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## ORIGINAL ARTICLE

# Desulphurization characteristics of bamboo charcoal from sulfur solution



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## KEYWORDS

Bamboo charcoal;  
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Na<sub>2</sub>SO<sub>4</sub>;  
Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>;  
S;  
Na<sub>2</sub>SO<sub>3</sub>

**Abstract** Sulfur powder and sulfur dioxide (SO<sub>2</sub>) often floated in air, produced acid rain and algal blooms, and could cause diseases. Bamboo charcoal could have adsorption and filtration properties. In order to figure out the optimal adsorption condition and the intrinsic change of the bamboo charcoal, five chemicals were adsorbed by bamboo charcoal and were analyzed by FT-IR. Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>'s, Na<sub>2</sub>SO<sub>4</sub>'s, Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>'s, S's, and Na<sub>2</sub>SO<sub>3</sub>'s optimal adsorption condition was the concentration of 19 g/1000 g and stir time of 20 min, 21 g/1000 g and stir time of 60 min, 7 g/1000 g and stir time of 120 min, 11 g/1000 g and stir time of 120 min, 21 g/1000 g and stir time of 60 min, respectively. FT-IR spectra showed that for FT-IR spectra of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup> and 2925 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 7 g/1000 g. For FT-IR spectra of Na<sub>2</sub>SO<sub>4</sub>, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 13 g/1000 g. For FT-IR spectra of Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup>, 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup> and 1060 cm<sup>-1</sup> achieved the maximum for 120 min and the concentration was 19 g/1000 g. For FT-IR spectra of S, the transmissivity of the peaks at 3435 cm<sup>-1</sup>, 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup> and 1060 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 11 g/1000 g, 17 g/1000 g and 21 g/1000 g. For FT-IR spectra of Na<sub>2</sub>SO<sub>3</sub>,

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the transmissivity of the peaks at  $3435\text{ cm}^{-1}$  achieved the maximum for 120 min and the concentration was  $5\text{ g}/1000\text{ g}$ , the transmissivity of the peaks at  $2925\text{ cm}^{-1}$ ,  $1630\text{ cm}^{-1}$  and  $1060\text{ cm}^{-1}$  achieved the maximum for 120 min and the concentration was  $11\text{ g}/1000\text{ g}$ . In these states, the number of the transmissivity of the maximum peaks is the largest.

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## 1. Introduction

The majority of sulfur comes from industrial waste water, such as chemical fertilizers, processed meat, leather and other industries, city life sewage and farmland irrigation are also the main sources (Luo, 2013; Wang, 2010). Sulfur is a rich nutrient pollutant, after entering water can cause algal blooms, cause eutrophication of the water body, their spread will pollute the environment and disrupt the ecological balance, will also harm human health through food chain channels, it is likely to lead to drinking-water toxicosis. Sulfide formation of acid rain in the air and water and other substances reaction (Chen and Yao, 2009). In Shanghai, the researchers found that:  $\text{SO}_2$  concentrations in the atmosphere for every  $10\text{ }\mu\text{m}^3$ , respiratory disease deaths in increments of 5% (Zou, 1991). Sulfur powder and sulfur dioxide ( $\text{SO}_2$ ) often floated in air. Whenever and wherever, it could cause diseases.

In China, Bamboo planting is very large, it has a kind of short growth cycle and timber fast biomass resources. Therefore, bamboo charcoal is a natural, renewable environmental protection material and functional material. Bamboo charcoal was created by heating bamboo at temperatures of  $600\text{--}900\text{ }^\circ\text{C}$ , then the charcoal itself was processed and mixed in with fabrics as part of the growing field of nanotechnology (Yang et al., 2005; Abe et al., 2001; Kawashita et al., 1994; Mizuta et al., 1994; Wang et al., 2006; Xue et al., 2014; Cui et al., 2014, 2015; Peng et al., 2012a, 2014a,b). Bamboo charcoal has a lot of positive qualities (Yang et al., 2005; Abe et al., 2001; Kawashita et al., 1994). The highly porous structure of the bamboo fabric, could absorb sulfur-based compounds (Abe et al., 2001; Kawashita et al., 1994; Mizuta et al., 1994; Wang et al., 2006; Xue et al., 2014; Cui et al., 2014). What's more, bamboo charcoal, which contained potassium, calcium and other minerals, could have adsorption and filtration of extractives, oil, and other substances (Peng et al., 2013a,b,c, 2012a,b, 2011; Xiao et al., 2013; Wang et al., 2013; Liu et al., 2008; Zhang et al., 2008; Qi et al., 2012). That was beneficial for people's health. But so far, the bamboo charcoal in coal-fired flue gas pollution control in the field of study is less reported. In order to figure out the optimal adsorption condition and the intrinsic change of the bamboo charcoal, five chemicals were adsorbed by bamboo charcoal and were analyzed by FT-IR.

