chemical Society Publications. He is a member of Indian Thermodynamics Society, India.



Ishwerdas L. Muthreja graduated in Mining Engineering from the Ravishankar University, Raipur in 1979. He obtained M Tech. in Mining Engineering at the Indian School of Mines, Dhanbad. He is working as Associate Professor in Mining Engineering at Visvesvaraya National Institute of Technology, Nagpur. His areas of interest are Mine Environment, Mine Planning and Slope Stability. He has publishes more than 40 papers in various International Journals, National Journals, International Conference and National Conference. He has completed two collaborative research projects in the area of Mine Environment with University of Exeter, UK , funded by The British Council and three research projects funded by Ministry of Human Resource Development, Govt. of India and Western Coalfields Ltd, Nagpur.