Study of Phenol adsorption from aqueous solution onto Aluminium-activated carbon: Kinetics, equilibrium and Thermodynamic

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ABSTRACT

Adsorptive efficiency of phenol onto a Al-AC were examined via batch adsorption process. Batch experiments were accomplished as a function of several parameters such as influence of adsorbent dose (5-60 g/l), contact time (2–40hr), pH (4-10), initial concentration (100–100mg/L) and temperature (20-40^{0}C). The rate of removal of phenol by using Al-AC was very fast and equilibrium attained within hr. The kinetics of adsorption of phenol was calculated and was found that pseudo-second order kinetic model as best fitted model. The intra-particle diffusion has been identified to be the rate-limiting step. Adsorption equilibrium isotherm data was well fitted to Freundlich, Redlich-Peterson and Toth model. Thermodynamic modelling studies specified that the phenol adsorption onto Al-AC as spontaneous and exothermic in nature. The regeneration studies show that Al-AC could be efficiently used for the recovery and removal of phenol.

Keywords: Adsorption, Equilibrium Isotherm, Kinetic, Phenol, Thermodynamic.

1. Introduction

Phenol and its derivatives are mostly measured to be one of the utmost significant organic pollutants released into the environment producing unpleasant odour and taste of drinking water [M.Ahmaruzzaman, 2008,G.Busca, 2008]. The main sources of phenol in the aquatic environment are from several industries such as pharmaceuticals, refineries, plastics, coal processing, paint and paper, wood products, pesticide, industries [G.Busca,2008]. Their occurrence in the water, even at low concentrations, is toxic and unwanted to the aquatic life comprising fish. The consumption of phenols polluted wastewater have very toxic to the human health and reason negative influences on the brain, eye, digestive system, kidney, heart, lung, liver, skin and the unborn child, and peripheral nerve. In agreement with the World Health Organization (WHO) regulation, 0.002 mg/l is the acceptable limit for concentration of phenol in drinking water [S.K. Srivastava,1997].Therefore,the elimination of phenol is of great significance and has been established specific concerns in the last few years. Numerous wastewater management methods have been used containing advanced oxidation, electrochemical oxidation membrane filtration ,photocatalytic degradation, biological degradation, and adsorption [K. Rzeszutek 1998, S. Esplugas, 2002, A.P. Annachhatre,1996,Z.F. Guo 2006, J.D. Rodgers,1999,A. Dabrowski, 2005, D.M. Nevskaia 1999]. All these treatment methods have their particular advantages and disadvantages. Among these treatment methods, adsorption is the furthermost effective and attractive techniques owing to its high removal efficiency, easy design and low-cost. Several adsorbents such as carbon nanotubes zeolites, clay and polymers have been considered for the elimination of phenol and phenolic contaminants from wastewater(M. Ahmaruzzaman,2008,. M. Ghiaci, 2004,B. Pan, 2008, I. Vazquez 2007, K. Yang,2008). Remarkable a wide range of adsorbents have been studied for the elimination of phenol from waste water, among which Granular activated carbon is established as the best powerful adsorbent, therefore being widely used .For high strength of phenolic wastewaters, phenol elimination by adsorption using powdered / granular activated carbon has been generally used [Srivastava VC, 2006]. Surface modification and impregnation methods were used to enhance surface adsorption and removal capacity[R. Leyva Ramos,1999]. According to Leyva Ramos et al., the efficiency of aluminium-impregnated carbon for the removal of fluoride was observed 3–5 times that of plain carbon. Though, the adsorption of phenol onto surface modified/impregnated activated carbon is not well recognized. Most of the literatures on phenol removal share out with the adsorptive kinetics and equilibrium and thermodynamics. The equilibrium studies were characterized by various equilibrium isotherm models, viz. two parameter models of Freundlich, and Langmuir ,three parameter models of Redlich–Peterson and Toth Model and Four parameters model of Fritz-Schlunder [Kermani M,2006, Farzadkia M, 2012,S.kumar,R.K.Singh,2008]. Temperature is recognized to have noticeable effect on adsorption occurrence and intraparticle diffusion process. In the current study surface modified with aluminium Granular Activated Carbon has been used for the elimination of phenol from aqueous solution. For optimization purpose effects of such parameters as adsorbent dose, pH, contact time, temperature, and initial concentration on the adsorption of phenol have been examined. The kinetics of adsorption process has been calculated using different kinetic models. The adsorption efficiency of the adsorbent has been calculated using the adsorption equilibrium isotherm technique. Experimental data were close-fitted to numerous isotherm model equations to define the better isotherm to compare the experimental data. Effect of temperature for adsorption of phenol onto Al-GAC has also been examined. Thermodynamics of process have been calculated and changes in enthalpy and Gibbs free energy have also been determined.

