EVALUATION OF SINGLE-STEP STEAM PYROLYSIS-ACTIVATED CARBONS FROM LESOTHO AGRO-FORESTRY RESIDUES

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ABSTRACT

Activated carbon has been widely used worldwide as an effective filtration or adsorption material for removing biological and chemical contaminants from drinking water. The potential of producing activated carbon (AC) from local agroforestry residues by single-step steam pyrolysis processes was investigated. The research aims to promote innovative use of local raw materials and relatively low-cost techniques in production of activated carbon. Four varieties of activated carbons from four different agroforestry residues, pine (Pinus contorta) *cones (PC), Abies (Abies cilicica) seeds (AS), maple* (Acer ginnala) *seeds (MS) and peach (*Prunus persica*) stones (PS), were prepared and evaluated. The ACs were evaluated for % carbon yield and their characteristics - iodine number, phenol specific area, ash content, pH, moisture content, and solubility in water and in HCl. The % AC yields for PS, PC, AS and MS were found to be 23.0%, 18.0%, 17.8% and 14.6% respectively, which are generally comparable to the commercially recommend minimum AC yield (20%). The phenol specific areas for the ACs were 399, 388, 381 and 415m^2/g, while iodine values were 73.6, 61.4, 52.2 and 100.3g/100g for PSAC, MSAC, ASAC and PCAC, respectively. Phenol and iodine values for a commercial activated carbon (CAC) were 600 m^2/g, and 172.9g/100g. Although the adsorption properties for the experimental ACs were generally lower than those of the analyzed CAC, the results still revealed that the experimental ACs possesses high absorptive properties as desired in industrial applications. Other investigated properties namely pH (ranging 8.3 to 9.8), solubility in HCl (2.2 to 4.7%) and solubility in water (2.3 to 5.0%) also showed that single-step steam pyrolysis can produce ACs of close comparison to CAC. Overally, this preliminary investigation has demonstrated potential in application of any of the four materials, coupled with the single-step steam pyrolysis technique, in production of AC.*

INTRODUCTION

Conventional water treatment plants use processes such as pre-chlorination, fluoridation, alum coagulation with hydraulic flocculation, sedimentation, dual anthracite and sand filtration and post-chlorination for disinfection and removal of organic and metallic substances from the waters (Ahmed *et al*. 2004). In developing countries, the costs associated with manufacturing or more often importation of water-treatment chemicals tend to push the costs of processed water to levels that are not affordable to many people. Consequently, significant proportion of people in those countries lack access to conventionally processed water. The provision of safe water to the people is an urgent development priority of the Southern African Region (WHO 2010). With global water sources becoming more contaminated coupled with improved knowledge about water-borne diseases, poor communities are turning to low-cost household water treatment processes such as boiling and point-of-use disinfection using relatively cheap chemicals (Doocy and Burnham 2006). Multi-pronged efforts towards

provision of quality water to all communities have ignited interest in research focusing on low-cost technologies and products for treatment of drinking water (Kadirvelu *et al*. 2003). Some of the positive outcomes of such research include the utilization of plant residues as adsorbents for the removal of impurities from water, which is now gaining prominence in some parts of the world (Yongabi et al. 2011). The use of a natural coagulant from seeds of the *Moringa oleifera* tree to replace conventional coagulants such as aluminium salts in both domestic and large scale water treatment and the use of activated carbon as adsorbent in the treatment of drinking water, are now considered an effective and efficient method of removing undesirable chemicals from contaminated waters (Gautam and Vikram 2011). AC possesses some capacity to remove heavy metals, organic compounds, bacterial and viral pathogens, pesticides and algal toxins from drinking water (Budiniva *et al*. 2002, Misiharabgwi *et al.* 2007). The AC works by either adsorbing the impurities, especially organic chemical or by entrapping them in its pores (Hugo *et al.* 2010). In most developing countries, the activated carbon is imported at high cost, limiting the quantities of safe drinking water available to the people.

