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Life Cycle Inventory Analysis (LCIA) of production of activated carbons from selected agricultural materials

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ABSTRACT

Life Cycle Assessment was successfully carried out on activated carbons produced from milk bush kernel shell (MB), flamboyant pod back (FB) and rice husk (RH) in order to determine their environmental burden and to assess the potential health impacts. The analysis covered the whole processes involved in producing activated carbon from the raw agricultural wastes. In this work the carbonaceous part of the agricultural wastes were carefully obtained, washed, with distilled water, dried in the oven, to remove moisture before being carbonized at 300 - 600^{0}C. The carbonized chars were further activated with H_3PO_4, dried in the oven, washed with distilled water and $NaHCO_3$ to remove any residual acid and finally dried in the oven. The solid pollutants generated in the production of activated carbon from MB, FB and RH ranged from 40.21 to 41.65%, 36.31 to 36.92%, and 15.34 to 21.55%, respectively, while the air pollutants generated in the production ranged from 11.85 to 12.15%, 11.83 to 11.94%, and 18.39 to 19.12%, respectively. Similarly, the liquid pollutants generated in the production activated carbon from MB, FB and RH ranged from 46.50 to 46.88%, 51.25 to 51.75%, 60.06 to 64.82%, respectively. Generally the order of the waste generated in the process was liquid > solid > air pollutants except for rice husk which produced more air pollutants than solid pollutants. The analysis of the solid pollutants showed that they can be recycled as fuel, thus leaving little quantity of solid wastes after process. Similarly the air and liquid pollutants generated were well contained within the acceptable environmental practice.

Introduction

The volume and impact of solid wastes accompanying various production processes involving solid materials have attracted concerns, particularly, in terms of public health and safety as well as sustainable development (Liamsanguan and Cheewala, 2008). An effective tool currently employed to assess these concerns in production process leading to solid waste generation is Life Cycle Assessment (LCA) (Chriestensen et al, 2007 and Ekvall, et al, 2007).

It is a stage-wise approach employed to analyse the environmental impact of using a raw material and service system to produce a desired product (Aelion et al., 1995; Curran, 1995; Chubbs and Stainer, 1998). Furthermore, it involves thorough procedures, Life Cycle Inventory Analysis (LCIA), which account for the environmental impact emanating from the processing of a product from raw material to finished stage (Chubbs and Stainer, 1998). This analysis has been used in waste management such as solid waste management and wastewater treatment (Barton and Patel, 1996; Finnveden, 1998; Suh and Rousseaux, 2001; Consonni et al., 2005; Björklund and Finnveden, 2007; Bilitewski and Winkler, 2007; Gheewala and Liamsanguan, 2008; Manfredi and Christensen, 2009; and Khoo, 2009). Environmental load and impact as well as mass, energy and waste Eco-vectors are identified by Aelion et al., (1995) as main components in the LCIA of a product and service systems.

LCA approach to analyze waste management

Life Cycle Inventory Analysis (LCIA) of activated carbons produced was employed in this study to identify and quantify the materials used in the laboratory procedure of producing activated carbon from flamboyant pod back (FB), milk bush kernel shell (MB) and rice husk (RH). The material balance approach to LCIA (figure1) was conducted as suggested by National Pollution Prevention Centre for Higher Education (NPPCHE, 1995) and data generated from the laboratory procedures was used for the analysis, using the material balance approach (Babu and Ramakrishna, 2003). Furthermore, few items, such as consumption of natural resources, renewable raw material, and generation of pollutants (Table 1) of the procedure were selected for the LCIA due to their significance particularly with respect to environmental aspects (Aelion et al., 1995).

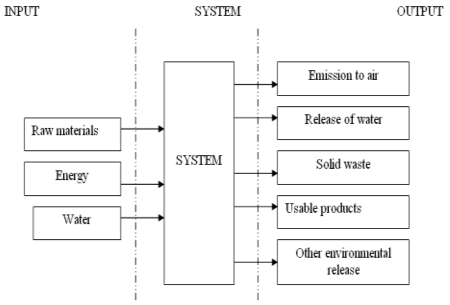

Figure 1: Material balance approach to Life Cycle Inventory Analysis (LCIA)

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The mass eco-vector for the LCIA of this study was determined for the raw material consumption and waste releases with respect to the material input. The mass densities of the acid and base used were assumed to be equal to the density of water because their concentrations were very low (Babu and Ramakrishna, 2003). From the breakdown of both inputs and outputs in the production process of activated carbons from the selected raw materials, the material balance obtained is as summarized in table 2. The purpose of this study is to conduct Life Cycle Inventory Analysis (LCIA) on the activated carbons produced from agricultural resources in order to determine the type and volume as well as the eco-safety of wastes generated in the process. The material balance approach of (LCIA) was employed in the study according to Babul and Ramakrishna (2003).

