

The Removal of Phenol from Aqueous Solutions Using Modified Saxaul ASH

¹Razieh Khaksefidi, ²Hamed Biglari, ³Somayeh Rahdar, ⁴Mohammad Mehdi Baneshi,
⁵Morteza Ahamadabadi, ⁶Mohammad Reza Narooie, ⁷Arsalan Salimi, ⁸Mehdi Saeidi and ⁹Vali Alipour
¹Department of Environmental Health Engineering, School of Public Health,
Zahedan University of Medical Science, Zahedan, Iran
²Department of Environmental Health Engineering, School of Public Health,
Social Development and Health Promotion Research Center,
Gonabad University of Medical Sciences, Gonabad, Iran
³Department of Environmental Health Engineering, School of Public Health,
Zabol University of Medical Sciences, Zabol, Iran
⁴Social Determinants of Health Research Center, Yasuj University of Medical Science, Yasuj, Iran
⁵Department of Environmental Health Engineering,
Torbat jam Faculty of Medical Sciences, Torbat Jam, Iran
⁶Department of Environmental Health Engineering, School of Public Health,
Iranshahr University of Medical Sciences, Iranshahr, Iran
⁷Research Center for Environmental Determinants of Health,
Kermanshah University of Medical Sciences, Kermanshah, Iran
⁸Department of Environmental Health Engineering School of Health,
Torbat Heydariyeh University of Medical Sciences, Torbat Heydariyeh, Iran
⁹Department of Environmental Health Engineering, School of Public Health,
Research Center for Social Determinants in Health Promotion,
Hormozgan University of Medical Sciences, Bandar Abbas, Iran

Abstract: Phenol and its derivatives enter water sources through different natural and artificial routes. Phenol compounds are resistant to biologic degradation, soluble in water and are considered toxic to human and other species capable of causing unpleasant odor in water, mutations and birth defects. The objective of the present study was to investigate the potential of modified Saxaul ash to remove phenol from Aqueous Solutions in this experimental study, the effect of influential factors such as pH (2, 3, 5, 7, 8, 10, 12), contact time (5-120 min), adsorbent dose (0.1, 0.3, 0.5, 0.7, 0.9, 1.0 and 1.5 g L⁻¹) and phenol initial concentration (10-200 mg L⁻¹) was also determined. Adsorption isotherm was investigated using Freundlich, Langmuir and Temkin Isotherm Models. Results indicated that the maximum efficiency of modified Saxaul ash removing phenol was 91% that was achieved at pH of 3, 60 min contact time, 0.7 g L⁻¹ adsorbent dose and phenol initial concentration of 100 mg L⁻¹. In addition, adsorption isotherm study showed the most fitness of data into Langmuir Adsorption Model (R² = 0.996).

Key words: Phenol, aqueous solutions, saxaul ash, adsorption, adsorbent

INTRODUCTION

The accumulation of chemical pollutants on the planet earth is threatening for human and the environment (Bazrafshan *et al.*, 2012a-c). Among organic pollutants of water sources, phenol and its derivatives are the most abundant one. Known as a hydroxyl group bound to benzene ring, phenol compounds are highly resistant and toxic at lower concentrations (Arutchevian *et al.*,

2005). Presence of phenol in surface and groundwater sources has been confirmed in several studies. Phenol is highly soluble in water and creates acidic condition once dissolved in water which promotes solubility of other pollutants. Phenol and its derivatives enter water resources through different natural and artificial routes (Biglari *et al.*, 2005a, b) and are present in high amounts in industrial wastewater such as that of coal refinery, petrochemical industry, resin and paint industry,