Raw materials together with the production method determine the final characteristics of the activated carbon product as well as the overall economic viability. The quality and activity of AC is determined by factors such as surface area, ash content, solubility, pH and moisture content of carbons. For instance, high ash content and low pH values are known to reduce the activity of AC (McConnachie *et al*. 1994).

Among the many processing schemes known for the production of AC, arguably the simplest and most economic is steam pyrolysis. Steam pyrolysis is a physical activation process in which the precursor material is heat-treated in the presence of steam to form activated carbon - a porous carbonaceous char. Physical activation generally involves two-steps - carbonization of the carbonaceous raw material to a carbonaceous char and activation of the char in the presence of suitable activating medium such as carbon dioxide, steam, air or their mixture. Carbonization generally occurs between 400 and 800ºC, while activation mostly occurs between 600 and 900ºC (Cetin *et al*. 2004).

Traditionally, coal, lignite, coconut shell and wood peat are the main raw materials in production of commercial AC (Bansode *et al*. 2002). However, several researches have been devoted to investigating potential of various agro-forestry wastes, including macadamia (*Macadamia. integrifolia*) nutshells, *Jatropha curcas* cakes, maize (*Zea mays*) cobs, baobab (*Adansonia digitata*) husks, pigeon pea (*Cajunus cajana*) husks, *Moringa oleifera* husks, marula (*Sclerocarya birrea*) stones and rice (*Oryza sativa*) husks, as sources of activated carbon (Girgis *et al*. 2000, Aygun *et al*. 2003, Ahmedna *et al*. 2004, Ntuli 2007). Some of the researches have already demonstrated potential in some of the materials, such as macadamia nut-shells (Ahmedna *et al*. 2004, Ntuli 2007), as raw materials for commercial AC.

Although no quantitative data could be found, the authors' preliminary qualitative surveys revealed a potential availability of abundant agroforestry wastes in Lesotho, making them potentially cheaper raw materials for AC, if suitability is proven. Presently, most of the agro-forestry wastes have little or no economic use, and their disposal is not only costly but often an environmental concern. This study was therefore aimed at evaluating activated carbons from locally available resources.

MATERIALS AND METHODS

Raw Materials:

The raw materials used were pine *(Pinus contorta)* cones (PC), Abies *(Abies cilicica)*

seeds (AS), maple *(Acer ginnala)* seeds (MS) and peach *(Prunus persica)* stones (PS). The raw materials were collected from sources around Roma and Maseru, Lesotho. The raw materials were first cleaned by scraping off all unwanted adherents followed by a wash in distilled water and then dried in an oven at 60 ^{o}C for 24 hours.

Production of Activated Carbons

The dried raw materials were activated and carbonized using single step steam pyrolysis. Approximately, 250-g samples of each material were crushed into small pieces and placed in a stainless steel tray (22cm x 15cm x 10cm) and inserted into a size 1 Gallenkamp box furnace (supplied by Griffin and George Limited, England), fitted with a regulated steam generation system. Steam was generated by injecting water into the furnace at a rate of 20 ml/min, starting when the furnace temperature was at 100^{o}C until the end of the soak period (30min). The treatment (soak) temperatures were determined by preliminary experiments in which temperature was varied (range from 400 to 1000^{o}C) while the derived ACs were characterized for %AC yield and iodine number only. Optimized temperatures were taken as those giving the best compromise between % yield and iodine number. For raw materials MS and AS, 500^{o}C was found suitable and for PC and PS 800^{o}C met the criteria. Basically, treatment temperatures were selected to ensure minimum ashing and good adsorption properties of the ACs. After the soak period the samples were allowed to furnace-cool to 100^{o}C before removing the ACs for washing. The ACs were washed with distilled water for 30 min at 60^{o}C to remove ash, then dried in the oven at 60^{o}C for 24 hours and weighed. The ACs were ground to powder and sieved through an 80-mesh sieve (0.177 mm).

