Adsorptive Removal of Phenolics from Wastewater; A Review

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Abstract – In this article, adsorption as an effective method for removing phenol and its compound from wastewater has been reviewed. It is clear from the literature survey that adsorption can be achieved through different materials such as commercial activated carbon, naturally occurring materials, synthetic polymer, waste material and activated carbon from waste materials. However, there is need to study more on the effect of other pollutants on adsorption of phenolics so as reduce its environmental and health effects.

Key Words – Activated carbon; Adsorption; Phenol; Phenolics; Pollutants; Synthetic polymer

1 Introduction

Phenol is naturally found in rotting dead organic matters like rotting plants and in coal. The German chemist, Runge isolated phenol from coal tar in 1834 and named it karbolsaure (coal-oil acid or carbolic acid), though its composition was not known until 1841 (Basha et al., 2010). Phenol is a colourless-to-white solid when pure; however, the commercial product, which contains some water, is a liquid. Phenol has a distinct odour that is sickeningly sweet and tarry (Ahmaruzzaman, 2008). It can be produced naturally or synthetically. Industrial scientists have found many applications of phenol in the synthesis of dyes, aspirin, and one of the first high explosives, picric acid.

It was also found that phenol could be condensed with aldehydes (for example methanal) to make resinous compounds called phenolmethanal (formaldehyde) resins. These resins are the basis of the oldest plastics, still used to make low cost thermosetting plastics such as melamine and bakelite used in electrical equipment. They are also used extensively as bonding agents in manufacturing wood.
products such as plywood. Phenols are also used to make chemical intermediates for a wide range of other applications ranging from plastics to pharmaceuticals and agricultural chemicals (Basha et al., 2010).

Phenol has attracted much public attention due to its presence in groundwater, rivers and drinking waters (Entezari et al., 2003). Even in low concentration, phenol causes toxicity and foul odour to the water. This is due to its reactivity with chlorine (Cl) and nitrate (NO\textsubscript{3}) in the soil to form chlorophenol and nitrophenol respectively. Most countries specify maximum allowable concentration of phenol in wastewater to be less than 1 ppm (Mahamuni and Pandit, 2005; Maleki et al., 2005). The exposure of phenol and its derivative compounds to human and animals causes liver and kidney damage, central nervous system impairment, diarrhea, and excretion of dark urine (Sarkar and Acharya, 2006, Olujimi et. al., 2010). This makes it necessary to develop methods that allow one to detect, quantify and remove phenol from wastewater (Mahvi, 2008).

Several conventional methods are available for treating phenolic wastewater which include reverse osmosis, anaerobic processes, the electro Fenton method, combined applications of flotation and coagulation processes, stripping and oxidation, solvent extraction etc. (Busca et al, 2008). Among various methods used in phenolic wastewater treatment, ‘adsorption’ process is considered better due to its simplicity of design, ease of operation and convenience.

Adsorption is a process in which a substance (adsorbate), in gas or liquid phase, accumulates on a solid surface (adsorbent). It is based on the capability of porous materials with large surfaces to selectively retain compounds on the surface of the solid (adsorbent). The adsorption process of the adsorbate molecules from the bulk liquid phase into the adsorbent surface is presumed to involve the following stages:

a. Mass transfer of the adsorbate molecules across the external boundary layer towards the solid particle.

b. Adsorbate molecules transport from the particle surface into the active sites by diffusion within the pore–filled liquid and migrate along the solid surface of the pore.

c. Solute molecules adsorption on the active sites on the interior surfaces of the pores.

d. Once the molecule adsorbed, it may migrate on the pore surface through surface diffusion. (Mohamed, 2011)

The extent of adsorption also depends on the nature of the solid surface (adsorbent) especially its porosity and surface area. As such various adsorbents that has high porosity and large surface area have been developed. The porous structure does not only enhance the increase in surface area thereby facilitating adsorption, it also affects the kinetics of the adsorption. Thus, for a good adsorbent, it must have a large surface area and requires less time for adsorption equilibrium (Bhatnagar and Minocha, 2006). Some of the important adsorbents used in adsorption of phenol and its derivatives are discussed herein.

