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INVESTIGATION OF COCONUT SHELLS ACTIVATED CARBON AS THE COST EFFECTIVE ABSORBENT IN DRINKING WATER FILTER

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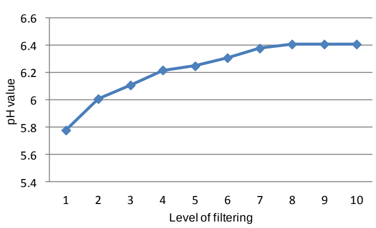
Graphical abstract



Abstract

Utilization of activated carbon for organic contaminant removal from drinking water is commonly practiced in point-of-use (PUO) water applications in Malaysia. Public health concerns and demands on water purity with the stated goal in Millennium Development Goals (MDGs) of improving access to safe drinking water by halve ahead of the 2015 has prompted the need to feasible conversion and sustainable solutions. This study investigated the efficiency of activated carbon from coconut shells as the potential cost effective absorbent material in drinking water filter due to its nature of greater micro-pores, inexpensive and abundantly available over other agricultural by-products. Activation of the coconut shell carbon was first carried out by carbonization in the exposure to nitrogen (N_2) atmosphere followed by heating with the activating agents for a specific retention period. pH test and dynamic testing of filtered water were conducted using the protocol established by ANSI/NSF Standard 53 (Health Effects of Water Treatment System). The pH value was indicated to increase proportionally to the level of filtering, which has achieved a constant value of 6.41 after eight times of filtering. Additionally, the activated carbon has removed Methyl Tertiary-butyl Ether (MTBE) to non-detectable level, which is less than 1 part per billion (ppb). The non-detectable level has sufficiently reduced the odour and taste problems. Therefore, activated carbon from coconut shells has considerable potential as the cost effective absorptive material in a drinking water filter.

Keywords: Coconut shells; activated carbon; drinking water filter.

1.0 INTRODUCTION

There are various natural materials used as a base material to produce activated carbons. To date, utilization of agricultural wastes based activated carbon as the adsorbent to remove organic contaminants is an alternative, knowing that the agricultural wastes are low cost and abundantly available. The most common materials used in water purification are coal, wood and coconut shells. Coconut shell appears to be the most favourable renewable resources among the other agricultural wastes with million of acres of plantations per year in tropical countries [1-2]. Apparently, coconut shells are disposed after their inner contents were extracted. These wastes can be recycled into useful activated carbons which can be used to treat drinking water commercially as well as keeping the eco-system clean[1]. Activated carbon is a group of carbonaceous adsorbents with a vast of crystalline form and extensional growth of internal pore structures. Activated carbon is activated through an attentively controlled process in gaseous atmospheric and high temperature environment to develop remarkably porous carbon structures with a huge surface area, which permits the carbon to adsorb a variety range of compounds, as well as removes large amounts of impurities in a small confined region. Three forms of activated carbon commonly known are granular activated carbon, powder activated carbon and pelletized activated carbon. The granular activated carbon consists of the particles of irregular shape with 3 to 70 mesh range of sizes. The powder form is predominantly less than 70 mesh size of carbon. On the other hand, the pelletized activated carbon consists of cylindrical and extruded shaped with 3 to 20 mesh of diameters. The optimized granular coconut shell activated carbons (CSAC) used in this study is approximately 10 to 20 mesh to remove the acidic organic contaminants in direct pipe water by adsorption process. Adsorption is known as the process where the surface concentration fluid molecules are absorbed by forces physically or chemically. Three basic steps of adsorption start with the adsorption of substances to the exterior of the carbon surface and then moving into the carbon pores, followed by the adsorption of substances into the interior wall of the carbons. Base material and the activation process were found as the main variables that affect the pore sizes distribution to allow diffusion into the pores [1,4]. Several studies have been conducted to investigate the adsorption efficiency of coconut shell activated carbons as the organic contaminants removal. These studies also proposed that there is a significant linear relationship between the dimensions of activated carbon filter to the pH values of drinking water[2]. Therefore, the current study aims to present an investigation on optimum thickness required for the coconut shell activated carbon filter to absorb acidic residues that contained in direct pipe water. Most of carbonaceous materials adhere to their own degree of porosity and can be distinguished by their pore diameters. Generally, activated carbons are categorized as macropores (above 0.4 mesh diameter), mesopores (0.4 to 10 mesh diameters) and micropores (below 10 mesh diameter). The exhibition of predominance micropores of coconut shell activated carbons can be defined by their degree of burn-off. Activated carbons have been widely used as the reduction medium of the methyl tertiary-butyl ether (MTBE) which presence in many chlorinated water supplies. The major use of MTBE is as the petrol additive to oxygenate the exhaust discharge and improve combustion. Spills and leaks of petrol storage tanks are seen as a potentially treat for ground drinking water supplies as MTBE moves fast through soil, simply dissolve in water and takes longer time to resolve than some other chemicals. Typically, water with significant concentrations of MTBE was indicated to taste and smell like turpentine. However, agricultural wastes based activated carbons can absorb and reduce the tastes and odours through the water treatment process. Therefore, the main purposes of the present study are to investigate the efficiency of coconut shell activated carbons as the possible absorbent to remove organic contaminants, and to indicate the optimum filtering level of coconut shell activated carbons to achieve constant and safe drinking pH value as well as the potential of coconut shell activated carbons to reduce the MTBE concentration to non-detect levels.

