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Amit Bhatnagar[abc]; A. K. Minocha[a]; Eva Kumar[b]; Mika Sillanpää[c]; Byong-Hun Jeon[b]
[a] Environmental Science & Technology Division, Central Building Research Institute (CBRI), Roorkee, India [b] Department of Environmental Engineering, Yonsei University, Wonju, Gangwon-do, South Korea [c] Laboratory of Applied Environmental Chemistry (LAEC), Department of Environmental Sciences, University of Kuopio, Mikkeli, Finland

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Removal of Phenolic Pollutants from Water Utilizing *Mangifera indica* (Mango) Seed Waste and Cement Fixation

Amit Bhatnagar,[1,2,3] A. K. Minocha,[1] Eva Kumar,[2] Mika Sillanpää,[3] and Byong-Hun Jeon[2]

[1]Environmental Science & Technology Division, Central Building Research Institute (CBRI), Roorkee, India
[2]Department of Environmental Engineering, Yonsei University, Wonju, Gangwon-do, South Korea
[3]Laboratory of Applied Environmental Chemistry (LAEC), Department of Environmental Sciences, University of Kuopio, Mikkeli, Finland

Abstract: A process for the removal of two chlorophenols (2-chlorophenol and 2,4-dichlorophenol) from water using surface modified mango seed waste by adsorption process followed by cement fixation of the phenols-laden adsorbent is investigated. The two main objectives of this study were to develop efficient adsorbent utilizing mango seed waste by physiochemical activation and to an environmentally-friendly disposal of phenols-laden adsorbent into cement by a fixation process. The results of the present study reveal that the modified mango seed adsorbent showed an efficient adsorption potential for chlorophenols removal from water. The maximum adsorption potential of modified mango seed adsorbent for 2-chlorophenol and 2,4-dichlorophenol was 40.6 and 72.3 $mg\,g^{-1}$, respectively at 25°C. Adsorption kinetic data of chlorophenols adsorption on mango seed adsorbent could be described more favorably by a pseudo-second-order kinetic model. After the adsorption studies, the phenol-laden adsorbent was immobilized in cement for its ultimate disposal. Leachates from the fixed phenols-laden adsorbent exhibit phenols concentrations lower than the drinking water standards. Results from this study suggest the potential utility of

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Address correspondence to Amit Bhatnagar, Department of Environmental Engineering, Baekun Hall #332, Yonsei University, 234 Maeji Heungup, Wonju 220-710, Gangwon-do, South Korea. Tel.: +82-33-760-2814; Fax: +82-33-760-2194. E-mail: amit_b10@yahoo.co.in

agricultural wastes as one of the most promising activated carbon precursors for phenols removal from water and wastewater and the safe disposal of phenol-laden adsorbent into cement by fixation process.

Keywords: Adsorption study, cement fixation, chlorophenols, mango seed waste, surface modification

INTRODUCTION

Phenol and substituted phenols are considered as priority pollutants which are generally present in the industrial effluents (1,2). The discharge of effluents containing phenolic pollutants from various industries into natural water bodies is an ongoing and serious threat to human health and natural water quality. Chlorophenols are of commercial importance, extensively used as fungicides, herbicides, insecticides, pharmaceuticals, as preservative for wood, glue, paint, vegetable fibers, and leather, and intermediates in chemical synthesis (3). Chlorophenols may also be formed by the degradation of chlorinated pesticides, by the reaction of chlorinated water supplies with phenol in the environment, and during incineration of organic material in the presence of chloride. Phenolic compounds impart an objectionable taste and odor to drinking water at a concentration as low as $0.005\,mg\,L^{-1}$ (4). They are also toxic to all living organisms even at low concentrations (5,6). The ubiquitous nature of phenols, their toxicity even in trace amounts, and the stricter environmental regulations make it necessary to develop processes for the removal of phenols from wastewaters.

The methods used for the removal of phenols include biological methods (7), membrane filtration (8), ion exchange (9), photocatalytic degradation (10), oxidation with ozone/hydrogen peroxide (11), reverse osmosis (12), electrochemical oxidation (13), and adsorption (14–17). Dutta et al. (18) have classified these processes into two categories:

i. destruction processes such as oxidation with ozone, hydrogen peroxide, and manganese oxide and
ii. recuperative processes such as adsorption, membrane separation, and solvent extraction.

The treatment of industrial effluents containing high concentrations of chlorophenols has been challenging and it is still the subject of intense research.

