

Thermodynamics of the Sorption of Pb(II) from Aqueous Solution on NCRH

Upendra Kumar and Jyotikusum Acharya

Abstract—A new adsorbent material for removing lead ions from aqueous solutions has been investigated. Present study deals with the sorption of Pb(II) from aqueous solution on chemically pretreated rice husk. Batch kinetic studies were conducted for the adsorption of Pb(II) on NCRH (sodium carbonate treated rice husk). At the adsorbent dose of 10 g/l and initial Pb(II) concentration of 10 mg/l, 96 to 98.5 % removal were observed when the temperature increases from 15° to 50° C. Equilibrium time was found to be 60 min. This paper attempts to develop simple and easily understandable thermodynamic parameters related sorption process at the equilibrium. The overall scenario represented by thermodynamic parameters was found to be a better indicator of understanding the process mechanism. Sorption of Pb(II) on NCRH followed pseudo second-order kinetic equation. The Gibbs free energy ΔG° values for the adsorption processes of Pb(II) at 15°, 30°, 40° and 50° C was obtained as -7.55, -9.80, -10.41 and -11.06, kJ/mol respectively. The negative value, ΔG° confirms the feasibility of the adsorption process and spontaneous nature of adsorption. The values of ΔH° and ΔS° for Pb(II) were obtained as 21.31 kJ/mol and 101.11 J/mol respectively. The positive value of ΔH° indicates endothermic nature of adsorption, while positive ΔS° value confirms the increased randomness at the solid-liquid interface during adsorption. The activation energy for the sorption of Pb(II), was found as 20.02 kJ/mol indicating chemisorptions.

Index Terms—Activation energy, Gibbs free energy, NCRH, lead, thermodynamics, sorption.

I. INTRODUCTION

Lead is a heavy, soft, malleable, bluish gray metal. Lead is systemic poison causing anemia, kidney and gastrointestinal malfunction, tissue damage of brain and even death in extreme poison [1]. The removal Pb(II) from industrial effluents is major problem due to the difficulty in treating such waste waters by conventional treatment method. The presence of lead in wastewater is dangerous to aquatic flora and fauna even in relatively low concentration and stringent environmental regulation attracts the attention of chemists and environmental engineers for its control. The major sources containing lead are the wastewater from process industries engaged in lead acid battery, paints, oils, mental phosphate, fertilizer, electronic goods. Production and also combustion of fossil fuel, forest fires, mining activity, emission, sewage wastewater, sea spray etc are just few examples [2]–[4]. The industrial wastewaters are

considered to be the main source of lead impurities. The presence of high levels of lead in the environment may cause long-term health risks to humans and ecosystems. It is therefore mandatory that their levels in drinking water, waste water and water used for agricultural and recreational purposes must be reduced to within the maximum allowable concentrations recommended by national and international health authorities such as world health organisation. Its removal from wastewater prior to discharge into environment is, therefore, necessary. Current drinking water standard for lead as per are USEPA, WHO and BIS (Beuro of Indian Standard IS: 10500-1983) are 0.05 mg/l, 0.1 mg/l and 0.05 mg/l respectively; but a level of 0.02 mg/l has been proposed and is under review [5]. According to BIS, the tolerance limit for discharge of lead into inland surface waters is 0.1 mg/l, Public sewer is 1.0 mg/l and discharge in marine costal area is 1.0 mg/l. Increasingly stringent legislation on the purity of drinking water has created a growing interest in the development of conventional treatment processes. Various chemical and physical-chemical methods for the treatment of wastewaters containing lead wastes are known, such as chemical precipitation, electrochemical reduction, ion exchange, biosorption and adsorption [6]–[10]. The choice of treatment depends on effluent characteristics such as concentration of lead, pH, temperature, flow volume, biological oxygen demand, and the economics involved and the social factor like standard set by government agencies. However, adsorption on to the surface of activated carbons is the most widely used method [11]–[16]. Despite its prolific use in industries, activated carbon remains an expensive material. In our continued study on the use of low-cost material for the removal of organic and organic pollutants from water and wastewater we investigated rice husk as a sorbent for the removal of Pb(II). Some simple and low-cost chemical modifications resulted in increasing the sorption capacity of raw rice husk. The highly efficient low cost and the rapid uptake of Cd(II) by NCRH indicated that it could be an excellent alternative for the removal of heavy metal by sorption process [17]. The present research work was to investigate the use of NCRH for the removal of Pb(II) at different temperature range of 15 to 50 °C. This paper attempts to develop simple and easily understandable thermodynamic parameters related sorption process at the equilibrium, such as entropy change, enthalpy change, Gibbs free energy and activation energy of sorption. The overall scenario represented by thermodynamic parameters was found to be a better indicator of understanding the process mechanism. To the best of our knowledge this is the first report where NCRH is being used for study of thermodynamic parameters for the sorption of Pb(II) from aqueous solution.

