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Production and pre-oxidation of the activated carbon fibre needle felt using in the prevention and control of water pollution

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ABSTRACT

This paper attempts to explore the properties of activated carbon fibre (ACF) nonwovens, especially ACF needle felt. Specifically, needle felts were made by blending acrylic fibres with viscose fibres at the ratio of 1:4. Then, the product was pre-oxidised in air at 230°C–250°C. Then, the production and pre-oxidation of the ACF needle felt were discussed in details. Through the analysis, the optimal parameters of pre-oxidation were determined as the pre-oxidation temperature of 250°C, the pre-oxidation time of 50 min, and the air velocity of 1,000 mL/min. The water content of the pre-oxidised needle felt was controlled at 8.02%, which is suitable for the production of ACF. This research sheds new light on the production and application of the ACF needle felt, a well-accepted green material.

Keywords: Activated carbon fibre (ACF); Viscose; Needle felt; Pre-oxidisation

1. Introduction

With the growth in environmental awareness, many environmental friendly products have entered the market. A typical example is the popular air purifier of porous activated carbon [1]. As the third generation of activated carbon, activated carbon fibre (ACF) enjoys better performance than powdered and granular activated carbons. With a small diameter and narrow distribution of pore size, the ACF can achieve a low minimum dosage and fast adsorption and desorption. The ACF cloth, as a novel activated carbon adsorbent, has been extensively applied in industrial production [2]. Nevertheless, there is few report on the application of ACF nonwovens, especially ACF needle felt [3,4].

To make up for the gap, this paper produces needle felts by blending acrylic fibres with viscose fibres and then pre-oxidising the product in air at 230°C–250°C. Then, the production and pre-oxidation of the ACF needle felt were discussed in details.

2. Production of ACF needle felt

2.1. Raw materials

It is difficult to produce pure acrylic nonwovens, due to the smooth surface, high rigidity, and poor spinning performance of acrylic fibres [5]. Fortunately, the acrylic ACF shares a similar production process with viscose-based carbon fibre, which boasts a good spinnability. The previous studies have shown that the optimal blending ratio between viscose fibre and acrylic fibre is 1:4. Besides, there is no need to add oil during carding and needling, because the oil hinders the

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absorbability of the ACF. The properties of the raw materials are shown in Table 1.

2.2. Production process

The ACF needle felt was produced through the following steps: mixing acrylic and viscose fibres, air delivery, open-air mixing, carding, fibre network stacking, pre-needling, primary needling, trimming, and winding.

The ACF needle felt thus produced is smooth on surface and uniform in thickness, without any tear, oil, impurity, or stratification. The main parameters of the felt are as follows: width 2 mm, thickness 3 mm, mass 300 g/cm, longitudinal strength 185 N/5 cm, and lateral strength 174 N/5 cm.

3. Pre-oxidation

3.1. Pre-oxidation process

The ACF needle felt was subjected to pre-oxidation in a homemade batch pre-oxidation furnace (Fig. 1).

First, the needle felt was placed on a stainless steel mesh. Then, the stainless steel mesh, together with the needle felt, was relocated onto the bracket of the pre-oxidation furnace. After closing the door of the furnace, the needle felt was heated up from 20°C to pre-oxidation temperature (200°C–300°C) at the rate of 10°C/min. The pre-oxidation lasts for about 30–60 min. Meanwhile, the air was introduced from a compressed air cylinder into the furnace at a certain flow, aiming to ensure the effect of pre-oxidation and remove the heat and by-products.