2. Experimental protocols

2.1. Materials

Phenol (AR) was obtained from Himedia Himedia Laboratories Pvt. Ltd. Mumbai India. Chemical was used as received without any purification. The standard stock solution of the adsorbate for the batch adsorption experiments was prepared by dissolving suitable amount of phenol into distilled water and diluted to form the desired concentrations.

2.2. Preparation of adsorbent

The Activated Carbon used in this study was washed carefully with distilled water to eliminate fines, and then dried at 105 ^{0}C for overnight. The activated carbon was impregnated with aluminum by adding an aluminum nitrate solution of 2:1 liquid to solid ratio in an oven until complete water evaporated. After that the activated carbon was washed with distilled water and was dried in an oven at 100^{o}C for 24 h. Finally Al-AC kept in a plastic bag for further use.

2.3. Adsorption studies

The phenol adsorption onto Al-AC was carried out by using batch method. The batch adsorption experiments were carried out in 250 mL round flasks. 20 gm of Al-AC was added to 100 ml of phenol solution of well-known concentration in flask which was positioned in temperature control cum orbital shaking assembly. The flasks were wrapped to prevent variation in solution volume throughout the experiments. The solution was continuously stirred at constant temperature for a definite time to accomplish the equilibration. After equilibrium time, Al-AC was filtered by using Whatman filter No. 41. The residual concentrations of phenol in the aqueous solution before and after adsorption were observed using a UV–Vis spectrophotometer at 270 nm. A number of parameters such as contact time (2-40hr), pH (4-12), initial phenol concentration (100-1000mg/l) and temperature (20-40^{0}C) were changed to optimize the adsorption process. Kinetics studies of adsorption process were achieved at the phenol concentration 300 mg/l. The samples were collected at several time intervals until equilibrium reached. Isotherm and thermodynamic studies were achieved by changing the initial concentration of phenol solution (100-1000mg/l) and reaction temperature (20-40 ^{0}C).

The percent adsorption (%) of phenol and the amount of adsorbed phenol at equilibrium, qe (mg/g) was computed as follows:

$$q_t = (C_o - C_t)V/W \quad (1)$$

$$q_e = (C_o - C_e)V/W \quad (2)$$

The percent removal of phenol was calculated as follows:

$$Percentage\ \mathrm{Re}\,moval = ((C_o - C_f)/C_o)*100 \quad (3)$$

where qe is amount of adsorbed phenol at equilibrium (mg/g), qt is amount of adsorbed phenol at equilibrium time t (mg/g),qe is amount of adsorbed phenol at equilibrium, Co and Ce are the initial and final concentrations (mg/l) of phenol in solution at equilibrium, respectively, C_t is the concentrations (mg/l) of phenol in solution at equilibrium t, C_f is the final concentration of phenol, V is the volume of phenol solution in litre, and W is the weight (gm) of adsorbent.

2.4 Validity of Model

The hybrid error function (HYBRID) was used to measure the goodness-of-fit. HYBRID can be defined as:

$$HYBRID = \frac{100}{N-P}\sum_{i=1}^{N}\left[\frac{(Q_{e,\exp} - Q_{e,cal})^2}{Q_{e,\exp}}\right] \quad (4)$$

The smaller value of HYBRID indicates more exact estimation of *q*e value. The applicability of the kinetic model to define the adsorption process, was further validated by average relative error (ARE) which are defined as

$$ARE = 100/n \sqrt{\sum_{i=1}^{p} \left(\frac{Q_{e,i}^{\exp} - Q_{e,i}^{cal}}{Q_{e,i}^{\exp}} \right)^2} \qquad (5)$$

where $Q_{e,\exp}$ is the observed from the experiment , $Q_{e,cal}$ is the approximation from the isotherm model for equivalent $Q_{e,\exp}$, N is the number of observations in the experimental equilibrium isotherm and P is the number of parameters in the regression model. The smaller value of HYBRID shows more exact estimation of Q_e value [K. Vasanth Kumar,2008].