Characterisation of Activated Carbons

All the experimentally produced activated carbons (ACs) plus a commercial activated carbon (CAC) were analyzed for the following parameters: pH, moisture content, ash content, solubility in water and 0.2M HCl, iodine number and phenol adsorption (surface area). For each sample, the characterization experiments were carried out in triplicate and all given values are average values of the triplicate tests. The CAC used was sourced from SAARCHEM HOLPRO analytical PVT, Krugersdorp, SA.

pH

Slurries of the ACs were prepared by adding 0.2 g AC samples to 100 ml distilled water in 250 ml flasks. The flasks were shaken at 200 rpm using a shaker (Vacutec Cat N° 10 x 400 xx 2), for 2 h, under ambient conditions. The mixtures were filtered and pH of each filtrate was measured.

Moisture Content

Moisture content was determined following a method by Kadirvelu *et al.,* 2003.

Ash Content

Approximately 2g AC samples were ashed for 12 hours at 900°C in the furnace (Gallenkamp box). The residue was cooled to room temperature in a desiccator. The ash content was calculated as the weight ratio of the residues to the original sample.

Solubility in Water and HCI

For water solubility, 0.2-g AC samples were added to 100 ml of distilled water in 250 ml flasks and shaken at 200 rpm in a shaker (Vacutec Cat N° 10 x 400 xx 2) for 2 h at ambient temperature. The mixtures were filtered through pre-weighed Whatman N°.1 size 15 filter papers. The filter papers containing the residual carbons were dried in the furnace (Gallenkamp) for 12 h at 105°C. After cooling to ambient temperature, in a desiccator, the filter papers together with residual carbons were weighed. The percentage solubility in water was calculated as the weight ratio of unrecovered carbon to the original sample. For solubility in HCl, the same method was followed but 0.2M HCI was used instead of water (Kadirevelu *et al*. 2003).

Iodine Numbers
Iodine numbers, as an indication for adsorption capacity, were determined according to standard procedures ASTM, 1991a.

Phenol Adsorption (Surface area)
Phenol adsorption isotherms were used to calculate specific surface area (SSA) for the ACs. Five-point, single-adsorbate isotherms were constructed for phenol at 0.2, 0.3, 0.4, 0.5, and 0.6, mM of phenol. AC samples (0.1 g) were added to adsorbate solution (100 ml) in 250 ml stoppered Erlenmeyer flasks, sealed, and then shaken at 100 rpm in a temperature controlled shaker bath (Vacutec Cat N° 10 x 400 xx 2) for 24 h, at 25°C. Then the suspensions were filtered through Whatman N°.1 size 15 filter papers. Residual adsorbate concentrations were determined using a UV spectrophotometer (Shimadzu UV -160A), at 270 nm. The adsorption isotherms were analyzed using the Langmuir aqueous phase adsorption model that apply equation (1) below, to establish best fit (McConnachie *et al.*, 1994). The model assumes formation of a monolayer of the adsorbate on the carbon surface and is represented by equation (1):

$$q_e = \frac{bq_m C_e}{1 + bC_e} \qquad (1)$$

Where q_e is the amount of solute adsorbed on the carbon ($mol.g^{-1}$); C_e is the equilibrium concentration of solute ($mol.l^{-1}$); q_m is the Langmuir monolayer coverage constant
($mol.g^{-1}$) and b is the Langmuir adsorption coefficient. q_m and b can be derived from a linear plot of $1/ C_e$ against $1/q_e$.

