Remediation of Emerging Pollutants in Industrial Contaminated Water using Oxytenanthera abyssinica and Bambusa vulgaris in a Treatment Media

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Abstract. Remediation of emerging pollutants is an aspect of environmental research with sparse information and knowledge, and the disposal of, these pollutants to the environment are mostly unregulated and on the increase. In view of this, the study examined the adsorptive capacity of adsorbent produced from Oxytenanthera abyssinica (COA 350°C KCl) and Bambusa vulgaris (CBV 350°C H\textsubscript{3}PO\textsubscript{4}) in remediating Pharmaceutical actives contaminants (PhACs) and polycyclic aromatic hydrocarbons (PAHs). Fourier Transform Infrared Spectroscopy, Scanning Electron Microscopy, Energy Dispersive X-ray were used in characterizing adsorbents. Derivative form of Solid Phase Extraction (SPE) and Liquid-Liquid extraction procedures were used for extracting selected PhACs and PAHs from sampled solutions respectively. Batch experiments were performed to study the adsorption capacity of adsorbents at varying contact time of 30min, 2hrs and 12hrs for PAHs and 30, 180, 360, 720 and 1440 mins for PhACs. Analysis of PhACs and PAHs concentrations for each sampling were determined by UV spectrophotometer and GC-MS respectively. The samples showed sharp absorption peaks at 3432 and 1632 cm\textsuperscript{-1} indicating O-H stretched and N-H stretched. The adsorbents showed both open and close pores. Carbon, Oxygen and Nitrogen in the adsorbent for CBV were 62.00, 33.53 and 3.98 and COA were 71.00, 22.80 weight percent, respectively. The adsorbents had good surface areas, pore volumes and pore sizes. Removal efficiency of COA showed the highest efficiency for PhACs removal at (73.3%, 78.1% and 86.2%) while CBV (63.9 %, 66.7% and 82.2%) for paracetamol, salbutamol and chlorpheniramine, respectively. CBV and COA ranged from 42.5-81.2% and 8.9-65.5% for PAHs removal respectively. The experimental result showed that adsorbents made from Oxytenanthera abyssinica and Bambusa vulgaris can efficiently adsorb selected PhACs and PAHs in industrial Contaminated Water.

Keywords: Pharmaceutical actives contaminants, polycyclic aromatic hydrocarbons, adsorbent, Oxytenanthera abyssinica, Bambusa vulgaris

1. Introduction

Lately, most research that involves the remediation of water contaminates focuses on the use of agricultural products as adsorbent. In Nigeria the use of agricultural products as adsorbents in the removal of heavy metals, trace metals, anions and cations as well as biological contaminates from water...
and wastewater had been flooded over flogged [1,2,3,4]. The tremendous advancement in research on environmental pollutants has led to various discoveries of contaminants in environmental bodies such as water, soil, and air. The twelve initial persistent organic pollutants (POPs) were first identified as the “dirty dozen”, At the Stockholm Convention of 2001 and include: aldrin, chlordane, dichloro diphenyl trichloroethane (DDT), dieldrin, endrin, heptachlor. Mirex and Toxaphene, Hexa-chlorobenzene (HCB), Polychlorinated Biphenyls (PCB), Chlorinated Dioxins and Chlorinated Furans [5]. Other substances such as polybrominated diphenyl ethers (PBDEs), unintentional-by-products such as dioxin furans and polycyclic aromatic hydrocarbons (PAHs) were added later at the Conference of the Parties (COP 4) of the Stockholm’s Convention on POPs in 2009 and are called the “Nasty nine”. These groups of organic contaminants are persistent in the environment with the ability to travel far across the atmosphere or move through waters to settle in areas far from where they were originated. They bio-accumulate in fat tissues and are toxic to wildlife and human beings. They are difficult to biodegrade due to their chemical persistence and semi-volatile nature [5].