In order to calculate the goodness of the fit of experimental data and accuracy of the isotherm models applied in the present work, the resulting statistical indices are employed for the mono component system [M.R. Raoufy,2009, E.Z. Panagou, 2009).

$$B_{Fac} = 10\left(\sum \log_{10} (Q_{e,cal} / Q_{e,\exp}) / N\right) \qquad (6)$$

$$NSD = \sqrt{\frac{\sum \left(1 - Q_{e,cal} / Q_{e,\exp}\right)^2}{N}} \times 100 \qquad (7)$$

$$RMSE = \sqrt{\frac{\sum \left(Q_{e,\exp} - Q_{e,cal}\right)^2}{N}} \qquad (8)$$

2.5. Regeneration studies

To examine the reusability of adsorbent for phenol adsorption, the adsorption and desorption procedure was performed. The regeneration studies were achieved by batch mode. Al-AC (20 gm) was saturated with 300mg/l phenol solution for 2 hr. After that, adsorbent was washed many times with distilled water to eliminate the additional amount of phenol. To regenerate the saturated adsorbent, it was treated with 100 mL of 0.01 M HCL solution. After 2 hr, the solution was filtered and remaining concentration of phenol in aqueous solution was determined by UV spectrophotometric method. The regenerated adsorbent was washed with deionized water several times and dried for overnight at 60^0C. The same process was repeated for four consecutive cycles.

3. Results and discussion

3.1. Removal study of phenol from aqueous solution by batch method

3.1.1. Effect of dose and pH

The effect of adsorbent dosage is an essential parameter owing to the circumstance that a known mass of adsorbent can adsorb only a fixed quantity of adsorbate from the aqueous solution. The effect of Al-AC dosage on phenol removal was determined for the adsorbent dosage range of 0.5–60 g/L 30^0C. The results are specified in Fig. 1. It was detected that the removal of phenol increased from 67.02 % to 80.71% .when the Al-AC dosage increased from 5 to 20 g/L. This may possibly described by the circumstance that the increase in adsorbent dose resulted in additional existing adsorption sites for the adsorption of phenol. A Al-AC dosage of 20 g/L was used for further studies.

The most significant parameter affecting the adsorption efficiency is the pH of adsorption process. The pH of the adsorption process plays an vital role in the adsorption process for its effect on the surface charge of adsorbent surface for removal of phenol from mono solute system as a function of pH is revealed in Fig. 2. The effect of pH for the phenol adsorption onto Al-AC was calculated in the pH range 4-10. It is observed from Fig. 2 that the adsorption of phenol first increased from pH 4 to 8 and then declined with the further increment of pH 8-10. The maximum adsorption of phenol was observed at pH 8 (Fig. 2).Essentially, phenol has a pKa value of 9.89 . Phenol occurs in the form of phenol molecules, in the acidic solution and adsorbent will act together with the H+ ions (maximum movement) of the acidic solution, which is unfavourable for the adsorption process. Phenol makes phenolate ions in basic solution. The low adsorption of phenol at high pH was due to the electrostatic repulsion between the negatively charged surface of adsorbent and the phenolate anions in aqueous solution(C.M. Castilla, 2004, S. Lagergren,1898).

