IMPROVEMENT OF AIR PERMEABILITY OF BUBBFIL NANOFIBER MEMBRANE

by

Fei-Yan WANG[a,b], Ji-Huan HE[c*], Qi-Long SUN[a], and Jin YU[a]

[a] School of Textile and Clothing, Nantong University, Nantong, China
[b] College of Textiles, Donghua University, Songjiang District, Shanghai, China
[c] National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering, Soochow University, Suzhou, China

Original scientific paper
https://doi.org/10.2298/TSCI160715142W

Nanofiber membranes always have extremely high filter efficiency and remarkably low pressure drop. In order to further improve air permeability of bubbfil nanofiber membranes, the plasma technology is used for surface treatment in this paper. The results show that plasma treatment can improve air permeability by 4.45%. Under higher power plasma treatment, earthworm like etchings are produced on the membrane surface with fractal dimensions of about 1.138.

Key words: *air permeability, nanofiber, bubbfil spinning, fractal dimension, melt-blown non-woven fabric*

Introduction

A nanofiber membrane always has extremely excellent properties, *e. g.*, extremely high filter efficiency, relatively high air permeability, and high temperature resistance [1-3], so it can be widely used in water/air filtration and other advanced applications [4]. This paper is to search for a potential approach to further improvement of air permeability by plasma technology for industrial applications. Higher air permeability means lower energy loss, this is an extremely important for energy saving and environment protection.

The plasma technology is widely used in textile engineering to produce functional fabrics, *e. g.*, superhydrophobic fabrics [5, 6], to extend fabric's applications. Most previous work was focused on air permeability of fabrics [7], however, no research has been carried out so far for nanofiber membranes.

In general, the plasma is etched on the surface of the treated object. This paper will use fractal geometry to elucidate the basic property of the etched surface.

Air permeability

The air permeability is calculated using the formula:

$$K = \frac{Q}{\Delta PA} \tag{1}$$

where K [mms^{-1}], [Lm^{-2}s^{-1}] is the air permeability, Q – the flow rate, ΔP – the pressure drop, and A – the permeability area. During treatment, argon gas was used. After plasma treatment, the air permeability is changed, tab. 1.

* Corresponding author, e-mail: hejihuan@suda.edu.cn

Table 1. Air permeability change

Air permeability	Original [mms^{-1}]	After treatment [mms^{-1}]	Change [%]
Bubbfil nanofiber membrane	41.36	43.2	+4.45
Meltblown non-woven fabric	155.73	132.62	–14.84

The fiber diameter in the meltblown non-woven fabric is generally in micrometers, while that in the nanofiber membrane is in nanometers, and the average porosity diameter scales to the fiber diameter. So the meltblown non-woven fabric has a higher air permeability. Table 1 also elucidates that the air permeability of meltblown non-woven fabric decreases greatly from 155.73 mm/s to 132.62 mm/s after plasma treatment. This change is due to the plasma's etched surfaces and heat transfer during plasma treatment, which results in inter-fiber friction force [8] induced by the plasma treatment.

On the contrary, the bubbfil nanofiber membrane gives an increase in air permeability by 4.45% after plasma treatment. This change is possibly due to the morphology change of nanofiber structure. The plasma treatment has an etching effect and increases the functionality of the surface of nanofiber membrane.

The bubbfil nanofiber membrane considers three layers, the outer layers are non-woven fabrics, and the middle layer is the nanofiber membrane. The plasma treatment makes the outer layer non-woven fabric etched, as a result, the porous size of outer layer becomes smaller, which makes a matching hierarchical structure with nano porosity in nanofiber membrane. It has already proved that a hierarchical structure always sees high air permeability as shown in cocoons [9].

Pressure drop through a fabric with thickness of L depends mainly on fiber diameter, D, and fabric's porosity, δ:

$$\frac{\Delta p}{L} \propto \frac{f(\delta)}{D^2} \tag{2}$$

where $f(\delta)$ is a function of fabric's porosity.

The air permeability scales as:

$$K \propto D^2 \tag{3}$$

Equation (3) implies that the meltblown non-woven fabric has a higher air permeability than nanofiber membrane.

Surface etching

The bubbfil nanofiber membrane used in the experiments was supported by Nantong Bubbfil Nanotechnology Company Ltd. The meltblown non-woven fabric (24.4 g/m^2) was produced by Nantong University.

The plasma treatments were carried out using an atmospheric pressure plasma manufactured. The applied voltage 140 V (power 700 W) and 160 V (power 920 W) were considered, respectively. In this experiment; the period of treatment was 20 seconds.