Adsorption onto activated carbon proved to be an efficient and reliable physiochemical treatment methodology in wastewater treatment. In

spite of the usefulness of activated carbon as an efficient adsorbent for wastewater treatment, the high cost of activated carbon inhibits its large-scale use as adsorbent. Hence, an economical and easily available adsorbent would certainly make an adsorption-based process a viable alternative for the treatment of wastewater containing phenolic pollutants.

In the recent past, considerable attention has been devoted to develop the low-cost adsorbents from various natural as well as agro-industrial waste materials (19). Various adsorbents have been investigated for the removal of phenol and substituted phenols from water and wastewaters (20–29). However, the prepared adsorbents have not been found to be as efficient as commercial activated carbon in water pollution control. Therefore, the search for efficient low-cost adsorbents is ongoing. Additionally, most adsorption studies do not propose any environmentally safe disposal methods for the pollutants-laden adsorbent generated as a result of the adsorption process.

Agricultural solid wastes are gaining wide attention as these are cheaper, renewable, abundantly available, contain relatively high fixed carbon content, and possess a porous structure. Mango (*Mangifera indica*) is one of the major fruits produced in many countries and India is the largest producer of mangoes in the world. The world production of mango was estimated as 33.4 million tons in 2007 (30). Therefore, huge amounts of solid wastes (peel and seed or pit) are generated annually from the mango fruit. A thorough literature survey indicated that mango seed waste has not been examined as adsorbent for chlorophenols removal from water.

The present study was therefore undertaken with two main objectives:

i. to utilize mango seed waste as an adsorbent after proper treatment for the removal of 2-chlorophenol and 2,4-dichlorophenol from water and,
ii. to dispose of the phenol-laden adsorbent in cement by the solidification/stabilization (S/S) technology, which is a widely accepted technology to control the release of hazardous waste directly into the environment.

EXPERIMENTAL

Materials

2-chlorophenol (2-CP) and 2,4-dichlorophenol (2,4-DCP) were purchased from Sigma Chemical Co., Germany, and were used without further purification. A standard solution of both chlorophenols were

prepared in double-distilled water and diluted further as needed. All reagents used were of analytical reagent grade. Commercial Ordinary Portland cement 43 grade was used for fixation studies.

Preparation of Adsorbent Using Mango Seed Waste

The adsorbent was prepared by the method described by Mohd. Din et al. (31) with some modifications. The mango seeds were first washed with deionized water and dried in an oven at 80°C for 24 h. The dried seeds were then ground. The material was then carbonized at 500°C in air for 1 h. An accurate weight of produced char then was impregnated with an equivalent weight of potassium hydroxide at an impregnation ratio of 1:1. The mixture was then dehydrated in an oven at 100°C for 24 h. The dried solid mixture was then employed in a stainless steel vertical tubular reactor and pyrolyzed in a vertical tube furnace under high purity nitrogen till it reached the desired temperature of 800°C.

The gas was subsequently switched to carbon dioxide and the activation was continued for 1 h. The product was then cooled at room temperature and washed with deionized water and hydrochloric acid (0.1 M). The resulting product was dried at 100°C for 24 h.

Adsorption Experiments

The adsorption of chlorophenols on the prepared adsorbent was studied at room temperature by employing the batch method. A known volume of chlorophenols solution of varying initial concentrations, taken in 50 mL tubes, was shaken with a fixed dose of adsorbent for a specified period of contact time in a temperature-controlled shaking assembly. After equilibrium, the concentration of the adsorbate in the residual solution was determined spectrophotometrically at λ_{max} of 274 and 284 nm for 2-CP and 2,4-DCP, respectively. The reproducibility during concentration measurements was ensured by repeating the experiments at least three times under the same conditions and average values are reported. Standard deviations were found to be within $\pm 3.0\%$. The pH of the solutions was adjusted using 0.1 N HCl and 0.1 N NaOH.

