TIMBER TECHNOLOGY BULLETIN
NO. 65, 2016
ISSN: 139-258
MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT, MALAYSIA

THE POTENTIAL OF ACTIVATED CARBON FROM BAMBOO FOR HIGH END ELECTRONIC APPLICATIONS

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Introduction

Lignocellulosic materials such as wood, coconut shell, bamboo and rice husk are the most promising natural and renewable resources essential to the functioning of modern industrial societies. A considerable amount of such materials, as waste by-products, are being generated through agricultural practices mainly from various agro based industries. Sadly, much of the lignocellulosic biomass is often disposed of by burning, which is not restricted to developing countries alone. Recently lignocellulosic biomasses have gained increasing research interests and special importance because of their renewable nature (Zahid et al. 2014).

It would be surprising for the public to know that activated carbon (AC) from agricultural by-products is possible to be used in high end electronic applications when the appropriate process is followed. Various types of biomass from agricultural crops and their residues are annually disposed in large quantities and considered to be solid pollutants to the environment (Figure 1). The conversion of inexpensive, easily processed, abundant and eco-friendly lignocellulosic biomass as value-added products has been considered as an alternative for commercial activated carbon (Chowdhury et al. 2013). In Malaysia, the abundance and availability of agricultural by-products such as coconut shell (Mohd Iqbaldin 2013) and bamboo (Mahanim et al. 2010, 2011 and 2012) are the ready sources of raw materials for the production of AC.

(a) (b) (c)

Figure 1 (a) wood (b) coconut shell (c) bamboo

AC (Figure 2) is a crude form of graphite which is extremely porous and "spongy" and has extraordinary high specific surface area; a common approximation is that 1 gram of AC has a surface area of roughly 250 square metres, which is about the size of a tennis court. The porous structure of AC is important for ion to migrate and occupy the pores of carbon repetitively to form layers at the interface of electrode-electrolyte in electrochemical energy storage devices (Mohd Iqbaldin et. al. 2013).

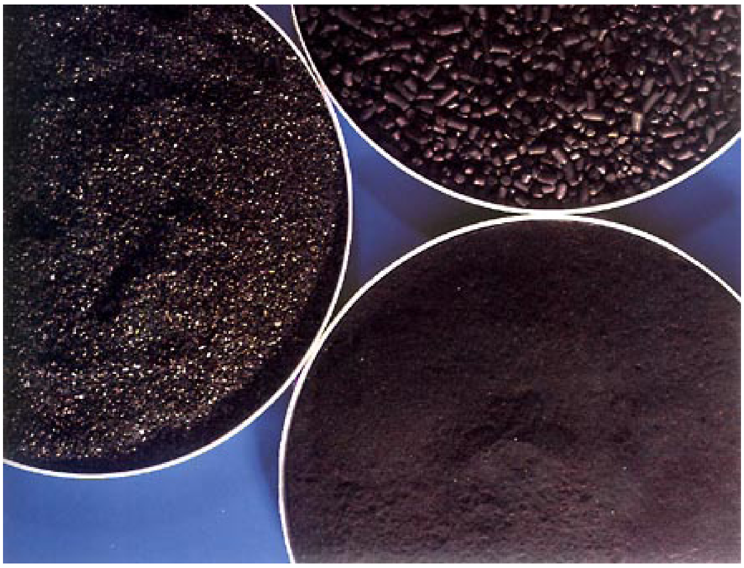

Figure 2 Activated Carbon
http://www.desotec.com/carbonology/activated-carbon-carbonology/

The development of an extensive macropore structure is found when either peat or wood is used as the raw material. The characteristics of AC depend on the physical and chemical properties of the raw materials as well as the activation method used. Physical properties of AC, such as ash content and moisture content can affect the use of a granular AC and render them either suitable or unsuitable for specific applications (Otulana and Oluwole 2015).

Ac for supercapacitor

AC generally has a porosity incorporating all three types of pore sizes: micropores (less than 2 nm), mesopores (between 2 nm to 50 nm) and macropores (greater than 50 nm), but only micropores and mesopores make a significant contribution to the capacitance. High surface areas of AC, from 1150 to 2570 m^2/g, would strongly improve the performance and yielding of the capacitance. Supercapacitors may become an attractive power solution for energy storage. It can utilize the high surface area of AC as a component in electrode materials to achieve capacitance. With the use of electrolytes in the application, the value of capacitance should range from 150 to 300 F/g (Farad/gram) (Aaron and Aiping 2011).