1.1 Activated carbon

Activated carbon is the most popular and widely used adsorbent in waste water treatment. Charcoal has been recognized as the oldest adsorbent known in waste water treatment. It is used for the removal of bad tastes and odours from water in 1970. However, the emergence of commercial activated carbon can be attributed to Raphael Von Ostrejko in 1900. Due to the high cost of this type of activated carbon, some activated carbon has been prepared from carbon-containing materials such as coke, olive stones, rice husk, palm shell, sawdust, coconut shell, bituminous coal etc.
1.2 Naturally Occurring materials

Due to the high cost of activated carbon, there is a need to look for cheaper materials especially natural things that are easily available e.g. clay, soil, bituminous coal etc. The most important characteristics that is required is their porosity. This can be improved on by activating these materials.

1.3 Synthesized materials

Substances such as polymers that can be synthesized in the laboratory can be used to treat wastewater so far they have pores that can adsorb.

2 Adsorption of phenolics by commercial activated carbon

Stoeckli et al reported the adsorption of phenols and 3-chlorophenol from aqueous solution by activated carbon. They found that the phenolics are adsorbed as monolayers by different types of activated carbon both porous and non-porous provided that the surface properties are basic and the pH is below that of dissociation of the compounds.

Chern and Chien (2003) studied the competitive adsorption of benzoic acid and \( p \)-nitrophenol onto activated carbon: isotherm and breakthrough curves. They observed that the binary adsorption isotherms are well explained by Langmuir isotherm model successfully. Both the equilibrium data and isotherm model parameters showed the high affinity of activated carbon to \( p \)-nitrophenol than benzoic acid.

Qadeer and Rehan reported the adsorption of phenol by commercial activated carbon and found that the equilibrium time was very short or instantaneous (five minutes). The data obtained were subjected to various isotherms but Langmuir isotherm fitted best with \( r^2 > 0.99 \).

Activated carbon, further activated by ozonation was also used to adsorb phenol, \( p \)-nitrophenol and \( p \)-chlorophenol from aqueous solution by Alvarez et al. They reported that the porous structure of the ozone-treated carbon remained unchanged with regard to the virgin activated carbon and that the ozone treatment at either room temperature (about 25°C) or 100°C gave rise to acidic surface oxygen groups. They also observed that the treatment with ozone at room temperature decreased the ability to adsorb the phenolics but at 100°C, the adsorption rate did not decrease but was enhanced especially in the adsorption of phenol and \( p \)-nitrophenol.

Commercial activated carbon was also used by Vasu to adsorb phenol and \( o \)-cresol from aqueous solution. He reported that there was no significant change on adsorption when pH was varied but there was a slight decrease in adsorption when there was increase in pH. He suggested that this could be due to the increased solubility of phenol molecules at alkaline conditions resulting into greater affinity for phenol molecules to remain in solution rather than to get adsorbed onto the surface of carbon. He also noted that adsorption of the phenolics (phenol and \( o \)-cresol) increased with increase in temperature suggesting that the process was endothermic and that desorption can be achieved by adding dilute hydrochloric acid. When the data were subjected to various isotherms, the Langmuir isotherm fitted best. The monolayer adsorption capacities were found out to be 0.7877 and 0.5936mmole/g.
respectively and the kinetic studies showed that the sorption processes can be represented better by pseudo-second order kinetics.

Mohanty et al investigated the use of activated carbon in a novel multi-stage external loop airlift reactor in the treatment of phenolic wastewater. They reported that nearly 95% removal of phenol was achieved with a lower removal time. They also noted that the kinetic data were fitted to the models of intra-particle diffusion, pseudo-second order and Lagergren model but it followed Lagergren pseudo-first order closely. The equilibrium data were also observed to fit both the Langmuir and Freundlich model well. They also reported that the optimum parameters for the removal of phenol were found to be pH of 3.5 and adsorbent dose of 2g/l.

Moraitopoulos et al studied the adsorption of phenol and 3-nitrophenol from aqueous solutions onto an activated carbon column under semi-batch and continuous operation. They reported that on comparing the two different operations (semi-batch and continuous with reflux) the adsorption of the adsorbates after 1 hour was higher by the continuous operation with reflux that by the semi-batch operation. They also observed that the adsorption of phenol is higher than that of 3-nitrophenol for both operations.

Dabhade et al (2009) investigated the adsorption of phenol on granular activated carbon from nutrient medium. They observed that the adsorption reaches equilibrium around 300 minutes. The data fitted the Langmuir isotherm better with and the kinetic data fitted the pseudo-second order. Adsorptive removal of phenol from industrial wastewater was studied by Kiran and Chandrajit (2011). They reported that the optimum pH was 8 and that increase in temperature increases adsorption. They also observed that the optimum adsorbent dose was 30g/L and the equilibrium time was 24 hours.