Preparation and Curing of Cement Pastes and Mortars

A separate batch adsorption experiment similar to that described previously (under similar conditions) but with a larger volume (1 L) of

the adsorbate solution with a larger quantity of adsorbent (10 g) was conducted to produce the phenol-laden adsorbent for the preparation of the solidified specimens. After the equilibration time, the solid was separated from the liquid. The phenol-laden adsorbent was then dried in an oven at 110°C for 24 h. After drying, the phenol-laden adsorbent was added in different proportions to cement and sand to produce a cementitious system. Well-mixed mortar pastes were cast in 2.78″ cubic iron molds. The cubes were demolded after 24 h and were kept dipped in water for curing. These cubes were tested for compressive strength on 3, 7, 28, 60, and 90 days of curing. Three replicates were tested for each time and the average value was compared with the values obtained for the blank sample (without the addition of phenol-laden adsorbent). All the cement pastes and mortars were prepared by the methods described in the IS: 4031-1968 guidelines (32).

Leaching Studies

Leaching study has been carried out by following the standard method No. 1311 as recommended by the United States Environmental Protection Agency (USEPA) (33). Crushed solid material was placed in a hazardous waste filtration system with a zero head space extractor. A known volume of water was added and this assembly has been agitated for 24 h continuously in the agitator. A filtered extract was collected in a closed vessel and was analyzed for phenol concentration by using the UV-Vis.

RESULTS AND DISCUSSION

Effect of Contact Time

In order to establish the equilibration time for maximum uptake and to know the kinetics of the adsorption process, the adsorption of two chlorophenols on the mango seed adsorbent was studied as a function of contact time and the results are shown in Fig. 1. It is seen from the figure that the rate of uptake of both the chlorophenols is rapid in the beginning and ca. 50% adsorption is completed within 2 h. Figure 1 also indicates that the time required for equilibrium adsorption is 8 h. As prolonged standing of phenol solutions leads to the appearance of turbidity (34,35), an equilibration period of 10 h was selected for further studies.

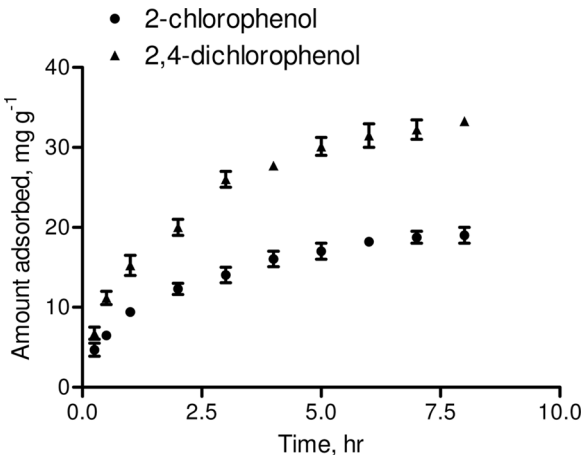


Figure 1. Effect of contact time on adsorption of chlorophenols on mango seed adsorbent.

Kinetic Modeling

Three simplified kinetic models, viz. pseudo-first-order, pseudo-second-order, and Weber and Morris intraparticle diffusion models have been discussed to identify the rate and kinetics of adsorption of chlorophenols on the prepared adsorbent.

Pseudo-First-Order Kinetic Model

The Lagergren's rate equation (36) is one of the most widely used for the sorption of the solute from the liquid solution. The linear form of pseudo-first-order rate expression of Lagergren is given as:

$$\log(q_e - q_t) = \log q_e - \frac{k_f}{2.303} t \tag{1}$$

where, q_e and q_t are the amount of chlorophenols adsorbed (mg g^{-1}) at equilibrium and at time t, respectively, and k_f is the pseudo-first-order rate constant. A plot of the linear form of the pseudo-first-order kinetic model is shown in Figure 2(a). The slope and intercept of the plot of the $\log(q_e - q_t)$ versus t were used to determine the pseudo-first-order rate constants (k_f) and $q_{e(cal)}$ and are compiled in Table 1 along with correlation coefficients values. It was observed that the correlation coefficients