Supercapacitors are new breakthrough in energy storage device technology that have attracted considerable attention because of their high capacitance, better power delivery performance and long life cycle. They have the potential for modern devices such as smartphones, tablets and other electronic devices that require fast charging ability together with longer power retention.

Figure 3 show the working concept of a supercapacitor in general. The proper selection of these properties will allow us to optimize the supercapacitor (Martinez et al. 2005).

Imagine charging your laptop in seconds and then having that charge last for up to a month. This is also due to the advantages of supercapacitors which are more environmentally friendly, longer lifespans, much cleaner, safer, low energy consumption, more efficient and made using non-corrosive or non-toxic chemicals or metals. Supercapacitors can be charged and recharged indefinitely (Anonymous 2013).

A quick look at the difference between batteries and supercapacitors (also called ultracapacitors or electrochemical capacitors) should help explain why the two systems complement each other (Mandakini et al. 2013). Table 1 show the comparison and performance of a typical supercapacitor and Lithium-ion batteries in general.

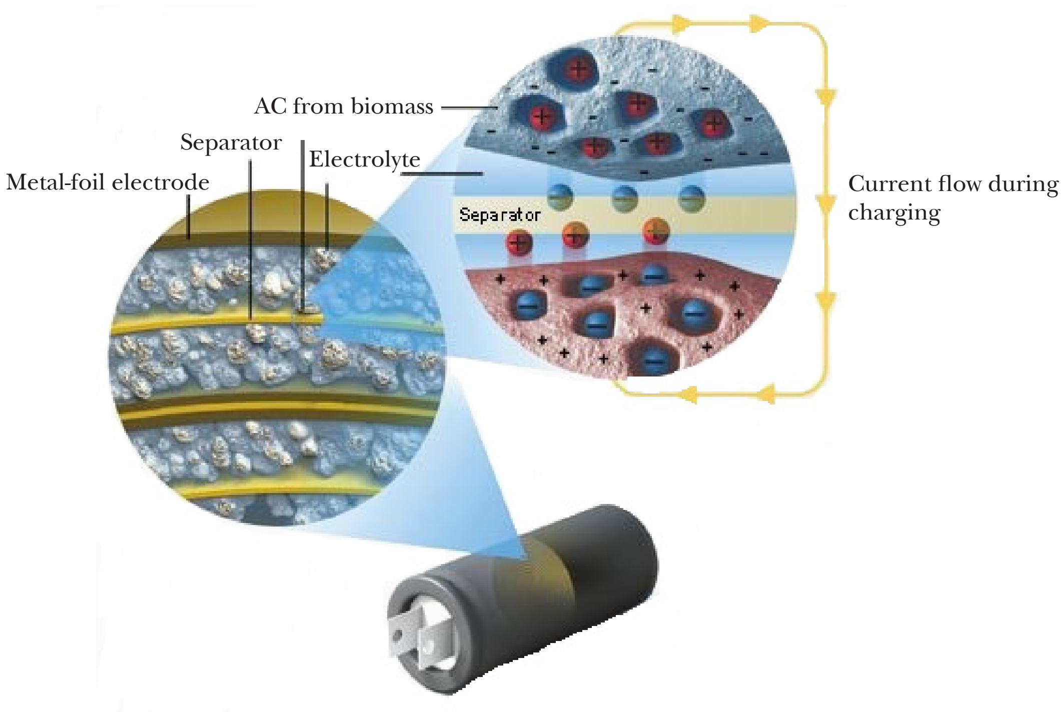

Figure 3 Working concept of supercapacitor
http://www.nesscap.com/product/how.jsp

Table 1 Comparison between the performance of a typical supercapacitor and Lithium-ion batteries

Function	Supercapacitor	Lithium-ion (general)
Charge time	1-10 seconds	10-60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75 V	3.6 to 3.7 V
Specific Energy (Wh/kg)	5 (typical)	100-200
Specific Power (W/kg)	Up to 10,000	1,000-3,000
Service life (in vehicle)	10 to 15 years	5 to 10 years

As mentioned earlier, the electrode is the most important component in a supercapacitor, and the most commonly used materials are metal oxides, polymers, and porous materials such as activated carbons and carbon aerogels. Activated carbon from biomass has the potential to be used as a basic material for the production of electrode for supercapacitors, because of its high surface area, good thermal and electric conductivity, good anti-causticity, high stability, low cost, and commercially available (Andrian et al. 2010).

