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ADVANCEMENT IN THE PRODUCTION OF ACTIVATED CARBON FROM BIOMASS USING MICROWAVE HEATING

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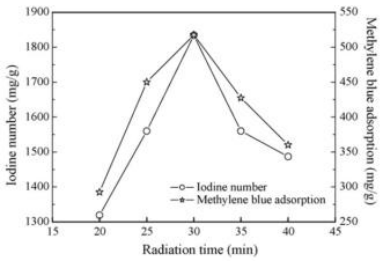
Graphical abstract



Abstract

An overview of recent advancement in the production of activated carbon (AC) from biomass using microwave heating is presented. The use of microwave heating method for the thermal conversion of biomass to useful products has been on the increase in the last decade because it offers fast and uniform heating, and a higher level of automation. The effects of process parameters (microwave power and radiation time, agent flow rate in physical activation and impregnation ratio in chemical activation) on the properties and adsorption capacity of the AC are reviewed. From the results reported in the literature, it can be seen that the influence of the preparation parameters on the adsorption capacity of the prepared AC followed the same pattern. In the physical activation process, microwave power and radiation time have more pronounce effects on the properties of the AC than the activation agent flow rate. Furthermore, the properties of the AC were found to be at their best when the process parameters are at the optimum values wether individually or collectively, and further increase in the process value beyond optimum value resulted in decrease in their adsorption capacity.

Keywords: Biomass, microwave heating, activated carbon, pore structure

Abstrak

Gambaran keseluruhan kemajuan terkini dalam pengeluaran karbon teraktif (AC) daripada biomas menggunakan ketuhar pemanas dibentangkan. Kaedah penggunaan ketuhar pemanas untuk penukaran haba biomas kepada produk berguna telah meningkat dalam dekad ini kerana ia menawarkan pemanasan cepat dan seragam, dan tahap automasi yang lebih tinggi. Kesan daripada parameter proses (kuasa dan masa sinaran gelombang mikro, ejen aliran kadar dalam pengaktifan fizikal dan nisbah pengeraman dalam pengaktifan kimia) atas kapasiti ciri-ciri dan penjerapan telah dikaji. Dari keputusan yang dilaporkan dalam kajian literasi, ia boleh dilihat bahawa pengaruh parameter penyediaan terhadap keupayaan penjerapan karbon teraktif mengikuti pola yang sama. Dalam proses pengaktifan fizikal, kuasa dan masa sinaran gelombang mikro lebih dinyatakankan berkesan ke atas ciri-ciri karbon teraktif berbanding daripada kadar aliran ejen pengaktifan. Selain itu, ciri-ciri karbon teraktif didapati berada pada tahap terbaik apabila parameter proses yang berada pada nilai optimum sama ada secara individu atau berkumpulan, dan kenaikan seterusnya dalam proses nilai melebihi nilai optimum mengakibatkan penurunan dalam keupayaan penjerapan.

Kata kunci: Biomas, ketuhar pemanas, karbon teraktif, struktur liang

1.0 INTRODUCTION

Activated carbon (AC), a carbonaceous material, is characterised by large surface area, high micropore volume, controllable pore structure, thermal stability, low acid/base reactivity and rapid adsorption capability [1]. As such, AC has been applied in diverse areas such as treatment of volatile organic compounds (VOC) [2], purification of air and gases[3], purification of industrial effluents [4], water treatment [5-9] and energy storage [10-13].

Properties, quality, and cost of AC depend significantly on both the raw materials and the preparation technique employed in the production of the AC. It is a known fact that most of the commercial activated carbons are prepared from fossil fuel based materials such as coal, peat, and lignite, thus making the AC expensive. The search for alternate raw materials leads to the attention being focused on biomass, particularly those from agricultural by-products and wastes. Vast quantities of biomass are being generated daily from the harvesting and processing of various crops, thus making biomass abundantly available and less expensive. Also, agricultural biomass is renewable, sustainable and environmentally friendly. The effective utilisation of the biomass is, therefore, the desired outcome as well as a welcome development for effective waste disposal management that has hitherto been a great challenge.

