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# PHENOL REMOVAL FROM AQUEOUS SYSTEMS BY SORPTION OF USING SOME LOCAL WASTE MATERIALS

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#### ABSTRACT

The pollution of water with phenol from petrochemical industries is a highly important environmental problem, first of all because of the propagation of the pollution, and second because of its unfavorable consequences on the aquatic life, on the organoleptic properties and uses of water.

The potential of (local waste materials) Almond Shell residues, Date stones, Coffee ground, Black Tea Leaves, Olive Leaves and Activated Carbon for phenol adsorption from aqueous solution was studied. Batch process and isotherm studies were carried out under varying experimental conditions of contact time and phenol concentration.

The suitability of the Freundlich and Langmuir adsorption models to the equilibrium data were investigated for each phenol-adsorbent system. The results showed that the equilibrium data for the phenol-adsorbent systems fitted the Freundlich model best within the concentration range studied, specially the concentrations below 100 ppm. The study showed that, there are some local materials can be used as low-cost alternatives for phenol removal from water and wastewater.

#### **KEYWORDS**

Adsorption; Phenol, Wastewater, Isotherm.

# INTRODUCTION

There is growing concern about wide spread contamination of surface and ground water by various organic compounds due to the rapid development of chemical, petrochemical and oil refining industries over the past several decades. So, many industrial wastes contain phenolic compounds which are difficult, or impossible to be removed by conventional biological treatment processes (Lee and Lim, 2003; Wang et al., 2002). In the past several decades, extensive research has been conducted to develop innovative and promising adsorbent materials to deal with treatment problem of contaminate industrial effluents (Lin and Chery, 2002).

Phenols as a class of organics are similar in structure to the more common herbicides and insecticides in that they are resistant to biodegradation, (Mahvi et al., 2004).Some phenols are very soluble in water and presence in water supplies are noticed due to that taste and odor. The odor threshold for phenol is 0.04ppm according to regulations EPA (EPA, 2002). In the presence of chlorine in drinking water, phenols form chlorophenol, a well pronounced medicinal taste, that is unacceptable by the World Health Organization (WHO, 1994). Phenols are considered as priority pollutants since they are harmful to organisms at low concentrations and many of them have been classified as hazardous pollutants because of their potential harm to human health. String EPA regulation call for lowering phenol content in the wastewater below 1mg/l (EPA, 2002).

There are many methods such as oxidation (He and Lei, 2004; Manojlovic et al., 2007), precipitation (Xian et al., 2005), ion exchange (Carmona et al., 2006), solvent extraction (Parka et al., 2006) and adsorption (Lin and Chery, 2002; Banat et al., 2000; Street et al., 1995; Mostafa et al., 1989) for removing phenol from aqueous solution.

Adsorption is a well established and powerful technique for treating domestic and industrial effluents. However, in water treatment the most widely used method is adsorption onto the surface of activated carbons (Estevanho et al., 2006; Tomaszewska et al., 2004; Jung et al., 2001). Activated carbons remove many of the impurities occurring in water and wastewater (Sawyer and Mc Carty, 1994; Halouli and Drawish, 1995; Metcalf and Eddy, 2004). In spite of these characteristics, the high cost and variable performance of carbon regeneration, single use materials are more desirable (Rengaraj et al., 2002; Kummar et al., 1987). This has led many workers to search for more economic, practical and efficient techniques. Bottom ash, brick kilm ash, fly ash peat, soil, rice husk, wood, sow dust, bagasse and carbonized bark are some new adsorbent used for organic pollutants (Mahavi et al., 2004; Cardenas et al., 2005; Dakiky et al., 2004; Estevanho et al., 2006; Bras et al., 2005; Tsai et al., 2001; Navarro et al., 2008). Cheaper and effective locally available agriculture waste materials to develop low-cost wastewater filters in the developing countries cannot be overemphasized.