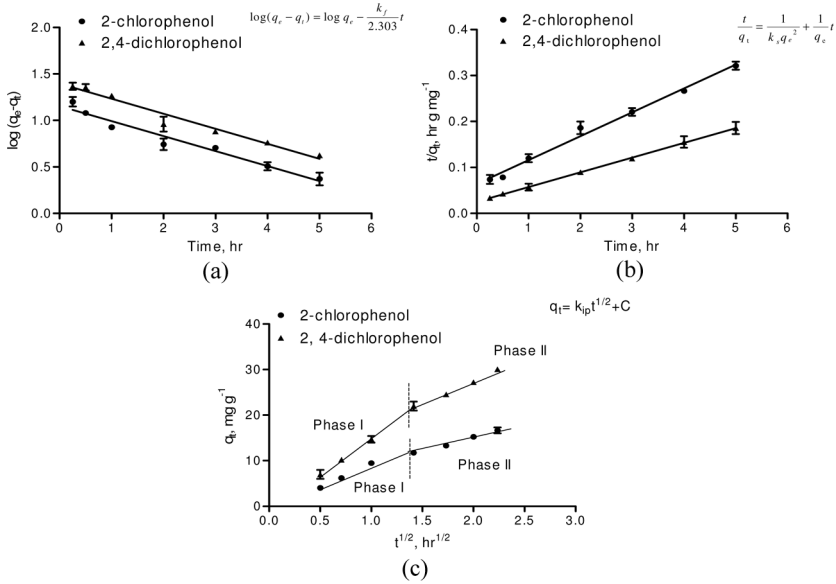


Figure 2. Kinetic modeling of chlorophenols adsorption on mango seed adsorbent (a) Pseudo-first-order kinetic model; (b) Pseudo-second-order kinetic model; (c) Weber and Morris intraparticle diffusion model.

for the pseudo-first-order kinetic model were less than 0.99 and the calculated q_e values, $q_{e(cal)}$ for the pseudo-first-order model did not give reasonable values with regard to the experimental uptake values $q_{e(exp)}$. This suggests that the present adsorption system did not follow pseudo-first-order kinetics.

Pseudo-Second-Order Kinetic Model

The adsorption kinetics was also described as pseudo-second-order process (37,38):

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

where, q_e and q_t are the amount of chlorophenols adsorbed (mg g^{-1}) at equilibrium and at time t and k_s is the rate constant of pseudo-second-order adsorption. The plots between t/q_t versus t were drawn and are shown in Fig. 2(b). The slope and intercept of plot of

Table 1. Comparison of pseudo-first-order, pseudo-second-order and Weber and Morris models parameters, and calculated $q_{e(cal)}$ and experimental $q_{e(exp)}$ values for chlorophenols

Pseudo-first-order model

Phenol	$q_{e(exp)}$ (mg g^{-1})	k_f (h^{-1})	$q_{e(cal)}$	Correlation-coefficients
2-chlorophenol	18.04	3.93×10^{-1}	14.42	0.9344
2,4-dichlorophenol	33.55	3.69×10^{-1}	25.51	0.9474

Pseudo-second-order model

Phenol	$q_{e(exp)}$ (mg g^{-1})	k_s (g mg^{-1} h^{-1})	$q_{e(cals)}$ (mg g^{-1})	Correlation-coefficients
2-chlorophenol	18.04	4.89×10^{-2}	18.94	0.9911
2,4-dichlorophenol	33.55	2.94×10^{-2}	34.48	0.9949

Weber and Morris model

Phenol	k_{ip1} (mg g^{-1} h$^{-0.5}$)	Correlation-coefficients	k_{ip2} (mg g^{-1} h$^{-0.5}$)	Correlation-coefficients
2-chlorophenol	10.09	0.9882	5.56	0.9877
2,4-dichlorophenol	15.74	0.9778	10.81	0.9858

t/q_t versus t were used to determine the pseudo-second-order rate constants (k_s) and $q_{e(cal)}$ and are compiled in Table 1 along with the correlation coefficients values. As can be seen from Table 1, the theoretical $q_{e(cal)}$ values agree well with the experimental $q_{e(exp)}$ ones in the case of the pseudo-second-order kinetic model with good correlation coefficients (>0.99). This suggests that the present adsorption system can be defined more favorably by the pseudo-second-order kinetic model.

In order to understand the diffusion mechanism, the Weber and Morris intraparticle diffusion model (39) was tested in the present study.

Intraparticle Diffusion Model

The concentration dependence of the rate of adsorption is frequently used to analyze the nature of the "rate-controlling step," and the use of the intraparticle diffusion model has been greatly explored in this

regard which is represented by Eq. (3) to elucidate its mechanism (39):