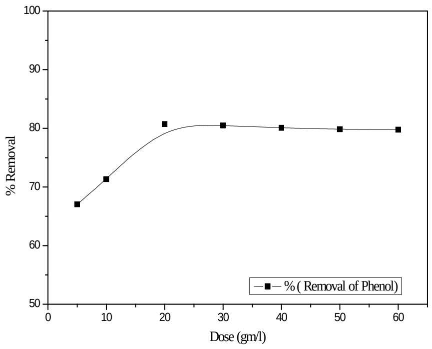

Fig:1 Effect of Dose

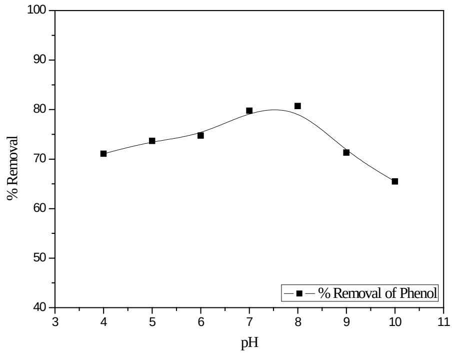

Fig:2 Effect of pH

3.1.2 Effect of contact time and temperature

The adsorption of phenol onto Al-AC was carried out at contact time from 2-40 hr. It is observed from Fig. 3 that adsorption of phenol was fast at initial stage and equilibrium was attained in 34 hr where 81.04 % phenol was removed. After 34 hr, no notable increment was found. The fast removal of phenol at the beginning may be due to the accessibility of maximum number of vacant sites on the adsorbent surface. Owing to which, the molecules of phenol were accrue on the surface and as a result, the left over vacant sites were problematic to be occupied due to the development of repulsive forces between the remaining available vacant sites as well as phenol molecules [A.H. Al-Muhtaseb,2011].

The temperature study was carried out at different temperatures, i.e. 20,25,30,35,and 40^0C . Percentage removal of phenol with temperature is shown in Fig. 4. It was detected that the adsorption of phenol decreased from 81.40 % to 79.45 % with the increase in temperature from 20 to 40^0C, respectively. The decrease in adsorption of phenol with the increase temperature was due to the flagging of the attractive force between adsorbent and phenol, and relatively due to the improvement of thermal energies of adsorbate. This is due to fact that production of attractive forces between phenol and Al-AC is not strong sufficient to hold the adsorbed molecules at sites [P. Canizares,2006].

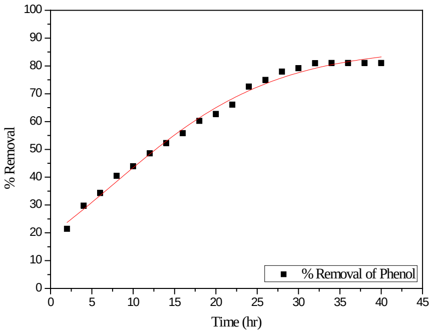

Fig:3 Effect of Contact Time

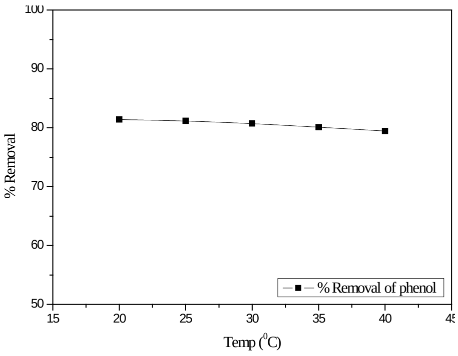

Fig:4 Effect of Temperature

3.1.3. Effect of initial concentration of phenol

The effect of initial concentration of phenol on percentage removal and specific uptake of phenol has been shown in Fig. 5 This figure indicates that the percentage removal of phenol decreases and specific uptake increases with the increase in initial concentration, for the reason that high phenol concentration leads to saturation of the binding ability of adsorbent, which subsequently decreases the removal efficiency.

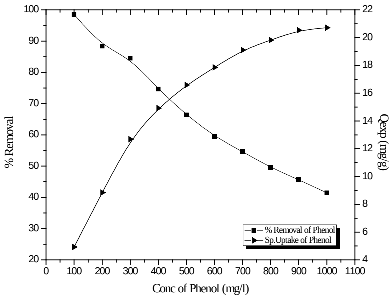

Fig:5 Effect of Initial conc. of phenol and uptake capacity

3.2. Adsorption kinetics

The kinetics of adsorption process defines the rate of uptake of adsorbate onto the adsorbent surface and it controls the equilibrium time. The kinetic parameters give information for modeling and designing the processes. The kinetics of adsorption of phenol onto Al-AC was examined by using pseudo first-order, pseudo second-order and intraparticle diffusion models. The correlation between experimental and model predicted values was stated by the ARE. A comparatively low value of ARE indicate that the model effectively defined the kinetics of phenol adsorption.