In this assignment, an attempt has been made to examine the utilization of waste materials in its dual role as an inexpensive and efficient locally available resource for the removal and detection of phenol present in aqueous solutions.

	C <sub>6</sub> H <sub>5</sub> OH
	0 <sup>—H</sup>
	$\bigcirc$
Formula	
Molecular weight (g/mol)	94.11
Melting Temperature (° C)	40.9
Boiling Point (° C)	181.75
Water solubility (r.t.)	9.3gphenol /100 mlH2 O
рКа	9.89
Flammability limits in air (vol%)	1.7 (lower) - 8.6 (higher)
Flash point (° C)	79 (closed cup)
Auto-ignition temperature (° C)	715

Table 1 Chemical and physical properties of phenol, (Busca et al, 20
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#### PHENOL CHEMICAL AND PHYSICAL PROPERTIES

Some chemical and physical properties of phenol (also called phenic acid or carbolic acid) are reported in Table 1. Phenol was first isolated from coal tar in 1834 by the German chemist Runge (Jordan et al., 2002). It is an aromatic hygroscopic crystalline solid at ambient temperature and pressure. When pure, solid phenol is white but is mostly colored due to the presence of impurities. Phenol is very soluble in ethyl alcohol, ether and several polar solvents, as well as in hydrocarbons such as benzene. In water it has a limited solubility and behaves as a weak acid. As a liquid phenol attacks rubber, coatings, and some forms of plastic. Hot liquid phenol attacks aluminum, magnesium, lead, and zinc metals. It is characterized by a typical pungent sweet, medicinal, or tar-like odor (Amore and Hautala, 1983). Furthermore, it is a combustible compound.

### PHENOL HEALTH EFFECTS

The sterilizing activity of phenol was discovered by the English surgeon Joseph Lister in 1865. The germicidal activity of phenol appears attributed to its protein denaturing ability. Due to its lipofile properties, it binds itself to the batteric proteine by hydrogen bonds (Weissermel,1997). Due to its raped absorption by skin it can be a serious health hazard to workers at production sites and in handling in addition it can cause eye irritation and lead to coma, convulsion, cyanosis and damage to lungs, vascular system, liver and kidneys under extreme conditions of exposure. In Nazi Germany phenol was used in extermination of prisoners. Death was coming up in a few seconds and the throaty lethal injections due to its rapid effect (Lifton, 1986). However, there is no evidence that phenol has any carcinogenic potential.

### PHENOL SOURCES AND STANDARDS

Phenols are present in wastewater of various industries, such as oil refineries (6–500 mg/l), coking operations (28–3900 mg/l), coal processing (9–6800 mg/l), and petrochemicals plants (2.8–1220 mg/l). Phenols represent the main organic constituents present in condensate streams in coal gasification and liquefaction processes. Other sources of wastewater containing phenols are production sites of pharmaceuticals, plastics, wood products, paint, pulp and paper industries within 0.1–1600 mg/l concentrations (Busca et al, 2008). As a particular case we can cite olive oil mill wastewaters, rich in phenol and polyphenol derivatives that give rise to relevant phytotoxicity. They represent a significant problem in the Mediterranean area.

Due to its toxic nature phenol-containing wastewater may not be conducted into open water without treatment. The EPA has set a water purification standard of less than 1ppb of phenol in surface waters. In Libya, the limit for phenols in potable and mineral waters is 0.5 ppb, while the limits for wastewater emissions are 0.5 ppm for surface waters and 1 mg/l for the sewerage system.

# MATERIALS AND METHODS

# CHEMICALS:

Phenol solutions were prepared by diluting of stock solution of phenol to the desired concentrations. A stock solution was obtained by dissolving 1g of phenol (obtained from WINLAB) in 1000ml distilled water.

### ANALYSIS OF PHENOL:

The concentrations of residual phenol were measured using an UV-Visible spectrophotometer (Unicam 8700). The absorbance of the colored complex of phenol with 4-amino antipyrine was read of 500nm (Standard Methods, 1999).