## 2. Materials and methods

### 2.1. Materials

Bamboo charcoal,  $\text{Fe}_2(\text{SO}_4)_3$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{Na}_2\text{S}_2\text{O}_8$ , S, and  $\text{Na}_2\text{SO}_3$  were purchased from the market.

### 2.2. Methods

$\text{Fe}_2(\text{SO}_4)_3$  powder was weighed in amounts of 7 g, 19 g, and 21 g. These powder and 4 g over dry bamboo charcoal were put into beaker which equipped with 1000 ml water, respectively. It was stirred in a beaker for 20 min, 40 min and 60 min.  $\text{Na}_2\text{SO}_4$  powder was weighed in amounts of 13 g, 19 g, 21 g. These powder and 4 g over dry bamboo charcoal were put into beaker which equipped with 1000 ml water, respectively. It was stirred in a beaker for 20 min, 60 min and 80 min.  $\text{Na}_2\text{S}_2\text{O}_8$  powder was weighed in amounts of 7 g, 13 g, 19 g. These powder and 4 g over dry bamboo charcoal were put into beaker which equipped with 1000 ml water, respectively. It was stirred in a beaker for 40 min, 100 min and 120 min. The S powder was weighed in amounts of 11 g, 17 g, 21 g. These powder and 4 g over dry bamboo charcoal were put into beaker which equipped with 1000 ml water, respectively. It was stirred in a beaker for 20 min, 100 min and 120 min. The  $\text{Na}_2\text{SO}_3$  powder was weighed in amounts of 5 g, 11 g, 21 g. These powder and 4 g over dry bamboo charcoal were put into beaker which equipped with 1000 ml water, respectively. It was stirred in a beaker for 40 min, 60 min and 120 min. Each bamboo charcoal was removed, dried, and weighed, respectively.

FT-IR spectra. FT-IR spectra of the above samples were obtained using a Thermo Scientific Nicolet iN10 FT-IR microscope as previously (Lin et al., 2015; Peng et al., 2014c; Sun et al., 2014).

### 3. Result and analysis

Based on the above test, the results of adsorption were obtained and listed in Table 1.