The activation process plays a significant role in the pore structure and distribution, and adsorption capacity of the prepared AC. There are two types of activation process, namely, physical and chemical activation. Chemical activation involves the impregnation of the precursor material with dehydrating agents, which may either be acidic or basic solution, such as $ZnCl_2$, KOH, NaOH, H_3PO_4 and K_2CO_3 to influence the pyrolytic decomposition of the precursor material, lower the activation temperature and suppress the formation of tar [14, 15]. Physical activation involves the partial gasification of the carbonaceous precursor material in an inert environment at high temperature followed by activation using oxidising gasses such as carbon dioxide, steam, air or a combination of them[15].Although chemical activation has many advantages such as low activation time, single step activation, low activation temperature, better porous structure and higher yield, the physical activation process is widely preferred by the commercial activated carbon manufacturers. The ability to produce AC with well-developed microporous structure and desirable physical characteristics coupled with the simplicity of process are the reasons adduced for the wide adoption of physical activation process by industries for the commercial production of AC[16].

For several decades, the conventional heating method remains the most preferable and applicable technique for the preparation of AC. However, the application of microwave heating technology for the production of AC from biomass has been on the increase in the last decade because comprising of some advantages over the conventional heating method. In the conventional heating method, the heating is from the surface to the interior part of each particle resulting in what is called temperature gradient. Thermal gradient could be avoided through slow heating. However, slow heating usually leads to a long preparation process, thus leading to a greater energy consumption, in homogeneous and distorted microstructure in the prepared activated carbon [17]. Whereas, in microwave heating, there is a direct interaction between the microwaves and the particles inside the pressed compact material leading to quick volumetric heating [18].

In this paper, a review of the advancement in the activation processes using microwave heating technology for the preparation of AC from biomass and their effects on the physical and chemical properties of AC is presented. The review does not include the effect of preparation process on the various applications of the AC.

2.0 MICROWAVE HEATING

Microwave heating is a process and belongs to the group of electroheat techniques that utilize specific part of electromagnetic spectrum. These methods supplement or replace (in some specific cases) the conventional heating systems used in industries [19]. Other members of the group are induction, direct resistance, infra-red heating and radio frequency. In the electromagnetic spectrum, microwave lie between infrared radiation and radiowaves with a frequency range of 0.3 GHz to 300 GHz and wavelength (λ) of 1 mm to 100 cm [20]. There are many distinct frequency bands allocated for domestic, industrial, scientific and medical use. However, to avoid interference with telecommunications frequencies, the main frequencies are positioned at 896 MHz (915 MHz in the US) and 2.450 GHz [19] with the corresponding wavelength of 37.24 cm and 12.24 cm [21] respectively. Usually, the shorter wavelengths (2.450 GHz, 12.24 cm) are used for drying and heating materials in thin layer with large surface area. Whereas the longer wavelength (37.24 cm) which can provide power up to 100 kW are used for larger process heating because of the ability to penetrate deep into the material [21]. Figure 1 [22] depicts a typical electromagnetic spectrum with their frequency range.

Over the last few years, microwave equipment and ovens have undergone series of development

and modifications resulting in what we have today – a robust and mature technique that find application in wide areas such as material science [23], information technology and telecommunications [24], polymer synthesis [25], wood drying, plastic and rubber treating as well as curing and preheating of ceramics [26] and analytical chemistry [27].