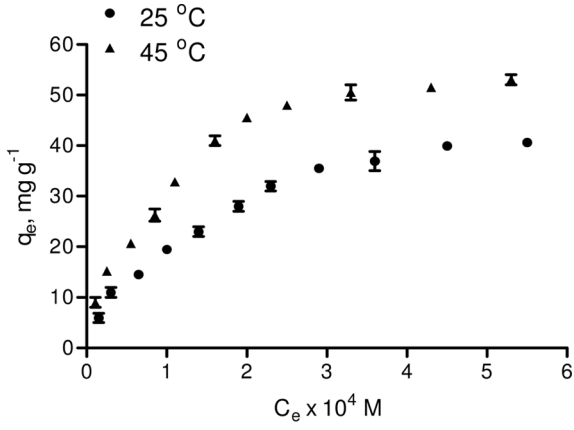
$$q_t = k_{ip} t^{1/2} + C \tag{3}$$

where, C is the intercept and k_{ip} is the intraparticle diffusion rate constant. According to this model, if the adsorption of a solute is controlled by the intraparticle diffusion process, a plot of q_t versus $t^{1/2}$ should yield a straight line. The Weber and Morris plots of the adsorption of chlorophenols on the mango seed adsorbent are shown in Fig. 2(c). It is clear from the figure that there are two separate zones: first linear portion (phase I) and second linear part (phase II). In phase I, the rapid uptake of chlorophenols onto the adsorbent can be attributed to the immediate utilization of the most readily available adsorbing sites on the adsorbent surface. Phase II may be ascribed to very slow diffusion of the adsorbate from the surface site into the inner pores. Thus the initial portion of chlorophenols' adsorption by the adsorbent may be governed by the initial intraparticle transport of chlorophenols controlled by the surface diffusion process and the latter part controlled by pore diffusion. The values of k_{ip1} and k_{ip2} (intraparticle diffusion rate constants for phase I and II, respectively) obtained from the slope the of the linear plots are listed in Table 1. The intercept of the line fails to pass through the origin and the correlation coefficients values are also less than 0.99 suggesting that the mechanism of the chlorophenols' adsorption onto the prepared adsorbent is not solely governed by the intraparticle diffusion process. The deviation of a straight line in the Weber and Morris model might be due to the difference in the rate of mass transfer in the initial and final stages of adsorption (40).

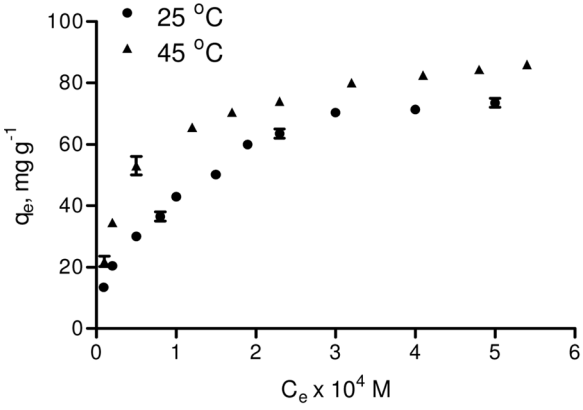
Adsorption Isotherms of Chlorophenols on Mango Seed Adsorbent

In order to evaluate the efficacy of the prepared adsorbent, the equilibrium adsorption of both the chlorophenols was studied as a function of concentration. The adsorption isotherms of both the chlorophenol on mango seed adsorbent are shown in Fig. 3. The maximum adsorption from these adsorption isotherms has been calculated and compiled in Table 2.

It is seen from Table 2 that the extent of adsorption of two chlorophenols on prepared adsorbent follow the order: 2,4-dichlorophenol > 2-chlorophenol. It has been reported that in the adsorption of phenols on the carbon surface, the role of the donor-acceptor complex mechanism involving carbonyl oxygen groups of the carbon surface



(a)



(b)

Figure 3. Adsorption isotherms of chlorophenols on mango seed adsorbent at different temperatures (a) 2-chlorophenol (b) 2,4-dichlorophenol.

Table 2. pKa, aqueous solubility and amount adsorbed of chlorophenols on mango seed adsorbent at 25°C

Phenol	pKa	Solubility in water (g L^{-1})	Amount adsorbed (mg g^{-1})
2-chlorophenol	8.52*	28.0*	40.6
2,4-dichlorophenol	7.90*	4.5*	72.3

*Reference 52.

acting as an electron donor and the aromatic ring of the adsorbate as acceptor is important (41). Thus, it is expected that the electron withdrawing groups, which deactivate the ring, would promote adsorption through complex formation occurring via the donor-acceptor mechanism. The order of deactivation of the ring would be, 2,4-dichlorophenol > 2-chlorophenol, and consequently the adsorption via the donor-acceptor mechanism would follow this order. As a result of higher deactivation of the ring in 2,4-dichlorophenol, there would be a higher tendency of adsorption through a donor-acceptor complex mechanism resulting in maximum adsorption.