Ekpete et al (2012) investigated the adsorption of phenol and chlorophenol in aqueous solution on a commercial activated carbon in batch sorption system. They observed that the equilibrium time was reached after 60 minutes and the optimum pH was 6. They also noted that the optimum adsorbent dosage was 0.2g and the increase in temperature leads to decrease in adsorption suggesting that there is weakening of the attractive forces between the adsorbate and adsorbent with increase in temperature. The adsorption data when subjected to Langmuir and Freundlich model showed a better fit to Langmuir with adsorption capacity of 34.48 and 31.25mg/g for chlorophenol and phenol respectively.

Omer et al (2012) studied adsorption of phenol and its derivatives (o-cresol and p-cresol, o-aminophenol and p-aminophenol, o-chlorophenol and p-chlorophenol, o-nitrophenol and p-nitrophenol) from aqueous solution on activated carbon. The equilibrium data was subjected to five adsorption isotherm models namely; Langmuir, Freundlich, Tempkin, Dubinin-Radushkevich and Generalized. The results revealed that the adsorption isotherm models fitted the data in the order; Langmuir > Generalized > Tempkin > Freundlich > Dubinin-Radushkevich. They also reported that the uptake of ortho and para-substituted phenols increases in the order; Phenol < cresol < aminophenol< chlorophenol< nitrophenol which correlates well with the respective increase in hydrophobicity and decrease in water solubility and pKa value.

### 2.1 Adsorption of phenolics by naturally occurring materials

These materials because of their availability and abundance were investigated to know if they can play an important role in adsorption. Some of these materials were found to work effectively alone and some may need activation to work effectively.
Juang et al (2002) investigated the adsorption of phenol, m-nitrophenol and o-cresol from aqueous solutions onto surfactant-modified montmorillonite (a type of clay). They observed that the sorption capacity decreased in the order of phenol > o-cresol > m-nitrophenol and the data fitted Langmuir isotherm better. The kinetic data fitted the pseudo-second-order kinetic model which supported the fact that chemisorption is a rate-controlling step in the process.

The biosorption of phenol and o-chlorophenol from aqueous solutions onto chitosan (obtained from chitin; a natural polymer from crustacean shells e.g. prawns, crabs, shrimps etc.)-calcium alginate blended beads was studied by Nadavala et al (2009). They reported that the adsorption is feasible at neutral pH (pH=7.0) after which adsorption decreases. The data was subjected to three isotherm models namely; Langmuir, Freundlich and Dubinin-Radushkevich. The data fitted in the order of Langmuir > Dubinin-Radushkevich > Freundlich. The kinetic data fitted the pseudo-first and pseudo-second order for phenol while that of o-chlorophenol followed intra-particle diffusion (Weber-morris model). They also noticed that the adsorbent showed higher adsorption capacity for phenol than o-chlorophenol.

Potgieter et al (2009) used South African coal fly ash to remove phenol, 2-nitrophenol and 4-nitrophenol from wastewater. They reported that the rate of adsorption follows first–order kinetics with 4-nitrophenol having the highest sorption rate followed by phenol and 2-nitrophenol having the lowest. They also observed that the adsorption data fitted the Freundlich model better with maximum adsorption capacity of $6.51 \times 10^{-2}$ mg/g for 4-nitrophenol, $6.00 \times 10^{-2}$ mg/g for 2-nitrophenol and $6.31 \times 10^{-2}$ mg/g for phenol. They noted that the desorption studies suggested that the desorption of 4-nitrophenol was the most difficult of the three adsorbates. The desorption efficiency was found to be 17.9% for phenol, 18.8% for 2-nitrophenol and 10.2% for 4-nitrophenol.

Cardenas et al (2005) studied the adsorption of phenol and dichlorophenols (2,5 dichlorophenol and 3,4 dichlorophenol) from aqueous solutions by porous clay heterostructure. They observed that the equilibrium data fitted Freundlich isotherm better for the dichlorophenol while Langmuir was the best to describe the data for phenol. The maximum adsorption capacity were 48.7, 45.5 and 14.5 mg/g for 3,4-dichlorophenol, 2,5-dichlorophenol and phenol respectively. They reported that the results indicated that the adsorbent have both hydrophobic and hydrophilic characteristics due to presence of silanol and siloxane groups formed during the pillaring and preparation of the adsorbent.

Alzaydien and Manasreh (2009) studied the adsorption of phenol onto activated phosphate rock. They reported that the optimum pH was 8.0 and the optimum temperature was 20°C. The data fitted the Langmuir model best with adsorption capacity of 38.34mg/g. The kinetic study revealed that it followed pseudo-second order model. They also observed that increase in temperature resulted in decrease in adsorption indicating that the process is exothermic.