### ADSORBENTS:

Some waste materials (almond shell, date stone, olive leaves, black tea residual, coffee ground and activated carbon) were separately crushed and sieved by a 300um sever and dried at 105°C to obtain a constant weight. Properties of used activated carbon was obtained from (RIEDEL-DEHAEN).

# CONTACT TIME:

To obtain the optimum time, 2g of adsorbent were added to 100ml of phenol aqueous solution with 100ppm concentration in 250ml glass bottles and shaken for 5min, 10min, 30min, 1h, 2h, 3h, 6h and 24h.

#### **Adsorption Studies:**

Phenol adsorption isotherms were obtained using batch equilibrium technique. The batch adsorption experiments were carried out by using 1g of adsorbent added to 100ml of phenol aqueous solutions in 250ml glass bottles. Initial phenol concentration solutions ranged from 1 to 1000ppm (pH was 6.8). The bottles were subsequently capped and shaken in an orbital action shaker at 100rpm for the optimum time (3h) at 25°C. At the end of the equilibrium period the contents of the bottles were filtered by glass wool.

### STATISTICAL ANALYSIS:

The mean and standard deviation values of the triplicate samples were calculated. The collected data were analyzed with a parametric two way analysis of variance (ANOVA) to test the significant differences between treatments (p = 0.01). The goodness of fit between the experimental data and predicted values was expressed by the correlation coefficient ( $R^2$ , values close or equal 1), it's not to ascribe more meaning to it than is warranted to obtain the constants of the models from the best fitting. Just because  $R^2$  is close to 1, this does not mean that the fit is necessarily good, (Chapra and Canale, 1998). Therefore, the conformity between the experimental data and the model predicted values was expressed by the total mean error (E%), equation (1), (Press et al., 1989; Ayar et al., 2008).

$$E \% = \frac{\sum_{i=1}^{n} \left| \left( q_{e(Exper.)} - q_{e(Calc.)} \right) \right|}{\sum_{i=1}^{n} q_{e(Eper.)}}$$

### **RESULTS AND DISCUSSION**

#### **EFFECT OF CONTACT TIME**

The results show that the equilibrium time required for the adsorption of phenol on all samples is about 3h as illustrated in figure 1. The result also indicate that used adsorbents would require less residence time for the complete removal of phenol. This is a lesser time duration if compared to some other material as rice husk (Mahavi et al., 2004); bentonite (Banat et al., 2000); porous clay (Cardenas et al., 2005); pine bark (Bras et al., 2005); organobentonites (Lin and Chery, 2002).



#### **INITIAL CONCENTRATION EFFECT:**

The effect of initial phenol concentrations was tested by using several concentrations (1, 5, 10, 25, 50, 100, 500 and 1000ppm). The effect of phenol initial concentration variation on the percentage removal in six type used as adsorbents is illustrated in Figure 2 the results show that the initial concentration increases as the removal of phenol decreases, especially for initial concentration lower than 100ppm. Maximum percentage removal of phenol by each adsorbent are 98.6±0.06, 86±0.11, 72±0.51, 87±0.4, 94±0.46 and 88±0.12% at activated carbon, black tea residual, coffee ground, almond shell, date stone and olive leaves, respectively. Due to its small surface porosity, coffee ground is prove to be the worst adsorbent compared to the other adsorbents as reported by Nakamura et al. (2003). The high adsorption of phenol on Date Stone with high significant (P < 0.001) can be attributed to the presence of nitrogen compounds like proteins and amino acids (Haider et al., 1965). The statistical analysis display reveals that, there are no statistically significant differences (P >0.05) between almond shell, black tea residual and olive leaves. Good adsorption of phenol at used adsorbents is referred to the presence of -OH and C=C aromatic bonds, that may induce phenol molecules can establish, respectively, hydrogen bounds and hydrophobic interactions with the adsorbent surface (Estevanho et al., 2006).