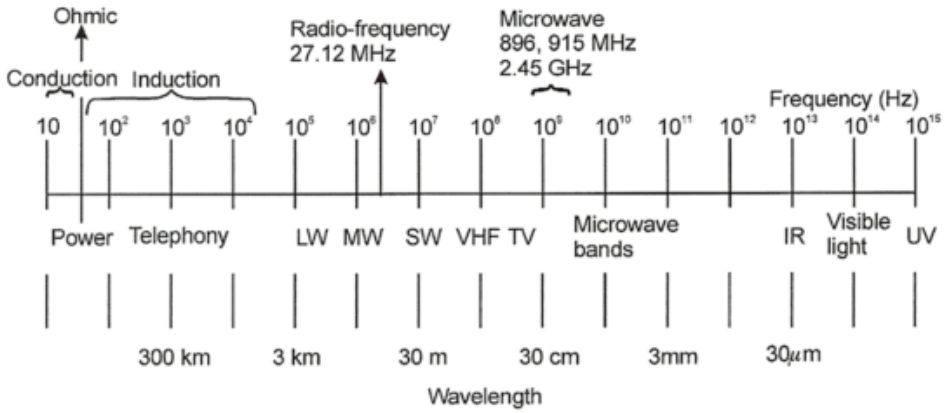


Figure 1 A typical electromagnetic spectrum with their frequency range[22]

Materials can be classified into three broad groups according to their interaction with the microwave. The groups, as illustrated in Figure 2, are conductors, insulators, and absorbers [26]. Materials, such as metals and alloys, which microwave cannot penetrate but instead reflect are called conductors while insulators are low loss materials that are substantially transparent to the microwave. Insulators including materials such as glasses, fused quartz, Teflon, polypropylene and ceramics can reflect partially and transmit the incident waves traveling through materials. On the other hand, absorbers, such as polar solvent and aqueous solution, are high loss materials that absorb microwave radiation and cause energy transfer. By doing so, they can be effectively heated at room temperature [28]. Microwave absorbers are also known as dielectric materials.

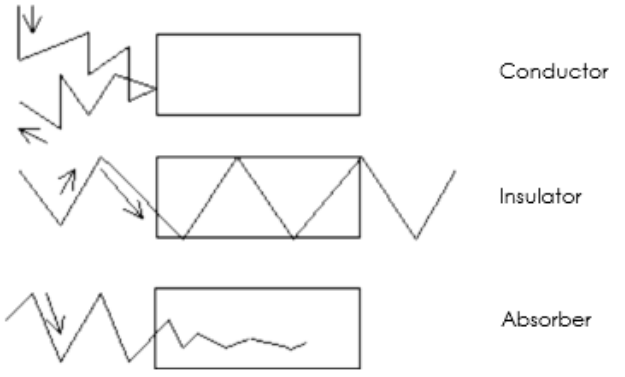


Figure 2 Microwave absorption characteristics for conductor, insulator and absorber [26]

The material's ability to be polarised and heated using microwave field is defined by its dielectric loss tangent [29]and is given by:

$$\tan\delta = {}^{\varepsilon''}/_{\varepsilon'} \quad (1)$$

where ε' is the dielectrict constant (or real permittivity) and it is a measure of the material's capability to retard microwave energy passing through it and ε'' is the dielectric loss factor (or imaginary permittivity) which is a measure of the material's capability to dissipate the energy [30].
Thus,

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (2)$$

where ε is the complex permittivity and j is equal to $(-1)^{1/2}$.

3.0 PREPARATION OF ACTIVATED CARBON

Activated carbon with excellent surface functionality and well-developed porosity can be prepared by thermal decomposition of carbonaceous materials such as coal, peat, lignite and various agricultural by-products in a furnace (conventional heating) or a microwave under controlled heat and atmosphere. The thermal processing of carbonaceous materials to obtain AC usually involves two stages, i.e. carbonisation/pyrolysis and activation that are usually carried out by physical or chemical activation process.