Table 1
Properties of raw materials

Fibre	Acrylic	Viscose
Strength, (cN·dtex^{-1})	4.5	4.2
Elongation at break, %	16–19	8
Density, g·cm^{-3}	1.19	1.52
Regaining rate, %	0.6	1.3
Fineness, μm	11	12
Length, mm	51–65	51–65
Blended ratio, %	80	20

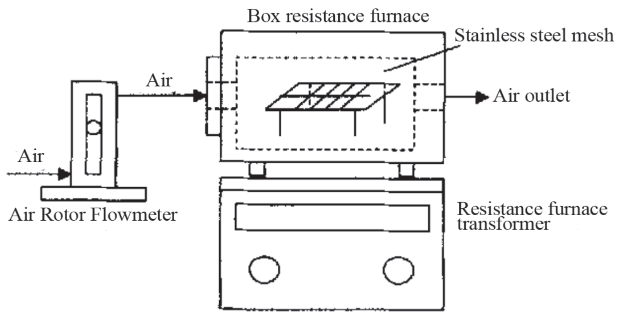

Fig. 1. Pre-oxidation furnace.

The pre-oxidation involves several exothermic reactions, such as oxidation, dehydrogenation, denitrification, and macromolecular cyclisation. The heat released from these reactions were carried away timely by the air flow, so that the heat did not build up and the fibre was not burnt. The air flow also ensures the constant and uniformity of the furnace temperature, such that the pre-oxidation could proceed smoothly.

During the pre-oxidation, the fibres in the needle felt shrank physically and chemically. The physical shrinkage rate is 4%–16% and the chemical shrinkage rate is 14%–35%. Due to shrinkage, the pre-oxidised fibres became thick, brittle, and fragile. To prevent these negative effects, stainless steel clips were applied to fix the four sides of the nonwoven fabric onto the stainless steel mesh.

3.2. Pre-oxidation degree

Through pre-oxidation, oxygen-containing polar groups were produced in the cyclic ladder structure of fibre macromolecules. These groups formed hydrates with water, pushing up the water content of the fibres. The oxygen content in pre-oxidised fibres is positively correlated with the cyclisation degree and the water content. Hence, the water content can be expressed as the pre-oxidation degree of the fibres.

To determine the pre-oxidation degree, an experiment was carried out using a 0.0001 g balance, an oven with the temperature range of 0°C–300°C, a dryer with colour-changing silica gel, and a constant weight weighing bottle. First, a certain amount of needle felt sample was weighed on the balance. The wet weight of the sample is denoted as m_1 (g). Then, the sample was placed into the pre-dried weighing bottle, and relocated to the oven for drying at 105°C–110°C for 2 h. The dry weight of the sample is denoted as m_2 (g). Finally, the water content M of the sample can be obtained by the following:

$$M = (m_1 - m_2)/m_1 \times 100\% \quad (1)$$

4. Results and discussion

4.1. Orthogonal test results

The pre-oxidation degree is affected by three factors such as pre-oxidation temperature, pre-oxidation time, and air velocity. The three factors are displayed on four levels in Table 2. Without considering the interaction between these factors, an orthogonal test $L_{16}(4^3)$ was designed, and the results were recorded in Table 3. The analysis of variance (ANOVA) results of the test are displayed in Table 4.

Table 2
Three factors and four-level table

Level	Temperature, °C	Time, min	Air velocity, mL·min^{-1}
1	230	30	1,000
2	240	40	1,200
3	250	50	1,400
4	260	60	1,600

As shown in Table 4, the pre-oxidation temperature and pre-oxidation time directly bear on the water content, but the air velocity has little to do with the water content. During the production of the needle felt, the degree of pre-oxidation must be controlled within an appropriate range. Otherwise, the mechanical properties of the ACF will be undermined. The optimal water content of pre-oxidised acrylic fibre is 8%. From Tables 3 and 4, the optimal parameters can be derived from the results of the No. 11 test: pre-oxidation temperature of 250°C, pre-oxidation time of 50 min and the air velocity of 1,000 mL/min. With these parameters, the water content of the pre-oxidised needle felt can be controlled at 8.02%.

4.2. Single-factor test

Based on the results of orthogonal test, a single-factor test was carried out with two of the three optimal parameters being constants. The test results are shown in Figs. 2–4.

As shown in Figs. 2–4, the water content increased with pre-oxidation temperature, pre-oxidation time, and air velocity. Among them, the temperature has the greatest effect on the water content, followed by time and air velocity. The practice has shown that the air velocity must be determined according to the thickness of the needle felt. So, the proper data should be identified based on the actual situation.