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II. MATERIALS AND METHODS

A. Preparation of NCRH

Fresh rice husk was obtained from a local rice mill of Silchar, Assam (India) and was passed through different sieve size. The fraction of particle between 425 and 600 μ m (geometric mean size: 505 μ m) was selected. Rice husk was washed thoroughly with distilled water and was dried at 60 °C. This was treated with 0.1 N sodium carbonate solution at room temperature for 4 h. Excess of sodium carbonate was removed with water and the material was dried at 40 °C. Sodium carbonate treated rice husk was designated as NCRH [17],[30].

B. Batch Kinetic Studies

All the chemicals used in the study were of from Merck (India) Ltd. and Qualigens Glaxo (India) Ltd. Analytical grade. Stock solutions of 1000 mg/l was prepared for Pb(II) using lead nitrate. In order to avoid hydrolysis as well as high adsorption of species in the flask wall the stock solution was prepared with HNO₃ 2% (v/v), which were diluted with distilled water to prepare working solutions. pH of the working solutions were adjusted to 6 \pm 0.2 for all studies using dilute NaOH solution. The experiments were carried out with 10 g/l of sorbent dose for initial metal concentration of 10 mg/l. The mixture was agitated using a thermal shaker at 140 rpm in the temperature range of 15 ° – 50 ° C. At the end of the experiment the sample was allowed to settle for about 1 min and the supernatant sample was analyzed for its Pb(II) concentration using atomic absorption spectrophotometer (AA-6650, Shimadzu, Japan).

III. RESULT AND DISCUSSION

A. Effect of Temperature

It was observed that removal of Pb(II) occurred in two stage i.e an initial rapid uptake within 15- 20 minute followed by subsequent slow uptake from 20 to 60 minute. The removal kinetics of Pb(II) by NCRH were obtained at 15°, 30°, 40°and 50° C (Fig.1). At an equilibrium time of 60 min for initial Pb(II) concentration of 10 mg/l, the percentage removal increases from 96 to 98.5 % with the increase in temperature from 15 ° to 50 ° C (Fig-2). The sorption capacity increases with increase in temperature indicating that the sorption process was endothermic and the sorption of metal ions by NCRH may involve not only physical but also chemical sorption [18], [19], [30]. The increase in sorption capacity of NCRH at high temperature may be attributed to enlargement of pore size or increase in the active surface for sorption. This could also be due to the enhanced mobility of the metal ions from the bulk solution towards the adsorbent surface and extent of penetration within NCRH structure overcoming the rate of intraparticle diffusion [19], [30]. As the temperature increase then is a greater mass transfer by collision at higher temperature. While the frequency of collision increases, probability of successive collision leading to adsorption gets higher. As a result more ions are adsorbed to give higher removal. Chemisorptions occurs when the extend of adsorption is enhance at elevated temperature. It is short and strong interaction involving orbital over lapping and electrons exchange. An increase of temperature causes an activation of active site of adsorption and higher temperature reduces

mass transform resistance for ion diffusion for binding sites [27], [28]. Most potential sorption sites are situated on cellulose, hemicelluloses and pectins on the cell wall, and active functional groups such as a hydroxyl carboxylic, carbonyl and amino groups [29].

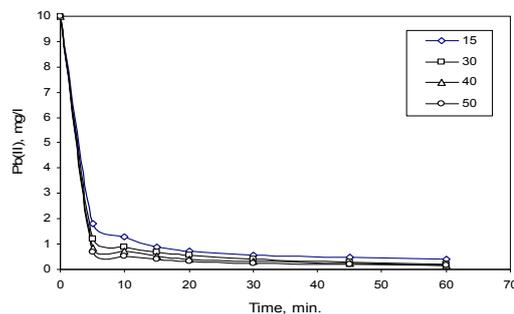


Fig. 1. Kinetic profile of Pb(II) uptake at 15, 30, 40 and 50 ° C.