### **3.3.** Adsorption isotherms:

There are several models have been reported in the literature to describe experimental data as adsorption isotherms. Analysis of the isotherm data is important in order to develop equations that represent the results which could be used for design purposes. In this study two models (Freundlich and Langmuir) were used to describe the relationship between the amount of phenol adsorbed and its equilibrium concentration for all adsorbents.

Freundlich isotherm is expressed as follow:

$$q_e = K_f \left( C_e \right)^{l/n} \tag{2}$$

Where,  $q_e$  is the amount adsorbed at equilibrium (mg/g),  $C_e$  is equilibrium concentration of the adsorbate (mg/l), and k and 1/n are the Freundlich constants related to adsorption capacity and adsorption intensity respectively of the adsorbent. The values of k and 1/n can be obtained from the intercept and slope respectively of the linear plot of  $log q_e$  versus  $log C_e$ , (Reynolds and Richards, 1982; Sawyer and Mc Carty, 1994; Ibrahim and Abushina, 2008). The linear form of the Freundlich isotherm model is given by the following relation:

$$Log q_e = log k + 1/n log C_e \qquad .....(3)$$

$$Langmuir \text{ isotherm is expressed as follow :}$$

$$CmbC$$

$$q_e = \frac{CmbC_e}{1 + CmC_e} \tag{4}$$

where,  $q_e$  is the amount adsorbed at equilibrium (mg/g),  $C_e$  is equilibrium concentration of the adsorbate (mg/l), and  $c_m(mg/g)$  and b (l/mg) are the Langmuir constants related to the maximum adsorption capacity and the energy of adsorption, respectively. These constants can be evaluated from the intercept and slope of the linear plot experimental data of  $l/q_e$  versus  $l/C_e$  (Reynolds and Richards, 1982; Sawyer and Mc Carty, 1994; Ibrahim and Abushina, 2008).

The linear form of the Langmuir isotherm model can be represented by the following relation:

$$1/q_e = 1/c_m + 1/(b c_m) * 1/C_e$$
 ......(5)

The linearized Freundlich and Langmuir adsorption isotherms of each adsorbent for phenol are shown in Fig.3 and Fig. 4 respectively. The Langmuir and Freundlich constants are listed in Table.2. The results reveal that the adsorption of phenol on used the adsorbents obeys the Freundlich adsorption isotherm specially at concentrations below 100 ppm (Fig. 3). However, E% values which are a measure of goodness-of-fit (Table.2), show that both the Langmuir and Freundlich isotherm models can adequately describe the adsorption data. The higher value of k, the Freundlich constant, showed easy uptake of phenol from aqueous solution (Rengaraj et al., 2002; Aksu and Yener, 2001; Halouli and Drawish, 1995).



The adsorption capacity k is the lowest for the coffee ground. The n value, which reflects the intensity of adsorption, presents the opposite trend, but as seen from Table.2 for all the sorbents and pollutants, n values were found high enough for separation. The higher fractional value of 1/n (0 < 1/n < 1) signifies. That the surface of the adsorbent is heterogeneous in nature (Cerofolini et al., 1978).

The magnitude of  $c_m$  indicates that the amount of phenol per unit weight of adsorbent to form a complete monolayer on the surface operate to be significantly higher for phenol – activated carbon and date stone systems in comparison to other adsorbents.

Adsorbent		I anomuir constants						
Ausorbent	r reunation constants				Langmuir constants			
	K	1/n	$\mathbf{R}^2$	<b>E%</b>	$C_m$	b	$\mathbf{R}^2$	<b>E%</b>
Activated Carbon	o.849	0.689	0.932	01.94	0.45	9.174	0.951	09.88
Date Stone	0.407	0.671	0.983	07.36	0.131	4.739	0.999	08.24
Olive Leaves	0.183	0.641	0.991	13.74	0.217	1.305	0.992	16.59
Almond Shell	0.187	0.632	0.988	11.24	0.228	1.304	0.996	14.91
Tea Residual	0.180	0.637	0.981	12.36	0.216	1.233	0.994	17.11
Coffee Ground	0.08	0.559	0.974	16.4	0.152	0.687	0.990	18.08