fungicide and herbicide products and textile industry (Biglari *et al.*, 2016a, b; Leitao *et al.*, 2007; Das *et al.*, 2014). Chlorinated phenol compounds cause unpleasant odor and flavor in water at concentrations $<5 \mu\text{g L}^{-1}$ that are toxic to aquatic species, plants and humans (Das *et al.*, 2014; Hashemi *et al.*, 2014; Daraei *et al.*, 2010). Drinking water polluted with phenol leads to degradation of proteins and tissues, dysfunction of central nervous system, damage to kidney, liver and pancreas (Khosravi *et al.*, 2013; Yousef *et al.*, 2011). World Health Organization (WHO) has set the maximum allowable concentration of phenol in drinking water at 0.001 mg L^{-1} (Mukherjee *et al.*, 2007) and the American Environmental Protection Agency (USEPA) has recommended standard level of $<0.5 \mu\text{g L}^{-1}$ phenol in drinking water (Biglari *et al.*, 2016). The USEPA has determined allowable concentration of 1 mg L^{-1} phenol in wastewater disposed (Balasubramanian and Venkatesan, 2012). To protect human and environmental health from adverse effects of phenols present in wastewater, an efficient method of refinement prior to disposal of wastewater seems necessary (Moussavi *et al.*, 2010). There are several methods of phenol elimination from aqueous solutions such as adsorption, chemical oxidation, biologic refinement, chemical sedimentation, ion exchange, membrane processes and reverse osmosis (Alipour *et al.*, 2014; Kilic *et al.*, 2011). Simple chemical oxidation and biologic degradation are not efficient enough due to the conversion of phenol to secondary compounds that are mainly toxic (Sajjadi *et al.*, 2016).

Among all elimination methods, adsorption method is mostly used due to its higher efficiency, appropriate selectivity, lower cost of operation, lower chemical end products, the lack of need for dangerous chemical material from biologic sludge and ease of design and application (Liu *et al.*, 2010; Ahmaruzzaman, 2008). The adsorption methods are capable of eliminating most forms of organic material and their efficiency remains stable even in toxic environments (Shetty *et al.*, 2007). Today, simple and low cost adsorbents especially agricultural waste products such as wheat straw, rice bran ash, palm kernel and avocado seeds are effectively used in eliminating pollutants from? (Ahmed and Theydan, 2012; Kermani *et al.*, 2012; Rodrigues *et al.*, 2011). Saxaul also is an agricultural waste product that is called Tagh in Persian and Haloxylonpersicum in Latin language. This plant is Iran aboriginal and therefore it is called Iranian Saxaul. The plant is distributed in dry and desert areas such as Zabol, Tabas and Garmsaar and has a key role in stabilizing moving sands. Since, root of Saxaul penetrates up to 20 m beneath the earth seeking water, it can be cultivated in dry and barren areas. This study aimed at determining the adsorption potential of saxaul in ash to remove phenol from aqueous solutions.

MATERIALS AND METHODS

Most chemicals used in the study were obtained from the Merck and Sigma Aldrich. Saxaul tree was from Zabol, Iran. The Saxaul tree was initially washed to remove probable contaminations and then was cut into approximately 1 cm^2 pieces. The small pieces were rinsed using deionized water prior to 12 h of incubation in oven at 105°C . To obtain modified adsorbent, Saxaul tree was soaked in 30% sodium hydroxide solution (volume based) for 24 h with the plant mass being twice as that of sodium hydroxide to account for the modification of the adsorbent capacity of adsorption. Subsequently, the solution was again incubated in the oven at 105°C and then was transferred to the furnace with 650°C for 3 h. The obtained ash was cooled in desiccator and to eliminate contaminations and impurities it was washed with 2% chlorhydric acid and double distilled water for several time. The modified ash was dried at 105°C for 12 h and then it was ground using Chinese mortar before they were passed through standard ASTM sieves with 60 and 200 mesh size to adjust particle size at 0.075-0.25 mm. The final product was cooled and stored at desiccator (Vijayaraghavan and Yun, 2008).

