Effect of Activation Temperature on Properties of H$_3$PO$_4$-Activated Carbon

Wei Xu, Junli Liu,* Kang Sun, Yanyan Liu, Chao Chen, Ao Wang, and Hao Sun

The effects of different activation temperatures ($T_a$), ranging from 300 to 750 °C, on the ash content, yield, ignition point, microcrystalline structure, surface functional group, pore structure, and adsorption performance of activated carbon in preparing activated carbon by phosphoric acid (H$_3$PO$_4$) were systematically studied. The yield and volatile content of activated carbon decreased with the increase of $T_a$, while the ash content, ignition point, and graphitization degree showed the opposite results. The turning point of ash content increasing rate of activated carbon occurred at 500 °C. The thermal decomposition temperature of phosphonate compounds was approximately 450 °C. With increased $T_a$, micropores were generated first, followed by mesopores. The ignition point of activated carbon was related to the volatile content and the degree of graphitization. Activated carbon with low ash content, high yield, well-developed pore structure and good adsorption performance was prepared at 350 to 425 °C. With increased $T_a$, the volatile content decreased, and the ignition point of activated carbon increased. At $T_a$ higher than 500 °C, the aromatic and condensed ring structure, graphitization degree, and mesopore ratio of the activated carbon increased, yielding decreased adsorption performance.

Keywords: Activated carbon; Activation temperature; H$_3$PO$_4$-activation; Adsorption performance

Contact information: Institute of Chemical Industry of Forest Products, CAF; National Engineering Lab. for Biomass Chemical Utilization; Key Lab. of Chemical Engineering of Forest Products, National Forestry and Grassland Administration; Key Lab. of Biomass Energy and Material, Jiangsu Province; Jiangsu Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, Longpan Road, Nanjing, 210042, China; *Corresponding author: liujunli1974@126.com

INTRODUCTION

Producing activated carbon from biomass waste is a good way to reduce environmental pollution and the use of limited resources (Hesas et al. 2014; Jain et al. 2016). Phosphoric acid (H$_3$PO$_4$) is used industrially for preparing activated carbon from lignocellulosic materials (Heidarinejad et al. 2020). H$_3$PO$_4$ is effective for producing mesopores at lower temperatures. In addition, H$_3$PO$_4$ provides an easier way to recover the carbon product during processing stage by rinsing with water (Yahya et al. 2015). Compared with other activating compounds such as KOH (Mao et al. 2015), ZnCl$_2$ (Duan et al. 2019), and K$_2$CO$_3$ (Mao et al. 2020), it also gives higher yield of activated carbon and has non-toxic properties (Romero-Anaya et al. 2012). The H$_3$PO$_4$ method has been used for almost 40 years. At present, approximately 0.2 million tons of activated carbon is produced by H$_3$PO$_4$ in China (Environmental Monitoring Center Station of Ningxia 2018). With a huge market demand, the activated carbon is an indispensable and important chemical product for the national economy and ecological environment construction.

Activation temperature ($T_a$) is an important factor in the preparation of H$_3$PO$_4$-activated carbon because H$_3$PO$_4$ works above 300 °C (Jagtoyen and Derbyshire 1998; Zuo...
The $T_a$ affects the thermal decomposition of cellulose, hemicellulose, and lignin (Yang et al. 2007; Chen et al. 2018). Moreover, $T_a$ affects the formation and thermal transformation of phosphonate compounds to connect and crosslink biopolymer fragments (Zuo et al. 2018). Finally, $T_a$ is a direct factor for H$_3$PO$_4$ to dehydrate and polymerize itself (Kang et al. 2018). The influence of $T_a$ on the surface area, pore development, and yield of activated carbon have been investigated. Increasing temperature is beneficial for the formation of pores in the carbon, especially when the temperature increases from 400 to 500 °C (Luo et al. 2019). This is ascribed to the use of activating agent releasing the tar from the cross-linked framework (Foo and Lee 2010). However, with further increases in temperature, violent gasification reactions destroy part of the micropore structure, leading to decreased surface area and pore volume (Chen et al. 2013). Moreover, increased temperature elevates the ash and fixed carbon percentage, decreasing the volatile matter and the solid yield (Ioannidou and Zabaniotou 2007). A final $T_a$ of 400 °C is suitable for producing high-surface-area activated carbon (Yorgun and Yildiz 2015; Kang et al. 2018). This temperature is favorable for increasing yield and reducing ash content. Thus, the $T_a$ is usually in the range of 400 to 500 °C (Demiral and Şamdan 2016; Villota et al. 2017; Villota et al. 2019), and the activated carbon prepared at these temperatures can have well-developed porous structure and large adsorption capacity, which is beneficial for decolorization, water purification, catalytic carriers, and other industrial needs (Malaika et al. 2018; Wu et al. 2019).