Table 2 Parameters of Freundlich and Langmuir Isotherm Models

A larger value of *b* implies stronger bonding of phenol occurring with the adsorbent (Annadurai et al., 2002; Nowosielski and Fein, 1998) similar observation have been reported of the adsorption of phenol on; bentonite, organobentonite, plume seed coat activated carbon and rice husk (Tomaszewska et al., 2004, Mahvi et al., 2004; Aksu and Yener, 2001; Srivastava et al., 1997), and the adsorption of organic acids on coffee ground, nickel on olive leaves, chromium on black tea residual and pentachlorophenol on almond shell (Nakamura, et al., 2003; Demirbas, 2002; Mahvi etal., 2004; Hossain, 2005; Estevanho et al., 2006)



### CONCLUSIONS

This study has shown that some local wastes can be used as effective and inexpensive adsorbent for the removal of phenol from water. Detection experiments reveal that, the rate of formation of the colored complexes increases with the increase in duration of the contact time. The percent removal of phenol from water increases with decrease in initial phenol concentration.

The suitability of the Freundlich and Langmuir adsorption models to the equilibrium data were investigated for each phenol- adsorbent system. The phenol- adsorbent systems fitted the Freundlich isotherm model is best within the concentration range studied if compared with Langmuir isotherm model, especially for concentrations below 100 ppm.

### REFERENCES

1. Aksu, Z. and Yener, J., A comparative adsorption/boisorption study of monochlorinated Phenols onto various sorbent, *Waste Management*, 21, pp. 695-702, (2001).

- 2. Amore, J.E., and Hautala, E., Odor as an aid to chemical safety: odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution, *J. Appl. Toxicol.*, 3, pp.272–290, (1983).
- 3. Annadurai, G., Jeang, R. and Lee, D., Factor optimization for phenol removal using activated carbon, *J. Envi. Sci. and Health*, 37(2), pp.149-161, (2002).
- Ayar, A., Gursal, S., Gurten, A., and Gezici, O., On the removal of some phenolic compounds from aqueous solutions by using a sporopollenin-based ligand-exchange fixed bed-Isotherm analysis, *Desalination*, 219, pp. 160–170, (2008).
- 5. Banat, F., B. Al-Bashir, S. Al-Asheh and O. Hayajneh, Adsorption of phenol by Bentonit, *Envi*. *Pollution*, 107, pp. 391-398, (2000).
- 6. Bras, I., Lemos L.T., Alves A., Pereira M. R., Sorption of pentachlorophenol on pine bark, *Chemosphere*, 60, pp. 1095–1102, (2005).
