ORIGINAL ARTICLE

Desulphurization characteristics of bamboo charcoal from sulfur solution

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Abstract
Sulfur powder and sulfur dioxide (SO\textsubscript{2}) 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\textsubscript{2}(SO\textsubscript{4})\textsubscript{3}'s, Na\textsubscript{2}SO\textsubscript{4}'s, Na\textsubscript{2}S\textsubscript{2}O\textsubscript{8}'s, S's, and Na\textsubscript{2}SO\textsubscript{3}'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\textsubscript{2}(SO\textsubscript{4})\textsubscript{3}, the transmissivity of the peaks at 3435 cm\textsuperscript{-1}, 2925 cm\textsuperscript{-1}, 1630 cm\textsuperscript{-1}, 1060 cm\textsuperscript{-1} and 660 cm\textsuperscript{-1} achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm\textsuperscript{-1}, 1060 cm\textsuperscript{-1} and 660 cm\textsuperscript{-1} achieved the maximum for 60 min and the concentration was 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 Na\textsubscript{2}SO\textsubscript{4}, the transmissivity of the peaks at 1630 cm\textsuperscript{-1}, 1060 cm\textsuperscript{-1} and 660 cm\textsuperscript{-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 Na\textsubscript{2}S\textsubscript{2}O\textsubscript{8}, the transmissivity of the peaks at 3435 cm\textsuperscript{-1}, 2925 cm\textsuperscript{-1}, 1630 cm\textsuperscript{-1}, 1060 cm\textsuperscript{-1} and 660 cm\textsuperscript{-1} achieved the maximum for 20 min and the concentration was 13 g/1000 g, 19 g/1000 g and 21 g/1000 g. For FT-IR spectra of S, the transmissivity of the peaks at 3435 cm\textsuperscript{-1}, 2925 cm\textsuperscript{-1}, 1630 cm\textsuperscript{-1}, 1060 cm\textsuperscript{-1} and 660 cm\textsuperscript{-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 Na\textsubscript{2}SO\textsubscript{3},

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the transmissivity of the peaks at 3435 cm\(^{-1}\) achieved the maximum for 120 min and the concentration was 5 g/1000 g, the transmissivity of the peaks at 2925 cm\(^{-1}\), 1630 cm\(^{-1}\) and 1060 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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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: SO\(_2\) concentrations in the atmosphere for every 10 \(\mu\)m/ \(m^3\), respiratory disease deaths in increments of 5% (Zou, 1991). Sulfur powder and sulfur dioxide (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 600–900°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, Fe\(_2\)(SO\(_4\))\(_3\), Na\(_2\)SO\(_4\), Na\(_2\)S\(_2\)O\(_8\), S, and Na\(_2\)SO\(_3\) were purchased from the market.

Fe\(_2\)(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. Na\(_2\)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. Na\(_2\)S\(_2\)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 Na\(_2\)SO\(_4\) 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 Fe\(_2\)(SO\(_4\))\(_3\) were 7 g/1000 g, 19 g/1000 g, 21 g/1000 g, Fe\(_2\)(SO\(_4\))\(_3\)’s adsorption capacity were 0.99 g/100 g, 6.84 g/100 g, 2.98 g/100 g, 1.26 g/100 g, 0.75 g/100 g, 5.32 g/100 g, 0.74 g/100 g, 0.5 g/100 g, 3.79 g/100 g for the stir time of 20 min, 40 min, 60 min, respectively. When the concentrations of Na\(_2\)SO\(_4\) were 13 g/1000 g, 19 g/1000 g, 21 g/1000 g, Na\(_2\)SO\(_4\)’s adsorption capacity were 0.7 g/100 g, 0.5 g/100 g, 0.5 g/100 g, 0.25 g/100 g, 1.26 g/100 g, 0.5 g/100 g, 4.23 g/100 g, 0.25 g/100 g, 2.01 g/100 g, 1.99 g/100 g for the stir time of 20 min, 40 min, 60 min, 80 min, respectively. When the concentrations of Na\(_2\)S\(_2\)O\(_8\) were 7 g/1000 g, 13 g/1000 g, 19 g/1000 g, Na\(_2\)S\(_2\)O\(_8\)’s adsorption capacity were 1.76 g/100 g, 1.52 g/100 g, 1.77 g/100 g, 0.75 g/100 g, 1 g/100 g, 0.5 g/100 g, 4.36 g/100 g, 0 g/100 g.
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, Na2SO4’s adsorption capacity were 7 g/1000 g, 2.23 g/1000 g, 3 g/1000 g, 6.84 g/1000 g, 0.25 g/1000 g, 3.5 g/1000 g, respectively. For FT-IR spectra of Na2SO4, the transmissivity of the peaks at 1630 cm⁻¹ and 660 cm⁻¹ achieved the maximum for 60 min and the concentration was 13 g/1000 g, the transmissivity of the peaks at 660 cm⁻¹ 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⁻¹ and 1630 cm⁻¹ achieved the maximum for 20 min and the concentration was 21 g/1000 g, the transmissivity of the peaks at 2925 cm⁻¹ achieved the maximum for 20 min and the concentration was 11 g/1000 g, the transmissivity of the peaks at 1060 cm⁻¹ achieved the maximum for 20 min and the concentration was 17 g/1000 g, the transmissivity of the peaks at 660 cm⁻¹ achieved the maximum for 100 min and the concentration was 11 g/1000 g.

