Study on Surface Modification and Properties of Filtration for Industrial Flue Gas Fine Particulate Matter Control and Low Carbon Emission

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Abstract. In order to further improve the filtration performance of glass fiber filter material, the surface of glass fiber filter material was modified by preparation of nano-$\text{SiO}_2$ and polytetrafluoroethylene (PTFE) emulsion compound finishing solution, and the permeability and filtration efficiency of the filter material before and after modification were tested. The results show that the filtration performance of the filter material is improved after surface modification. The content of $\text{SiO}_2$ is 0.8g, the mass fraction of PTFE is 5%, the finishing time is 6h, the filtration efficiency of the modified filter material is 64.67%. At this time, the quality factor is the maximum, and meet the requirements of high efficiency and low resistance.

Keywords: Filtration material, surface modification, filtration performance, air permeability.

1. Introduction
With the progress of the society, the public has more awareness of environmental protection. In order to control fine particulate matter of industrial flue gas and achieve ultra-low emission, the use of bag dust remover accounts for 90% or more in steel industry, cement industry, waste incineration and other industrial fields [1,2]. As the core material of industrial dust catcher, filter material plays a decisive role in winning the battle of pollution prevention and control. Because the needle filter material has the characteristics of small porosity, good filtration accuracy, low filtration resistance, excellent air permeability and high capture efficiency. In recent years, it has attracted much attention. However, the actual working environment is harsh and complex, and most of the filter materials can not maintain their basic performance under the conditions of high temperature, high humidity and strong corrosion. In order to meet the different use environment of the filter material differential and functional requirements, the need to filter material after finishing. Exploring the post-finishing process and performance differences of different types of filter materials, from the perspective of improving the collecting efficiency and prolonging the service life of filter materials. Glass fiber filter material is used more in medium and high temperature dust filtration. It can resist the high temperature of 350°C instantaneously, and can be used continuously in the environment of 280°C without alkali working condition. It has low shrinkage rate at high temperature, good dust stripping ability, low energy...
consumption for ash removal, great price advantage, but poor wear resistance and folding resistance [3]. The P84/ microfiber composite filter material was modified with PTFE emulsion to improve the filtration performance and mechanical properties of the filter material [4]. In this paper, nano-SiO$_2$ dispersion and PTFE emulsion are used to prepare the finishing solution to modify the glass fiber needle punched filter material, and exploring the influence of different factors and levels on the air permeability and filtration performance of the filter material. The reasonable development and utilization of filter media has very important practical application significance for protecting the environment.

2. Experimental

2.1. Materials and equipment

Glass fiber needle punched filter material (mass per unit area of 950g/m$^2$, Hebei Fengmiao Environmental Protection Equipment Co., Ltd.), nano-SiO$_2$ (particle size 20nm, Wuxi Taipeng Metal Material Co., Ltd.), silane coupling agent KH550 (Shanghai Macklin Biochemical Technology Co., Ltd.), PTFE (mass fraction 60%, Dongguan Zhanyang Polymer Materials Co., Ltd.), polyvinyl alcohol 105 (Shanghai Macklin Biochemical Technology Co., Ltd.) polyethylene glycol 2000 (Shanghai Macklin Biochemical Technology Co., Ltd.), deionized water (resistivity 18.25 MΩ·cm, laboratory made).

GZX-9146MBE electric heating blast drying oven (Shanghai Boxun Industrial Co., Ltd.), FA2004 analytical balance (Shanghai Hengping Instrument Instrument Factory), DF-101S heat-collection constant temperature heating magnetic agitator (Zhengzhou Biochemical Instrument Co., Ltd.), KQ-300B ultrasonic cleaner (Kunshan Ultrasonic Instrument Co., Ltd.), HH-6 digital display constant temperature water bath (Jantian City Youlian Instrument Research Institute), YG (B) 461E automatic fabric breathable performance tester (Wenzhou City Darong Textile Instrument Co., Ltd.), ZFT filter material automatic tester (Beijing Institute of Labor Protection Science).

2.2. Preparation of finishing solution

KH550 was added into the deionized water, stirred for 30min, and set aside. Nano-SiO$_2$ was added into the deionized water and stirred for 1h at a rotating speed of 1000r/min, followed by ultrasonic vibration for 20min to obtain a stable nano-SiO$_2$ suspension. PTFE emulsion, KH550 solution, nano-SiO$_2$ suspension, polyvinyl alcohol and polyethylene glycol solid powder were taken to prepare the finishing solution according to the proportion. The finishing solution was mixed in a magnetic stirrer at 1000r/min for 1h at a temperature of 80°C.

2.3. Surface modification finishing

Ultrasonic cleaning machine is used to clean the original sample of the filter material. The electric power is 300W, the frequency is 40KHz, and the ultrasonic cleaning time is 10min. The press cloth sample was put into the finishing solution and heated in a water bath at 80°C. After impregnation for different times, the excess finishing solution was removed and removed. The filter material was dried at 105°C for 60min.