#### 3.1. SC effect

Based on Table 1, when the concentrations of  $\text{Fe}_2(\text{SO}_4)_3$  were  $7\text{ g}/1000\text{ g}$ ,  $19\text{ g}/1000\text{ g}$ ,  $21\text{ g}/1000\text{ g}$ ,  $\text{Fe}_2(\text{SO}_4)_3$ 's adsorption capacity were  $0.99\text{ g}/100\text{ g}$ ,  $6.84\text{ g}/100\text{ g}$ ,  $2.98\text{ g}/100\text{ g}$ ,  $1.26\text{ g}/100\text{ g}$ ,  $0.75\text{ g}/100\text{ g}$ ,  $5.32\text{ g}/100\text{ g}$ ,  $0.74\text{ g}/100\text{ g}$ ,  $0.5\text{ g}/100\text{ g}$ ,  $3.79\text{ g}/100\text{ g}$  for the stir time of 20 min, 40 min, 60 min, respectively. When the concentrations of  $\text{Na}_2\text{SO}_4$  were  $13\text{ g}/1000\text{ g}$ ,  $19\text{ g}/1000\text{ g}$ ,  $21\text{ g}/1000\text{ g}$ ,  $\text{Na}_2\text{SO}_4$ 's adsorption capacity were  $-0.7\text{ g}/100\text{ g}$ ,  $0.5\text{ g}/100\text{ g}$ ,  $0.5\text{ g}/100\text{ g}$ ,  $0.25\text{ g}/100\text{ g}$ ,  $1.26\text{ g}/100\text{ g}$ ,  $4.23\text{ g}/100\text{ g}$ ,  $0.25\text{ g}/100\text{ g}$ ,  $2.01\text{ g}/100\text{ g}$ ,  $1.99\text{ g}/100\text{ g}$  for the stir time of 20 min, 60 min, 80 min, respectively. When the concentrations of  $\text{Na}_2\text{S}_2\text{O}_8$  were  $7\text{ g}/1000\text{ g}$ ,  $13\text{ g}/1000\text{ g}$ ,  $19\text{ g}/1000\text{ g}$ ,  $\text{Na}_2\text{S}_2\text{O}_8$ 's adsorption capacity were  $1.76\text{ g}/100\text{ g}$ ,  $1.52\text{ g}/100\text{ g}$ ,  $1.77\text{ g}/100\text{ g}$ ,  $0.75\text{ g}/100\text{ g}$ ,  $1\text{ g}/100\text{ g}$ ,  $0.5\text{ g}/100\text{ g}$ ,  $4.36\text{ g}/100\text{ g}$ ,  $0\text{ g}/100\text{ g}$ ,

**Table 1** Adsorption results.

SC [%]	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>			SC [%]	Na <sub>2</sub> SO <sub>4</sub>			SC [%]	Na <sub>2</sub> S <sub>2</sub> O <sub>8</sub>			SC [%]	S			SC [%]	Na <sub>2</sub> SO <sub>3</sub>		
	Stir time [min]				Stir time [min]				Stir time [min]				Stir time [min]				Stir time [min]		
	20	40	60		20	60	80		40	100	120		20	100	120		20	100	120
0.7	0.99	1.26	0.74	1.3	-0.7	0.25	0.25	0.7	1.76	0.75	4.36	1.1	1	2.23	6.22	0.5	-1.5	0.25	1.49
1.9	6.84	0.75	0.5	1.9	0.5	1.26	2.01	1.3	1.52	1	0	1.7	0.5	3.5	0.25	1.1	-0.7	0.5	2
2.1	2.98	5.32	3.79	2.1	0.5	4.23	1.99	1.9	1.77	0.5	1.47	2.1	0.25	0.5	4.52	2.1	1.99	3	0.75

Note: SC – Concentration of sulfur solution.

1.47 g/100 g for the stir time of 40 min, 100 min, 120 min, respectively. When the concentrations of S were 11 g/1000 g, 17 g/1000 g, 21 g/1000 g, S's adsorption capacity were 1 g/100 g, 0.5 g/100 g, 0.25 g/100 g, 2.23 g/100 g, 3.5 g/100 g, 0.5 g/100 g, 6.22 g/100 g, 0.25 g/100 g, 4.52 g/100 g for the stir time of 20 min, 100 min, 120 min, respectively. When the concentration of Na<sub>2</sub>SO<sub>3</sub> were 5 g/1000 g, 11 g/1000 g, 21 g/1000 g, Na<sub>2</sub>SO<sub>3</sub>'s adsorption capacity were -1.5 g/100 g, -0.7 g/100 g, 1.99 g/100 g, 0.25 g/100 g, 0.5 g/100 g, 3 g/100 g, 1.49 g/100 g, 2 g/100 g, 0.75 g/100 g for the stir time of 40 min, 60 min, 120 min, respectively. It showed that the adsorption capacity changed at regularity difference. It might be because rapid stirring lead to a small amount of chemical medicine that was adsorbed by the bamboo charcoal. The Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>'s optimal adsorption condition was the concentration of 19 g/1000 g and stir time of 20 min, the Na<sub>2</sub>SO<sub>4</sub>'s optimal adsorption condition was the concentration was 21 g/1000 g and stir time of 60 min, the Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>'s optimal adsorption condition was the concentration was 7 g/1000 g and stir time of 120 min, the S's optimal adsorption condition was the concentration of 11 g/1000 g and stir time of 120 min and the Na<sub>2</sub>SO<sub>3</sub>'s optimal adsorption condition was the concentration of 21 g/1000 g and stir time of 60 min.