To determine the optimum pH and adsorbent dose on the samples polluted with phenol, a 1000 mg L^{-1} stock solution of phenol was prepared. The initial pH of the sample (2, 3, 5, 7, 8, 10 and 12) was set using sulfuric acid and 0.1 N NaOH and a basic-UB10 pH meter (Denver Ultra, USA). The adsorbent dose (0.1, 0.3, 0.5, 0.7, 0.9, 1 and 1.5 g L^{-1}), contact time (5, 10, 30, 60, 90 and 120 min) and phenol initial concentration (10, 30, 50, 100, 150, 200 g L^{-1}) were some other parameters investigated. To perform the experiments, samples with predefined conditions were initially dispensed in 250 mL erlenmeyer flasks on the shaker set at 150 rpm. At the end of each contact time, samples were filtered through $0.45 \mu\text{m}$ whatman filter papers and the changes in phenol concentration was read by spectrophotometry with 4 aminoantipyrine reagent using spectrophotometer (PD-303 UV, USA) at 500 nm wavelength. The standard curve was drawn based on absorption of samples at dominant wavelength and was used to determine phenol concentration in the samples. Finally, the amount of phenol adsorbed (mg g^{-1}) and the removal efficiency (%) was calculated using following Eq. 1 and 2:

$$q_e = \frac{(C_0 - C_e)V}{M}$$

$$\text{Percentage} = \frac{(C_0 - C_f)}{C_0} \cdot 100$$

Where:

C_0 and C_e = Represent the initial and final concentration (mg L^{-1}) of phenol in aqueous phase, respectively

V = The volume of the solution (L)

M = The amount of adsorbent used (g) (Biglari *et al.*, 2016)

C_f = Represents the equilibrium concentration of phenol in aqueous phase

RESULTS AND DISCUSSION

Effect of pH: The initial pH affects the degree of phenol ionization and surface characteristics of the adsorbent. Regarding the adsorbent, it appears that increased acidity or alkalinity can affect the ionization of positively charged amino acids of protein creatine (Banat *et al.*, 2000). The effect of pH on the phenol adsorption capacity of modified Saxaul ash was investigated using different pH values (2, 3, 5, 7, 8, 10, 12) keeping phenol initial concentration at 100 mg/L , adsorbent dose at 0.5 g L^{-1} and temperature at $22 \pm 2^\circ\text{C}$ for 30 min contact time. According to Fig. 1, the adsorption of phenol by modified Saxaul ash decreased with increasing pH from 3-12. The maximum adsorption efficiency and amount of dye adsorbed were 89% and 178 mg g^{-1} , respectively which were achieved at pH of 3. Therefore, pH of 3 was considered as the optimum and all subsequent experiment were performed at this pH. Changes in pH of solution influence degradation and dissociation of conjugated groups on the active surface of the adsorbent which leads to changes in adsorption reaction synthetics and characteristics of adsorbent adsorbate equilibrium. In lower pH values the adsorbent surface is positively charged and therefore the efficiency of phenol removal is higher in acidic than alkaline conditions. This higher efficiency can be attributed to higher amounts of H^+ in acidic condition which promotes formation of OH radicals. Phenol is a weak acid the adsorption of which decreases at higher pH values due to competition with OH and electrostatic reactions between phenol and adsorbent surface because positively charged adsorbent surface cannot adsorb phenol ion due to electrostatic repulsion (Busca *et al.*, 2008; Uddin *et al.*, 2007; Srivastava *et al.*, 2006). Same results with phenol adsorption by activated carbon, bentonite and sugar cane ash have also been reported (Halhouli *et al.*, 1995; Banat and Asheh, 2000; Srivastava *et al.*, 2006).

Effect of adsorbent dose: The effect of adsorbent dose on the phenol adsorption capacity of modified Saxaul ash was investigated with different doses of adsorbent ($0.1, 0.3, 0.5, 0.7, 0.9, 1$ and 1.5 g L^{-1}), phenol initial concentration of 100 mg L^{-1} , pH of 3 and contact time of 30 min at $22 \pm 2^\circ\text{C}$. Phenol adsorption by modified