Pseudo-first order Model: = $q_t = q_e(1-\exp(-K_1 t))$ (9)

Pseudo second order Model: $q_t = k_2 q_e^2 t/(1+q_e K_2 t)$ (10)

Intra-particle diffusion Model: $q_t = K_{id} \times t^{0.5} + c$ (11)

The rate constant K_1 and K_2 for the phenol adsorption was studied by Pseudo first order and pseudo second order, respectively [Y.S. Ho,1998]. where, qt is the amount of phenol adsorbed at time t, qe is the amount of phenol at equilibrium, and k1and k2 is the rate constant for pseudo first-order adsorption and pseudo second-order (hr^{-1}). K_{id} is the intra-particle diffusion rate constant (mg/g min.), and C is the intercept (mg g/1).

All kinetic models are presented in Fig. 6a and 6b. The values of kinetic model constants are presented in Table 1. From the fig.6a and table 1, it could be observed that pseudo-second-order model fitted well with experimental data with lower value of ARE compared to the pseudo-first-order model.

The intra-particle diffusion plot for the phenol adsorption by using Al-AC (Fig. 6b) did not pass through origin, so intraparticle diffusion was not only rate defining step the adsorption mechanism [M.C. Xu 2008]. The values of intra-particle diffusion model constant K_{id} were designed from the slope of the plots qt versus $t^{0.5}$ and these values were more which showed a well mechanism of adsorption that is correlated to an better bonding between Al-AC and phenol. The plot of Intra-particle Diffusion model states that there are two steps with dissimilar rate constants affecting the adsorption process. Linear fits were applied to each region of the graph and the results were specified in Table 1. The first region may also be recognized to the boundary layer diffusion influence, though the second region may be owing to intra-particle diffusion influence. In this study, the rate constant (Kid), was found to be 0.860 and 0.799 (with R^2 values of 0.994 and 0.514). So, the intra-particle diffusion has been stated to be the rate-limiting step[M.C. Xu 2008].

Table:1 Kinetic parameter for phenol removal

	Al-AC	
Model	Parameters	Phenol
Pseudo First Order	Qtcal	4.724
	Kt1	0.097
	ARE	2.46
Pseudo Second order	Qtcal	6.011
	Kt2	0.016
	ARE	1.902
Intraparticle	K_{id1}	0.860
	R^2	0.994
	K_{id2}	0.799
	R^2	0.514

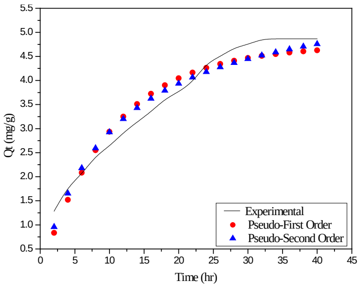

Fig: 6a Comparison of kinetic model

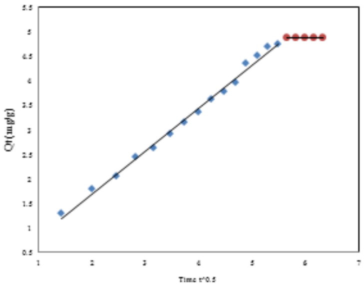

Fig:6b Intra-particle diffusion model

3.3. Adsorption isotherms

The intention of the adsorption equilibrium isotherms is to relate the adsorbed quantity at the interface and the concentration of adsorbate in the bulk solution. In the current study, the adsorption isotherm results were analyzed by using the Langmuir, Freundlich, Redlich-Peterson, Toth and Fritz-Schlunder Model isotherms (M.F. Sawalha,2006, M.F. Carvalho,,2007). The value of isotherm model parameter are given in Table.1 and Statistical indices values for the isotherm models are also tabulated in table 2.

The Non-linear form of the isotherm models can be written as:

Langmuir Model

$$q_e = (Q_0 b C_e)/(1 + bC_e) \tag{12}$$

Freundlich Model

$$q_e = K_F C_e^{1/n} \tag{13}$$

Redlich-Peterson Model

$$q_e = \frac{K_{RP}.C_{eq}}{1 + a_{RP}.C_{eq}^{\beta}} \tag{14}$$

Toth Model

$$q_e = \frac{q_e^{\infty}.C_{eq}}{(a + C_{eq}^{n})^{1/n}} \tag{15}$$

Fritz-Schlunder Model

$$q_e = \frac{\alpha_1.C_{eq}^{\beta_1}}{1 + \alpha_2 C_{eq}^{\beta_2}} \tag{16}$$