### 3.2. FT-IR analysis

FT-IR spectra were recorded to investigate the functional groups of bamboo charcoal during adsorption of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, Na<sub>2</sub>SO<sub>4</sub>, Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>, S, and Na<sub>2</sub>SO<sub>3</sub>. Spectra of the samples were shown in Supporting Information Fig. 1–5. In the spectrum of adsorption, the O–H stretch, –C–H stretch, C=O or C=C stretch, C–O stretch, C–H, were observed at 3435 cm<sup>-1</sup>, 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup>, 660 cm<sup>-1</sup>, respectively (listed in Table 2) (Lin et al., 2015; Peng et al., 2014a, 2014b; Sun et al., 2014; Peng et al., 2015; Wang et al., 2009; Pednekar et al., 2013).

For FT-IR spectra of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup> and 2925 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 7 g/1000 g.

For FT-IR spectra of Na<sub>2</sub>SO<sub>4</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup> and 2925 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 21 g/1000 g, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 13 g/1000 g.

For FT-IR spectra of Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup>, 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup> and 1060 cm<sup>-1</sup>

achieved the maximum for 120 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 660 cm<sup>-1</sup> achieved the maximum for 40 min and the concentration was 7 g/1000 g.

For FT-IR spectra of S, the transmissivity of the peaks at 3435 cm<sup>-1</sup> and 1630 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 21 g/1000 g, the transmissivity of the peaks at 2925 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 11 g/1000 g, the transmissivity of the peaks at 1060 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 17 g/1000 g, the transmissivity of the peaks at 660 cm<sup>-1</sup> achieved the maximum for 100 min and the concentration was 11 g/1000 g.

For FT-IR spectra of Na<sub>2</sub>SO<sub>3</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup> achieved the maximum for 120 min and the concentration was 5 g/1000 g, the transmissivity of the peaks at 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup> and 1060 cm<sup>-1</sup> achieved the maximum for 120 min and the concentration was 11 g/1000 g, the transmissivity of the peaks at 660 cm<sup>-1</sup> achieved the maximum for 40 min and the concentration was 11 g/1000 g.

### 4. Conclusion

As we can see from the above methods, Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>'s, Na<sub>2</sub>SO<sub>4</sub>'s, Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>'s, S's, and Na<sub>2</sub>SO<sub>3</sub>'s adsorption capacities were different for several stir times and several concentrations, respectively. The Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>'s optimal adsorption condition was the concentration of 19 g/1000 g and stir time of 20 min, the Na<sub>2</sub>SO<sub>4</sub>'s optimal adsorption condition was the concentration of 21 g/1000 g and stir time of 60 min, the Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>'s optimal adsorption condition was the concentration of 7 g/1000 g and stir time of 120 min, the S's optimal adsorption condition was the concentration of 11 g/1000 g and stir time of 120 min and the Na<sub>2</sub>SO<sub>3</sub>'s optimal adsorption condition was the concentration of 21 g/1000 g and stir time of 60 min.

FT-IR spectra showed that bamboo charcoal had five characteristic absorption bands. The O–H stretch, –C–H stretch, C=O or C=C stretch, C–O stretch, C–H, were observed at 3435 cm<sup>-1</sup>, 2925 cm<sup>-1</sup>, 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup>, 660 cm<sup>-1</sup>, respectively. For FT-IR spectra of Fe<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>, the transmissivity of the peaks at 3435 cm<sup>-1</sup> and 2925 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 60 min and the concentration was 7 g/1000 g. For FT-IR spectra of Na<sub>2</sub>SO<sub>4</sub>, the transmissivity of the peaks at 1630 cm<sup>-1</sup>, 1060 cm<sup>-1</sup> and 660 cm<sup>-1</sup> achieved the maximum for 20 min and the concentration was 13 g/1000 g. For FT-IR spectra of Na<sub>2</sub>S<sub>2</sub>O<sub>8</sub>, the

**Table 2** Group attribution of bamboo charcoal during adsorption of  $\text{Fe}_2(\text{SO}_4)_3$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{Na}_2\text{S}_2\text{O}_8$ , S and  $\text{Na}_2\text{SO}_3$  (%).