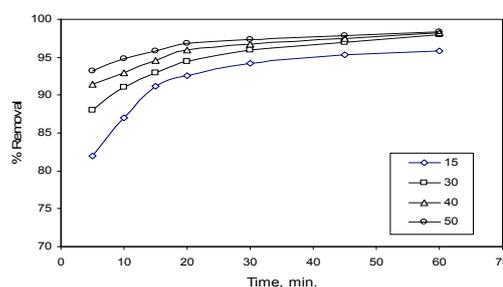


Fig. 2. The rate of removal efficiency of Pb(II) at 15, 30, 40, and 50 ° C.

B. Sorption Kinetic

Pseudo second-order kinetic model has been widely used for the sorption kinetics [20]–[22]. It was observed that most of the sorption systems followed a pseudo second-order kinetic model as also reported by Ho and McKay (1999), [20] which can be expressed as

$$\frac{t}{q} = \frac{1}{h_0} + \frac{t}{q_e} \quad (1)$$

The initial sorption rate can be obtained as t approaches zero ($t \rightarrow 0$):

$$h_0 = K_{p2} q_e^2$$

where h_0 is the initial sorption rate (mg/g min), t is the contact time (min), q and q_e are the quantities of sorbate (in mg/g), sorbed at time t and at equilibrium respectively and K_{p2} is the rate constant (g/mg min). The rate constant K_{p2} was found out from the slope of the linear test plot between t/q versus time t as shown in Fig. 3 and Table 1. The correlation coefficients of pseudo second-order kinetic model were observed to be highest and almost equal to 1.

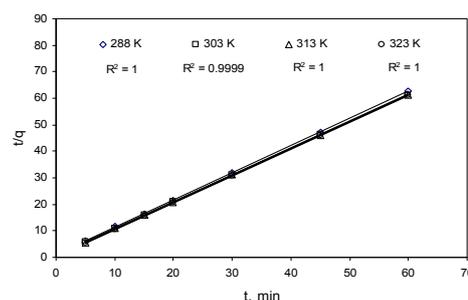


Fig.3. Pseudo second order model plot for Pb(II) at different temperature in K.

This shows that the sorption process follows the pseudo second-order kinetics and which agrees with chemisorption as the rate-limiting mechanism, through sharing or exchange of electron between sorbent and sorbate [20].

TABLE I: PSEUDO SECOND-ORDER RATE CONSTANT AND CORRELATION COEFFICIENTS (R^2) OF Pb(II)

Temp (°C)	K_{p2} (g/mg min)	q_e (mg/g)	h_o (mg/g min)	R^2
15	0.956	0.976	0.910	1.0
30	1.136	0.992	1.117	0.9999
40	1.652	0.990	1.619	1.0
50	2.369	0.989	2.319	1.0

C. Thermodynamic Parameters of Adsorption

The adsorption process of metal ions can be summarized by the following reversible process, which represents heterogeneous equilibrium.

Metal ions in solution \leftrightarrow Metal ions adsorbent. The apparent equilibrium constant (K_c) of the adsorption is defined as:

$$K_c = \frac{C_A}{C_e} \quad (2)$$

$$\Delta G^\circ = -RT \ln K_c \quad (3)$$

$$\ln K_c = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad (4)$$

where C_A is the solid phase concentration at equilibrium (mg/l), C_e is the equilibrium concentration (mg/l), T (K) the absolute temperature, R the gas constant (8.314 J/mol K), ΔS° the entropy change (J/mol) and ΔH° the enthalpy change (kJ/mol). ΔH° and ΔS° values were obtained from the slope and intercepts of van't Hoff plot, $\ln K_c$ versus $1/T$ (Fig. 4). The K_c value thus obtained is also used to determine the Gibbs free energy ΔG° at different temperature. The Gibbs free energy indicates the degree of spontaneity of the adsorption process and the higher negative value reflects a more energetically favorable adsorption [23]–[26].