As mentioned in section 1.0, the activation process, as well as the heating technique, play asignificant role in the pore structure development and adsorption capacity of the prepared AC. In the conventional heating method, heat is transferred by

conduction, convection or radiation from the external source to the material. This method is saddled with the problem of heat loss to the surrounding, heat transfer resistance, damage to the reactor walls due to continuous electrical heating and utilisation of the portion of heat supplied to the biomass [31]. This method of heating also results in the temperature gradient from the hot surface of the particle to the interior of each particle. The thermal gradient causes distortion and non-homogeneous microstructure in the AC due to the impediment in the removal of gaseous products from the biomass to the surroundings [14, 17]. To avert the problem of the thermal gradient, a slower heating rate is used. However, the slow heating usually leads to longer activation time with attendant higher energy consumption. In microwave heating method, unlike the conventional heating method, there is no heat transfer into the biomass. Instead electromagnetic energy is converted into heat energy within the dielectric material by dipole rotation and ionic conduction [32].Thus, a larger amounts of heat could be transferred to the interior of the dielectric material resulting in minimal effects of differential synthesis and fast volumetric heating [18, 30]. Microwave heating technique was developed as a response to the problem of conventional heating method [33, 34].Other advantages of microwave heating method, as enumerated by Metaxas [19] and Haque [30], are (i) non-contact heating, (ii) selective material heating, (iii) compactness of equipment, (iv) speed of switching on and off, (v) pollution-free environment and (vi) a higher level of automation and safety. Owing to these advantages, the use of microwave heating for the preparation of AC from various agricultural by-products has been on the increase in the last decade.

3.1 Microwave-induced Physical Activation

Microwave-induced physical activation is usually carried out in two phases, i.e. carbonisation of raw material and then activation of the resulting char, just like in the conventional heating method. In the conventional heating method, carbonsation involves the heating of the precursor material to a temperature range of 400 °C to 850 °C and then held at this temperature for some time before cooling down under an inert atmosphere. The resulting char is then activated at an elevated temperature between 600 °C and 900 °C by controlling gasification under the flow of activating gasses such as carbon dioxide, steam, air or a mixture of these gases [35]. However, in microwave heating method, it is almost impossible to measure the sample temperature accurately due to the volumetric and internal nature of the microwave heating. As such, the temperature could not be used as a variable parameter in the preparation of AC. Instead, the microwave power is used as a variable parameter [36]. Although CO_2 is widely preferred as an activating agent due to its cleanliness and ease of handling, however, the precursor material is a major determinant of the choice activating agent because to achieve high surface area, different activating agents are required for different materials [37].

Till date, there are limited number of studies reported in the literature on the preparation of AC via microwave-induced physical activation process. And among these studies, it is only in our previous study [38] that char prepared by microwave heating was used as a precursor for AC preparation. In all other reported studies, the char was prepared using the conventional heating method. The use of the conventional heating method for carbonisation is because biomass is a poor microwave absorber, and as such required a dielectric material such as carbon material to initiate the process of heating. In our previous study [38], coconut-based commercial activated carbon (CAC) was used as the absorber during the process carbonization.

Xin-hui *et al*. [39] performed microwave-assisted activation of jatropha hull using both steam and CO_2 as an activating agent and compared the results with activated carbons prepared by conventional heating. They found out that while the porosity, i.e. pore volume, and surface area, of the microwave-assisted steam AC, doubled the conventional heating that of the microwave-assisted CO_2 AC is of the same order of magnitude with the conventional heating.

3.2 Microwave-induced Chemical Activation

In chemical activation, the precursor material may be carbonised before activation e.g.[14, 40] or may not be carbonised before activation e.g.[41]. Because prior carbonisation is not prerequisite in chemical activation, the process usually refers to as a single stage activation process. Microwave-induced chemical activation process involves the exposure of the precursor material to microwave irradiation after it has been impregnated with chemical activating agents such as $ZnCl_2$, NaOH, KOH, K_2CO_3, $FeCl_3$, and H_3PO_4. In addition to their role as oxidants and dehydrating agents, the chemical activating agents also serve as microwave absorbers because of their dielectric properties. However, none of the previous studies incorporate the dielectric properties of the chemical activating agents [42]. One major advantage of the microwave-induced chemical activation processes is its ability to produce carbons with high surface area. However, like in the conventional chemical activation process, there is an additional cost due to post-activation washing of the carbons that is required to clean off the reactants and inorganic residues from the carbons.