RESULTS AND DISCUSSION

Suitability of Raw Material

The softer materials, MS and AS were treated at 500°C, while the harder materials, PC and PS, were treated at 800°C; and the percentage activated carbons yields were found to be 14.6%, 17.8%, 18.0% and 23.0% respectively. PS gave not only the highest yield, but also a percent yield, which falls within specified commercial limits of 20 to 40 %. Production of activated carbon is dependent on the nature of raw material and activation temperatures used. Preferably raw materials with hard structure are used for activated carbon production commercially due to high yield. Hard raw materials contain a higher percentage of lignin as compared to other components and soft raw materials, are those with more cellulose and hemicellulose as compared to lignin (Murayama et al. 2000). A higher percentage of cellulose and hemicellulose is susceptible to pyrolytic decomposition at temperatures of up to 500°C compared to lignin, thus higher ash content of MS and lower yield of activated carbon than PS. High activation temperatures of up to 800°C produce activated carbon with high adsorptive capacities as evident from PC and PS activated carbons. This is because high temperatures generate new pores (mesopores and micropores) in addition to macropores (Gergova 1994). However, higher activation temperatures tend to give lower %AC yields due to increased endothermic reactions between carbon and steam (water-gas reactions), which can be represented by:

$$H_2O + C \rightarrow CO + H_2 \qquad (1)$$
$$2H_2O + C \rightarrow CO_2 + 2H_2 \qquad (2)$$
$$CO_2 + C \rightarrow 2CO \qquad (3)$$

Properties of Activated Carbons from Local Resources

Each of the activated carbons has its own characteristic properties and variation exists in the efficiency of removal of a range of impurities from waste water. Characterisation of the carbons is important in the formulation of a consistent quality carbon that can be used in water treatment plants or any other industrial applications.

Ash Content and pH
Ash contents for PCAC, MSAC, PSAC and ASAC were 3.03%, 3.90%, 3.03% and 5.35% respectively as shown in Table 1. The ash content is related to the alkalinity of

the ACs and therefore the measure of pH values were 8.43, 8.64, 8.58 and 9.76 for PCAC, MSAC, PSAC and ASAC, respectively. The ash content is related to basic pH because ash consists mainly of salts and oxides of the chemical elements dominating plant tissue, which include calcium salts, alkali carbonates, and silica. Fe, Al, Mn and Mg are present in small amounts. It is important to note that the pH values are comparable to pH values reported by Budinova et al. 1994 for activated carbons from olive seeds, coconut, cherry stone, peach stone, apricot stone and *Moringa* husks which ranged from 8 to 12. The high pH values are indicative of soluble inorganic material, which may need to be removed from the AC for specific uses such as solvent recovery processes, adsorption gas chromatography and catalyst supports (Aloko and Adebayo 2007). The pH is a major determinant of the corrosivity of water. In general, the more acidic the water (pH < 6) is, the higher the corrosivity. Generally, AC for water treatment industries should have pH values in the range of 6.5 to 8. Health-wise, human exposure to high alkalinity water levels (pH >8.5) results in irritation of the eyes, skin, and mucous membranes (WHO, 1996). Arguably, the experimental ACs exhibited acceptable pH levels for most applications including medical, environmental and water treatment purposes.

High-ash content raw materials contain high levels of impurities that lead to blockage of pores during the activation process reducing the surface area of the AC. All the experimental materials gave low ash contents, impacts positively on surface area parameter.

Table 1: Characteristics of the experimental carbons and the commercial carbon

Carbon Sample	Ash content (%)	pH	Moisture content (%)	Water Solubility (%)	Solubility in 0.2M HCl (%)	Iodine value (g/100g)	Phenol specific area (m^2/g)
ASAC	5.35±0.13	9.76±0.28	0.59±0.06	5.0±0.16	4.7±0.18	52.2±0.23	381±0.66
MSAC	3.90±0.09	8.64±0.17	0.68±0.05	3.0±0.19	4.0±0.11	61.4±0.07	388±0.45
PCAC	3.03±0.16	8.34±0.10	0.82±0.08	2.3±0.10	2.7±0.03	100.3±0.11	415±0.10
PSAC	3.03±0.11	8.58±0.25	1.19±0.03	2.5±0.24	2.2±0.14	73.6±0.20	399±0.06
CAC	2.00±0.22	8.20±0.13	0.11±0.03	1.8±0.04	1.0±0.03	172.9±0.32	600±0.50