With the increasing need for special activated carbon, especially for activated carbon with low ash content, high ignition point, and controlled pore size, the existing activated carbon products no longer meet the market demand. While there have been studies on the formation of ash, the change of ignition point, and the relationship between pore development and adsorption properties of activated carbon, research on the heat treatment process is limited. Therefore, it is necessary to systematically study the influence of $T_a$ on the properties of H$_3$PO$_4$-activated carbon. This study examined the influence of $T_a$ on the ash content, yield, pore structure, adsorption performance, ignition point, microcrystalline structure, surface functional groups, and changes in microstructure. The results of this research can be used for reference in the preparation of special activated carbon with controllable pore structure, good adsorption, low ash content, or high ignition point.

**EXPERIMENTAL**

**Materials**

Analytical grade H$_3$PO$_4$ (85% by mass), iodine, methylene blue, and sodium thiosulfate were purchased from Aladdin Co. Ltd. (Shanghai, China). Fir sawdust (FS, 10- to 35-mesh, lignin content of 31.46%) was provided by Yuanli Active Carbon Co. Ltd. (Fujian, China). The ultimate analysis and proximate analysis of FS are listed in Table 1.

**Table 1. Ultimate Analyses and Proximate Analyses of FS**

<table>
<thead>
<tr>
<th>Ultimate Analyses ar/wt%</th>
<th>Proximate Analyses ar/wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>N</td>
</tr>
<tr>
<td>49.73</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Preparation of activated carbon

FS (50 g) was soaked with H₃PO₄ solution (55 wt%) according to the immersion ratio of 1.5:1. After stirring for 30 min, the mixture was pretreated in an oven at 140 °C for 120 min, then moved to a muffle furnace under N₂ flow and activated at 300 °C to 750 °C for 120 min. After activation, they were taken out, washed in deionized water (500 mL) for 3 times (each time for 3 min), and dried to obtain the activated carbon.

Test Standards

The ash content, iodine number, methylene blue number, ignition point, and volatile matter of activated carbon were determined as per GB/T 12496.3 (1999), GB/T 12496.8 (2015), GB/T 12496.10 (1999), GB/T 12496.6 (1999), GB/T 20449 (2006), and GB/T 17664 (1999), respectively.

Methods

The BET specific surface area was measured using a Micromeritics ASAP 2460 apparatus (Norcross, GA, USA) at 77 K. The pore size distribution was computed based on the density functional theory (DFT) method. Thermogravimetric analysis (TG) was carried out by a Netzsch STA449C apparatus (Selb, Germany). A 10 mg sample was heated to 800 °C under the protection of the nitrogen with a heating rate of 10 °C/min. The X-ray diffraction (XRD) was performed on a Bruker D8 Advance X-ray diffractometer (Karlsruhe, Germany) with Cu Kα radiation (λ=0.154 nm), Scanning range was 10 to 80° with 0.1°/s. The Fourier transform infrared (FTIR) was tested on a Magna-IR spectrometer 550 (Madison, WI, USA) in the range of 4000 to 400 cm⁻¹ with a resolution of 4 cm⁻¹.

RESULTS AND DISCUSSION

Effect of \( T_a \) on Ash Content and Yield of Activated Carbon

Low ash content in activated carbon is necessary when used for injection, wine, catalyst support, etc. In order to explore the preparation method of low ash content activated carbon, the effect of \( T_a \) on the ash content of activated carbon was studied, as shown in Fig. 1(a). The ash content of activated carbon increases with the elevation of \( T_a \). At the \( T_a \) lower than 350 °C, activated carbon with ash content less than 2% was prepared. When the \( T_a \) ranged from 350 to 500 °C, the ash content increased slightly. When the temperature was raised from 500 to 550 °C, the ash content greatly increased from 3.54% to 6.00%. This means that the turning point of ash content increasing rate of activated carbon occurred at 500 °C. Further elevation of the \( T_a \) caused only slight changes in the ash content of activated carbon. The results indicated that the \( T_a \) should be lower than 500 °C for preparation of low ash content activated carbon.