Hoseinzadeh Hesas *et al*. [43] produced AC from oil palm shell via microwave-induced $ZnCl_2$ activation and found out that the BET surface area of

the AC increases with increase in the impregnation ratio until the impregnation ratio reaches 0.65 (Zn/palm shell) and then decreases with further increase in the impregnation ratio.

4.0 PROPERTIES AND CHARACTERIZATION OF ACTIVATED CARBON

The application of AC is highly dependent on the porosity (i.e. surface area and pore structure) of the carbon materials. The raw material, activation method, and parameters are the factors that could be used to control the pore structure of the AC [44]. According to IUPAC (The International Union of Pure and Applied Chemistry), porous materials can be classified into micropores (< 2 nm), mesopores (2-50 nm) and macropores (> 50 nm). Table 1 and Table 2 depict the physical properties of the activated carbons produced by microwave heating with chemical and physical activation respectively.

N_2 and CO_2 sorption analyses are standard procedures for the determination of the porosity of activated carbons. Specific surface area, pore size distribution, and pore volume are three important properties of the AC that determine the adsorption capacity of the AC and are highly influenced by the preparation conditions. An adsorbent with large BET surface area usually has a better adsorption performance. Also, the reactivity and combustion behaviour of AC is exceedingly dependent on the BET surface area[15].

The pore size distribution, defined as the degree of heterogeneity in the structure of the porous material, represents a model of the solid structure and the structural heterogeneity [45]. In addition to the preparation conditions, the nature of the precursor material vastly influences the pore structure and pore size distribution of porous materials.

Table 1 Physical properties of the activated carbons produced by microwave heating with chemical activation

Material	Agent	S_{BET} (m^2/g)	S_{micro} (m^2/g)	$S_{external}$ (m^2/g)	V_{tot} (cm^3/g)	V_{micro} (cm^3/g)	V_{meso} (cm^3/g)	Ave. Pore size (Å)	Ref.
Coconut husk	KOH	1356.25	725.77	630.48	0.78	0.392	0.388	22.97	[46]
Sugarcane bagasse	$ZnCl_2$	1489	229	-	1.3	0.33	0.85	-	[11]
Pineapple peels	KOH	1006	521	485	0.59	0.28	0.31	23.44	[47]
	K_2CO_3	680	538	142	0.45	0.28	0.17	25.97	
Rice Husks	KOH	752	346	406	0.64	0.26	0.38	34.14	[48]
	K_2CO_3	1165	607	558	0.78	0.33	0.45	26.89	
Cotton stalks	KOH	729.33	529.46	199.88	0.38	0.26	0.12	-	[32]
Durian shell	NaOH	1475.48	863.29	612.19	0.841	0.467	0.374	22.81	[49]
	K_2CO_3	621.47	384.67	236.8	0.38	0.11	0.27	-	
Orange peels	K_2CO_3	1104.45	420.09	684.36	0.615	0.247	0.368	22.27	[50]
Pistachio nut shells	KOH	700.53	-	-	0.375	-	-	-	[51]
Oil palm (Elaeis) EFB	KOH	807.54	-	-	0.45	-	-	21.93	[5]
Oil palm fibers	KOH	1223	796	427	0.72	0.42	0.3	23.57	[52]
Oil palm residues	KOH	1372	821	551	0.76	0.44	0.32	22.06	[53]
Oil palm shell	$ZnCl_2$	1253.5	-	-	0.83	0.46	0.37	-	[54]
Oil palm fiber	KOH	707.79	-	-	0.381	-	-	22.11	[40]
Bamboo	H_3PO_4	1432	1112	-	0.696	0.503	0.1903	-	[55]
Cotton stalks	H_3PO_4	652.82	127.18	525.64	0.476	0.057	0.419	-	[56]
Oil palm shell	KOH	895.16	-	-	0.491	-	-	-	[57]
Lotus stalks	H_3PO_4	1434	453.93	928.39	1.337	0.307	1.03	-	[58]
Waste tea	H_3PO_4	1157	1623	687.3	0.829	0.573	0.256	35	[41]
Jackfruit peel	NaOH	1286.7	656.95	629.75	0.764	0.356	0.408	-	[59]
Cotton stalks	$ZnCl_2$	794.84	156.69	-	0.63	0.083	0.547	32	[60]
Palm kernel shell	H_3PO_4	630	-	-	-	-	-	-	[61]
Pine wood powder	$ZnCl_2$	1459	-	-	0.7	-	-	-	[62]
Industrial waste lignin	$ZnCl_2$	1172.7	1002	162.4	0.64	0.457	0.174	20.82	[63]
Pomelo skins	NaOH	1355	524	811	0.77	0.29	0.48	23.09	[64]
Peanut shell	$ZnCl_2$	1552	-	-	1.75	0.02	1.73	-	[65]
Rice Husks	$ZnCl_2$	1527	-	-	1.96	0.02	1.94	-	[65]
Oil palm shell	KOH	895	-	-	0.491	-	-	21.91	[66]