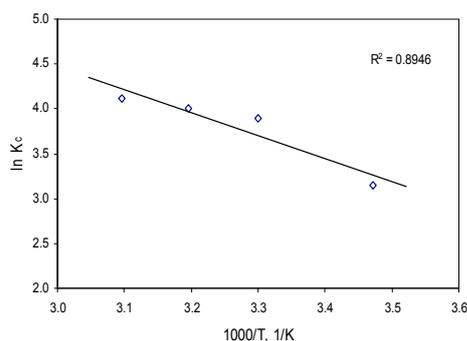


Fig.4. Van't Hoff plots for Pb(II)

The ΔG° values for the adsorption processes of Pb(II) at 15°, 30°, 40° and 50° C was obtained as –7.55, –9.80, –10.41, –11.06, kJ/mol respectively using equation (3). The negative value ΔG° confirms the feasibility of the adsorption process and spontaneous nature of adsorption. The values of ΔH° and ΔS° for Pb(II), was obtained as 21.31, kJ/mol and 101.11 J/mol respectively. The positive value of ΔH°

indicates endothermic nature of adsorption while positive ΔS° value confirms the increased randomness at the solid-liquid interface during adsorption [23]–[26].

TABLE 2: THERMODYNAMIC PARAMETERS FOR THE ADSORPTION OF Pb(II).

C_0 (mg/l)	ΔH° (kJ/mol)	ΔS° (J/mol)	ΔG° (kJ/mol)			
			15	30	40	50
10	21.31	101.11	–7.55	–9.80	–10.41	–11.06

Enthalpy change is an energy interaction with the environment while the reaction takes place. An exothermic reaction emits heat and therefore final energy state is lower than initial energy state to give a negative enthalpy change and vice versa. Entropy is an indication for the system degree of freedom and on the reversibility of the system. For a system communicating to an external heat sink or source, entropy must be increase or remain the same. As the entropy increase, uniformity of system is improved. Hence the process occurs spontaneously. Entropy change is a measurable for reversible and irreversible heat flow through a boundary. As final entropy is greater to give positive entropy change, there is an irreversible heat flow through a system.

A positive enthalpy change obtained implies that the sorption on Pb(II) ions on NCRH is endothermic. An input of energy is required to bring about the bond formation. This is because the bonding is short and as a result, energy is needed to overcome the repulsive force of attraction as ions bind in a short distance from sorbent. As external source of heat energy is needed for the endothermic reaction to occur. High temperature favors an endothermic reaction and it is deduced that chemisorptions occurs due to the formation of stronger bonds which remain bonded at high temperature [31].

D. Activation Energy

The increase in the pseudo-second order rate constant with temperature may be described by the Arrhenius equation which is used to calculated the activation energy for the metal ion sorption [18]–[20], [30] as given below:

$$\ln k_{p2} = \ln A_0 - \frac{E_a}{RT} \quad (5)$$

k_{p2} is the rate constant of sorption (g/mg min), A_0 is the temperature-independent factor (g/mg min), E_a the activation energy of sorption (kJ/mol), R the gas constant (8.314 J/mol K) and T the solution temperature (K). The kinetic profile of Pb(II) uptake at 15, 30,40, and 50° C as shown earlier in the Fig. 1 was utilized to find the rate constant k_{p2} from the pseudo second order plot (Figs. 3)

When $\ln k_{p2}$ is plotted versus $1/T$, a straight line with slope $-E_a/R$ is obtained. The magnitude of the activation energy may give an idea about the type of sorption. Two main types of adsorptions may occur: physical and chemical. In physical adsorption equilibrium is usually rapidly attained and easily reversible, because the energy requirement is small (usually no more than 4.2 kJ/mol) and since the forces

involved are weak. Chemical adsorption is specific and involves forces much stronger than physical adsorption. So the activation energy for chemical adsorption is of the same magnitude as the heat of chemical reactions which means that the rate varies with temperature according to finite activation energy (between 8.4 and 83.7 kJ/mol) in the Arrhenius equation (Aksu et al., 2004) [18] [30]. The activation energy for the sorption of Pb(II), was found as 20.02 kJ/mol respectively from the slope of Fig. 4 indicating chemisorptions

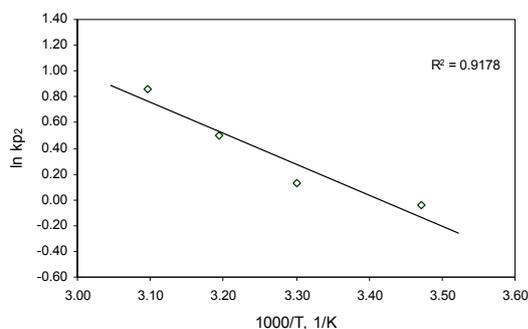


Fig. 5. $\ln k_{p2}$ vs. $1/T$ plots for Pb(II)