The influence of \( T_a \) on ash content is closely related to the polymerization of H₃PO₄ at different temperatures. With the increase of \( T_a \), H₃PO₄ dehydrates continuously to form viscous liquid or solid such as pyrophosphoric acid, metaphosphoric acid, polyphosphoric acid, and phosphorus pentoxide (Greenwood and Earnshaw 2012; Kang et al. 2018), which block the pores of activated carbon. Most of these polyphosphates are recycled during activated carbon rinsing. The unremoved polyphosphate remains in the pores of activated carbon, creating an important source of ash. The rapid increase of ash content of activated carbon at 500 to 550 °C means that there was more polyphosphoric acid generated in this temperature range, and it is difficult to elute. In addition, water-insoluble phosphate was
formed via the reaction of H$_3$PO$_4$ and metal salts in raw materials under high temperature. The phosphonate compounds were produced by condensation of H$_3$PO$_4$ and hydroxyl groups of high glycan (include their degradation products) are also important sources of ash.

Fig. 1. (a) Ash content and (b) yield of activated carbon with different $T_a$

As shown in Fig. 1(b), the yield of activated carbon was affected by $T_a$. During the preparation of activated carbon, the yield of activated carbon continuously decreased with the increase of $T_a$. When $T_a$ was 300 °C, the yield was 67.4%, and the yield decreased to 48.6% at 450 °C. The turning point of the curve occurred at 450 °C, showing that the pyrolysis rate was faster and the degree of pyrolysis was higher before 450 °C. The effect of $T_a$ on the yield is related to the degree of pyrolysis of raw materials at different temperatures. With increasing temperature, the cellulose, hemicellulose, and lignin making up the sawdust are pyrolyzed gradually, resulting in a continually decreased yield. To compare the influence of H$_3$PO$_4$ on the pyrolysis process of sawdust, TG (Fig. 2) was carried out for FS and fir sawdust impregnated H$_3$PO$_4$ (FS-H$_3$PO$_4$). The thermal decomposition of FS was concentrated in 250 to 400 °C, and the mass loss in this range was increased from 4.28% to 71.4%. After the FS was soaked with H$_3$PO$_4$, the thermal decomposition range was changed into two stages, 130 to 450 °C (mass reduced from 91.4% to 66.9%) and 450 to 700 °C (mass reduced from 66.9% to 28.2%). Comparing the TG curves for the two specimens, the addition of H$_3$PO$_4$ improved the yield and changes the thermal decomposition process of FS (Yagmur et al. 2018). In the pyrolysis process, the catalytic dehydration of H$_3$PO$_4$ makes the weight loss of FS-H$_3$PO$_4$ more obvious before 334 °C. Above 334 °C, H$_3$PO$_4$ forms stable phosphonate compounds with FS, protects the pyrolysis of FS, and enhances the yield (Yakout and Eldeen 2016), whereas the pyrolysis of FS unimpregnated H$_3$PO$_4$ is more obvious. The weight drop of FS-H$_3$PO$_4$ after 450 °C can be explained by the destruction of phosphonate compounds (Solum et al. 1995; Jagtøyen and Derbyshire 1998) and the volatilisation of phosphorus compounds (Suarezgarcia et al. 2004; Puzy et al. 2005). It is more appropriate to assume that P$_2$O$_5$ (formed by dehydration of H$_3$PO$_4$) behaves as an oxidant, which can react with carbon, reducing the yield and forming new pores (Olivaresmarin et al. 2006). The mechanism of this process is shown in Fig. 3, and the result is consistent with the turning point of yield in Fig. 1(b) at 450 °C. The volatilisation of phosphorus compounds does not lead to the decrease of ash content of activated carbon, and it can be inferred that the phosphorus compounds are not the only source of ash in activated carbon.
Effect of $T_a$ on Ignition Point and Volatile of Activated Carbon

The ignition point is an important index to evaluate the thermal stability of activated carbon in gas phase application. As shown in Fig. 4, the ignition point of activated carbon increased with elevated $T_a$. Before 450 °C, the ignition point of activated carbon was lower than 300 °C. When the $T_a$ increased to 500 °C, the ignition point of the activated carbon exceeded 300 °C, and flame-retardant activated carbon with an ignition point greater than 400 °C was prepared at a $T_a$ of 750 °C. The effect of $T_a$ on the ignition point may be related to the reduction of volatile content of activated carbon. This is because CO, H₂, CH₄, and other gaseous organics from pyrolysis are conducive to the combustion of activated carbon. The relationship between the content of volatile matter and the ignition point of activated carbon was studied (Fig. 4). The volatile content of activated carbon decreased with the increased $T_a$, which is contrary to the change trend of ignition point with $T_a$. It was
concluded that the ignition point is correlated negatively to the volatile content of activated carbon. When the $T_a$ increased from 300 °C to 425 °C, the volatile content decreased from 27.3% to 23.4%, and the volatile content decreased to 21.9% with the $T_a$ at 750 °C. Compared with the volatile content (81.2%) of FS, the pyrolysis of FS was sufficient at 300 to 425 °C (Ferrera-Lorenzo et al. 2014; Li et al. 2015), which may be a basis for the formation of developed pore structure of activated carbon at low $T_a$.