Wood sawdust	K_2CO_3	1496.1	892.79	603.26	0.864	0.47	0.394	23.06	[67]
Coconut shell	KOH	1768.8	-	-	-	-	-	-	[68]
Date stones	KOH	856	-	-	0.468	-	-	21.82	[69]
Langsat EFB	NaOH	1293.3	839.38	453.88	0.752	0.449	0.303	23.23	[70]
Sunflower seed oil residues	K_2CO_3	1411.55	-	-	0.836	-	-	23.6	[71]

Table 2 Physical properties of the activated carbons produced by microwave heating with physical activation

Material	Agent	S_{BET} (m^2/g)	V_{tot} (cm^3/g)	V_{micro} (cm^3/g)	V_{meso} (cm^3/g)	Ave. Pore size (nm)	Ref.
Oil palm stone	CO_2	412.5		-	-	-	[36]
Coconut shell	Steam	891	0.7233	-	-	-	[1]
Coconut shell	Steam	2079	1.212	0.9735	0.2385	-	[16]
	CO_2	2288	1.299	1.012	0.287	-	[16]
	Steam+CO_2	2194	1.293	1.01	0.283	-	[16]
Jatropha hull	Steam	1350	1.07	0.4366	0.6334	3.10	[39]
	CO_2	1284	0.87	-	-	2.71	[39]
Oil palm shell	CO_2	151	0.089	0.077	0.012	-	[38]

Table 3 Preparation conditions for microwave-induced physical activation

Material	Agent	S_{BET} (m^2/g)	Microwave power (W)	Radiation time (min)	Agent flow	Ref.
Oil palm stone	CO_2	412.5	750	60	200 ml/min	[36]
Coconut shell	Steam	891	4000	30	-	[1]
Coconut shell	Steam	2079	3000	75	1.35 g/min	[16]
	CO_2	2288	3000	210	600 ml/min	[16]
	Steam+CO_2	2194	3000	75	1.35 g/min + 600 ml/min	[16]
Jatropha hull	Steam	1350	3000	19	5 g/min	[39]
	CO_2	1284	3000	30	300 ml/min	[39]
Oil palm shell	CO_2	151	450	15	2 L/min	[38]

4.1 Effects of Preparation Conditions on the Properties of the Physically Activated Carbon

Generally, physical activation requires a higher level of microwave power and longer radiation time than chemical activation, just like in the conventional heating method where high temperature and time are required. As can be seen from Table 3, the microwave power and radiation time are the two major factors that significantly affect the surface area of the AC. Also, from Table 3, the surface area of the AC prepared by Xin-hui *et al*. [39] from jatropha hull is higher than the AC prepared by Li *et al*. [1] from coconut shell, thus indicating the effect of the precursor material.