IV. CONCLUSION

Batch kinetics studies showed a rapid removal from 15 ° to 50 °C of Pb (II) by NCRH and it increases with increase in temperature. The sorption systems followed a pseudo second-order kinetic model with very high correlation coefficients. The sorption process was endothermic and it was further conformed by the positive value of ΔH° (21.31 kJ/mol) and further positive value of ΔS° (101.11 J/mol) confirms the increased randomness at the solid-liquid interface during adsorption. The adsorption processes of Pb(II) was obtained as -9.80 kJ/mole. The Gibbs free energy ΔG° at 15°, 30°, 40° and 50°C was obtained as -7.55 , -9.80 , -10.41 , -11.06 , KJ/mol respectively. The negative value, ΔG° confirms the feasibility of the adsorption process and spontaneous nature of adsorption. The activation energy for the sorption of Pb(II), was found as 20.02 kJ/mol indicating chemisorptions. NCRH is a favorable sorbent for the removal of Pb(II) from aqueous solutions.

REFERENCES

- [1] J. Acharya, J. N Sahu, C. R. Mohanty, and B. C. Meikap, "Removal of lead(II) from wastewater by activated carbon developed from Tamarind wood by zinc chloride activation," *Chemical Engineering Journal* Vol. 149, pp. 249-262, October 2009.
- [2] V. K. Gupta, M. Gupta, and S. Sharma, "Process development for the removal of lead and lead from aqueous solutions using redmud-an aluminum industry waste," *Water Res.*, vol. 35, pp. 1125-1134, 2001.
- [3] R. Jalali, H. Ghafourian, Y. Asef, S. J. Davarpanah, and S. Sepehr, "Removal and recovery of lead using nonliving biomass of marine algae," *J. Hazard. Mater.* vol. 92, pp. 253-262, June 2002.
- [4] K. Conrad and H. C. B. Hansen, "Sorption of zinc and lead on coir," *Bioresour Technol.*, vol. 98, pp. 89-97, January 2007.
- [5] A. Groffman, S. Peterson, and D. Brookins, "Removing lead from wastewater using zeolites," *Water Environ. Technol.*, vol. 5, pp. 54-59, May 1992.
- [6] M. M. Husein, J. H. Vera, and M. E. Weber, "Removal of lead from aqueous solutions with sodium caprate," *Sep. Sci. Technol.*, vol. 33, pp.1889-1904, August 1998.