![Graph](image)

**Fig. 4.** Ignition point and volatile of activated carbon with different $T_a$

**Effect of $T_a$ on Microcrystalline Structure and Surface Functional Groups of Activated Carbon**

XRD was employed to analyze the effect of different $T_a$ on the microcrystalline structure of the activated carbon. As shown in Fig. 5a, three diffraction peaks at 16°, 22°, and 34° for FS represent the (101), (002), and (004) crystal planes of cellulose (Ma et al. 2017). Two obvious peaks are observable at 24° and 42° for activated carbon corresponding to the (002) and (100) planes of amorphous carbon (Chen et al. 2017). These changes indicate that the crystalline area of cellulose was destroyed after activation, representing the formation of amorphous carbon. The amorphous carbon produced above 300 °C is the basis for the formation of pores. The pores are produced by removing various carbon-containing compounds and disordered carbon between the basic crystallites of amorphous carbon during the preparation of activated carbon (Wigmans 1986). With the increase of $T_a$, the diffraction peak of amorphous carbon gradually increases and shifts to the high angles, the stacking thickness of carbon layer along (100) direction increases, and the degree of graphitization increases (Wada et al. 2010). The exception occurs at 650 °C and 750 °C, when the (002) shifts to low angles, which may be related to the channel collapse at high temperature. The elevated degree of graphitization makes the internal structure of activated carbon orderly and regular. The reduction of the spacing of microcrystalline layers may make the internal phosphoric acid unable to elute. The formation of stable graphite-like microcrystalline structures may also reduce their tendency to spontaneous combustion.
The changes in functional groups on the surface of activated carbon prepared at different $T_a$ were studied by FTIR, as shown in Fig. 5b. In all spectra, the band located at 3430 cm$^{-1}$ can be assigned to the O-H stretching mode. The band of activated carbon prepared at 300 °C is obviously asymmetric, indicating the existence of hydrogen bond (Ma et al. 2017). A small peak at 2920 to 2850 cm$^{-1}$ can be assigned to the C-H stretching mode, and its bending mode appears at 1440 cm$^{-1}$ (Mao et al. 2018). The band of C=O appears at 1700 cm$^{-1}$. With increased $T_a$, the intensity of C=O decreased and disappeared above 500 °C, and the band position shifted to a low wave number, indicating decarbonylation. This effect was apparent when the intensity of C-O (1060 cm$^{-1}$) increased with the elevated $T_a$. A strong band at 1580 cm$^{-1}$ was ascribed to the stretching vibration of aromatic ring (C=C), demonstrating that the carbonyl (1700 cm$^{-1}$) is conjugated with aromatic ring. A small red shift with the increase of $T_a$ indicated the growth of aromatic ring structure (Puziy et al. 2002), which is unfavorable to the adsorption performance of activated carbon but is the basis for the enhancement of the structural order and graphitization degree of activated carbon (Leung and Safford 1970). The increase of aromatic ring structure is caused by the catalytic dehydration of phosphoric acid, and the process is shown in Fig. 6 (Benaddi et al. 1998). The band at 1160 cm$^{-1}$ is assigned to phosphates with stretching mode of P=O, P-O-C, and P=OOH. The bands at 1060 cm$^{-1}$ are due to C-O stretching in alcohols, phenols, ethers, and esters, or P$^+$-O$^-$ (Puziy et al. 2005; Ma et al. 2018). The broad band between 750 cm$^{-1}$ and 900 cm$^{-1}$ corresponding to the out-of-plane bending mode of aromatic ring C-H weakened and disappeared when $T_a$ was higher than 500 °C. The change indicates that the functional group of activated carbon has replaced or formed a dense ring structure.
Effect of $T_a$ on Pore Structure and Adsorption Properties of Activated Carbon