Materials and method

Raw rice husk (RH) was obtained from Arowomole Rice Mill, Ogbomosho, Nigeria, flamboyant pod back (FB) which was sourced from the fields of Ladoke Akintola University of Technology, Ogbomosho while milk bush kernel shell (MK) was obtained from various schools fields in Ogbomosho, since the plant is grown as ornamental tree in most of the schools. The reagents used during the course of the experimental activities include sodium bicarbonate ($NaHCO_3$) and distilled water. Phosphoric acid (H_2PO_4) was used for the activation, acid activation often facilitate higher yield at lower temperature (Bello et al, 2011). All reagents were analytical grade.

Materials processing

Each material was sorted to remove the stones, shaft and debris (Joseph et al., 2009), thereafter, the backs of the flamboyant pod were removed mechanically and kept separately. Similarly, the milk bush kernel shells were cracked and the shells were carefully collected for further treatment. Furthermore, the backs and shells obtained were washed with copious amount of distilled water to remove surface impurities (Bulut and Tez, 2007, Joseph et al., 2009, Bello et al, 2011) and later dried in the oven at a temperature of 105 ^{0}C overnight to constant moisture level (Amuda and Ibrahim, 2006). The dried materials were crushed using milling machine so as to reduce their sizes to pellet-form and increase their surface area (Bulut and Tez, 2007).

Carbonization

Each agricultural material (1kg) was charged, separately, into the furnace (Vecstra, Model 184A, Italy), heated to 300 ^{0}C for 2hr after which they were collected and cooled at room temperature (28±2 ^{0}C). The procedure was repeated for all the materials at carbonization temperatures of 500 and 600 ^{o}C. The domain of variation of these factors was defined according to Bornemann et al., (2007). The cooled charred materials obtained were weighed to determine the yield of each material using the expression in equation (1) (Bornemann et al., 2007).

$$\text{Percentage Yield (\%)} = \left[\frac{W_F}{W_I}\right]\times 100 \qquad (1)$$

where W_I = Initial weight before carbonization and W_F = Final weight after carbonization

Activation

Samples of the carbonized material were weighed into beakers and then soaked in excess phosphoric acid (H_3PO_4) for 3 h (Kadirvelu et al., 2001). Johns et al., (1999) suggested that H_3PO_4 produces a better pore surface area and are relatively safer than $ZnCl_2$ and hence the choice for this study. The mixtures were then charged inside an oven at temperature of 200 ^{o}C for 24 h (Kadirvelu et al., 2001; Joseph et al., 2009) to ensure proper adsorbate drying to constant weight. The materials were removed from the oven, cooled for 2 h and washed with distilled water until leachable impurities due to free acid and adherent powder were removed (Amuda and Ibrahim, 2006). The samples were later soaked in 2% (w/v) $NaHCO_3$ to remove any residual acid left. The resulting mixture were further washed with distilled water to bring the pH to 7.0 and finally drained and dried overnight in an oven at 110 ^{o}C (Joseph et al., 2009). The samples were later cooled at room temperature, weighed to determine the amount of the material washed-off in the process and the percentage washed-off for each material was determined from the relation (equation 2). The dried sample was stored for its use as adsorbent for the removal of pollutants from wastewater. The procedures were repeated for all the materials except but with slight adjustment in the case of rice husk that was not cracked but sieved to remove impurities (Babul and Ramakrishna, 2003)

$$\text{Percentagewashed-off(\%)} \left[\frac{\omega_I - \omega_F}{\omega_I}\right]\times 100 \qquad (2)$$

where ω_I = Initial weight before activation and ω_F = Final weight after activation

Results and Discussion

The wastes generated in the production process of activated carbons from the selected raw materials are classified as air, water and solid pollution due to the destination and their compositions of the wastes produced, as illustrated in figure 2. The composition of air pollutants resulting from the production of MB ranged from 11.85 - 12.15%, and decreased with increased carbonization temperature from 300 – 600 ^{0}C. Similarly the composition of liquid pollutants in the waste generated (46.50 - 47.64%), decreased as the carbonization temperature increased from 300 – 600 ^{0}C.