Besides this, the solubility and pKa of the solute is also expected to affect the adsorption to a great extent. A decrease in both solubility and pKa of the solute is associated with an increase in the adsorption capacity (20). The solubility data and pKa values of both chlorophenols are given in Table 2 which indicates that the pKa and the solubility of chlorophenols decreases in the order, 2-chlorophenol > 2,4-dichlorophenol. A comparison of the pKa and the solubility and the adsorption capacity (Table 2) clearly indicates that there exists an inverse relationship between the extent of adsorption and solubility and the pKa of the solute. 2-chlorophenol having higher pKa (8.52) and higher aqueous solubility ($28\,g\,L^{-1}$) would be adsorbed in a lower amount at the solid–liquid interface. On the other hand, 2,4-dichlorophenol having lower solubility ($4.5\,g\,L^{-1}$) and lower pKa (7.9) is adsorbed to a comparatively greater extent. Thus, all these factors, i.e., the tendency to form more donor-acceptor complexes at the carbon surface, the low pKa, and the low aqueous solubility lead to the same order of adsorption and it is reasonable to believe that a combined effect of these factors is observed.

Effect of Temperature on Chlorophenols Adsorption on Mango Seed Adsorbent

In order to understand the effect of temperature on the adsorption of chlorophenols, experiments were also conducted at 45°C and the results are compiled in Fig. 3. A comparison of the adsorption isotherms at 25°C and 45°C shows that the adsorption increases with an increase in temperature indicating that the process is apparently endothermic. Similar results were also reported by other workers (35,42) dealing with the adsorption of phenol and chlorophenols by low-cost adsorbents. It seems that at higher temperatures, a dissociation of the phenol molecule occurs. However, the effect of temperature can mainly be explained on the basis of hydrogen bonding (43). In aqueous solutions of phenols, there exists

extensive hydrogen bonding between the phenol molecule and water resulting in appreciable solubility. These hydrogen bonds get broken at higher temperatures and this would cause phenols to be less soluble and therefore, exhibit a higher tendency to go to the adsorbent surface and get adsorbed rather than remaining in the solution. This would result in more adsorption at higher temperature (43). This phenomenon (more adsorption at higher temperatures) can also be explained on the basis of ''active surface centers'' (the presence of free hydroquinone and quinone groups on the carbon surface which could constitute the active surface centers for the adsorption of phenols by hydrogen bonding) (44). The workers suggested that the number of active surface centers available for sorption increase with increasing temperature resulting in a higher adsorption of phenols.

The adsorption data was further analyzed to Freundlich and Langmuir models and found to conform best to following the Langmuir model with good correlation coefficients:

$$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m b c_e} \tag{4}$$

where, q_e is the amount adsorbed at equilibrium concentration C_e, q_m is the Langmuir constant representing the maximum monolayer capacity, and b is the Langmuir constant related to the energy of adsorption. The plots between $1/q_e$ and $1/C_e$ for the adsorption of the phenols are drawn in Fig. 4. The values of monolayer capacity (q_m) and Langmuir constant (b) have been evaluated from the intercept and slope of these plots are given in Table 3. It is seen from Table 3 that the monolayer capacity (q_m) of the adsorbent for the phenols is comparable to the maximum adsorption obtained from adsorption isotherms.

The effect of the isotherm shape has been discussed with a view to predict whether an adsorption system is ''favorable'' or ''unfavorable'' (45). The essential feature of the Langmuir isotherm can be expressed in terms of 'R_L,' a dimensionless constant referred to as a separation factor or equilibrium parameter. R_L is calculated using Eq. (5):

$$R_L = \frac{1}{1 + bC_0} \tag{5}$$

The values of 'R_L' calculated as per above equation are incorporated in Table 3. As the 'R_L' values lie between 0 and 1, the adsorption isotherm is favorable.