According to Langmuir model, the adsorption takes place at exact homogeneous sites inside the adsorbent by monolayer adsorption without any contact between adsorbed molecules. When the adsorbate is attached on the homogeneous site, no additional adsorption can take place at site; which established that the nature of adsorption process is monolayer. Where, qe is the amount of phenol adsorbed (mg/g), Ce is the phenol concentration at equilibrium (mg/l), b and Qo are the Langmuir constants related to energy of adsorption and monolayer adsorption capacity, respectively. The values of Qo and b are given in Table 2.The adsorption capacity of Al-AC for the adsorption of phenol was found to be 16.149 mg/g. To calculate the effectiveness of the adsorption process, the dimensionless equilibrium parameter was obtained by using the subsequent equation [K.R. Hall, 1966].

$$R_L = 1/1 + bC_0 \quad (17)$$

where, Co (mg/l) is the initial concentration of phenol and b is Langmuir constant (L m/g). The value of $R_L = 1$, linear isotherm, $R_L < 1$ represents favorable sorption and $R_L > 1$unfavorable adsorption. The values of RL in the current study were found to be <1 which specified a favorable adsorption onto Al-AC.

In compare to Langmuir model, the Freundlich model accepts that the surface energy of adsorbent is heterogeneous. It is expected that stronger binding sites are engaged first and that binding strength reduces with the increasing of site occupation. The non-linear form of Freundlich model is given in equation 13. where, qe is the adsorbed amount of phenol (mg/g), Ce is the equilibrium concentration of phenol (mg/l), K_F and exponential n are the Freundlich model constants which specify the adsorption capacity and amount of the nonconformity from linearity, respectively. The value of Freundlich model constant given in table 2.The value of K_F was found to be 4.456. The value of n approaches zero, the heterogeneity of surface site increase. In this study, n > 1 recommended the favorable adsorption of phenol onto Al-AC [L. Wang, 2010].

The Redlich–Peterson model is a three parameter isotherm, which structures both Langmuir and Freundlich isotherms [O. Redlich, 1959]. It can be given by the equ.14. Where K_{RP} is Redlich–Peterson isotherm model constant (L/g), a_{RP} is Redlich–Peterson isotherm constant (L/mmol) and β is the exponent which lies between 0 and 1. Non-linear fittings were applied to the isotherm data of phenol adsorption onto Al-AC by using MS Office 2010 by the five isotherm models. The model parameters for each isotherm model were given in Table 2. It is clear from Table 2, that the between two parameter model Freundlich isotherm model fitted well with experimental data (with lower HYBRID value) while, the high value of HYBRID indicate the poor agreement of Langmuir model with the experimental data. The value of HYBRID for Redlich-Peterson Model is found slightly more than Toth Model indicate good fit of Toth Model between three parameter model. While, four parameter model Fritz-Schlunder indicate poor fit with experimental data with high value of HYBRID.

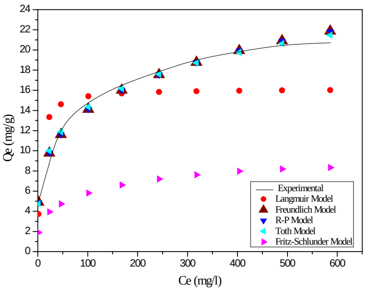

Fig:7 Comparison of isotherm model for phenol

Table:2 Isotherm model parameter for phenol

Single component isotherm Models	Values of model parameters	
Langmuir	Q_o	16.149
	b	0.2052
	HYBRID	25.6336

Freundlich	K_F	4.456
	n	4.006
	HYBRID	5.742
Redlich-Peterson	K_{RP}	266.95
	a_{RP}	59.31
	β	0.75213
	HYBRID	5.739
Toth	q_{to}	1951.25
	a	0.4039
	n	0.0554
	HYBRID	5.7174
Fritz-Schlunder	a1	1.71197
	a2	0.000061
	b1	0.265
	b2	1.90506
	HYBRID	67.1488