Kind	Peak ( $\text{cm}^{-1}$ )	Adsorption time (min)/Concentration (%)									Group
		20/0.7	20/1.9	20/2.1	40/0.7	40/1.9	40/2.1	60/0.7	60/1.9	60/2.1	
$\text{Fe}_2(\text{SO}_4)_3$	660	85.0	89.4	90.8	87.0	87.6	86.9	94.5	88.5	87.1	C—H
	1060	83.2	88.3	89.5	84.9	87.4	87.1	93.8	86.9	86.9	C—O stretch
	1630	84.5	88.0	88.3	85.4	87.3	87.3	89.3	88.0	86.8	C=O or C=C
	2925	88.1	89.3	89.1	87.8	88.9	89.2	89.0	89.6	89.1	—C—H stretch
	3435	75.5	80.8	79.5	77.3	79.9	78.1	77.6	81.2	76.8	O—H stretch
$\text{Na}_2\text{SO}_4$	Peak ( $\text{cm}^{-1}$ )	20/1.3	20/1.9	20/2.1	60/1.3	60/1.9	60/2.1	80/1.3	80/1.9	80/2.1	Group
	660	97.3	91.9	87.9	82.2	90.0	87.7	87.1	87.2	92.6	C—H
	1060	93.0	91.2	88.2	78.1	89.4	86.2	87.7	78.8	89.5	C—O stretch
	1630	89.1	87.6	87.7	84.2	87.0	87.1	86.8	86.0	86.7	C=O or C=C
	2925	88.7	88.8	88.9	88.3	88.6	89.4	88.9	88.5	88.0	—C—H stretch
	3435	78.1	76.6	80.6	75.6	77.8	81.3	77.6	76.6	77.5	O—H stretch
$\text{Na}_2\text{S}_2\text{O}_8$	Peak ( $\text{cm}^{-1}$ )	40/0.7	40/1.3	40/1.9	100/0.7	100/1.3	100/1.9	120/0.7	120/1.3	120/1.9	Group
	660	88.0	79.5	85.7	76.4	85.9	83.6	83.8	85.4	86.6	C—H
	1060	82.5	80.5	83.8	76.8	85.5	82.6	81.7	83.1	85.8	C—O stretch
	1630	86.5	84.1	86.3	83.0	85.2	85.1	84.5	83.7	87.1	C=O or C=C
	2925	88.8	88.2	88.7	88.2	88.3	88.4	87.0	87.5	89.4	—C—H stretch
	3435	75.5	77.5	77.9	79.5	76.7	78.9	79.1	74.2	81.5	O—H stretch
S	Peak ( $\text{cm}^{-1}$ )	20/1.1	20/1.7	20/2.1	100/1.1	100/1.7	100/2.1	120/1.1	120/1.7	120/2.1	Group
	660	90.3	90.0	89.2	93.5	86.6	87.3	84.4	88.4	89.5	C—H
	1060	89.1	90.2	88.1	91.8	85.0	85.5	82.8	87.6	88.5	C—O stretch
	1630	88.1	87.4	89.7	87.4	85.2	86.8	84.9	86.8	87.1	C=O or C=C
	2925	90.1	89.4	89.0	88.8	87.6	88.9	88.4	89.0	89.1	—C—H stretch
	3435	80.5	77.2	81.9	74.0	74.9	78.8	78.3	77.0	78.5	O—H stretch
$\text{Na}_2\text{SO}_3$	Peak ( $\text{cm}^{-1}$ )	40/0.5	40/1.1	40/2.1	60/0.5	60/1.1	60/2.1	120/0.5	120/1.1	120/2.1	Group
	660	85.8	92.9	83.4	86.9	87.5	87.1	83.5	89.2	88.6	C—H
	1060	85.5	86.3	82.1	87.0	87.7	78.8	78.7	88.3	86.6	C—O stretch
	1630	85.6	84.7	85.7	86.8	86.7	86.1	86.5	88.0	86.9	C=O or C=C
	2925	88.3	86.8	88.2	88.7	89.0	88.5	88.8	89.5	89.2	—C—H stretch
	3435	76.8	73.6	81.5	77.8	77.8	76.6	84.6	80.3	77.3	O—H stretch