Table 3
Orthogonal test results

Experiment number	Temperature, °C	Time, min	Air velocity, mL·min^{-1}	Moisture content, %
1	230	30	1,000	2.56
2	230	40	1,200	3.01
3	230	50	1,400	3.42
4	230	60	1,600	3.67
5	240	30	1,200	4.32
6	240	40	1,000	4.41
7	240	50	1,600	4.93
8	240	60	1,400	5.60
9	250	30	1,400	6.76
10	250	40	1,600	7.53
11	250	50	1,000	8.02
12	250	60	1,200	8.67
13	260	30	1,600	7.95
14	260	40	1,400	8.10
15	260	50	1,200	8.78
16	260	60	1,000	9.53

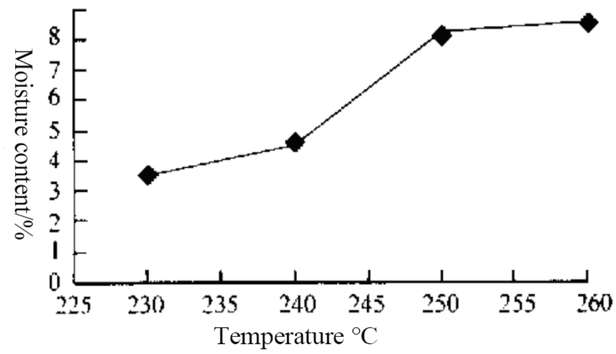

Fig. 2. Relationship between water content and pre-oxidation temperature.

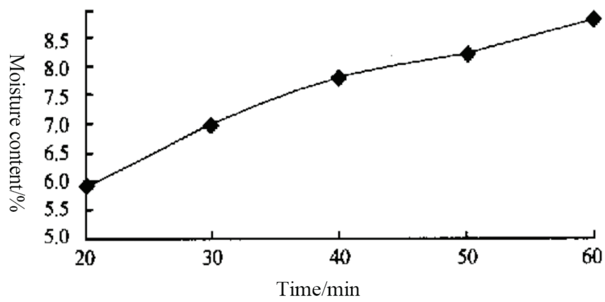

Fig. 3. Relationship between water content and pre-oxidation time.

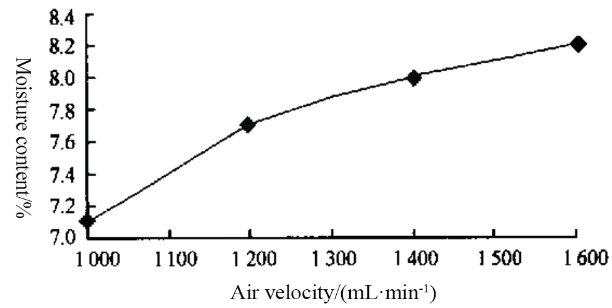

Fig. 4. Relationship between water content and air velocity.

Table 4
ANOVA results

Sources of variance	Sum of square	Degree of freedom	Sum of mean square	*F* value	Significance
Temperature	76.68	3	25.56	16.60	Obvious
Time	22.59	3	7.53	4.89	Obvious
Air velocity	9.56	3	3.19	2.07	Not obvious
Random error	9.26	6	1.54		
Sum	118.09	15			

Note: Fc(0.05) = 4.76 Fc(0.01) = 10.9.

5. Conclusions

This paper discusses the production of ACF needle felt and analyses the pre-oxidation of the product. With the blending ratio of 1:4 between viscose fibre and acrylic fibre, a uniform ACF needle felt was produced without adding any chemical oil. The elimination of oil is to prevent the negative impacts on ACF adsorption.

Through the analysis, the optimal parameters of pre-oxidation were determined as the pre-oxidation temperature of 250°C, the pre-oxidation time of 50 min, and the air velocity of 1,000 mL/min. The water content of the pre-oxidised needle felt was controlled at 8.02%, which is suitable for the production of ACF. This research sheds new light on the production and application of the ACF needle felt, a well-accepted green material.

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