The N$_2$ adsorption-desorption isotherms of the activated carbon are presented in Fig. 7(a). The isotherms of activated carbon prepared at 300 °C belong to type I (Sing 1982; Rouquerol et al. 1994). The micropores of activated carbon were confirmed by the abundant pores and in the range of 1 to 2 nm, as can be seen in Fig. 7(b) as low $V_{mes}/V_{tot}$ ratio and small $D_{ave}$ value (Table 2). When the $T_a$ is higher than 300 °C, the isotherms of activated carbon belong to type IV (Sing 1982; Rouquerol et al. 1994). The hysteresis loop appearing at high relative pressures ($P/P_0>0.4$) indicates that the mesopores of activated carbon are developed and corresponds with the large number of mesopores distributed at 2.7, 3.4, and 8.7 nm, as shown in Fig. 7(b). At the same relative pressure, the adsorption capacity of N$_2$ was consistent with the $S_{BET}$ and $V_{tot}$ of activated carbon, which is shown in Table 2. The pore structure of activated carbon prepared at different $T_a$ was distributed in the range of 0 to 50 nm. At the same diameter, the different proportion of pores reflect the amount of $V_{tot}$ of activated carbon prepared at different $T_a$.

Fig. 7. (a) N$_2$ adsorption-desorption isotherms and (b) DFT pore size distributions of activated carbon with different $T_a$

The pore parameters of activated carbon based on N$_2$ adsorption-desorption isotherms are given in Table 2. With increasing $T_a$, the $S_{BET}$ and $V_{tot}$ of activated carbon increased first and then decreased. When the $T_a$ is 300 °C, the pore structure of the prepared activated carbon is underdeveloped with the $S_{BET}$ of 799 m$^2$/g and $V_{tot}$ of 0.34 cm$^3$/g. When the $T_a$ increased from 300 to 350 °C, the $S_{BET}$, $V_{tot}$, and $V_{mes}/V_{tot}$ of the activated carbon increased, suggesting that the effect of H$_3$PO$_4$ is enhanced at this temperature. Increasing the $T_a$ to 450 °C, the $S_{BET}$ and $V_{tot}$ were further developed and tended to be stable. At an $T_a$ of 400 °C, the $S_{BET}$ and $V_{tot}$ of activated carbon reached maximum values, which were 1547 m$^2$/g and 0.89 cm$^3$/g, respectively. At the $T_a$ between 450 to 550 °C, the $S_{BET}$ and $V_{tot}$ of activated carbon showed a downward trend, relating to the destruction of the phosphate bond, the ablation of the cell wall, and the collapse of the pore structure during high temperature (Romeroanaya et al. 2012). A slight increase of $S_{BET}$ and $V_{tot}$ at 650 °C is related to the rearrangement of microcrystalline structure during skeleton contraction. The increase of $S_{BET}$ from 350 to 400 °C was not significant, but the $V_{tot}$ and $V_{mes}/V_{tot}$ were increased, indicating that this stage is conducive to the formation of mesopores. The $V_{mes}/V_{tot}$ ratio of activated carbon increased with the elevation of $T_a$ and reached the maximum at 450 °C, which can be ascribed to the formation of mesopores at the high $T_a$. 

(Jagtoyen and Derbyshire 1998). The change of $V_{\text{mes}}/V_{\text{tot}}$ was supported by the change trend of the $D_{\text{ave}}$.

**Table 2.** Pore Parameters of Activated Carbons with Different $T_a$

<table>
<thead>
<tr>
<th>$T_a$ (°C)</th>
<th>$S_{\text{BET}}$ (m²/g)</th>
<th>$V_{\text{tot}}$ (cm³/g)</th>
<th>$V_{\text{mes}}$ (cm³/g)</th>
<th>$V_{\text{mes}}/V_{\text{tot}}$ (%)</th>
<th>$D_{\text{ave}}$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>799</td>
<td>0.34</td>
<td>0.04</td>
<td>11.76</td>
<td>2.03</td>
</tr>
<tr>
<td>350</td>
<td>1434</td>
<td>0.72</td>
<td>0.30</td>
<td>41.67</td>
<td>2.36</td>
</tr>
<tr>
<td>400</td>
<td>1547</td>
<td>0.89</td>
<td>0.50</td>
<td>56.18</td>
<td>2.67</td>
</tr>
<tr>
<td>425</td>
<td>1421</td>
<td>0.86</td>
<td>0.51</td>
<td>59.30</td>
<td>2.79</td>
</tr>
<tr>
<td>450</td>
<td>1408</td>
<td>0.86</td>
<td>0.52</td>
<td>60.46</td>
<td>2.79</td>
</tr>
<tr>
<td>500</td>
<td>1274</td>
<td>0.76</td>
<td>0.43</td>
<td>56.58</td>
<td>2.72</td>
</tr>
<tr>
<td>550</td>
<td>1227</td>
<td>0.78</td>
<td>0.47</td>
<td>60.26</td>
<td>2.87</td>
</tr>
<tr>
<td>650</td>
<td>1285</td>
<td>0.77</td>
<td>0.43</td>
<td>55.84</td>
<td>2.68</td>
</tr>
<tr>
<td>750</td>
<td>1168</td>
<td>0.72</td>
<td>0.39</td>
<td>54.17</td>
<td>2.69</td>
</tr>
</tbody>
</table>