2.0 EXPERIMENTAL

2.1 Precursor Activation

Flow resistance and adsorption rate in a water filter are partly affected by the particle size distribution of granular activated carbon. Therefore, preparation of coconut shells began with milling, pulverizing and screening the known amount of sample (500 gram) to produce granules of 10 x 20 mesh which have been found to be sufficient for further activation process [5-8]. Particle sizes which are coarser than the tested mesh, was used to decrease the number of microporosity [9-10]. Further processing of granular coconut shells was carried out by carbonization heating at 170 °C for 2 hours, which employed nitrogen (N_2) gases as the inert atmosphere to form coconut chars. The resulting chars were then activated in the presence of catalyst at 275 °C for another 2 hours in reflow furnace to form activated carbons. Table 1 shows the activation method and catalyst used for preparation of activated carbons from granular coconut shells.

Table 1 Activation method and catalyst used for preparation of activated carbons

Activation method	**Catalyst**	**Temperature**	**Time**
Carbonization in an inert atmosphere, N_2	---	170 °C	2 hours
Chemical activation	Phosphoric acid (H_3PO_4)	275 °C	2 hours

Formation of micropores took place gradually when the granules of coconut shells reacted with the catalyst. Phosphoric acid (H_3PO_4) acted as the activating agent to form porous structures of the activated carbons through dehydration and degradation of the raw precursors. Finally, the activated carbons were cooled and cleaned with distilled water to remove impurities and chemicals.

2.2 Determination of the Degree of Burn-off

The degree of activated carbon burn-off, θ (wt%) was calculated through equation (1) as follow:

$$\theta = \frac{W_i - Wf}{W_i} \times 100 \qquad (1)$$

where W_i is the initial mass of the coconut shells sample (g) and W_f is the mass of the sample after subjected to activation (g). The objective of indicating the degree of activated carbon burn-off is to define the formation of microporous activated carbon when the extent of burn-off is less than 50 wt%. Dubinin and Zaverina proposed that a macroporous active carbon was formed when the burn-off degree is greater than 75 wt% and the sample has a mixed porous structure when the degree of burn-off is between 50 wt% to 75 wt%[3]. The later research of pore structures in activated carbon confirmed the linearity of pores size is ascended to the degree of burn-off[4].

2.3 Batch Experiments of Activated Carbon Absorption Capacity

Indication of pH value for filtered water was conducted to indicate the absorption capacity of coconut shell activated carbons by filtering the pipe water with these activated carbons for a fixed thickness for up to ten times of filtering. Dynamic testing was carried out using the water filter with optimized thickness indicated through pH testing according to ANSI/NSF Standard 53 (Health Effects of Water Treatment Systems) to identify the MTBE concentration of coconut shell activated carbons. The MTBE is the most common oxygenated fuel additive present in pipe water throughout the main filtration process. Additionally, commercial coal derived activated carbon was used as a reference in comparison with the MTBE absorption.

■3.0 RESULTS AND DISCUSSION

3.1 Burn-off Degree of Coconut Shell Activated Carbons

The total mass of the activated carbons after subjecting to chemical activation process was indicated as 362 gram. Equation (2) showed the value of burn-off degree of activated carbons at 27.6 wt% which is less than 50 wt%. Therefore, the porous structures formed are identified as microspores.

$$\theta = \frac{500 - 362}{500} \times 100 \qquad (2)$$
$$= 27.6 \text{ wt\%}$$

The capacity of absorption of coconut shell activated carbons relies predominantly on the existence of micropores. Micropores exhibit molecular dimension of 0.6 nm to 1.6 nm where the adsorption in these molecular pores takes place by filling of volume[5]. The capacity of absorption by these pores is greater than macropores due to the protruding of the absorption forces by the pore's walls adversely. The absorption is commenced by capillary condensation.