Varank et al (2012) investigated the removal of 4-nitrophenol from aqueous solution by two natural adsorbents (bentonite and zeolite). They observed that the optimum conditions for 4-nitrophenol by the two adsorbents was found to be pH 7.0, adsorbent dosage 5g/L and 20g/L for zeolite and bentonite respectively. They also noticed that increase in temperature results in decrease in adsorption indicating that the process is exothermic.
parameter isotherm models. The two-parameter isotherms used were Langmuir, Freundlich, Tempkin, Dubinin-Radushkevich. Amongst the four; Langmuir and Freundlich fitted best. Also, amongst the three-parameter, Toth and khan was the best to describe the adsorption to zeolite while bentonite does not fit into all the five three-parameter model. The adsorption kinetics were found to follow pseudo-second order. They also revealed that the negative value of $\Delta G^0$ indicates spontaneous nature and the positive value of $\Delta S^0$ obtained showed increase in randomness at the solid-solution interface during adsorption. They observed also that bentonite showed better adsorptive characteristics for the removal of 4-nitrophenol but higher amount was required.

Also, in 2012, Subramanyam and Ashutosh investigated the adsorption isotherm modelling of phenol onto natural soils – applicability of various isotherm models. They used two naturally available soil named Kalathur soil and Adhanur soil.

The experimental data were subjected to fourteen isotherm models ranging from single-parameter model to multi-parametric models (up to 5 parameters) of the system. They observed that Temkin isotherm model, Langmuir-Freundlich isotherm model and Fritz-Schlunder model as well as Baudu model were found to be the best fit models amongst the two-parametric models, three-parametric models and four parametric isotherms modelling, respectively.

### 2.2 Adsorption of phenolics onto synthetic polymer

The adsorption of phenols onto a polymeric sorbent (SP206, a polystyrene matrix crosslinked with divinyl benzene) by Moon et al (1991).The investigation showed that phenols’ (phenol, $p$-chlorophenol, $p$-nitrophenol) adsorption data fitted the Langmuir isotherm model best with adsorption capacity of 0.0626,0.736 and 0.815mg/g for phenol, $p$-chlorophenol and $p$-nitrophenol respectively. They also reported that the phenols retained on SP206 were desorbed very quickly by 0.05N sodium hydroxide solution within a few minutes.

Lásló (2001) investigated the adsorption of phenol and 2,3,4-trichlorophenol on carbon prepared from polyethylene(terephthalate).He observed that the adsorption properties of the phenols depended both on the pH of the solution. Li et al (2002) studied the adsorption of phenolic compounds (phenol, $p$-cresol, $p$-chlorophenol and $p$-nitrophenol) from aqueous solution by a water–compatible hypercrosslinked polymeric adsorbent. In the study, the authors compared a particular polymer named NJ-8 with the commercial polymers adsorbent Amberlite XAD-4.They observed that the adsorption capacities for the four phenolic compounds on NJ-8 were around two times higher than that of Amberlite XAD-4 within the temperature range of 283-323K which may be attributed to the microporous structure and partial polarity of NJ-8. NJ-8 also exhibits higher isosteric adsorption enthalpy changes for all the phenolic compound at low equilibrium concentration than that of Amberlite XAD-4.They concluded that the reaction is exothermic having negative $\Delta H$ and from the magnitude of $\Delta H$ the adsorption process is physical.

Pan et al (2003) investigated the role of amination of a polymeric adsorbent on phenol adsorption from aqueous solution. They investigated the adsorption on a hypercrosslinked polymeric adsorbent(CHA-111) and its dimethyl amine derivative. The phenols are phenol, $p$-cresol, 2-Naphthol, $p$-nitrophenol,2,4-Dichlorophenol, 2,4-Dinitrophenol.It was observed that dimethylamine derivative showed a higher adsorption capacity than ordinary polymeric adsorbent due to hydrogen bonding interaction with the amino groups and the adsorbate molecules. The adsorption enthalpy change indicated the uptake of phenols on dimethylamine derivative polymeric adsorbent (MCH-111) to be an enhanced physical adsorption because of the hydrogen –bonding interaction.
In 2004, Li et al studied the thermodynamics of adsorption of phenolic compounds (phenol, p-
creisol, p-chlorophenol and p-nitrophenol) from aqueous solution by a water–compatible hypercrosslinked
polymeric adsorbent. The authors observed that the negative value of ΔH indicated that the process is
exothermic and was a process of physical adsorption. They also noted that the negative value of ΔG
showed that the solute is more concentrated on the adsorbent than in the bulk solution and the negative
values of ΔS were consistent with the restricted mobilities of adsorbed molecules of phenolic
compounds as compared with the molecules in solution.