- 7. Busca, G., Beradinelli, S., Resini, C., Arrighi, L., Thechnologies for the removal of phenol from fluid streams, J. Hazardous Materials, 160, pp. 265-288, (2008).
- 8. Canadian Environmental Protection Act, Priority Substances List Assessment Report: Phenol, (1999), www.ec.gc.ca.
- Cardenas, S. A., Velazguez, T. G., Revill, G. O., Lopez, M. S., and Perea, B. G., Adsorption of phenol and dichlorophenols from aqueous solutions by porous clay heterostructure, *J. Mex. Chem. Soc.*, 49(3), pp. 287-29, (2005).
- Carmona, M., De Lucas, A., Valverde, J. L., Velasco, B., and Rodriguez, J. F., Combined adsorption and ion exchange equilibrium of phenol on Amberlite IRA-420, *J. Chemical Engineering*, vol. 117, pp. 155–160, (2006).
- 11. Cerofolini, G. F., Jaroniec M. and Sokosvski S., A theoretical isotherm for adsorption on heterogeneous surface, *Colloid and Polymer Sci.*, 256(5), pp. 471-477, (1978).
- 12. Chapra, S. C. and Canale, R.P., Numerical Methods for Engineers, 3<sup>rd</sup> edition, McGraw-Hill, (1998).
- Dakiky, M., Khamis M., Manassra A., and Mereb M., Selective adsorption of chromium(IV) in industrial wastewater using low-cost abundantly available adsorbents, *Adv. Envi. Res.*, 6, pp. 533– 540, (2002).
- 14. Demirbas A., Fuel characteristics of olive husk and walnut, hazelnut, sunflower and almond shells, *Energy Source*, 24, 215–221, (2002).
- 15. US-EPA, Toxicological review of phenol, United State Environmental Protection Agency, 635. R02.006, (2002).
- Estevinho, B., Ratola, N., Alves, A., and Santosl, Pentachlorophenol removal from aqueous matrices by sorption with almond shell residues, *J. Hazardous materials*, 137, pp. 1175-1181, (2006).
- Halouli, K.A. and Drawish, N.M., Effects of pH and inorganic salts on the adsorption of phenol from aqueous systems on activated decolorizing charcoal, *Sep. Sci. Technol.*, 30, pp. 3313-3324, (1995).
- Haider, K., Frederick, L. R., and Flaig, W., Reaction between amino acid compounds and phenols during oxidation, *Plant and Soil*, 22, pp. 49-64, (1965).
- 19. He F., and Lei L., Degradation kinetics and mechanisms of phenol in photo-Fenton process, J. *Zhejiang Univ. Sci.*, 5(2), pp. 198-205, (2004).
- Hossain, M. A., Kumita, M., Michigami, Y., and Mori, S., Kinetics of Cr (VI) Adsorption on used black tea Leaves, J. Chem. Eng. Japan, 38(6), pp. 402-408, (2005).
- 21. Ibrahim, H. G. and Abushina, E. A., Investigation on the removal of Chromium (III) from Tannery Wastewater by Cement Kiln Dust, *J. of the Ass. of Arab universities for Basic and Applied Sciences*, 5, pp. 59-71, (2008).