Key:
ASAC – Activated carbon produced from abies seeds
MSAC – Activated carbon produced from marple seeds
PCAC – Activated carbon produced from pine cones
PSAC – Activated carbon produced from peach stones
CAC – Commercial Activated Carbon

Moisture Content

The higher the moisture content, the more susceptible the carbon is to fungi growth; thus moisture content influences the storage and shelf-life of activated carbon. If the moisture content of AC is high, fungi and other micro-organisms degrade the carbon utilizing it in their metabolic processes. The micro-organisms can also multiply within the AC macro and micro-pores, blocking the pore structure, thereby reducing the adsorptive capacity of the carbon (Kadirvelu et al. 2003). The prepared ACs exhibited low moisture contents of 0.59 to 1.19 %, which are ideal for storage (Table 1). Generally, the recommended AC storage moisture content is < 3 % (Helleur et al. 2001).

Activated Carbon Solubilities

The ACs exhibited very low solubility in both water and acid, which is an indication that the carbons had been thoroughly washed. Any degree of solubility in either water or acid is an indication of presence of impurities. Pure carbon does not dissolve in either water or acid since carbon is very unreactive due to lack of electron donating or accepting species in the structure such as lone pair electrons (Minkova et al. 2003). The degree of wash was sufficient to render the ACs suitable for water treatment applications. ACs have various applications, which are dependent on the nature of the carbon including accompanying impurities. In some processes the AC impurities that are alkaline in nature play the vital role of neutralising acid species. The low solubility of AC is a vital attribute in water treatment and many other processes where dissolution of the carbon is undesirable. In water treatment, for instance, carbon dissolution would cause problems such as colour, odour and quick depletion of carbon adsorbent.

Iodine Value

The iodine value is an indicator of adsorption capacity of AC and is even relied upon in the water treatment industry for selection of AC from suppliers. The experimental carbons gave iodine values ranging from 52.2 to 100.3 g/100g; while the commercial carbon CAC gave iodine value of 172.9g/100g as shown in Table 1. Comparable results were also obtained by Warhurst (1997) on evaluating ACs from agricultural-wastes, almond shell, cherry stone and peach stone, which gave iodine values ranging from 75 to 145 g/100 g.

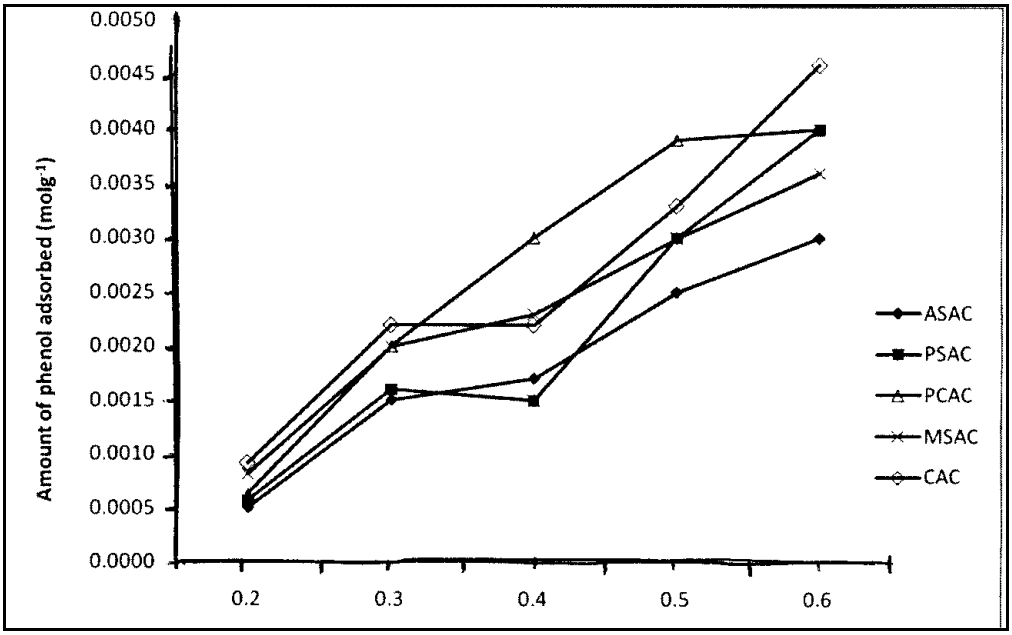

Figure1: Phenol adsorption isotherms of the four experimental carbons (PCAC, MSAC, PSAC and ASAC).