Aside the toxic POPs, other organic contaminants may produce subtle ecological effect but there are uncertainties surrounding their adverse effects on the environment. These are called emerging organic contaminants (EOCs). According to [6], EOCs are any synthetic or naturally occurring organic chemical(s) or microorganisms that are not commonly monitored but have the potential to enter the aquatic environment and impair the quality of raw water or cause known or suspected adverse human health or ecological effects. These EOCs may not be seen as active or passive chemical only but also include their metabolites and other transformation products and chemical by-products generated during production [7]. Their introduction into the environment is continuous because of their wide usage, and they are seen as micro-pollutants which include endocrine-disrupting compounds (EDCs), Pharmaceutically Active Compounds (PhACs), Personal Care Products (PCPs), Additives, Preservatives etc. [7, 8,9,10,11].

Emerging contaminants need not to be persistent in the environment to cause negative effects since their high transformation and removal rates can be offset by their continuous introduction into the environment. [6, 12, 13, 14] stated that many of these organic contaminants can cause cancers, neuro-behavioral deficits, reproductive disorders effects, endocrine disruption, allergies, damage of the central and peripheral nervous system, disruption to immune system and even death. However, [11] reported that there are no accurate data concerning the occurrences, eco-toxicity and risk assessment for most of the emerging contaminants, hence it is difficult to predict their effects on the environment and health, and they are therefore currently unregulated in most countries. Among many industries in Nigeria that contribute to organic contamination of water resources are the petroleum and pharmaceutical industries. The products from these industries are ubiquitous because of their daily usage and the pollutants that result from them are persistent as well as emerging [8].

Most of the organic contaminants in water and wastewater associated with the petroleum and pharmaceutical industries have been seen to generate an adverse effect on surface water, which is a source of livelihood. Identification and remediation processes for these contaminants are of a necessity if portable water will be available to everyone. Various analytical techniques such as gravimetric, UV-spectrophotometries, gas and liquid chromatography have been developed and employed in several literatures to identify the various organic contaminants [11]. The most effective methods so far that identified organic contaminants in their trace amount (or micro-pollutant) is gas chromatography or liquid chromatography with mass spectrophotometer followed by a clean-up method such as solid-phase extraction (SPE) and solid-phase micro-extraction (SPME) [11].

The petroleum industry makes use of conventional treatment methods such as the Induced Gas Flotation (IGF) or the Induced Air Flotation cells usually known as WEMCO with the Enviro-cell as the most recent technology in the class [15]. The conventional separation method employs the principle of gravity with differences in density between the oil and water. Similarly, the conventional wastewater treatment plants (WWTPs) are not always effective for the removal of these huge classes of pollutants and so further water treatments are necessary [16]. An alternative method of treatment that has been researched and still in research is the use of adsorption mechanism [11]. Activated carbon is one of the most popular adsorbents used in numerous industries for the removal and recovery of organic and inorganic compounds from gaseous and liquid streams [17]. It has high adsorption capability due to its high
internal surface area and porosity formed during carbonization process. The presence of activating agents and carbonization conditions influences the development of pore structures. However, the use of activated carbon is limited by its high cost which is a consequence of its production. Agricultural wastes or materials have been observed to be potential precursors in activated carbon production because of the abundant supply and low cost. Adsorption method of bioremediation had proven to be the choice treatment option for PAHs and PhACs and other micro-pollutant in aqueous media because its convenience advantages; efficiency, effectiveness and simplicity of design when compared to other form of treatment. Aside of these attributes, it adds no undesirable by-products or degradation metabolites which could be harmful [6, 10]. Adsorption is superior to any other wastewater treatment techniques because of its insensitivity to toxic substances and inexpensive nature of materials used as adsorbents [18]. However, full utilization of adsorption processes for water purification is impeded by inadequacies of commercial adsorbents like activated carbon and synthetic polymer resins. Therefore, the development of a low cost adsorbent is of necessity in environmental researches. Adsorbent produced from natural agricultural products have been the popular substitutes for commercial and synthetic adsorbents because of hydrophobic-oleophilic potential which is necessary in bioremediation processes [18, 19]. These views prompted the research designed to investigate the adsorptive capacity of a low-cost adsorbent (Bamboo) and examine the extent to which different modified Nigerian bamboo species can absorb PAHs and PhACs organic contaminants found in petroleum and pharmaceutical liquid waste respectively. The study also aims at evaluating the effectiveness of the most efficient modified bamboo species in a prototype developed treatment system