AC from Korean bamboo species, *phyllostachys,* has BET surface area of 445–1025 m^2/g (Chan et al. 2006). BET (Brunauer, Emmett and Teller) is the most common method used to describe specific surface area. Chan et.al. found that bamboo-based AC activated at 900 °C for 60 min exhibited the highest performance and the largest specific area value. It was agreed by Fuhu et al. 2010 when its mesocarbon microbeads (MCMBs) (BET surface area of 2230–2542 m^2/g) that was activated by potassium hydroxide (KOH) at 900 °C possess a good surface area characteristics, abundant micropores and closed-packed mesopores and macropores. In a previous work, Li et al. 2010 testified that the doped AC material also had the potential for high end applications.

In a supercapacitor, the AC used must have porous texture which is the main criterion of a double electric layer with high capacity and charge exchange. The pore structure of the AC used is important for optimal performance of carbon materials as an electrode for supercapacitor (Mohd Iqbaldin et al. 2013).

Besides porosity, the oxygen functionalities seem to enhance the capacitance value and influence electrical conductivity. Preparation method of the electrode and electrolyte characteristics such as ion dimension, dielectric constant, etc. also influence the capacitance.

Preparation of activated carbon

Two basic methods are available for the production of AC: physical or chemical activation. The challenge is to produce activated carbon with the desired pore size distribution and surface chemistry from low cost carbons. Physical activation includes carbonization of the precursor in an inert atmosphere and activation of the resulting charcoal by an activation agent such as carbon dioxide (CO_2), air or steam (Figure 4).

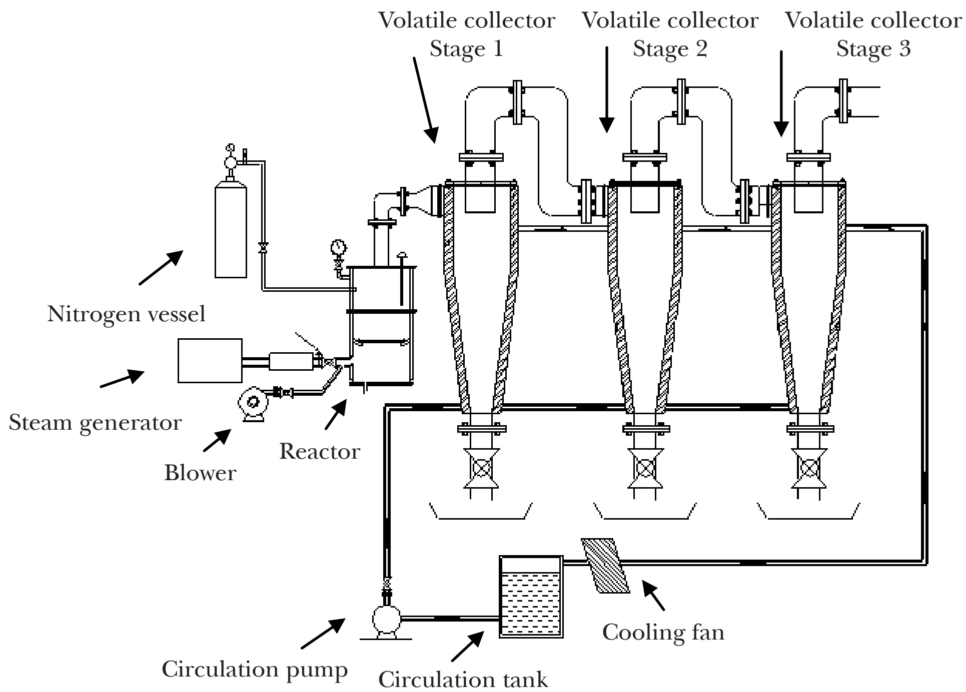

Figure 4 Activated carbon manufacturing

Chemical activation is a single-step process that involves the impregnation of a carbonaceous material with dehydrating agent prior to activation. The significance of the impregnation is to enhance the pore structure of the precursor and hence increases its surface area. The chemical agents used in the chemical process are normally alkali and alkaline earth metal containing substances and some acids such as KOH, sodium hydroxide (NaOH), zinc chloride ($ZnCl_2$) and phosphoric acid (H_3PO_4). The extent of the chemical activation can significantly alter the characteristics of the carbons produced (Otulana and Oluwole 2015).