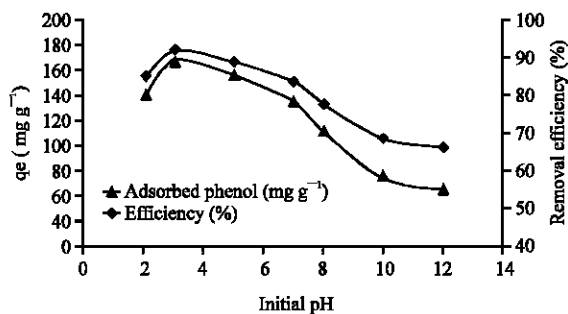


Fig. 1: Effect of PH

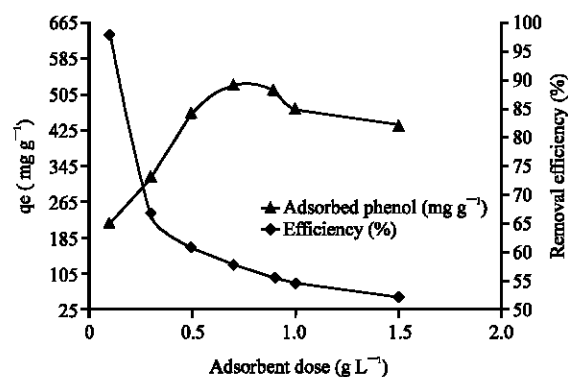


Fig. 2: The effect of adsorbent dose on phenol removal by modified Saxaul ash (Phenol initial concentration = 100 mg L^{-1} ; pH = 3; contact time = 30 min; temperature = 25°C)

Saxaul ash increased with increasing adsorbent dose from 0.1 – 0.7 g L^{-1} reaching maximum efficiency of 89% and 127.14 mg g^{-1} of dye adsorbed at 0.7 g L^{-1} adsorbent dose (Fig. 2). The removal efficiency decreased gradually with adsorbent doses over 0.7 g L^{-1} . Therefore, 0.7 g L^{-1} was considered as optimum adsorbent dose in the present study. Higher phenol adsorption with increasing adsorbent dose can be attributed to increased active adsorption area on the adsorbent surface (Bazrafshan *et al.*, 2012). On the other hand, decreased phenol adsorption at adsorbent doses above 0.7 g L^{-1} can be explained by decreased phenol concentration at higher adsorbent doses and desorption of phenol to the solution (Moussavi *et al.*, 2010). Researchers have suggested that decreased adsorption at higher adsorbent doses could be due to limited availability of active adsorption sites on adsorbent surface and therefore incomplete saturation of these sites (Rodrigues *et al.*, 2011). These findings are in line with those of Kumar *et al.* (2007) and Mahvi *et al.* (2004). In addition, in a similar study, Mishra and Bhattacharya (2007) observed that phenol elimination by leaf carbon decreased with increasing adsorbent dose.

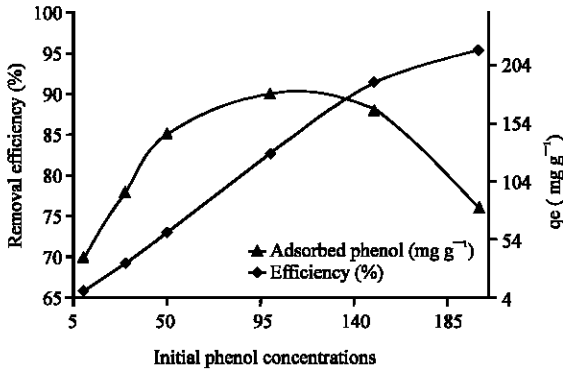


Fig. 3: The effect of phenol initial concentration on the removal by modified Saxaul ash (optimum adsorbent dose = 0.7 g L⁻¹; optimum pH = 3, contact time = 30 min; temperature; 25°C

Effect of initial concentration: The effect of phenol initial concentration on phenol adsorption capacity of modified Saxaul ash is shown in Fig. 3. With increasing phenol initial concentration from 10-100 mg L⁻¹, Phenol removal efficiency increased from 70.12-90.18% and the amount of phenol removed increased from 10-128.57 mg g⁻¹. However, with further increases in phenol initial concentration from 100-200 mg L⁻¹, the removal efficiency decreased from 90.18-76%. This might be explained by the saturation of adsorption active sites on the adsorbent surface at high phenol initial concentrations (Ghaneian and Ghanizadeh, 2009; Varghese *et al.*, 2004; Bazrafshan *et al.*, 2015) and increased mass transfer force (Bazrafshan *et al.*, 2015; Nagda *et al.*, 2007). These results are in agreement with those by Roostaei and Tezel (2004), Khosravi *et al.* (2013).