2. Materials & Methods
The Bamboos (Oxytenanthera abyssinaca and Bambusa vulgaris) were carbonized at temperature of 350°C in a Gallen kamp muffle furnace with aluminum foil as an oxidizing agent. After cutting at 20cm above the ground levels and processing them. The yield percentage of each carbonized bamboo species were then calculated thus:

\[
Yield (\%) = \frac{w_2 \times 100}{w_1}
\]  

where:

- \( w_1 \) = initial weight of bamboo specie before charring (g)
- \( w_2 \) = final weight of bamboo specie after charring (g)

Activation was done with Phosphoric acid (\( H_3PO_4 \)) and Potassium chloride (KCl) as dehydrating agent. About 26.25w/w of activator was used in activation of the carbon samples. Characterization was chemically done using Fourier Transform Infrared Spectroscopy (FTIR), to determine the surface functional groups. The Scanning Electron Microscopy (SEM) was used to view the surface structural of the samples at magnification of 100, 300, 500, 2000 and 5000 times the original size in order to view the pore space development and reveal other information such as texture (external morphology) and structural orientation. EDS in conjunction with SEM was used to determine the chemical composition or elemental analysis of the samples.

2.1. Adsorption Experiments
Adsorption behavior of PhACs in pharmaceutical effluents and Polycyclic Aromatic Hydrocarbon (PAHs) in petroleum wastewater onto bamboo activated carbon was studied in batch process. Experiments were carried out in ambient temperature and adsorption capacity of activated carbon from bamboo was tested on the basis of contact time. Half liter of pharmaceutical effluent was put into conical flasks of 600ml capacity. Two grammes of each selected bamboo activated carbons were weighed into conical flasks to form an adsorbent/solute solution. Solutions were agitated at stirring speed of 160rpm to ensure intimate contact of the adsorbent and solute in solution. Each solution was observed for 6hrs contact time at which it attains dynamic equilibrium. Thereafter, solutions were filtered with filter paper
0.45µm size. The filtrate of 300ml was poured into sampling bottles with tie cap sealed with aluminum foils and kept at temperature of 4°C for further analysis of extraction, clean up and Vis-UV. To obtain accuracy, all experimental analysis was duplicated. 200ml of simulated petroleum wastewater was sampled into different conical flasks of 250ml capacity. 1g of each selected bamboo activated carbon was weighed into the conical flasks to form an adsorbent/solute solution. Solutions were agitated at a stirring speed of 160 rpm to ensure intimate contact of the adsorbent and solute in solution, while observing each solution in equilibrium for 5hrs contact time to attain dynamic equilibrium. After 5 hrs solutions were filtered with filter paper 0.45µm and the filtrate of 150ml were poured into amber bottles with Teflon cap and kept at temperature of 40°C for further analysis of extraction, clean up and GC-MS. The 5hrs contact time was chosen based on the experiment performed at the terminal station of the oil and gas industry. To obtain accuracy, all experimental analysis was duplicated. The amount of PhACs ($q_e$) and PAHs ($q_e$) adsorbed by bamboo activated carbons can be expressed mathematically as:

$$q_e = \frac{C_o - C_e}{m} \times V$$

(2)

The percentage removal is evaluated using

$$\% \text{ Removal} = \frac{C_o - C_e}{C_o} \times 100$$

(3)

where

- $V$ is the volume of PhACs and PAHs in solution (L)
- $C_o$ is initial concentrations of PhACs and PAHs (mg/l)
- $C_e$ is equilibrium concentrations of PhACs and PAHs (mg/l)
- $M$ is the mass of the adsorbent (g)