- 22. Jordan, W., van Barneveld, H., Gerlich, O., Kleine-Boymann, M., and Ullrich, J., Phenol, in: Ullmann's Encyclopedia of Industrial Chemistry, Wiley-VCH Verlag, (2002).
- Jung, M. W., Ahn, K. H., Lee, Y., Kim, K. P., Rhee, J. S., Park, J.T., and Paeng, K.J., Adsorption characteristics of phenol and chlorophenols on granular activated carbons (GAC), *J. Microchem.*, 70, pp. 123–131, (2001).
- 24. Kummar, S., Upadhyay, S.N. and Upadhyay, Y.D., Removal of phenols by adsorption on fly ash, *J. Chem. Technol. Biotechnol.*, 37, pp. 281, (1987).
- 25. Lee, K. M. and Lim, P. E., Treatment of phenolic wastewater using agricultural wastes as an adsorbent in a sequencing batch reactor, *Water Sci. and Technol.*, 47 (10), pp. 41–47, (2003).
- 26. Lifton, R.J., The Nazi Doctors, Basic Books, pp. 254-268.(as cited in Busca et al, 2008) (1986).
- 27. Lin, S.H. and Chery, M. J., Adsorption of phenol & m-chlorphenol on organobentonites and repeated thermal regeneration, *Waste Management*, 22, pp. 595-603, (2002).
- 28. Mahvi, A. H., Maleki, A., and Eslimi, A., Potential of rice husk ash for phenol removal in aqueous systems, *American J. Appl. Sci.*, 1(4), pp. 321- 326, (2004).
- Manojlovic, D., Ostojic D.R., Obradovic B.M., Kuraica M.M., Krsmanovic V.D. and Puric J., Removal of phenol and chlorophenols from water by new ozone generator, *Desalination*, 213, pp. 116–122, (2007).
- 30. Metcalf, L., Eddy, H., Wastewater Engineering Treatment and Reuse, 4<sup>th</sup> ed., McGraw-Hill, (2004),.
- 31. Mostafa, M. R., Sarma, S. E. and Yousef, A.M., Removal of organic pollutants from aqueous solution: part1, adsorption of phenol by activated carbon, *Indian J. Chem.*, 28, pp. 94-98, (1989).
- Nakamura, T., Tokimoto, T., Tamura, T., Kawacaki, N., and Tanada, S., Dechloraization of acidic dye by charcoal from coffee grounds, *J. Health Sci.*, 49(6), pp.520-523, (2003).
- 33. Navarro, A.E., Portales, R.F., Sun-Kou, M.R. and Lianos, B.P., Effect of pH on phenol biosorption by marine seaweeds, *J. Hazardous Materials*, 156, pp.405-411, (2008).
- 34. Nowosielski, B. E., and Fein J. B., Experimental study of actanol water partition coefficients for 2,4,6-trichlorophenol and pentachlorophenol, *Appl. Geochem.*, 13, pp.893-904, (1998).
- 35. Parka Y., Skellandb, A.H.P., Forneyb, L. J. and Kim, J. H., Removal of phenol and substituted phenols by newly developed emulsion liquid membrane process, *Water Res.*, 40, pp. 1763–1772, (2006).
- 36. Press, W.H., Flannery, B.P., Teukolsky, S.A., and Vetterling, W.T., Numerical Recipes in Pascal: The Art of Scientific Computing, Cambridge University Press, Cambridge, (1989).
- Rengaraj, S., Seuny-Hyeon, M. and Sivabalan, R., Agricultural solid waste for the removal of organics: adsorption of phenol from water and wastewater by Palm seed coat activated carbon, *Waste Management*, 22, pp. 543-548, (2002).
- 38. Sawyer, C. N., and Mc Carty, P. L., Chemistry for environmental engineering, McGraw Hill, (1994).
- 39. Standard Methods for the Examination of Water and Wastewater, 18<sup>th</sup> ed., *American Public Health Association/American Water Works Association/Water Environment Federation*, Washington DC, (1992).
- 40. Street, M., Patrick, J.W., and Camporoperez, M.J., Sorption of phenol and pentachlorophenol from water using convention and novel activated carbons, *Water Sci. Res.*, 29, pp. 467, (1995).
- Srivastava, S.K., Tyagi, R., Pal, N., and Mohan, D., Process development for removal of substituted phenol by Carbonaceouse adsorbent obtained from fertilizer waste, *J. Envi. Eng.*, 123, pp. 842, (1997).
- 42. Tomaszewska, M., Mozia, S., and Morawski, W., removal of organic matter by coagulation enhanced with adsorption on PAC, *Desalination*, 162, pp. 79-87, (2004).

- 43. Tsai, W.T., Chang, C.Y., Lin, M.C., Chien, S.F., Sun, H.F. and Hsieh, M.F., Adsorption of acid dye onto activated carbons prepared from agricultural waste bagasse by ZnCl2 activation, *Chemosphere*, 45, pp. 51–58, (2001).
- 44. Wang, X., Wang, Y., Chansheng, Y., Wangle, L., and Han, S., Mechanism based quantitative structure phytutoxicity relationships comparative inhibition of substituted phenols on root elongation of curcumas sativa, *Envi. Contamination and toxicology*, 42, pp. 29-35, (2002).
- 45. Weissermel, K., Industrial Organic Chemistry, 3rd ed., pp.346–365, (1997).
- WHO, World Health Organization. IPCS Environmental Health Criteria 161. Phenol. 161: pp. 92-94, (1994).
- 47. Xian, X., He, P., Jin, J., and Ho, Z., Study on Us/O3 mechanism in pentachlorophenol decomposition, *J. Zhejiang Univ. Sci.*, 6(6), pp. 569-573, (2005).