For FT-IR spectra of Na2SO3, the transmissivity of the peaks at 3435 cm⁻¹ achieved the maximum for 120 min and the concentration was 5 g/1000 g, the transmissivity of the peaks at 2925 cm⁻¹, 1630 cm⁻¹ and 1060 cm⁻¹ achieved the maximum for 120 min and the concentration was 11 g/1000 g, the transmissivity of the peaks at 660 cm⁻¹ achieved the maximum for 120 min and the concentration was 11 g/1000 g.

### Table 1 Adsorption results.

| SC [%] | Fe₃(SO₄)₂ | SC [%] | Na₂SO₄ | SC [%] | Na₂S₂O₈ | SC [%] | S | SC [%] | Na₂SO₃ |
|--------|----------|--------|--------|--------|---------|--------|---|--------|--------|
| Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] | Stir time [min] |
| 20 | 0.7 | –0.7 | 1.76 | 1 | 0.75 | 4.36 | 1.1 | 2 | 2.23 |
| 60 | 0.99 | 0.25 | 0.25 | 0.5 | 0.5 | 1 | 1.7 | 0.5 | 6.22 |
| 120 | 1.3 | 1 | 0.75 | 1 | 0.5 | 0.25 | 1.1 | 0.7 | 2 |

Note: SC – Concentration of sulfur solution.

### 3.2. FT-IR analysis

FT-IR spectra were recorded to investigate the functional groups of bamboo charcoal during adsorption of Fe₃(SO₄)₂, Na₂SO₄, Na₂S₂O₈, S, and Na₂SO₃. 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, H=O, were observed at 3435 cm⁻¹, 2925 cm⁻¹, 1630 cm⁻¹, 1060 cm⁻¹, 660 cm⁻¹, 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 Fe₃(SO₄)₂, the transmissivity of the peaks at 3435 cm⁻¹ and 2925 cm⁻¹ achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm⁻¹, 1060 cm⁻¹ and 660 cm⁻¹ achieved the maximum for 60 min and the concentration was 7 g/1000 g.

For FT-IR spectra of Na₂SO₄, the transmissivity of the peaks at 3435 cm⁻¹ and 2925 cm⁻¹ achieved the maximum for 60 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 1630 cm⁻¹, 1060 cm⁻¹ and 660 cm⁻¹ achieved the maximum for 60 min and the concentration was 7 g/1000 g.

For FT-IR spectra of Na₂S₂O₈, the transmissivity of the peaks at 3435 cm⁻¹, 2925 cm⁻¹, 1630 cm⁻¹ and 1060 cm⁻¹ achieved the maximum for 120 min and the concentration was 19 g/1000 g, the transmissivity of the peaks at 660 cm⁻¹ achieved the maximum for 40 min and the concentration was 7 g/1000 g.
transmissivity of the peaks at 3435 cm\(^{-1}\), 2925 cm\(^{-1}\), 1630 cm\(^{-1}\) and 1060 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 cm\(^{-1}\), 2925 cm\(^{-1}\), 1630 cm\(^{-1}\) and 1060 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 Na\(_2\)SO\(_3\), the transmissivity of the peaks at 3435 cm\(^{-1}\) achieved the maximum for 120 min and the concentration was 5 g/1000 g, the transmissivity of the peaks at 2925 cm\(^{-1}\), 1630 cm\(^{-1}\) and 1060 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.

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