Effect of contact time: Contact time is one of the most important parameters influencing the pollutant adsorption by different adsorbent surfaces and adsorption efficiency that should be considered in designing experiments (Senturk *et al.*, 2009). Figure 4 shows the effect of contact time (5-120 min) on phenol removal and adsorption capacity by modified Saxaul ash at phenol optimum initial concentration of 100 mg L⁻¹ and adsorbent dose of 0.7 g L⁻¹. There was a remarkable increase in the adsorption capacity and phenol removal until 91% adsorption efficiency and 130 mg g⁻¹ of phenol adsorbed were achieved at 60 min of contact time. However, adsorption efficiency declined with a gentle slope at contact times over 60 min.

Kermani studied phenol removal using rice bran ash and activated carbon and reported a higher adsorption rate during early times of contact due to higher availability of adsorption active sites for the attachment of phenol reaching equilibrium in single layer adsorption of phenol on adsorbent surface after 60 min (Kermani *et al.*,

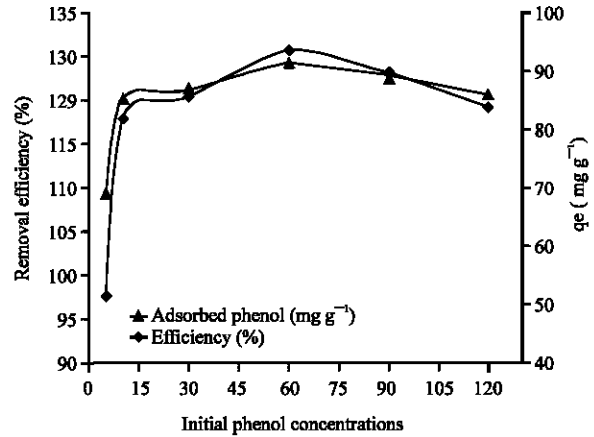


Fig. 4: The effect of contact time on the amount of phenol adsorbed by modified Saxaul ash (optimum adsorbent dose = 0.7 g L⁻¹; optimum pH = 3; optimum phenol concentration = 100 mg L⁻¹; temperature = 25°C)

2006). Liu studied the potential of carbon pores made of heated coal in removing copper and phenol and reported similar increasing trend followed by a decline in adsorption rate after 120 min of contact time and attributed this effect to higher availability of adsorption sites at early stages of adsorption process (Liu and Zhang, 2011).

Adsorption isotherms: We studied the adsorption of the pollutants on adsorbent surface and determined adsorption isotherms and adsorption capacity in the present study. Isotherms are used to interpret the way a pollutant is adsorbed on the adsorbent surface and to determine the relationship between pollutant concentration present in the solution and the degree of adsorption by the solid phase at the state of equilibrium (Sanchooli *et al.*, 2016). Following determination of optimum pH, contact time of equilibrium, optimum adsorbent dose and phenol initial concentration, the adsorption of the pollutant was investigated using Langmuir, Freundlich nad Temkin isotherms. Results (high R² value) showed that the adsorption data most fitted Langmuir adsorption isotherm. The desirability type of adsorption process in Langmuir Isotherm Model can be determined by the use of dimensionless factor (R_L) with R_L>1 representing undesirable adsorption, R_L = 1 linear adsorption, R_L = 0 irreversible adsorption and 0<R_L<1 desirable adsorption (Bayramoglu *et al.*, 2009). Calculated R_L shows desirable adsorption in the present study (Eq. 3):

$$RL = \frac{1}{(1 + K_L C_0)}$$

where, $1/n$ is a measure of adsorption intensity and represents the isotherm type. If $1/n = 0$ the adsorption is irreversible, if $0 < 1/n < 1$ it is desirable and if $1/n > 1$ the adsorption is undesirable (Aliabadi *et al.*, 2006). Since, $1/n$ is > 1 in the present study, the adsorption is undesirable and does not fit Freundlich isotherm.