The removal of phenolics species onto β-cyclodextrin modified poly (hydroxy-ethylmethacrylate-
ethyleneglycoldimethacrylate, poly HEMA-EGDMA) microbeads was studied by Abay et al
(2005). They investigated the adsorption of phenol , o-chlorophenol, p-nitrophenol, p-
nitrophenol on plain microbeads of β-cyclodextrin polymer and its modified derivative (Poly-HEMA-
EGDMA). They observed that the adsorption capacities of the species onto the plain adsorbent were
28.2, 17.0, 14.3, 9.8 and 1.92 mg/g for o-chlorophenol, p-nitrophenol, p-chlorophenol, o-nitrophenol
and phenol respectively while the adsorption capacities on modified microbeads were 274, 365, 128,
182 and 87 mg/g for phenol, o-nitrophenol, p-nitrophenol, o-chlorophenol and p-chlorophenol
respectively. It was also observed that the equilibrium adsorption time was reasonably short (10-
60 minutes) making it suitable for large scale industrial process.

Carmona et al (2006) studied the combined adsorption and ion exchange equilibrium of phenol on
Amberlite IRA-420. It was observed that the adsorption capacity does not depend on pH and that
adsorption was higher at acidic pH. Also, the removal of phenols from waste water with encapsulated
Horseradish peroxidase in calcium alginate was studied by Alemzadeh et al (2009). They observed that
the removal was highly dependent on pH, contact time and adsorbent dose.

Chen et al (2009) studied the adsorption of phenol and 4-nitrophenol on Mg Al-mixed oxide derived
from Mg Al–layered double hydroxide. They observed that it takes 10-12 hours for the adsorption of
4-nitrophenol to reach equilibrium while that of phenol is 20-25 hours. The kinetic process followed the
Langergren’s first–order model for 4-nitrophenol while that of phenol follows pseudo-second order
model. They also noted that the adsorption capacity for 4-nitrophenol can be as high as 367.8 mg/g
while that of phenol is 25.5 mg/g at room temperature. The Langmuir model fits the equilibrium data
for 4-nitrophenol well while the Freundlich model fits that of phenol. Also, the increase in temperature
shortened the equilibrium time.

Faghihian and Pourbasirat (2012) studied the adsorption of phenol by N-cetylpridinium-modified Beta
Zeolite. In the study, they compared adsorption capacity of the modified Beta Zeolite with ordinary
Beta Zeolite. They found out that the increase of pH to high alkalinity leads to increase in adsorption
capacity in the modified Beta Zeolite while that of Beta Zeolite decreases. The kinetic data showed
that the adsorption of phenol onto modified Beta Zeolite followed the pseudo-second order model and
the equilibrium data fitted Langmuir model better. Also, ΔG was negative, which indicated that the
adsorption process was feasible and spontaneous, ΔH was positive indicating an endothermic reaction.

The adsorption of o-nitrophenol onto nano iron oxide loaded calcium alginate beads was studied by
Soni et al (2012). It was observed that the optimum pH for the adsorption was 2. Also, the equilibrium
time was 4 hours with percentage removal of 96%. The equilibrium data can be best explained by
Freundlich isotherm model.
2.3 Adsorption of phenols on natural wastes/activated carbon from natural wastes

Moreno-Castilla et al (1995) studied the adsorption of phenols on activated carbons from a bituminous coal. They found out that the adsorption capacity depended on the surface area and porosity of the carbon, the solubility of the phenolic compound and the hydrophobicity of the substituents. They also observed that the adsorption depended on the pH of the solution. In 2006, Delval et al used an activated carbon prepared from agro-alimentary by-product to remove some phenolics from aqueous solutions. The phenolics removed in the study were p-nitrophenol, p-chlorophenol and pentachlorophenol. It was discovered that the adsorption data followed the Freundlich model more closely.

Uddin et al (2007) studied the adsorption of phenol from aqueous solution using water hyacinth ash. They discovered that the equilibrium data fitted the Langmuir model very well with sorption capacity of 30.49mg/L and that the kinetic data followed the pseudo-second order more closely. The study of the removal of phenolic compounds from olive-mill waste water using low cost biosorbent (banana peel) was done by Mandi et al (2009). They reported that the banana peel showed a high sorption capacity of 688.9mg/g and that the equilibrium data fitted Freundlich model best. Also, they observed that the adsorption process was very fast having the optimum equilibrium time of 3 hours and that the increase in pH leads to increase in adsorption capacity.