3.2 pH Value of Filtered Pipe Water by Activated Carbons

The dosing of chlorine and fluoride as the disinfectants in water treatment is specified under National Standard for Drinking Water Quality (NSDWQ) and strictly monitored by the Ministry of Health (MOH) in Malaysia. The amount of chlorine and fluoride used for disinfection is sufficient to destroy the microorganisms, but is at a safe level to drink. Even though the drinking water treatment adheres to approved standards, the residual contents of Iron, Manganese and Aluminium are considerable high causing precipitation in the household water distribution system and stay stagnant in the distribution system. These residuals could have not washed away by self-cleaning velocity and caused rusty in the pipe. In the present study, the pH value of direct pipe water without using the filtration system by coconut shell activated carbons was measured to be an acidic solution at pH 5.5. Figure 1 illustrates the pH values of water filtered by activated carbons for up to ten levels of filtering which the fixed thickness of each filtering level was measured at 4 mm. The pH value was indicated to increase proportionally to the level of filtering which has achieved a constant value of 6.41 after eight times of filtering with minimum thickness for filter of 32 mm.

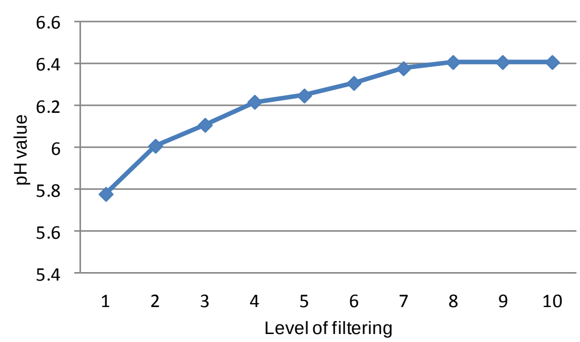


Figure 1 pH values of samplings vs level of filtering

3.3 Removal of MTBE by Activated Carbons

The methyl tertiary-butyl ether (MTBE) is the most common oxygenated fuel additive presents in ground water throughout the main filtering process. MTBE is normally added to petrol in controlled amount of less than 15% by volume to improve combustion and reduce the exhaust emissions, especially carbon monoxide. Ground water is always contaminated by petrol spills and seen as a potentially severe threat to drinking water supplies. Therefore, a comparative study was carried out to indicate the efficiency of utilizing coconut shell activated carbons as the potential absorbent in drinking water filter by taking the commercial coal activated carbons as reference. Yearly consumption of drinking water with MTBE level of approximately 20 to 40 parts per billion (ppb) is acceptable and do not possess harm to human body according to EPA's Drinking Water Advisory published in 2012[6]. In this study, the MTBE level of tested samplings was measured using dynamic testing in laboratory of Syarikat Air Johor (SAJ) at interval bed volumes for up to 5m^3. Table 2 shows the MTBE effluent concentration (ppb) of sample without filtration; sample filtered using commercial coal and coconut shell activated carbons respectively. The trends of these samplings corresponded with the MTBE effluent concentrations (ppb) were plotted in Figure 2.

Table 2 MTBE effluent concentrations (ppb) of activated carbons

MTBE effluent concentrations (ppb)					
Number of bed volume (m^3)	1	2	3	4	5
Without filter	12.8	13.5	13.9	14.3	15.2
Coconut shells	0.56	0.6	0.61	0.68	0.69
Commercial coal	2.5	2.8	3	4.2	5.02

It was established that the sample filtered by coconut shell activated carbons exhibited the lowest concentration of MTBE at 0.69 ppb after $5m^3$ water was treated, indicating its highest capacity as an absorbent as shown in Figure 2.

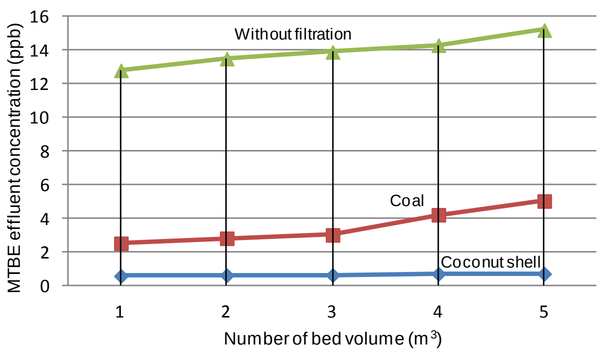


Figure 2 MTBE effluent concentrations (ppb) of activated carbon samplings

Nevertheless, a great difference was observed for water without filtration where the concentration of MTBE was recorded to have the highest reading at 12.8 ppb after $1m^3$ water was treated and ascended to 15.2 ppb after $5m^3$ water was treated. This is related to the contamination of ground water in dense traffic areas where the sample was taken. The commercial coal based activated carbons were observed to reduce the MTBE to about 5 ppb after $5m^3$ water was treated. All the samplings were reported tasteless and without odour threshold which the MTBE concentrations removed by these absorbents met the current NSF standard for MTBE removal. The activated carbons from coconut shell possessed substantially constant readings for MTBE concentration, whereas the readings for commercial coal based activated carbon were observed to increase proportionally from 2.5 ppb to 5.02 ppb. This confirmed that the coconut shell activated carbons contain predominance of high porous microspores to absorb the high soluble MTBE.