The effects of preparation conditions on the BET surface area of AC were shown by Guo and Lua [36]. In their study, they found that the BET surface area increases with increase in CO_2 flow rate until the flow rate reaches 200 cm^3/min, after which the BET surface area decreases with further increase in the flow rate. Xin-hui *et al*. [39] in their study prepared activated carbons from jatropha hull using both steam and CO_2 as activating agent. The results obtained show that the AC prepared using steam as activating agent has higher surface area than the AC prepared using CO_2 as activating agent despite the fact that the radiation time for steam activation was lower. To study the effects of preparation parameters, Yang *et al*. [16] prepared activated carbons from coconut shell using steam, CO_2 and a mixture of steam and CO_2 as activating agent. They observed that the BET surface area and pore volume increased with increase in the radiation time irrespective of the activating agent.

4.2 Effects of Preparation Conditions on the Properties of the Chemically Activated Carbon

Unlike microwave-induced physical activation process, many studies have been reported in the literature on the preparation of AC via microwave-induced chemical activation. As such, the effects of the preparation parameters on the properties of the

prepared AC have engaged the attention of researchers in their various investigations.

Deng *et al*. [32, 56, 60], Foo and Hameed [50, 53] and Liu *et al*. [55] investigated the effects of microwave power on the pore structure of AC in their various studies and obtained similar results. They observed that the pore structure development and ultimately the adsorption capacity of AC increased with increase in microwave power up to the optimum microwave power level. Beyond the optimum power level, the adsorption capacity of the AC was observed to be declining with further increase in power level, which according to Foo and Hameed [53] may be due to fierce reaction at high microwave power level resulting in greater weight loss by the carbon sample.

To study the effects of activation time on the pore structure and adsorption capacity of AC, Li *et al*. [14] prepared AC from tobacco stems via microwave-induced K_2CO_3 activation. In their experiment, microwave power and impregnation ratio were kept constant at 700 W and 1.5 (wt%) respectively while the activation time was varied from 20 to 30 minutes. They observed that the adsorption capacity is increased as they increased the activation time from 20 to 30 minutes. However, when radiation time was further increased to 40 minutes, a drop in the adsorption capacity was noticed. Foo and Hameed obtained similar results [50] from their study in which they prepared AC by microwave-induced K_2CO_3 activation from orange peel. Keeping the microwave power and impregnation ratio constant at 600 W and 1.25 (wt%) respectively, they varied the microwave radiation time from 4 to 6 minutes. They observed that as the activation time increases the adsorption capacity is enhanced. Also, they noted that when the activation reaches 6 minutes, the absorption and reflection of energy tend to balance, thus signaling the attainment of optimum activation time. Using the same experimental conditions, Foo and Hameed [67] prepared AC from wood sawdust and observed the same phenomenon in the results obtained. For both experiments the optimum preparation arrived at were microwave power 600 W, impregnation ratio 1.25 and radiation time 6 minutes. Although both Foo and Hameed and Li *et al*. have used the same chemical agent in their studies, however, the optimum conditions vary. The variation in the optimum conditions maybe attributed to the effect of the precursor material. Figure 3 and Figure 4 depict the effects of microwave radiation time on adsorption properties of AC reported by Li *et al*. [14] and Foo and Hameed [67]respectively.