CONCLUSION

In the current study, the adsorption of phenol on the modified Saxaul ash along with the effects of important parameters influencing the adsorption such as pH, contact time, adsorbent dose and phenol initial concentration was investigated. The results indicated that all aforementioned parameters influence the adsorption process. Phenol adsorption capacity of modified Saxaul ash was higher in lower pH values with the maximum removal efficiency of 91% at pH = 3, contact time of 60 min, adsorbent dose of 0.7 g L^{-1} and phenol initial concentration of 100 mg L^{-1} . Higher adsorption capacity at lower pH values can be attributed to electrostatic attraction between phenol and the adsorbent. In addition, results of the present study indicated that the removal efficiency is positively correlated to the contact time and negatively related to phenol initial concentration. Phenol removal fitted Langmuir Isotherm Model and the adsorption was single layer and homogenous. Overall, it can be concluded that modified Saxaul ash can be used as a low cost adsorbent to remove phenol from wastewater without generating chemical sludge.

REFERENCES

- Ahmaruzzaman, M., 2008. Adsorption of phenolic compounds on low-cost adsorbents: A review. *Colloids Surfaces Sci.*, 143: 48-67.
- Ahmed, M.J. and S.K. Theydan, 2012. Equilibrium Isotherms, Kinetics and thermodynamics studies of phenolic compounds adsorption on palm-tree fruit stones. *Ecotoxicol. Environ. Saf.*, 84: 39-45.
- Aliabadi, M., K. Morshedzadeh and H. Soheyli, 2006. Removal of hexavalent chromium from aqueous solution by lignocellulosic solid wastes. *Int. J. Environ. Sci. Technol.*, 3: 321-325.
- Alipour, V., S. Nasser, R.N. Nodehi, A.H. Mahvi and A. Rashidi, 2014. Preparation and application of oyster shell supported zero valent nano scale iron for removal of natural organic matter from aqueous solutions. *J. Environ. Health Sci. Eng.*, 12: 1-8.
- Arutchelvan, A., V. Kanakasabai, S. Nagarajan and V. Muralikrishnan, 2005. Isolation and identification of novel high strength phenol degrading bacterial strains from phenol formaldehyde resin manufacturing industrial wastewater. *J. Hazard. Mater.*, 27: 238-243.
- Balasubramanian, A. and S. Venkatesan, 2012. Removal of phenolic compounds from aqueous solutions by emulsion liquid membrane containing ionic liquid [BMMIM]+[PF6]-in tributyl phosphate. *Desalin.*, 289: 27-34.
- Banat, F.A. and A.S. Asheh, 2000. Biosorption of phenol by chicken feathers. *Environ. Eng. Policy*, 2: 85-90.
- Banat, F.A., B. Al-Bashir, S. Al-Asheh and O. Hayajneh, 2000. Adsorption of phenol by bentonite. *Environ. Pollut.*, 107: 391-398.
- Bayramoglu, G., I. Gursel, Y. Tunali and M.Y. Arica, 2009. Biosorption of phenol and 2-chlorophenol by *Funaliatrogii* pellets. *Bioresour. Technol.*, 100: 2685-2691.
- Bazrafshan, E., H. Biglari and A.H. Mahvi, 2012a. Phenol removal by electrocoagulation process from aqueous solutions. *Fresenius Environ. Bull.*, 21: 364-371.
- Bazrafshan, E., H. Biglari and A.H. Mahvi, 2012b. Humic acid removal from aqueous environments by electrocoagulation process using iron electrodes. *J. Chem.*, 9: 2453-2461.
- Bazrafshan, E., F.K. Mostafapour and A.H. Mahvi, 2012c. Phenol removal from aqueous solutions using pistachio-nut shell ash as a low cost adsorbent. *Fresenius Environ. Bull.*, 21: 2962-2968.
- Bazrafshan, E., M.F. Kord, S. Rahdar and A.H. Mahvi, 2015. Equilibrium and thermodynamics studies for decolorization of Reactive Black 5 (RB5) by adsorption onto MWCNTs. *Desalin. Water Treatment*, 54: 2241-2251.
- Biglari, H., A. Chavoshani, N. Javan and M.A. Hossein, 2016a. Geochemical study of groundwater conditions with special emphasis on fluoride concentration, Iran. *Desalin. Water Treatment*, 57: 22392-22399.
- Biglari, H., M. Saeidi, V. Alipour, S. Rahdar and Y. Sohrabi *et al.*, 2016b. Review on hydrochemical and health effects of it in Sistan and Baluchistan groundwater's, Iran. *Int. J. Pharm. Technol.*, 8: 17900-17920.
- Biglari, H., M. Afsharnia and S.A. Sajadi, 2005a. The removal of phenol from aqueous solution by plant roots from the ashes of the environment. *Persica J. Eng.*, 3: 15-25.
- Biglari, H., M. Afsharnia and S.A. Sajadi, 2005b. The removal of phenol from aqueous solution by plant roots from the ashes of the environment. *Persica J. Eng.*, 3: 15-25.