transmissivity of the peaks at  $3435\text{ cm}^{-1}$ ,  $2925\text{ cm}^{-1}$ ,  $1630\text{ cm}^{-1}$  and  $1060\text{ cm}^{-1}$  achieved the maximum for 120 min and the concentration was 19 g/1000 g. For FT-IR spectra of S, the transmissivity of the peaks at  $3435\text{ cm}^{-1}$ ,  $2925\text{ cm}^{-1}$ ,  $1630\text{ cm}^{-1}$  and  $1060\text{ cm}^{-1}$  achieved the maximum for 20 min and the concentration was 11 g/1000 g, 17 g/1000 g and 21 g/1000 g. For FT-IR spectra of  $\text{Na}_2\text{SO}_3$ , the transmissivity of the peaks at  $3435\text{ cm}^{-1}$  achieved the maximum for 120 min and the concentration was 5 g/1000 g, the transmissivity of the peaks at  $2925\text{ cm}^{-1}$ ,  $1630\text{ cm}^{-1}$  and  $1060\text{ cm}^{-1}$  achieved the maximum for 120 min and the concentration was 11 g/1000 g. In these states, the number of the transmissivity of the maximum peaks is the largest.

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### Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.sjbs.2016.09.005>.

### References

- Chen, W.H., Yao, G.S., 2009. Harm and controlling of acidity and ash content in liquid sulfur. *J. Chem. Eng.* 30, 55–57.
- Cui, L., Wan Xi, P., Zheng Jun, S., Li Li, S., Guo Ning, C., 2014. Weibull statistical analysis of tensile strength of vascular bundle in inner layer of moso bambooculm in molecular parasitology and vector biology. *Pak. J. Pharm. Sci.* 27, 1083–1087.
- Cui, L., Wan Xi, P., Zheng Jun, S., Huang Fei, L., 2015. Guoning Chen. Variability of macroscopic dimensions of Moso bamboo. *Pak. J. Pharm. Sci.* 28, 675–679.
- Liu, Q.M., Ying She, L., Shui Ping, Y., Sheng Ming, C., Dang Quan, Z., Wan Xi, P., 2008. Liquid rheology study on refined rapeseed oil. *J. Cent. South Univ. Technol.* 15, 525–528.
- Peng, W.X., Lan Sheng, W., Feng Juan, W., Qiu, X., 2011. 3-(4-Bromophenyl)-4-(4-hydroxyanilino)furan-2(5H)-one. *Acta Crystallogr. E* 67, O2329–U206.
- Peng, W.X., Lan Sheng, W., Qiu, X., Qing Ding, W., Shi Long, X., 2012a. TD-GC-MS analysis on thermal release behavior of poplar composite biomaterial under high temperature. *J. Comput. Theor. Nanosci.* 9, 1431–1433.
- Peng, W.X., Feng Juan, W., Lan Sheng, W., Qiu, X., 2012b. Crystal structure of 3-(4-bromophenyl)-4-(4-chlorophenylamino)furan-2(5H)-one  $\text{C}_{16}\text{H}_{11}\text{BrClNO}_2$ . *Z. Krist.-New. Cryst. St.* 227, 61–62.
- Peng, W.X., Zhi, L., Jun Bo, C., Fang Liang, G., Xiang Wei, Z., 2013a. Biomedical molecular characteristics of YBSJ extractives from *illicium verum* fruit. *Biotechnol. Biotechnol. Equip.* 27, 4311–4316.