2.2 Extraction techniques and Quantification of contaminants:

Extraction techniques and Quantification of PhACs and PAHs were examined using different techniques respectively. Pure standards of all active ingredients observed with minimum of 98.5-99% purity were used for this study. Derivative form of Solid Phase Extraction SPE extraction procedure was used for extracting PhACs from sampled solutions. 1cm of moderate packed cotton wool was placed at the bottom of each 10mm ID.250mm Loup chromatographic column used. 2g of activated silica gel 10ml of 1:1 acetonitrile and methanol was prepared and placed into the chromatographic column. To the top of the column was added 0.8cm of anhydrous sodium sulphate. The column was rinsed with additional 3ml of acetonitrile followed by 3ml of methanol and 3ml acidify ultra-pure milli-Q water to pre-elute the column. Elute was allowed to flow though the column at the rate of about 1ml/min until the liquid in the column was just above the sulphate layer and immediately 300ml untreated or treated sampled effluents were transferred into each prepared column. The sample bottles were rinsed with 1ml methanol eluent and added to the column as well. The eluent was collected into sampling bottles, after which acidified methanol pH 2 was immediately used to extract compounds adsorbed to the silica sorbent at a flow rate of 0.1ml/sec. Samples were collected in a graduated cylinder each and allowed to concentrate to 10ml under air vacuum after which sample was increased to 20ml by adding 10ml of methanol and kept at 4°C temperature before Vis-UV analysis. All solvents and chemicals used are of analytical grade with 99.0% purity. A standard mixture of 16 priority PAHs of 2.0 mg/ml each was used to calibrate the GC-MS used for PAHs analysis. Liquid-Liquid extraction procedures were used for extracting selected PAHs from sampled solutions. Mixture of dichloromethane (DCM) and n-Hexane in ratio 3:1 was used as extractant. The separatory funnels were shaken vigorously for at least 5min and the organic layers were allowed to separate clearly from the aqueous phase by gravitation technique for a period of 5-10 mins. Thereafter, the organic layers were collected in separate glass bottles of about 50ml that was well capped. The extraction processes were repeated twice for each sample. Cleanup of selected PAHs was carried out with 1cm of moderate packed cotton wool placed at the bottom of each 10mm ID 250mm loup chromatographic column used. Two
grammes of activated silica gel and 10ml of 3:1 (DCM and hexane) was prepared and placed in the chromatographic column. To the top of the column was added 0.8cm of anhydrous sodium sulphate. The column was rinsed with additional 20ml mixture of 3:1 (DCM and Hexane) to pre-elute the column. Elute was allowed to flow though the column for about 2min or until the liquid in the column was just above the sulphate layer. Thereafter, 3ml of extracted samples was transferred into each prepared column. The extraction bottles were rinsed with 1ml of DCM (3) and Hexane (1)/eluent and added to the column as well. The stop cork of the column was opened and the aromatic extract collected into 10ml graduated cylinder each was allowed to concentrate and evaporate under oxygenated conditions and later kept at 4°C before GC-MS analysis.

Quantification of PhACs and of PAHs was by an external standard method, which relies on the reproducibility of the standard preparation. The linearity of external calibration was done by preparing different concentration of Paracetamol, Salbutamol and Chlorpheniramine standards at different dilution rate of between 0.2to3.5 ppm. Similarly, the linearity of external calibration of PAHs were done by preparing different concentration of PAHs mix standards at dilution rate of 12.5,25,50,100 and 200ppm according to the specification given by the International Conference for Harmonization [11] that requires a 5 point calibration curve serial dilution. The linearity was evaluated at different concentration using response factors and all showed good linearity with regression coefficients ranging from 0.972 to 1.000 for all PAHs. USEPA method 8270 was employed in GC-MS analysis.

Visible Ultra-violet spectrophotometry, UV-Vis spectrophotometer S/N 18-1901-01-0243 was further used to analysis the pharmaceutical effluents in order to ascertain concentration of PhACs of interest in the simulated pharmaceutical effluents. The software used in interpreting concentration of pollutant or chromatogram was UV win5 spectrophotometer version 5.2.0. Extracted concentrated analytes were further diluted with methanol and scanned with visible-UV to determine the wavelength of each PhACs in the samples. The wavelength of Paracetamol, Salbutamol and Chlorpheniramine was set at 257, 278 and 262nm respectively. The concentrated analytes were transferred into 10ml cuvette to read each concentration of PhACs with UV win5 spectrophotometer version 5.2.0 at different determined wavelength. Prior to each UV reading, the instrument was blanked with methanol in order to set a new baseline.