2.4. Performance test and characterization

2.4.1. Air permeability test. According to GB/T 24218.15-2018 "Textiles Nonwovens Test Method Part 15: Determination of Air Permeability", the pressure difference was set at 200 Pa, the area of the test table was 20 cm$^2$, and the pre-temperature and humidity test conditions were 20±2°C, 65±2%. Testing the air permeability for 5 times and take the average value.
2.4.2. Filtration performance test. According to GB 2626-2006, the filter material automatic tester is used to test the resistance and filtration efficiency of the filter material. During the test, salt NaCl particles with particle size of 0.3 μm were used, and the test area was 80 cm². Under the condition of air flow of 85L/min, the filtration efficiency (η) of the filter material is tested. The efficiency is determined by the upstream (\(C_{\text{up}}\)) and downstream (\(C_{\text{down}}\)) concentrations of the filter material measured by the air particle counter. The equation for the calculation of the filtration efficiency is as follow:

\[
\eta = 1 - \frac{C_{\text{down}}}{C_{\text{up}}}
\]

Each sample is tested for 5 times at different positions and the average value is obtained.

3. Results and Discussion

3.1. Air permeability

The change in the permeability of the filter material before and after surface modification is represented by the reduction of the permeability, that is, the absolute value of the difference of the permeability of the filter material before and after surface modification, see Fig. 1-3. Under the same condition of PTFE mass fraction and finishing time, when the content of nano-SiO₂ is 1.3g, the permeability of the filter material decreases by 532.02mm/s. Under the same conditions of nano-SiO₂ content and finishing time, the reduction of filter material permeability is 532.02mm/s when the mass fraction of PTFE is 10%. Under the condition of the same content of nano-SiO₂ and mass fraction of PTFE, the reduction of air permeability is 580.92mm/s when the finishing time is 6h.

\[\text{Figures 1-3.} \]

3.2. Filtration performance

Filtration efficiency is an important index to measure the performance of the filter material. The filtration efficiency of the glass fiber filter material before surface modification is 36.035%, and the filtration resistance is 100Pa. By changing the factors and levels, the surface of the filter material was modified, and the filtration efficiency and filtration resistance were measured, see Table 1. When the mass fraction of PTFE and finishing time are the same, the filtration efficiency and filtration resistance are 72.540% and 189Pa, when the content of nano-SiO₂ is 0.8g. When the content of nano-SiO₂ and the
finishing time are the same, the filtration efficiency is 64.49% and the filtration resistance is 183Pa, when the mass fraction of PTFE is 10%. When the content of nano-SiO₂ and the mass fraction of PTFE are the same, the finishing time is 6 hours, the filtration efficiency is 64.67%, and the filtration resistance is 233Pa.

Table 1. The influence of different factors and levels on filtration efficiency and filtration resistance.

| Nano-SiO₂ content (g) | Filtration efficiency (%) | Resistance (Pa) | PTFE mass fraction (%) | Filtration efficiency (%) | Resistance (Pa) | Time (h) | Filtration efficiency (%) | Resistance (Pa) |
|-----------------------|---------------------------|----------------|------------------------|---------------------------|----------------|---------|---------------------------|----------------|
| 0.3                   | 52.766                    | 155            | 5                      | 64.49                     | 183            | 3       | 63.60                     | 237            |
| 0.8                   | 72.540                    | 189            | 10                     | 63.60                     | 237            | 4       | 55.04                     | 185            |
| 1.3                   | 63.596                    | 237            | 15                     | 62.91                     | 250            | 5       | 58.56                     | 213            |
| 1.8                   | 60.143                    | 196            | 20                     | 53.15                     | 247            | 6       | 64.67                     | 233            |

3.3. Quality factor
A good filter material should not only give high efficiency but also keep pressure drop across the filter material as low as achievable. Consequently, the quality factor, Q, is introduced to evaluate the filtration characteristics of the filter material. Q value is greater, the filter material can meet the requirements of high efficiency and low resistance. The equation for the calculation of the quality factor is as follow:

\[
Q = -\frac{\ln(1-\eta)}{\Delta P}
\]

(2)

Where \(\Delta P\) is the filtration resistance.

Quality factors of each group are calculated, see Fig. 4-6. Without surface modification of the glass fiber filter material quality factor Q=0.00447. When the mass fraction of PTFE and finishing time are the same, the content of nano-SiO₂ is 0.8g, Q=0.00684. When the content of nano-SiO₂ and finishing time are the same, and the mass fraction of PTFE is 5%, Q=0.00566. When the content of nano-SiO₂ and the mass fraction of PTFE are the same, and the finishing time is 6h, Q=0.00446.
4. The Reaction Mechanism
Using KH550 as the coupling agent, the silyl alcohol group generated after hydrolysis reaction can be condensed with the hydroxyl groups on the surface of glass fiber and nano-$\text{SiO}_2$, they can be chemically grafted onto the surface of the fiber. The reaction process is shown in Fig. 7.

\[ \text{Si}-\text{OC}_2\text{H}_5 + 3\text{H}_2\text{O} \xrightarrow{\text{hydrolysis}} \text{Si}-\text{OH} + 3\text{C}_2\text{H}_5\text{OH} \]

\[ \text{Si}-\text{OH} \xrightarrow{\text{condensation}} \text{SiO}_2 + 2\text{H}_2\text{O} \]

Figure 7. The reaction process.

5. Conclusion
By mixing nano-$\text{SiO}_2$ dispersion with PTFE emulsion and modifying the surface of the glass fiber filter material, the filtering efficiency of the filter material can be effectively improved. When the content of $\text{SiO}_2$ is 0.8g, the mass fraction of PTFE is 5%, and the finishing time is 6h, the filtration efficiency of the modified filter material is 64.67%. At this time, the quality factor is the largest, can meet the requirements of high efficiency and low resistance.

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