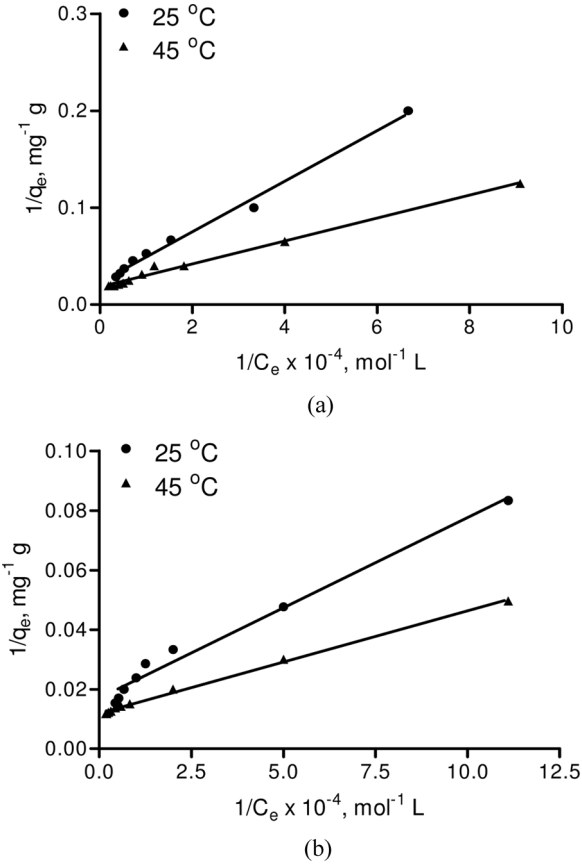


Figure 4. Langmuir plots of chlorophenols adsorption on mango seed adsorbent (a) 2-chlorophenol (b) 2,4-dichlorophenol.

Table 3. Langmuir constants and separation factor for the adsorption of chlorophenols on mango seed adsorbent at 25°C

Phenol	q_m (mg g^{-1})	b (L mol^{-1})	Correlation-coefficients	R_L
2-chlorophenol	43.7	7.6×10^3	0.9928	2.4×10^{-1}
2,4-dichlorophenol	84.1	11.9×10^3	0.9920	1.7×10^{-1}

Thermodynamic Parameters

The thermodynamic parameters were calculated to confirm the adsorption nature of the present study. The thermodynamic constants, free energy change (ΔG°), enthalpy change (ΔH°), and entropy change (ΔS°) were calculated to evaluate the thermodynamic feasibility of the process and to confirm the nature of the adsorption process.

The thermodynamic parameters were calculated using the Eqs. (6–8):

$$\Delta G^\circ = -R\ T\ ln\, K \tag{6}$$

$$ln\frac{K_2}{K_1} = \frac{\Delta H^\circ}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \tag{7}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \tag{8}$$

where, R is the universal gas constant ($8.314\,J\,mol^{-1}\,K^{-1}$), T is the temperature in Kelvin, and K is the equilibrium constant, related to the Langmuir constant 'b' via Eq. (9), where the value 55.5 corresponds to the molar concentration of the solvent (in this case water) with units of $mol\,L^{-1}$ (46–48).

$$K = b \times 55.5 \tag{9}$$

The values of the above stated parameters are summarized in Table 4. The ΔH° values are positive due to the effect of temperature on breaking of hydrogen bonds which resulted in increased adsorption. Thus, the pre-adsorption step (breaking of hydrogen bonds between phenol and water molecules at higher temperatures) gives rise to positive ΔH° values. These positive ΔH° values are only apparent heat of adsorption. As a matter of fact, ΔH° values reflect the combined effect of the endothermic hydrogen bond breaking process and the exothermic adsorption process. The endothermic process predominates the exothermic adsorption process giving rise to positive ΔH° values. Further, negative ΔG° values indicate a spontaneous process. ΔS° values were found positive which indicate the

Table 4. Thermodynamic parameters for the adsorption of chlorophenols on mango seed adsorbent at 25°C

Phenol	K	ΔG° ($kJ\,mol^{-1}$)	ΔS° ($J\,mol^{-1}\,K^{-1}$)	ΔH° ($kJ\,mol^{-1}$)
2-chlorophenol	4.2×10^5	−32.1	131.5	7.1
2,4-dichlorophenol	6.6×10^5	−33.2	168.3	16.9

affinity of the adsorbent for chlorophenols and suggests an increased randomness at the solid-solution interface during the adsorption process.

Fixation Studies of Phenols-Laden Adsorbent with Cement

The phenol-laden adsorbent was added in different proportions to cement and sand to produce a cementitious system as described under the heading: ''Preparation and Curing of Cement Pastes and Mortars,'' and the prepared cubes were tested further to monitor the change in different properties of the cement.