- [7] S.W. Lin, and R. M. F. Navarro, "An innovative method for removing Hg₂₊ and Pb₂₊ in ppm concentrations from aqueous media," *Chemosphere*, vol. 39, pp. 1809-1817, 1999.
- [8] D. Petruzzelli, M. Pagano, G. Tiravanti, and R. Passino, "Lead removal and recovery from battery wastewaters by natural zeolite clinoptilolite," *Solvent Extract Ion Exch.* vol. 17, pp. 677-694, 1999.
- [9] A. Saeed, M. Iqbal, and M. W Akhtar, "Removal and recovery of lead(II) from single and multimetal (Cd, Cu, Ni, Zn) solutions by crop milling waste (black gram husk)," *J. Hazard. Mater.*, vol. 117, pp. 65-73, 2005.
- [10] S. Doyurum and A.Celik, "Pb(II) and Cd(II) removal from aqueous solutions by olive cake," *J. Hazard. Mater.* vol. 138, pp. 22-28, November 2006.
- [11] J. Goel, K Kadirvelu, C. Rajagopal, and V .K. Garg, "Removal of lead(II) by adsorption using treated granular activated carbon: batch and column studie," *J. Hazard Mater.*, vol. 125, pp. 211-220, October 2005.
- [12] N. Kannan and J. Balamurugan, "Removal of lead ions by adsorption onto coconut shell and dates nut carbons—a comparative study," *Indian J. Environ. Prot.*, vol. 25, pp. 816-823, 2005.
- [13] N. Kannan and M. S. Devi, "Studies on removal of copper (II) and lead (II) ions by adsorption on commercial activated carbon," *Indian J. Environ. Prot.*, vol. 25, pp. 28-37, 2005.
- [14] G. Issabayeva, K. M. Aroua, and N. M. N. Sulaima, "Removal of lead from aqueous solutions on palm shell activated carbon," *Bioresour Technol.*, vol. 97, pp. 2350-2355, 2006.
- [15] C. P. Dwivedi, J. N. Sahu, C. R. Mohanty, B. Raj Mohan, and B.C Meikap, "Column performance of granular activated carbon packed bed for Pb(II) removal," *J. Hazard. Mater.*, vol. 156, pp. 3596-3603, August 2008.
- [16] C. K. Singh, J. N Sahu, K. K. Mahalik, C. R. Mohanty, B. Raj Mohan, and B. C. Meikap, "Studies on the removal of Pb(II) from wastewater by activated carbon developed from Tamarind wood activated with sulphuric acid," *J. Hazard. Mater.* vol. 153, pp 221-228, May 2008.
- [17] U. Kumar and M. Bandyopadhyay "Sorption of cadmium from aqueous solution using pretreated rice husk," *Bioresour Technol.*, vol. 97, pp. 104-107, January 2006.
- [18] Z. Aksu and E. Kabasakal, "Batch adsorption of 2,4-dichlorophenoxy-acetic acid (2,4-D) from aqueous solution by granular activated carbon," *Sep. Purif. Technol.* Vol. 35, pp. 223-240, 2004.
- [19] A. Agrawal, K. K. Sahu, and B. D. Pandey, "Removal of zinc from aqueous solution using sea nodules residue," *Colloids and Surfaces A: Physicochem. Eng. Aspects*, vol. 237, pp. 133-140, April 2004.
- [20] Y. S. Ho and G. McKay, "Pseudo second-order model for sorption process," *Process. Biochem.* vol. 34, pp. 451-465, July 1999.
- [21] C. C. V. Cruz, A. C. A. da Costa, and A.S.L. Henriques, "Kinetic modeling and equilibrium studies during cadmium biosorption by dead *Sargassum* sp. Biomass," *Bioresour Technol.*, vol. 91, pp. 249-257, February 2004.
- [22] S. Rengaraj, Y. Kim, C. K. Joo, and J. Yi, "Removal of copper from aqueous solution by aminated and protonated mesoporous aluminas: kinetics and equilibrium," *J. of Colloid and Interface Sci.*, vol. 273, pp. 14-21, 2004.
- [23] A. A. Asem, D. M. Ahmed, and Y. M. Ahmed, "Removal of some hazardous heavy metals from aqueous solution using magnetic chelating resin with iminodiacetate functionality," *Separation and Purification Technology*, vol. 61, pp. 348-357, 2008.
- [24] A. M. Sevim, R. Hojiyev, A. Gül, and M.S. Celik, "An investigation of the kinetics and thermodynamics of the adsorption of a cationic cobalt porphyrine onto sepiolite." *Dyes and Pigments*, vol. 88, pp. 25-38, January 2011.
- [25] L. Wang, J. Zhang, R. Zhao, C. Li, Y. Li, and C. Zhang, "Adsorption of basic dyes on activated carbon prepared from *Polygonum orientale* Linn: Equilibrium, kinetic and thermodynamic studies." *Desalination*, vol. 254, pp. 68-74, May 2010.
- [26] S. Chegrouche, A. Mellah, and M. Barkat, "Removal of strontium from aqueous solutions by adsorption onto activated carbon: kinetic and thermodynamic studies," *Desalination*, vol. 235, pp.306-318, January 2009.
- [27] S. Diwan, "Biosorption of Copper (II) from aqueous by non-living *Spirogyra* sp.," *J. Environ. Res. Develop.*, vol. pp. 227-231, 2007.
- [28] A. K. Meena, G.K. Mishra, P. K. Rai, C. Rajagopal, and P. N. Nagar, "Removal of heavy metal ions from aqueous solution using carbon aerogel as an adsorbent," *J Hazard. Mat.*, vol. 122, pp. 161-170, June 2005.
- [29] P. M. Davaprasath, J. S. Soloman, and B. V. Thomas, "Removal of Cr (VI) from aqueous solution using natural plant material," *J. App.Sci. Environ. Sanit.*, vol. 2, pp.1-8, 2007.

- [30] U. Kumar, "Thermodynamics of the Adsorption of Cd(II) from Aqueous Solution on NCRH" *International Journal of Environmental Science and Development*, Vol. 2, No. 5, pp. 334-336, October 2011.
- [31] V. S. Sethu, Y. L. Kua, W. S. Quek, K. V. Lim, and J. M. Andresen, "Adsorption thermodynamics of Cu(II) ions from water using neem-leaf based biosorbents" *Journal of Environmental Research and Development*, vol. 6, pp. 26-33, September 2011.



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