Specific Surface Area

Adsorption isotherms for the different ACs are shown in Fig 1. The adsorption isotherms were used to assess the adsorptive capacity of carbons by estimating the surface area available for a monolayer of a molecule of phenol. Higher phenol specific area indicates large micropore volume for the carbon. The phenol specific areas range between 318m^2/g (for PSAC) and 415 m^2/g (for PCAC). The shape of the adsorption isotherms can provide preliminary qualitative information on the adsorption mechanism and on the porous structure of the carbons. All isotherms at lower phenol concentration, < 0.3 mM, present a sharp increase typical of adsorption taking place by primary filling of micropores; followed by some kind of levelling of the curve (between 0.3 to 0.4 mM concentration), marking the end of primary filling. From about 0.4 mM concentration there is another sharp increase in adsorption representing secondary filling of supermicropores. Based on the shape of graphs (Fig 1), it observed that the characteristics resemble Langmuir isotherms, similar to those reported by Okeola and Odebunmi (2010), Ntuli (2007), Aloko and Adebayo (2007). The surface area of AC is generally proportional to its adsorptive capacity; and the surface area depends on the mass removed during the activation process, which creates pores in the material.

CONCLUSION

On the basis of specific surface areas (381 to 415m^2/g), iodine number (52.2 to 100.3 g/100g), solubility (2 to 5%) and pH (8.34 to 9.76), all the four investigated agro-forestry wastes – AS, MS, PC and PS – gave ACs of good quality by simple steam pyrolysis process. With the exception of MS, all the other raw materials gave relatively high yields of activated carbon, up to 23.0 %, making them potential commercial materials for the production of activated carbon. The carbons can be deemed suitable for drinking water treatment, however the high pH value (9.76) of ASAC, may make it less suitable for that application.

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REFERENCES

Ahmad ER, Namasivayam C and Kadirvelu K 2004 Coirpith, an agricultural waste by-product, for the treatment of dyeing wastewater. *Bioresource Technol*. **48**: 79-81.

Ahmedna M, Marshall WE and Rao M 2004 Production of granular activated carbon from select agricultural by-products and evaluation of their physical, chemical and adsorption properties. *Bioresource Technol.* **71**:113-123.

Aloko DF and Adebayo GA 2007 Production and characterization of Activated Carbon from Agricultural wastes (Rice-husk and Corn-cob). *J. Engin. Appl. Sciences*. **2**: 440-444.

ASTM (199Ia) D2862-82. Standard test method for particle size distribution of activated carbon. American Society for Testing and Materials, Philadelphia, U.S.A.

Aygun A, Yenisoy S and Duman I 2003 Production of granular activated carbon from fruit stones and nutshells and evaluation of their physical, chemical and adsorption properties. *Micropore. Mesopore. Matter.* **66**: 189-195.

Bansode RR, Losso JN, Marshal WE, Rao RM and Portier J 2002 Adsorption of metal ions by pecan shell based granula activated carbon. *Bioresource Technol.* **89**:115-119.

Budiniva ZI, Ghali AE, Ramiro A and Gonzelez JF 2002 Pyrolysis of two agricultural residues, olive stones and grape seeds. Influence of particle size and

temperature. *Biomass Bioenergy*. **11**: 397-409.

Budinova TK, Gergova KM, Petrov NV and Minkova VN 1994 Removal of metal ions from aqueous solution by activated carbons obtained from different raw materials. *J. Technol. Biotechnol.* **60**: 177-182.