The gas chromatography that was used was Agilent Technologies 7890-A GC system G-3440-A A.01.14 series, coupled with Mass spectrometry detector (MS) Agilent Technologies 5975-C VL MS D series with Agilent Technologies 7683-B series injector powered with MSD chem-station G1701-EA E.02.10.1177 software to identify and quantify analytes in compounds. Selected hydrocarbon compounds were identified on the basis of their retention time and by comparing them to those of analytical standards. Matrix spikes, duplicates, solvent, and method blanks were also analyzed as quality control samples.

3. Results & Discussion

Figure 1(a & b) shows the FTIR spectra of CBV 350°C H₃PO₄ and COA 350°C KCl. The modified bamboo species revealed large number of functional groups, the spectra also indicates that the surface functional groups of the adsorbents do not exhibit significant difference irrespective of the activating agent used. Differences were slightly noticed on the intensity of the bands and spectrum shapes, with some functional groups shifted to different frequency levels. For the activated carbons analyzed the spectra shows a broad absorption peak at 372 - 3424cm⁻¹. The 3424cm⁻¹ wave length was associated to OH hydrogen bonded phenol, alcohol hydroxyl group with H bonded to OH stretch was seen as most predominate in the adsorbent. The results for the carbon tested show similar functional groups but different structural shapes. This can be linked to the different activating salt.
Fourier Transform Infrared Spectrometer of COA 350°C KCl

Fourier Transform Infrared Spectrometer of CBV 350°C H₃PO₄

(Parkin Elmer FT-IR system RX spectrum v5.3.1 Multidisciplinary Central Research Laboratory (MCRL) of the University of Ibadan, Ibadan, Nigeria.)

**Figure 1** Fourier Transform Infrared Spectrometer of the absorbent used

The SEM-EDS analysis reveals the porous structure of the samples, the amount of pores within each species for sorption and the agglomeration of particles within the structures in distinctive irregular shapes. Both species show layers of micro pore material clustered and woven together with a semi-permeable bio-membrane indicating that bamboo can undergo both filtration and adsorption processes progressively. The SEM image CBV 350°C H₃PO₄ seem to have more open pores when compared with COA 350°C KCl which has a close pore with a thread-like surface. This indicates that CBV 350°C H₃PO₄ may be better in adsorption or sorption processes when compared with COA 350°C KCl.

**Figure 2** SEM images of Bambusa vulgaris and Oxytenanthera abyssinaca

The elemental composition of elements in the bamboo species, revealed the electron dispersion spectral of the selected areas. The SEM-EDS monograph of the modified bamboo species reveals that the chemical composition on the surface of each mapped spectrum include carbon, oxygen, nitrogen, silicon, chlorine, zinc, potassium, phosphorus, magnesium and titanium. While table 1 shows the elemental constituents of COA 350°C KCl and CBV 350°C H₃PO₄.

**Figure 3**: Elemental dispersion spectral of selected areas on SEM-EDS for modified Absorbents
Table 1: Elemental Composition of Modified Bamboo Species

| Modified Bamboo Activated Carbon | Mapped Spectrum Area | Elements | Weight (%) | Atomic (%) |
|----------------------------------|----------------------|----------|------------|------------|
| Bambusa Vulgaris(CBV) 350°C H3PO4| Spectrum 1            | C        | 62.00      | 68.62      |
|                                  |                      | N        | 3.98       | 3.74       |
|                                  |                      | O        | 33.53      | 27.64      |
|                                  |                      | Ti       | 34.48      | 14.80      |
| Oxytenanthera abyssinaca(COA) 350°C KCl| Spectrum 1     | C        | 71.07      | 78.38      |
|                                  |                      | O        | 22.80      | 18.88      |
|                                  |                      | P        | 4.43       | 1.90       |
|                                  |                      | Mg       | 0.56       | 0.30       |
|                                  |                      | Si       | 1.14       | 0.54       |

The results in table 1 revealed high intensity of carbon and oxygen, which can be deduced that modified bamboo species, has good adsorptive properties. The rather high concentration of silicon in Oxytenanthera abyssinaca implies that the adsorption processes will be rapid as confirmed by [19] that incorporation of silicon in a solid will dramatically increase the solid binding strength for some pollutants. Some of the elements introduced resulted from the dehydrating salt used while others are component of the bamboo species.