The initial and the final setting time (IST and FST) were determined following the method described in the Indian standard method IS: 8112-1989 (49). Both of these parameters were determined for the blank samples as well as after the addition of 1–5% phenol-laden adsorbent in cement. All the experiments were carried out in triplicate to assure accuracy and reproducibility. It is evident from the results (Fig. 5) that there was no significant change in the IST and FST on the addition of 1–5% phenol-laden adsorbent in cement. Another important property, the compressive strength of cement containing 1–5% of the phenol-laden adsorbent of cement, was also investigated (Fig. 6). The results of compressive strength on 3, 7, 28, 60, and 90 days of curing are reported here. The addition of a phenol-laden adsorbent in cement did not exhibit any noticeable effect on the rate of strength attainment as well as on the compressive strength of the binding system.

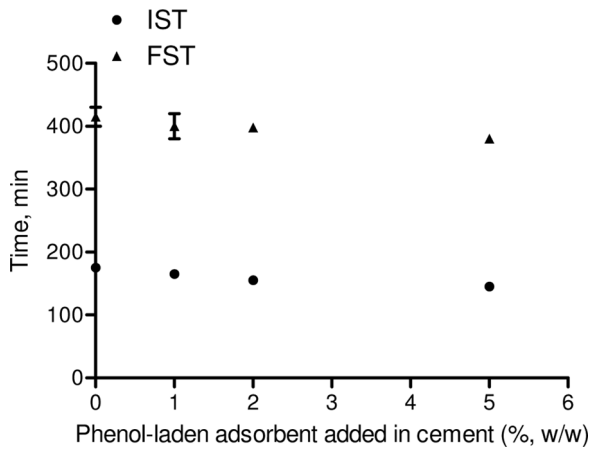


Figure 5. Effect of addition of 1–5% phenol-laden adsorbent on the initial (IST) and final setting time (FST) of cement.

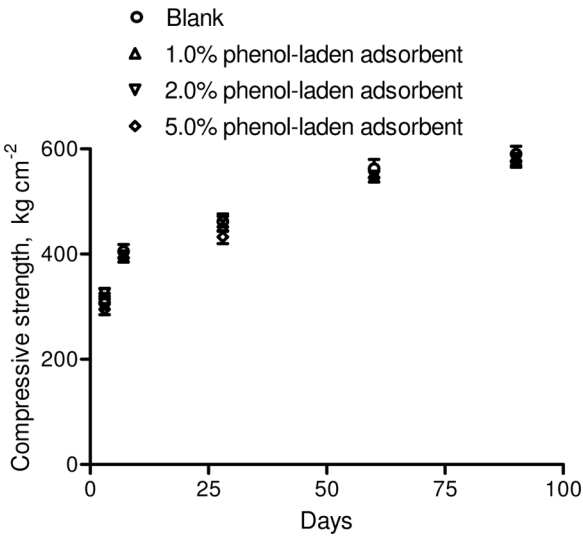


Figure 6. Effect of fixation of phenol-laden adsorbent on compressive strength of cement.

Further, preliminary results of the leaching study show that both the chlorophenols did not significantly leach from the mortar samples with 1–5% adsorbent composition. Leachates from the fixed phenols-laden adsorbent exhibit phenols concentration lower than the drinking water standards in India ($1.0\,\mu g\,L^{-1}$) (50). These results are in agreement with the previous observation where it has been reported that the use of regenerated powdered activated carbon in the S/S process reduced the leaching potential of phenol by ca. 600% compared to when no reactivated carbon was used (51). Further research regarding the role of several other factors influencing the leaching studies is in progress. These studies might be useful in identifying and elucidating the binding mechanism of phenol and other organic contaminants in cement.

CONCLUSIONS

The results of the present study reveal that the mango seed waste can be beneficially utilized as an effective adsorbent after proper treatment for the removal of chlorophenols from aqueous solutions. The adsorption capacities of the mango seed adsorbent for chlorophenols were found 40.6 and $72.3\,mg\,g^{-1}$ for 2-chlorophenol and 2,4-dichlorophenol, respectively at 25°C. The adsorption data conformed best to the Langmuir model. The Gibbs free energy was determined to be negative, indicating

the spontaneous nature of the adsorption process. The phenol-laden adsorbent was then immobilized into the cement for ultimate disposal. Leachates from the fixed phenols-laden adsorbent exhibit phenols concentrations lower than the drinking water standards.

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