R&D highlights

Research in FRIM was initiated in 2006 for the production of charcoal and AC from bamboo biomass using chemical and steam activation process. Previous studies showed that steam activation and $ZnCl_2$ activation methods were able to attain 719 m^2/g and 810 m^2/g of surface area respectively. The AC produced was only suitable for medium and lower-end application such as water purification and treatment of air pollution (Mahanim et al. 2011).

In 2011 research was geared towards the production of high surface area AC to be used for high end electronic applications such as in supercapacitor. Figure 5 shows the bamboo biomass used in the research for the production of charcoal and AC.

(a) (b) (c)

Figure 5 (a) Bamboo Biomass (b) Bamboo charcoal (c) Bamboo AC

In 2012, it was found that the simultaneous carbonization and KOH activation for AC processing methods on bamboo biomass could result in a surface area of 1492 m^2/g (Figure 6). The capacitance value obtained was 145 F/g at 25mV/s (milivolt per second) scan rate of the cyclic voltammetry analysis using potentiostat unit.

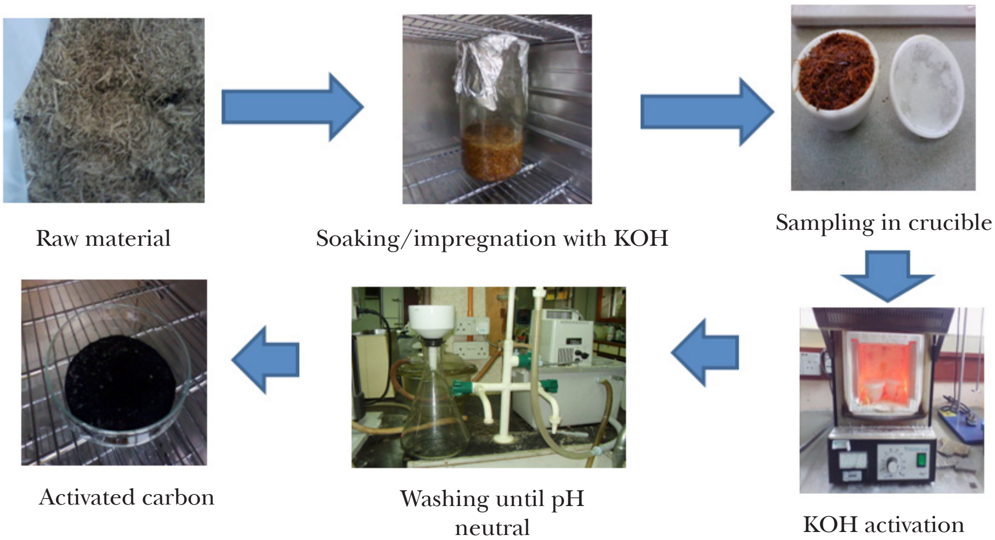

Figure 6 Simultaneous carbonization-KOH activation process

This process was improved by introducing a two stage carbonization and KOH activation that only gives 1193 m^2/g of AC surface area but surprisingly imparted higher capacitance value of 241 F/g at the same scan rate.This finding showed a big potential towards supercapacitor application as the capacitance value was higher (Figure 7).

Table 2 compares different carbon materials synthesized from biomass and their BET surface area and capacitance for supercapacitor applications.

From the results, dead Neem leaves achieved the highest capacitance value of 400 F/g followed by banana fibres of 368 F/g with BET surface areas of 1230 m^2/g and 1019 m^2/g respectively. This work has proven that AC from bamboo can achieve higher capacitance by modifying the chemical process from simultaneous to two stage method. The results also show that further research should be carried out to improve the performance of the AC before it could be used as the component in the electrode for supercapacitor.