S.No	Models	Cyanide		
		Bf	NSD	RMSE
1	Langmuir Model	0.925387	22.92739	3.139158
2	Freundlich Model	0.99607	5.132685	0.683488
3	Redlich–Peterson Model	0.996073	5.133171	0.674058
4	Toth Model	0.995789	5.113837	0.574033
5	Fritz Schlunder Model	0.399283	60.05976	9.852063

3.4 Adsorption Thermodynamics

Adsorption Thermodynamic considerations are essential to conclude whether the adsorption process is spontaneous or not. Thermodynamic parameters such as change in Gibbs free energy ΔG^0, change in enthalpy Δh^0 and the change in entropy Δs^0, can be calculated using equilibrium constants varying with temperature. The Gibbs free energy change ΔG^0 can be determined from the subsequent equation:

$$\Delta G^0 = -RT\ln k \qquad (18)$$

The Relation between Δs^0, Δh^0 and ΔG^0, can be stated by the given equations:

$$\Delta G^0 = \Delta h - T\Delta s^0$$

Or

$$\ln k = \frac{\Delta s}{R} - \frac{\Delta h}{RT} \qquad (19)$$

where R is gas constant = 8.314×10^{-3} kJ/mole/K, ΔG^0 is kJ/mole, T = temperature in °K, Δs^0 is kJ/mol K, Δh^0 is the kJ/mole, and k is the equilibrium constant (amount on adsorbent/amount in solution). Parameter Eq. Δh^0 and Δs^0 from equ 17 can be designed from the slope and intercept of the plot of ln K versus 1/T, respectively [H. Ucun, 2008]. The values of Gibbs free energy ΔG^0, enthalpy Δh^0, and entropy Δs^0 changes are specified in Table 3. The negative value of ΔG^0 show that adsorption process is thermodynamically reasonable, chemically controlled and spontaneous. The nature of adsorption process is found to be exothermic as stated from negative value of Δh^0. The negative value of Δs^0 indicates the reduced randomness at the solid/solution edge throughout the adsorption process.

Table:3. List of Thermodynamic model parameters

		Al-AC		
Adsorbate	Temp. ^{0}C	ΔG_0	Δh_0	Δs_0
Phenol	20	-35.9867	-4.8213	-0.0041
	25	-36.2318		
	30	-36.0999		
	35	-35.6882		
	40	-126.274		

3.5. Desorption and regeneration studies

To retain the adsorption process more reasonable, it is very essential to regenerate the adsorbent. Adsorption, desorption and regeneration studies were used to check the regaining of adsorbed phenol from adsorbent and reusability of exhausted adsorbent, respectively. It is evident from Fig. 8 that the adsorption was reduced from 75.8 % to 60.9 % after four repeated cycles and the recovery of phenol was decreased from 72.01 % to 54.7 %. The regeneration studies indicate that Al-AC could be capably used for the recovery and removal of phenol.

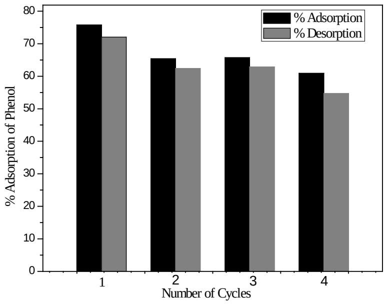

Fig:8 Adsorption and desorption study for phenol

Conclusions

For the removal of phenol from aqueous solutions by batch adsorption process have been carried out using Activate Carbon impregnated by using Al2O3. Maximum phenol removal efficiencies under the optimum conditions were found as 80.95 % onto Al-AC. The adsorption equilibrium isotherm studies indicated that Freundlich, Redlich-Peterson and Toth adsorption isotherm model satisfactorily defined the adsorption of phenol. The maximum adsorption efficiency was found to be 16.149 mg/g. It was revealed from kinetic study that the pseudo-second order kinetic model better defined the sorption kinetics with lower ARE value (1.902). The thermodynamic parameters Δs^0, Δh^0 and ΔG^0, indicated a chemically controlled, exothermic and spontaneous adsorption. The adsorbed phenol was recovered using 0.01 M HCL solutions and the regenerated adsorbent was successfully used for four repeated cycles without any considerable loss in the performance of adsorption process. In view of all these consequences, it may be concluded that Al-AC could be a possible adsorbent for the elimination and recovery of phenol from aqueous solution.

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