3.1. Effect of contact time on Adsorption Behavior

3.1.1. Effect of contact time on adsorption of PAHs

Figure 4 shows the Spectra of 16 priority PAHs in Simulated Petroleum wastewater. The effect of contact time in removal of PAHs from simulated petroleum wastewater by COA KCl and CBV H3PO4 are detailed in Figures 5 & 6. The varying contact times used were 30min, 2hrs and 12hrs and there were no much changes or differences in the adsorption rate per time.

It was revealed that the percentage removal efficiency of PAHs with time by COA KCl was not consistent. At 30min of adsorption rate; the percentage removal efficiency was 49.8% of total PAHs, while 39.1% of total PAHs was adsorbed at 2hrs and about 72.3% of total PAHs was adsorbed at 12hrs contact time. Similarly, the adsorption rate of PAHs by CBV H3PO4 was observed not to follow the adsorption pattern wherein adsorption rate increased with time. At 30min, about 85.1% was adsorbed; an increase in contact time to 2hrs shows a reduction in adsorption rate to 25.1% but further increase in time to 12hrs further increases adsorption efficiency to 87.7% which is the optimal contact time for CBV H3PO4 in adsorbing PAHs.

Since the pattern of adsorption does not follow the norms of adsorption, it could be deduced that adsorption of PAHs is in two stages. At the first stage the PAHs were adsorbed easily unto the accessible hydrophobic site within the adsorbent or granular activated carbon matrix for the first 30min. These could have resulted from the chemical interaction between the PAHs and the adsorbent surface. The reduction in adsorption rate implies that in the second stage, adsorption rate may be restricted by slow movement of PAHs to less available site associated with the micropores within the adsorbents matrix which could take hours. Same observation was deduced by [20, 21, 22]. [23] Further explained that the sorption of PAHs onto porous adsorbent such as GAC undergoes three consecutive stages. The first stage is assumed to occur rapidly without a rate-limiting stage in the adsorption of organic compounds on the adsorbent, but at the second stage the mass transfer proposed a main resistance during the diffusion of PAHs into the internal structure of the adsorbent. It can then be implied that the pore structure of the adsorbents used for these experiment consists of macropores, transitional pore (mesopore) and micropores as early deduced by SEM and EDX analysis.
Figure 4: Spectra of Simulated Petroleum wastewater indicating 16 priority PAHs,

Figure 5: Effect of contact time on adsorption rate of PAHs by COA KCl at (a) 30mins,(b) 2hrs and(c) 12hrs
Central Research Laboratory, University of Lagos

Figure 6: Effect of contact time on adsorption rate of PAHs by CBVH₃PO₄ at (a) 30mins,(b) 2hrs and (c) 12hrs.

3.1.2 Effect of contact time on adsorption of PhACs

Figures 7 a-c shows the adsorption rate and removal efficiency of PhACs by COA KCl and CBV H₃PO₄ at varying contact time of 30, 180, 360, 720 and 1440 mins.

The trend of adsorption in Figs. 6a-c revealed a slight reduction of adsorption rate before an increase after which equilibrium was observed for COA KCl adsorbent. Adsorption trend of CBV H₃PO₄ revealed a sharp reduction to a level and there after an increase was observed before equilibrium point was reached. These observations are consistent with [24,25&26] findings. It can be explained that absorption of PhACs with COA KCl and CBV H₃PO₄ occurred in two different stages. The first stage occurred during the first 30-360mins contact time, with high number of active binding sites on the adsorbents surfaces. Adsorption rate is rapid in this stage and points to adsorption being controlled by diffusion processes of paracetamol, salbutamol and chlorpheniramine molecule from the bulk phase to the adsorbent surface. The second stage of adsorption is an attachment-controlled processes due to decrease in the number of active site available for Paracetamol, salbutamol and chlorpheniramine.
molecule onto the adsorbents surfaces. Slow uptake of adsorbate and establishments of equilibrium over a longer period indicate strong chemical binding of adsorbate with adsorbent.