- Busca, G., S. Berardinelli, C. Resini and L. Arrighi, 2008. Technologies for the removal of phenol from fluid streams: A short review of recent developments. *J. Hazardous Mat.*, 160: 265-288.
- Daraei, H., M. Manshouri and A.R. Yazdanbakhsh, 2010. Removal of phenol from aqueous solution using ostrich feathers ash. *Mazand Univ. Med. Sci.*, 20: 81-87.
- Das, B.C., P. Sinha, K.M.S.D. Banik and M. Das, 2014. Studies on removal of Phenol from contaminated water source by microbial route using *Bacillus cereus*. *Int. J. Current Res.*, 2: 179-185.
- Ghaneian, M.T. and G. Ghanizadeh, 2009. Application of enzymatic polymerization process for the removal of phenol from synthetic wastewater. *Iran. J. Health Environ.*, 2: 46-55.
- Halhouli, K.A., N.A. Darwish and N.M. Aldhoon, 1995. Effects of pH and inorganic salts on the adsorption of phenol from aqueous systems on activated decolorizing charcoal. *Separat. Sci. Technol.*, 30: 3313-3324.
- Hashemi, F., H. Godini, S.G. Khorramabadi and L. Mansouri, 2014. Assessing performance of walnut Green Hull adsorbent in removal of phenol from aqueous solutions. *Iran. J. Health Environ.*, 7: 265-276.
- Kermani, M., H. Pourmoghaddas, B. Bina and Z. Khazaei, 2006. Removal of phenol from aqueous solutions by rice husk ash and activated carbon. *Pak. J. Biol. Sci.*, 9: 1905-1910.
- Kermani, M., M. Gholami, A. Gholizade, M. Farzadkia and A. Esrafil, 2012. Effectiveness of rice husk ash in removal of phenolic compounds from aqueous solutions, equilibrium and kinetics studies. *Iran. J. Health Environ.*, 5: 107-120.
- Khosravi, R., M. Fazlzadeh, Z. Samadi, H. Mostafavi and A.A. Taghizadeh *et al.*, 2013. Investigation of phenol adsorption from aqueous solution by carbonized service bark and modified-carbonized service bark by ZnO. *J. Health*, 4: 21-30.
- Kilic, M., V.E. Apaydin and A.E. Putun, 2011. Adsorptive removal of phenol from aqueous solutions on activated carbon prepared from tobacco residues: Equilibrium, kinetics and thermodynamics. *J. Hazard. Mater.*, 189: 397-403.
- Kumar, A., S. Kumar, S. Kumar and D.V. Gupta, 2007. Adsorption of phenol and 4-nitrophenol on granular activated carbon in basal salt medium: equilibrium and kinetics. *J. Hazardous Mater.*, 147: 155-166.
- Leitao, A.L., M.P. Duarte and J.S. Oliveira, 2007. Degradation of phenol by a halotolerant strain of *Penicillium chrysogenum*. *Int. Biodeterior. Biodegrad.*, 59: 220-225.
- Liu, Q.S., T. Zheng, P. Wang, J.P. Jiang and N. Li, 2010. Adsorption isotherm, kinetic and mechanism studies of some substituted phenols on activated carbon fibers. *Chem. Eng. J.*, 157: 348-356.
- Liu, Z. and F.S. Zhang, 2011. Removal of copper (II) and phenol from aqueous solution using porous carbons derived from hydrothermal chars. *Desalin.*, 267: 101-106.
- Mahvi, A.H., A. Maleki and A. Eslami, 2004. Potential of rice husk and rice husk ash for phenol removal in aqueous systems. *Am. J. Applied Sci.*, 1: 321-326.