*S$_{\text{BET}}$: BET surface area, $V_{\text{tot}}$: Total pore volume, $V_{\text{mes}}$: Mesopore volume, $V_{\text{mes}}/V_{\text{tot}}$: Mesoporosity, $D_{\text{ave}}$: Average pore diameter.

Iodine number (IN) and methylene blue number (MBN) are important references for evaluating the adsorption performance of activated carbon. The influence of $T_a$ on IN and MBN of activated carbon were studied (Fig. 8). With increased $T_a$, the curve of the IN showed a trend of first increasing and then decreasing. When the $T_a$ was 450 °C, the IN reached the highest value of 834 mg/g. Further increasing the $T_a$ to 500 °C, the IN decreases significantly. The IN of activated carbon does not change much at 500 to 750 °C. The influence of MBN on activated carbon is relatively weak by the $T_a$. Both low $T_a$ (425 °C) and high $T_a$ (650 °C) can prepare activated carbons with MBN exceeding 285 mg/g. The MBN on activated carbon prepared at 450 to 550 °C was less than 250 mg/g. The IN and MBN of activated carbon are used to measure the development of micropores and mesopores, respectively (Nunes and Guerreiro 2011; Hirunpraditkoonen et al. 2015). When the $T_a$ was lower than 400 °C, the IN of activated carbon was high enough. The MBN increased with the elevation of $T_a$ from 300 to 425 °C, indicating that mesopores were generated. This result was consistent with the conclusion that pore structure was affected by $T_a$. At $T_a$ higher than 500 °C, the IN and MBN of activated carbon were not regular with the collapse of old pores and the formation of new pores. Thus, activated carbon with higher IN and MBN should be prepared at a $T_a$ between 350 and 425 °C.

![Fig. 8. IN and MBN curves of activated carbon with $T_a$](image-url)
CONCLUSIONS

1. The activated carbon with low ash content should be prepared at an activation temperature ($T_a$) lower than 500 °C. This is because the turning point of ash content increasing rate of activated carbon occurs at 500 °C. The thermal decomposition temperature of phosphonate compounds about 450 °C, can be demonstrated by the weight reduction of FS-H$_3$PO$_4$. The yield curve of activated carbon turned at a $T_a$ value higher than 450 °C.

2. The volatile content is negatively relating to the ignition point of activated carbon. At a $T_a$ of 750 °C, activated carbon with ignition point higher than 400 °C can be prepared. The increase of $T_a$ promotes the aromatic ring structure of activated carbon. This relationship provides a basis for the improvement of structure order and graphitization degree of activated carbon. However, it is unfavorable for the adsorption performance of activated carbon, especially at high $T_a$.

3. With the increase of $T_a$, micropores are generated first, followed by mesopores. The $V_{mes}/V_{tot}$ ratio of activated carbon increases with the elevation of $T_a$ and reaches a maximum at 450 °C. The iodine number (IN) and methylene blue number (MBN) of activated carbon are related to micropore volume and mesopore volume, respectively. For preparation of activated carbon with high IN and MBN, the $T_a$ should be between 350 and 425 °C.

ACKNOWLEDGMENTS

This work was financially supported by the Biomass Energy & Materials Laboratory of Jiangsu Province (JSBEM-S-202010), and the National Key R&D Program of China (Project No. 2019YFB1503804). The authors are grateful for the analytic support of the Instrument Analysis Center and Pulp and Paper Research Lab at the Institute of Chemical Industry of Forest Products, CAF, Nanjing, China.

REFERENCES CITED


carbon production,” *Biomass Conversion and Biorefinery* 8(4), 889-897. DOI:10.1007/s13399-018-0329-3


Article submitted: October 13, 2020; Peer review completed: January 16, 2021; Revised version received and accepted: April 1, 2021; Published: April 20, 2021. DOI: 10.15376/biores.16.2.4007-4020