3.2. Compatibility test of COA KCl and CBV H₃PO₄ adsorbent with developed wastewater system

In order to test for the compatibility of the activated carbon alongside other treatment section as well as the efficiency of the wastewater treatment system. 15.9L of simulated wastewaters of each pollutant was used alongside 78.5g of selected activated carbon.

The volume of simulated wastewater used was calculated thus:

Height of developed system = 900mm or 0.9m
Diameter of developed system = 150mm or 0.15m
Volume of a cylinder = πr²h

→ \( \frac{22}{7} \times (0.075^2) \times 0.9 \rightarrow 0.015911 \text{m}^3 = 15.911 \text{L} \)

For carbon
If 200ml→1g
15900ml→x

Implying that 79.5g of selected adsorbent.

Tables 2 and 3 showed the initial concentration, final concentration and percentage removal efficiency of PhACs and PAHs in simulated wastewater by developed prototype wastewater system.

**Table 2** Remediation of PAHs by Developed Prototype wastewater Treatment System

| Compounds                  | Mass Concentration mg/l | Final concentration s of PAHS adsorbed by AC (KCl) mg/l | Removal Efficiency AC (KCl) % | Final concentration s of PAHS adsorbed by AC (H₃PO₄) mg/l | Removal Efficiency AC (H₃PO₄) % |
|---------------------------|-------------------------|--------------------------------------------------------|-----------------------------|--------------------------------------------------------|-----------------------------|
| Naphthalene               | BC                      | BC                                                     | BC                          | BC                                                     | BC                          |
| Acenaphthylene            | BC                      | BC                                                     | BC                          | BC                                                     | BC                          |
| Acenaphthene              | BC                      | BC                                                     | BC                          | BC                                                     | BC                          |
| Fluorene                  | 0.66                    | 0.23                                                   | 65.15                       | ND                                                     | ND                          |
| Phenanthrene              | 5.379                   | 3.275                                                  | 39.11                       | ND                                                     | ND                          |
| Anthracene                | 4.227                   | 2.1                                                    | 50.31                       | 1.27                                                   | 69.95                       |
| Flouranthenne             | 6.192                   | 3.805                                                  | 38.54                       | ND                                                     | ND                          |
| Pyrene                    | 6.57                    | 4.23                                                   | 35.61                       | ND                                                     | ND                          |
| Benzo(a)anthracene        | 16.2                    | 12.369                                                 | 23.64                       | ND                                                     | ND                          |
| Chrysene                  | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Benzo(b)fluoranthene      | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Benzo(k)fluoranthene      | 23.784                  | 20.34                                                  | 14.48                       | 20.61276                                               | 13.33                       |
| Benzo(a)pyrene            | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Benzo(a)pyrene            | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Dibenzo(a,h)anthracene    | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Indeno(1,2,3-cd)pyrene    | ND                      | ND                                                     | ND                          | ND                                                     | ND                          |
| Benz(e)acephenanthrylene  | 17.094                  | 14.056                                                 | 17.77                       | 13.567                                                 | 20.63                       |
| Benzo(e)pyrene            | 16.674                  | 12.476                                                 | 25.17                       | 11.457                                                 | 31.288                      |
| Benzo(g,h,i)perylenne     | 0.021                   | 0.005247                                               | 75.01                       | ND                                                     | ND                          |
| Total PAHS                | 96.801                  | 72.88625                                               | 24.70                       | 49.46676                                               | 48.898                      |

Below calibration; ND: Not detected, COA KCl: oxytenanthera abyssinaca activated with KCl; CBV H₃PO₄: Bambusa vulgaris activated with H₃PO₄; CA: Oclansorb from peat moss.
4. Conclusion
The experimental result in this study showed that adsorbents made from *Oxytenanthera abyssinaca* and *Bambusa vulgaris* can efficiently adsorb selected PhACs and PAHs in industrial Contaminated Water. The adsorption mechanism of trace organics followed same pattern though with little differences. For all organic pollutants, adsorption rate are in two stages viz: optimization and reduction followed by equilibrium. The removal efficiency of the developed prototype system highly depends on the tertiary treatment part which is the adsorbent used.

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