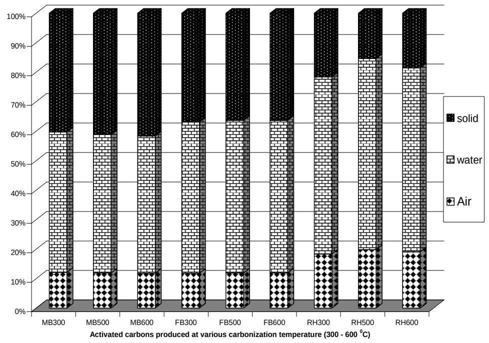

Figure 2: Percentage composition of solid, water and air pollutants in activated carbon produced from milk bush shell,Flamboyant pod back and rice husk

On the other hand, the percentages of solid pollutants in the waste ranged from 40.21 to 41.65%, which increased as the carbonization temperature increased (300 – 600 ^{0}C) and this is not a favourable development for the production of activated carbon from agricultural source (Ioannioudou and Zabanioutuo, 2007). However, the development may be tolerated from economic view due to the renewability of the agricultural materials. Maximum percentage composition of air, liquid and solid pollutants were obtained from MB300, MB300 and MB600 while minimum percentage compositions of these pollutants were obtained from MB600, MB600 and MB300 respectively.

The percentage of air pollutants in the wastes generated in the production process of activated carbon from FB ranged from 11.83 - 11.94% as the carbonization temperature increased from 300 – 600 ^{0}C. Furthermore, the composition of liquid pollutants in the process ranged from 51.25 - 51.75%, while the percentage composition of solid pollutants in the waste varied from were 36.31 - 36.92%. Nevertheless, these results did not show any relationship with respect to the increasing carbonization temperature. Overall assessment indicates that minimum percentages composition of air, liquid and solid pollutants were obtained from FB300, FB300 and FB500 respectively, while maximum outputs of the pollutants were from FB500, FB600 and FB300 for the air, liquid and solid pollutants respectively.

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The wastes generated in the production process of RH (300 and 600^{0}C), had percentage composition of air pollutants ranging from 18.39 to 19.84%, percentage compositions of liquid pollutants ranged from 60.06 to 64.82%, while the percentage compositions of solid pollutants ranged from 15.34 - 21.55%, in the waste generated. Similarly, the pattern of pollutants composition of the solid waste does not show the influence of increasing carbonization temperature from 300 – 600^{0}C. The maximum and minimum air pollutants accompanying the production of activated carbon from the rice husk were from RH500 and RH300 respectively. Similarly, the maximum and minimum liquid pollutants were obtained from RH500 and RH300 respectively, while the maximum and minimum solid pollutants were obtained from RH300 and RH500, respectively.

Comparatively, the sequence of percentage composition of air pollutants generated in the study shows that the RH has the height composition, followed by FB which share equal percentage with MB. Thus with low percentage composition of air emission, production of activated carbon from milk bush shell would be preferable raw material source (USEPA, 2001). The overall composition of liquid pollutants from this study indicates that RH has the highest percentage and next to it is FB, while MB has the least percentage composition. This development makes the production of activated carbon from milk bush kernel shell (MB) attractive, besides producing the lowest percentage composition of liquid pollutants, the choice can be justified because the activated carbon produced is targeted towards wastewater treatment thus low input from the treatment processes into water stream is environmentally acceptable (USEPA 1994, USEPA 2001).

The sequence of percentage composition of solid pollutants generated from the raw materials used in this study, is in the order MB > FB > RH. The solid residues from these materials may be used as fuel; however their quantities should have less input into the solid waste stream in the environment (Khitoliya, 2004). Although milk bush kernel possessed the highest solid input (40.21 – 41.65 %) into the environment, however, the seed fraction of the , which is about 40 % of the kernel, contains 60 % oil which is a good raw material oleochemicals and biodiesel production (Ibiyemi, et al, 2002; Oluwaniyi and Ibiyemi, 2003). The resulting seed cake is currently being detoxified in order to be applied as feed meal for livestock because of its high protein content (Usman et al, 2003).