4.0 CONCLUSION

The experimental results of this study have shown the potential ability of coconut shells to produce the optimized activated carbons with well developed microspores by chemical activation method with the addition of phosphoric acid (H_3PO_4) as the catalyst. It was established that coconut shells that were carbonized in a defined condition with exposure to inert N_2 atmosphere at 170 °C followed by activation at 275 °C with catalyst have created granules with microporous structures. These micropores were indicated by calculating the burn-off degree for these activated carbons. On the determination of pH value for water filtered by these activated carbons, as the level of filtering is increased, the pH value of the tested samplings increase and achieved a constant value at 6.41 after eight times of filtering. This constant pH value indicates the minimum thickness required for coconut shell activated carbon water filter is 32 mm. Nevertheless, water filtered by coconut shell activated carbons showed the lowest effluent concentration of MTBE as compared to typical commercial coal activated carbons and water without filtration at 0.69 ppb after $5m^3$ water was treated. The results indicated that activated carbons by coconut shell has consistently achieved high absorption capability to remove the effluent of MTBE concentration into non detect level which is less than 1 ppb. Therefore, activated carbon from coconut shells has a considerable potential as a cost effective absorbent material in drinking water.

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References

[1] P. Shankar. 2008. Coconut Shell Based Activated Carbon with No Green House Gas Emission, in Water Conditioning & Purification, Singapore. *Filtrex Technologies*. 1-4.

[2] M. K. G. B. V. &. L. G. Grassi. 2012. Removal of Emerging Contaminants from Water and Wastewater by Absorption Process In Emerging Compounds Removal from Wastewater. *Netherlands, Springer*. 15-37.

[3] S. F. G. S. C. &. P. R. Pollard. 1992. Lowcost Adsorbents for Waste and Wastewater Treatment. *A Review Science Environment*. 116: 31-52.

[4] R. &. K. R. W. Taylor. 1994. Removing Lead in Drinking Water with Activated Carbon. *Environmental Progress*. 13(1): 65-70.

[5] A. Aygun, K. S. Yenisoy and I. Duman. 2003. Production of granular activated carbon from fruit stones and nutshells and evaluation of their physical, chemical and adsorption properties. *Microporous Mesoporous Mater*. 66: 189-195.

[6] C. Duran–Valle, S. Gomez–Corzo, V. Gomez–Serano, J. Pastor–Villegas and M. Rojas–Cervantes. 2006. Preparation of charcoal from cherry stones. *Applied Surface Science*. 252(17): 5957–5960.

[7] P. Paraskeva, D. Kalderis and E. Diamadopoulos, 2008. Production of activated carbon from agricultural by-products. *Journal of Chemical Technology and Biotechnology.* 83(5): 581–592.

[8] C. Toles. W. Marshall. L. Wartelle and A. McAloon. 2000. Steam- or carbon dioxide-activated carbons from almond shells: physical. chemical and adsorptive properties and estimated cost of production. *Bioresource Technology.* 75(3): 197–203.

[9] W. Tsai, C. Chang. S. Wang. C. Chang. S. Chien and H. Sun. 2001. Cleaner production of carbon adsorbents by utilizing agricultural waste corn cob. *Resources Conservation Recycling.* 32: 42-53.

[10] M. Valixa, W. Cheung and G. McKay. 2004. Preparation of activated carbon using low temperature carbonisation and physical activation of high ash raw bagasse for acid dye adsorption." *Chemosphere.* 56(5): 493–501.

[11] M. Dubinin and E. D. Zaverina. 1955. Surface and sorption properties of active carbons. *Bulletin of the Academy of Sciences of the USSR. Division of Chemical Science* . 4(4): 531-538.

[12] Wan Daud, W. M. A., Wan Ali, W. S. and Sulaiman, M. Z. 2002. Effect of activation temperature on pore development in activated carbon produced from palm shell. *Journal of Chemical Technology and Biotechnology.* 78: 1-5.

[13] R. C. Bansal and M. Goyal. 2005. Activated Carbon Adsorption. United States: CRC Press.

[14] E. P. Agency. 2012. 2012 Edition Of The Drinking Water Standards And Health Advisories. Office of Water U.S. Environmental Protection Agency . Washington. DC.