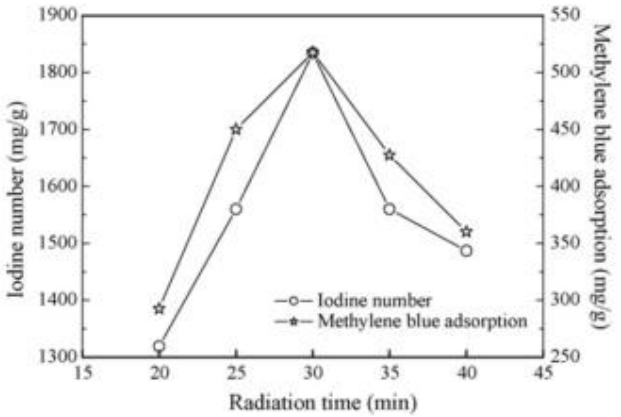


Figure 3 Effects of microwave radiation time on adsorption properties of AC [14]

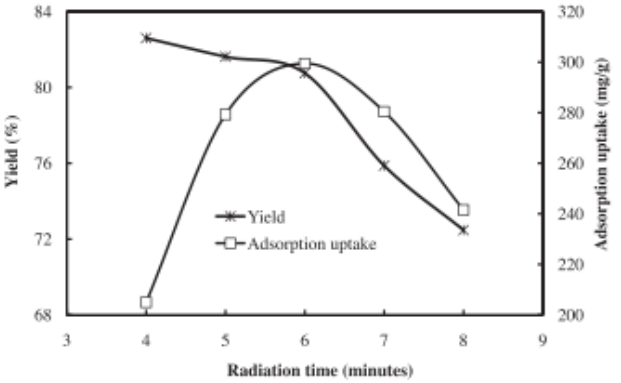


Figure 4 Effects of radiation time on adsorption capacity and carbon yield [67]

Biomass is a poor absorber of microwave, thus the chemical agent serves as the microwave absorber to initiate the pyrolysis process during microwave chemical activation process. Like the other two parameters, chemical agent plays a significant role in the development of porosity and adsorption capacity of the AC.

To investigate the effects of chemical agent impregnation ratio, Deng *et al*. [32] prepared activated carbon from cotton stalks by microwave-induced KOH and K_2CO_3 activation. They reported that the effects of microwave power, radiation time and impregnation ratio followed the same pattern at optimum preparation conditions. Foo and Hameed prepared activated carbons from rice husks [48] and pineapple peel [47] via microwave-induced KOH and K_2CO_3 activation and investigated the effects of the impregnation ratio on the prepared activated carbons. Experimental results obtained not only show the effects of the impregnation ratio but also show the additional effect of the precursor material. While in the case of rice husks-based activated carbons, the carbons prepared using K_2CO_3 as chemical agent have higher carbon yield, better pore

structure and good adsorption capacity. Whereas, the reverse was the case for pineapple peel-based activated carbons with KOH-activated carbon sample showing superior pore structure and good adsorption capacity. The results obtained by Deng *et al*. [32] and Foo and Hameed [47, 48] correlated with the earlier study by Li *et al*. [14]. In their study Li *et al*. [14] prepared AC from tobacco stems by microwave-induced K_2CO_3 activation. They reported that the increase in adsorption observed when K_2CO_3/C ratio was increased is due to the decomposition of K_2CO_3 and subsequent reduction of K_2CO_3 and K_2O by carbons given by the following equations.

$$K_2CO_3 \rightarrow K_2O + CO_2 \quad (3)$$

$$K_2CO_3 + K_2O + C \rightarrow 4K + 2CO_2 \quad (4)$$

According to them, the formation of pores was further enhanced by the diffusion of potassium into the layer of the carbon as the activation temperature reaches the boiling point of the potassium.

5.0 CONCLUSION

The results from this review clearly show that apart from the preparation conditions, the nature of the precursor material also has a significant influence on the properties and adsorption capacity of the prepared AC. The adsorption capacity and porosity development were used to investigate the effects of each preparation parameter on the physical properties of the AC. From the results reported in the survey literature, the properties of the AC are at their best when the parameters are at the optimum values whether individually or collectively. For all the parameters, an increase in the process value beyond the optimum value resulted in decrease in the adsorption capacity due to excessive carbon burn off.

Scale up of microwave equipment and control and use of temperature as a process parameter are some of the areas that deserve the attention of the research community.

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