Cetin E, Moghtaderi B, Gupta R and Wall TF 2004 Influence of pyrolysis conditions on the structure and gasification reactivity of biomass chars. *Fuel.* **83:** 2139-2150.

Doocy S and Burnham G 2006 Point-of-use water treatment and diarrhoea reduction in the emergency context: an effectiveness trial in Liberia. *Trop Med Int Health*. **11**: 1542-52.

Gautam K N, Vikram SG 2011 Removal of Janus Green dye from aqueous solution by phosphoric acid carbonized agro-industrial waste. *Science Asia* **37:** 38–42.

Gergova K, Petrov N and Eser S 1994 Adsorption properties and microstructure of activated carbons produced from agricultural by-products by steam pyrolysis. *Carbon* **32**: 693-702.

Girgis BS, Yunis SS and Soliman B 2000 Characterisation of activated carbon from pecan hulls in relation to conditions of preparation. *Matter.* **57**: 164-172.

Helleur R, Liu D and Ikura M 2001 Caracterisation and potential application of pyrolytic char from ablative pyrolysis of used tyres. *J. Annual. Appl. Pyrolysis*. **59**: 813-824.

Hugo SS, Silvia VR, Dolly LG and Juan MS 2010 Adsorption of Mercury (II) from Liquid Solutions Using Modified Activated Carbons. *Materials Research*. **13**: 129-134.

Kadirvelu K, Kavipriya M, Karthika C, Radhika M, Vennilamani N and Pattabi S 2003 Utilization of various agricultural wastes for activated carbon preparation and application for the removal of dyes and metal ions from aqueous solutions. *Bioresource Technol.* **87**: 129-132.

McConnachie G, Mtawali A and Young R 1994 Design aspects of hydraulic flocculates. **3**: 284-288.

Minkova V, Razvigorova M, Bjornbom E and Budinova T 2003 Effect of water vapour and biomass nature on yield and quality of the pyrolysis product from biomass. *Fuel Process Technol.* **70:** 53-61.

Misihairabgwi J, Ntuli V, Kasiyamhuru A, Zinyowera S, Ncube I and Chipofya V 2007 Application of locally produced activated carbons in water treatment. *UNESCO-IHE Institute of water education.*

Morton IF 1991 The horseradish tree, *Moringa pterygosperma* (Moringaceae)-a boon to arid lands economics. *Botanic.* **45**: 318-333.

Murayama H, Moriyama N, Mitobe H and Mukayi H 2000 Evaluation of activated carbon fibre filter for sampling of organochlorine pesticides in environmental water samples. *Chemosphere*. **52**: 825-833

Ntuli V 2007 Characterisation of activated carbon prepared from agroforestry wastes and application in water treatment. *MSc thesis*, Department of Biochemistry, University of Zimbabwe.

Okeola FO and Odebunmi EO 2010 Freundlich and Langmuir Isotherms Parameters for Adsorption of Methylene Blue by Activated Carbon Derived from Agrowastes. Advances *in Natural and Appl. Sciences*. **4**: 281-288.

Warhurst AM, McConnachie GL, Pollard SJT 1997 Characterisation and applications of activated carbon produced from *Moringa oleifera* seed husks by single step steam pyrolysis. *Water Resource*. **31**: 759-766.

WHO 1996 pH in Drinking-water. Guidelines for drinking-water quality, 2nd ed. Vol. 2. *Health criteria and other supporting information.* World Health Organization, Geneva, 1996.

WHO 2010 Access to safe drinking water improving; sanitation needs greater

efforts. A article in press 15 March 2010, Geneva, New York.

Yongabi KA, Lewis DM and Harris PL2011 Harris Indigenous plant based coagulants/disinfectants and sand filter media for surface water treatment in Bamenda, Cameroon. *Afri. J. Biotechnol*. **10**: 8625-8629.