In 2009, Srihari and Das investigated the adsorption of phenol from aqueous media by an agrowaste (Hemidesmus indicus) based activated carbon. They compared this agrowaste based activated carbon (HIC) with that of commercial activated carbon (CAC). They found out that the adsorption capacity of HIC (370.37mg/g) was higher than that of CAC (294.11mg/g) and that both equilibrium data fitted Freundlich model better. Also, the equilibrium contact time for HIC was 5 hours while that of CAC was 6 hours. They concluded that ‘the boundary layered effect of’ and ‘the pore diffusion coefficient for’ HIC was found to be almost double to and 1.5 times of CAC respectively.

Bello-Huitle et al (2010) studied the adsorption of phenol onto activated carbon from pecan nutshell and castle nutshell. They reported that the maximum adsorption capacity of the activated carbon from pecan nutshell (PN) was higher (158.7mg/g). They also found out that the equilibrium data fitted the Langmuir model very well. In 2010, Tagreed investigated the removal of phenol from aqueous solution by agricultural waste. They are waste tea (WT) and activated carbon from waste tea (WT-GAC). He observed that the equilibrium time for WT was 0.75 hour and that of WT-GAC was 10 minutes. He also found out that there was increase in adsorption when the pH was increased until neutral and then adsorption decreased at alkalinity pH. The equilibrium data were well represented by Freundlich isotherm model.

Lawal et al (2011) investigated the removal of phenol from aqueous solution by carbon adsorbents prepared by pyrolysis of sorghum and millet straws in orthophosphoric acid. They observed that the adsorption data for the two adsorbents fitted Freundlich isotherm model very well and the maximum adsorption capacities for the activated carbon from millet and sorghum were 80.36 and 82.34mg/g respectively. Hamad et al (2011) studied the removal of 4-chloro-2 methoxy phenol from aqueous solutions by adsorption to oil palm shell activated carbon (OPSAC) activated with K$_2$CO$_3$. They reported that adsorption increased as the contact time increased and that the highest adsorption was at acidic pH. The equilibrium data fitted the Langmuir isotherm with maximum adsorption capacity of 323.62mg/g and the kinetic data followed the pseudo-second order model. They concluded that from the thermodynamic parameter, $\Delta H$ and $\Delta G$, which are negative, the process was exothermic and the reaction occurred spontaneously.
Also in 2011, Mohamed et al investigated the competitive adsorption of phenolic compound from aqueous solution using sludge based activated carbon (SBAC). They compared the commercial activated carbons (PICA S23 and F22) with SBAC and used SBAC to adsorb four substituted phenols namely $p$-nitrophenol, $p$-chlorophenol, $p$-hydroxybenzoic acid, phenol singly and their mixture. They observed that Freundlich model explains the adsorption of the phenols except $p$-chlorophenol onto SBAC while Langmuir model fitted the equilibrium data of the commercial activated carbons. They concluded that the capacity of the studied activated carbons to adsorb phenols from a multi-solute system was in the following order: $p$-nitrophenol > $p$-chlorophenol > $p$-hydroxybenzoic acid > phenol.

Ekpete et al (2011) investigated the evaluation of activated carbon from fluted pumpkin stem waste for phenol and chlorophenol adsorption in a fixed-bed micro-column.

3 Conclusion

This paper has attempted to give insight into a wide range of adsorption of phenol and its compound. This ranges from the materials used for adsorption, the phenol compounds that were adsorbed and the method used in the adsorption. Certainly, the effectiveness of adsorption onto commercial activated carbon was high but the cost is also a barrier compared to using any other materials. In particular, the alternative adsorbents such as natural and synthetic polymers, activated carbon from natural materials/natural materials shows a good replacement for commercial activated carbon on adsorption of phenols.

However, there is a strong need to investigate extensively on the following points;

a To improve on the report of competitive adsorption of phenolic compounds on various adsorbents.

b To increase the studies on comparison of various adsorbents with commercial activated carbon in adsorption of phenols to ascertain the cost reduction.

c To study the effect of any other materials in the aqueous solution on the adsorption of phenol

With the above points been put into consideration, there will be little or no injury due to discharge of phenolics wastewater and this will contribute to the overall strategy of waste minimization.

References