- Peng, W.X., Lan Sheng, W., Zhi, L., Ming Long, Z., 2013b. Identification and chemical bond characterization of wood extractives in three species of eucalyptus biomass. *J. Pure Appl. Microbiol.* 7, 67–73.
- Peng, W.X., Lan Sheng, W., Ming Long, Z., Zhi, L., 2013c. Molecule characteristics of eucalyptus hemicelluloses for medical microbiology. *J. Pure Appl. Microbiol.* 7, 1345–1349.
- Peng, W.X., Qiu, X., Makoto, O., 2014a. Immune effects of extractives on bamboo biomass self-plasticization. *Pak. J. Pharm. Sci.* 27, 991–999.
- Peng, W.X., Sheng Bo, G., Dong Li, L., Bo, M., Dao Chun, Q., Makoto, O., 2014b. Molecular basis of antibacterial activities in extracts of *Eucommia ulmoides* wood. *Pak. J. Pharm. Sci.* 27, 2133–2138.
- Peng, W.X., Lan sheng, W., Ming Long, Z, Zhi, L., 2014c. Separation characteristics of lignin from *Eucalyptus camaldulensis* lignincelluloses for biomedical cellulose. *Pak. J. Pharmaceut. Sci.* 27, 723–728.
- Peng, W.X., Zhi, L., Hong, C., Jian Guo, W., 2015. Biochemical group characteristics of self-bonded boards during acidic oxidation for public health. *J. Pure Appl. Microbiol.* 9, 307–311.
- Qi, H.C., Wan Xi, P., Yi Qiang, W., Shu Bin, W., Gan Jun, X., 2012. Effects of alkaline extraction on micro/nano particles of eucalyptus *camaldulensis* biology. *J. Comput. Theor. Nanosci.* 9, 1525–1528.
- Sun, Y.C., Zhi, L., Wan Xi, P., Tong Qi, Y., Feng, X., Yi Qiang, W., Jing, Y., Yang Sheng, W., Run Cang, S., 2014. Chemical changes of raw materials and manufactured binderless boards during hot pressing: lignin isolation and characterization. *Bioresources* 9, 1055–1071.
- Wang, J.X., Li Xiong, W., Zhi, Hui W., Jian, Feng C., 2006. Immobilization of silver on hollow silica nanospheres and nanotubes and their antibacterial effects. *Mater. Chem. Phys.* 96, 90–97.
- Wang, Z.Z., Pin, L., Yuan, H., Ke Liang, H., 2009. Thermal degradation study of intumescent flame retardants by TG and FT-IR: melamine phosphate and its mixture with pentaerythritol. *J. Anal. Appl. Pyrol.* 86, 207–214.
- Wang, L.S., Wan Xi, P., Ming Long, Z., Zhi, L., 2013. Separation characteristics of lignin from eucalyptus lignincellulose for medicinal biocellulose preparation. *J. Pure Appl. Microbio.* 7, 59–66.
- Xiao, Z.P., Zhi Yun, P., Jing Jun, D., Rui Cheng, D., Xu Dong, W., Hui, O., Pan, Y., Juan, H., Yuan Feng, W., Man, Z., Xiao Chun, P., Wan Xi, P., Hai Liang, Z., 2013. Synthesis molecular docking and kinetic properties of beta-hydroxy-beta-phenylpropionyl-hydroxamic acids as *Helicobacter pylori* urease inhibitors. *Eur. J. Med. Chem.* 68, 212–221.
- Yang, F.C., Kuo Hui, W., Ming Jie, L., Wen Po, L., Ming Kuan, H., 2005. Evaluation of the antibacterial efficacy of bamboo charcoal/silver biological protective material. *Mater. Chem. Phys.* 113, 474–479.
- Zhang, D.Q., Sheng Ming, C., Wan Xi, P., Qi Mei, L., Zhen Jun, G., Shao Gang, F., Shun Yang, D., 2008. Rheology study of supercritically extracted tea-oil. *J. Cent. South Univ.* 15, 506–508.