Conclusions

The waste loads associated with the production of adsorbents from the selected agricultural materials were carefully studied and subjected to proper environment management service to reduce the effect on the environment. The reject from MB kernel shell were essentially the seed and shaft. The seed, which contains about 60% oil, can be used as source of oil seed for the production of biodiesel while the resulting cake can used in compounding livestock feed and the shaft can be used as supplementary for fuel for domestic and industrial applications (Babu and Ramakrishna, 2003; Oluwaniyi and Ibiyemi, 2003; Usman et al., 2003).

Similarly, the seed rejected from flamboyant pod back was hard and currently are of no known medicinal use. It is proposed that the seeds be used in horticulture particularly to produce seedlings in order to meet future demand for the pod for the production of activated carbon. Furthermore, the rejects from rice husk can be used as fuel supplementary (Vallupilai et al, 1997). The used distilled water and wastage can be used for agricultural purpose where the suspended particles will serve as compost materials (Babu and Ramakrishna, 2003)

The resulting acid and base wastes were discharged into the drains designed for the purpose in the laboratory, although their concentrations were relatively low, however, they may be recovered and recycled in the production process for industrial uses. The loss of moisture as well as acid and base retained in the agricultural materials through oven-drying and furnace heating is the main source of air pollution in the production process. The two equipment are expected to have inbuilt mechanism that would reduce the emission to acceptable level. Conclusively, it can be inferred that activated carbon can be produced from milk bush kernel shell (MB) with lesser environmental impact and consequently less health impact.

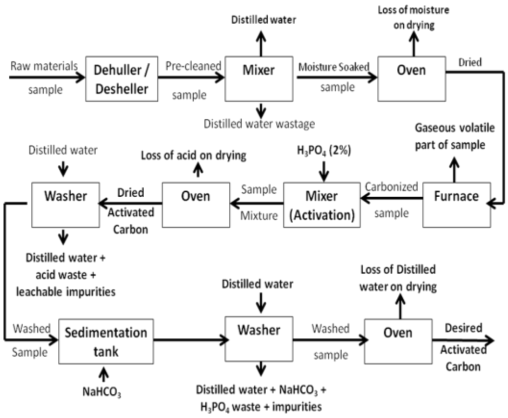

Figure 3: Process flow diagram of production of activated carbons from selected raw materials showing various points of waste generations

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Table 1: Items selected for Life Cycle Inventory Analysis

Item description	Environmental aspect
Selected agricultural material	Renewable raw material
Distilled water	Natural resources
Acid (H_3PO_4)	Non-renewable material
Base ($NaHCO_3$)	Non-renewable material
Non-shell materials (reject)	Solid waste
Loss of moisture on drying	Air emission
Wastage of distilled water	Liquid discharge (waste)
Wastage of acid (H_3PO_4)	Liquid discharge (waste)
Wastage of base ($NaHCO_3$)	Liquid discharge (waste)

Table 2: Life cycle inventory analysis summary for the production of activated carbon from selected agricultural raw material

Material balance	Item description	MB300	MB500	MB600	FB300	FB500	FB600	RH300	RH500	RH600
Input	Raw material (g)	2500	2500	2500	2000	2000	2000	1053	1053	1053
	Distilled water (ml)	3000	3000	3000	3000	3000	3000	3000	3000	3000
	H_3PO_4 acid (ml)	100	100	100	100	100	100	100	100	100
	$NaHCO_3$ (ml)	100	100	100	100	100	100	100	100	100
	Sub Total	5700	5700	5700	5200	5200	5200	4253	4253	4253
Waste	Loss of moisture (ml)	650	650	650	600	600	600	750	750	750
	Acid loss (H_3PO_4) (ml)	100	100	100	100	100	100	100	100	100
	$NaHCO_3$ loss (ml)	100	100	100	100	100	100	100	100	100
	Waste distilled water (ml)	2350	2350	2350	2400	2400	2400	2250	2250	2250
	Solid waste generated (g)	2151.69	2293.11	2282.88	1873.18	1824.06	1826.15	879.15	580.14	721.64
	Sub Total	5351.69	5493.11	5482.88	5073.18	5024.06	5026.15	4079.15	3780.14	3921.64
Product	Activated Carbon (g)	348.31	260.89	217.12	126.82	175.94	173.85	173.85	472.86	331.36