- Mishra, S. and J. Bhattacharya, 2007. Batch studies on phenol removal using leaf activated carbon. *Malaysian J. Chem.*, 5: 1-9.
- Moussavi, G., B. Barikbin and M. Mahmoudi, 2010. The removal of high concentrations of phenol from saline wastewater using aerobic granular SBR. *Chem. Eng. J.*, 158: 498-504.
- Mukherjee, S., S. Kumar, A.K. Misra and M. Fan, 2007. Removal of phenols from water environment by activated carbon, bagasse ash and wood charcoal. *Chem. Eng. J.*, 129: 133-142.
- Nagda, G.K., A.M. Diwan and V.S. Ghole, 2007. Potential of tendu leaf refuse for phenol removal in aqueous systems. *Appl. Ecol. Environ. Res.*, 5: 1-9.
- Rodrigues, L.A., D.M.L.C.P. Silva, M.M.O. Alvarez, D.R.A. Coutinho and G.P. Thim, 2011. Phenol removal from aqueous solution by activated carbon produced from avocado kernel seeds. *Chem. Eng. J.*, 174: 49-57.
- Roostaei, N. and F.H. Tezel, 2004. Removal of phenol from aqueous solutions by adsorption. *J. Environ. Manage.*, 70: 157-164.
- Sajjadi, S.A., G. Asgari, H. Biglari and A. Chavoshani, 2016. Pentachlorophenol removal by persulfate and microwave processes coupled from aqueous environments. *J. Eng. Appl. Sci.*, 11: 1058-1064.
- Sanchooli, M.M., S. Rahdar and M. Taghavi, 2016. Cadmium removal from aqueous solutions using saxaul tree Ash. *Iran. J. Chem. Chem. Eng.*, 35: 42-52.
- Senturk, H.B., D. Ozdes, A. Gundogdu, C. Duran and M. Soylak, 2009. Removal of phenol from aqueous solutions by adsorption onto organomodified Tirebolu bentonite: Equilibrium, kinetic and thermodynamic study. *J. Hazard. Mater.*, 172: 353-362.
- Shetty, K.V., R. Ramanjaneyulu and G. Srinikethan, 2007. Biological phenol removal using immobilized cells in a pulsed plate bioreactor: Effect of dilution rate and influent phenol concentration. *J. Hazard. Mater.*, 149: 452-459.
- Srivastava, V.C., M.M. Swamy, I.D. Mall, B. Prasad and I.M. Mishra, 2006. Adsorptive removal of phenol by bagasse fly ash and activated carbon: Equilibrium, kinetics and thermodynamics. *Colloids Surf. A: Physicochem. Eng. Aspects*, 272: 89-104.

- Uddin, M.T., M.S. Islam and M.Z. Abedin, 2007. Adsorption of phenol from aqueous solution by water hyacinth ash. *J. Eng. Applied Sci.*, 2: 11-17.
- Varghese, S., V.P. Vinod and T.S. Anirudhan, 2004. Kinetic and equilibrium characterization of phenols adsorption onto a novel activated carbon in water treatment. *Indian J. Chem. Technol.*, 11: 825-833.
- Vijayaraghavan, K. and Y. Yun, 2008. Biosorption of C.I. Reactive Black 5 from aqueous solution using acid-treated biomass of brown seaweed *Laminaria* sp. *Dyes Pig.*, 76: 726-732.
- Yousef, R.I., B. El-Eswed and A.A.H. Al-Muhtaseb, 2011. Adsorption characteristics of natural zeolites as solid adsorbents for phenol removal from aqueous solutions: Kinetics, mechanism and thermodynamics studies. *Chem. Eng. J.*, 171: 1143-1144.