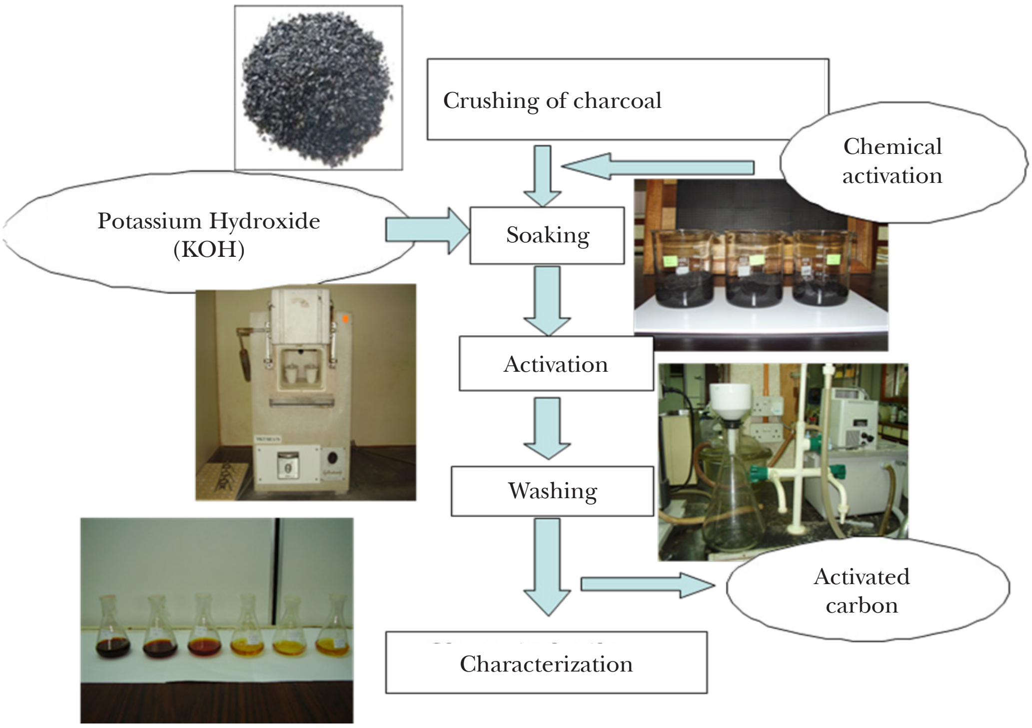

Figure 7 Two stage carbonization-KOH activation process

Table 2 Comparison of the properties of carbon materials synthesized from biomass

Materials	Activating Agent	BET surface area (m^2/g)	Maximum capacitance (F/g)	Measurements done at	References
Rice husk	NaOH	1886	210	0.2 mA/g	Mandakini et al., 2013
Firewood	H_2O	1131	140	25 mV/s	
Pistachio shell	KOH	1096	120	10 mV/s	
Bamboo	KOH	1251	260	1 mA/cm^2	
Banana fibres	$ZnCl_2$	1019	368	50 mA/g	
Dead Neem leaves	No activation	1230	400	500 mA/g	
Coconut shell	KOH	1769	156	2 mV/s	Mohd Iqbaldin, 2013
Bamboo (Simultaneos method)	KOH	1492	145	25mV/s	FRIM, 2012
Bamboo (Two stage method)	KOH	1193	241	25mV/s	FRIM, 2012

Conclusion

Highly porous electrodes with very high surface area are important for a supercapacitor. Increasing the surface area of AC material generally leads to increasing specific capacitance value of the material. A two stage carbonization and KOH activation of bamboo seemed to be effective in producing AC material with large surface area (1193 m^2/g). The activation process produced the largest surface area, which led to the highest specific capacitance at low current density (241 F/g). This paper shows the potential of using biomass as the basic material for the production of supercapacitors and further research is essential to make it a reality.

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Series Editor : MK Mohamad Omar
Managing Editor : S Vimala
Typesetter : Y Rohayu

Set in NewBaskerville 11

MS ISO 9001:2008

Printed by Publications Branch, Forest Research Institute Malaysia
52109 Kepong, Selangor