In order to further study the surface etching, a higher voltage 180 V (power 1080 W) was also considered, the period of treatment was 30 seconds.

Under the lower power (700 W, 920 W) plasma treatment, the surface of the two kinds non-woven fabric have not visible changes to the naked eyes. So it is feasible to study their air permeability. But when the power reaches a threshold of 1020 W, etched curves are observed on the surface of nanofiber membrane, and only small dots are found on the melt-blown non-woven fabric, figs. 1. and 2, respectively.

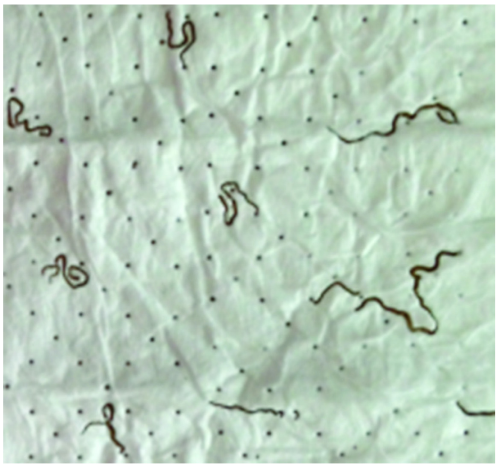

Figure 1. The surface of bubbfil nanofiber membrane

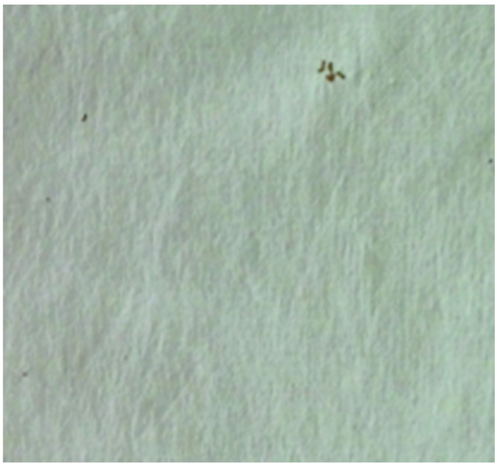

Figure 2. The surface of meltblown non-woven fabric

The bubbfil nanofiber membrane has three layers, but the meltblown non-woven fabric has only one layer. With the same power treatment, the surface of bubbfil has obviously etched, but the other no obviously changes to the naked eyes. Plasma treatment has a significant effect on the bubbfil nanofiber membrane, but it has no obvious effect on the meltblown non-woven fabric. In fact, it can lead to the decrease of the air permeability of the non-woven fabric.

Fractal analysis

Pressure drop through the meltblown non-woven fabric follows the Hagen-Poiseuille law:

$$\Delta P == \frac{128\mu LQ}{\pi d^4} \tag{4}$$

where d is the average porosity diameter, L – the thickness of the fabric, and μ – the dynamic viscosity. Equation (1) for meltblown non-woven fabric can be written in the form:

$$K = \frac{Q}{\Delta PA} = \frac{\pi d^4}{128\mu LA} \tag{5}$$

Compared with nanofiber membrane, the porosity diameter of meltblown non-woven fabric is much larger than that in nanofiber membrane, and a high air permeability is predicted, see tab. 1.

Pressure drop through nanofiber membrane has to be modified as [10]:

$$\Delta P = \frac{128\mu L^{\beta} Q}{\pi (d^{\alpha})^2} \tag{6}$$

where α and β are fractal dimensions for the section and height, respectively. Air permeability for the nanofiber membrane reads:

$$K = \frac{Q}{\Delta P A} = \frac{\pi (d^2)^{\alpha}}{128\mu L^{\beta} A} \tag{7}$$

The value of α is revealed in the etched curve. Plasma treatment enhances the connection among the porosities, resulting in improvement porous area, this is the reason why plasma treatment can improve air permeability greatly for nanofiber membranes. However, when a higher power of plasma treatment is used, etched curves are observed, tab. 2. The value of the fractal dimensions of etched curves are equivalent to α. In this paper 35 curves are randomly selected from the surface of the bubbfil nanofiber membrane, and their fractal dimensions are calculated by the mathematic expression [11]:

$$D = \frac{\ln M}{\ln N} \tag{8}$$

where M is the number of new units within the original unit with a new dimension, and N – the ratio of the original dimension to the new dimension. Fractal dimensions are calculated for each sample listed in tab. 2. The average fractal dimension obtained is 1.138.

Table 2. Fractal dimensions of etched curves

No.	1	2	3	4	5
Curve					
D	1.289	1.152	1.029	1.04	1.182
No.	6	7	8	9	10
Curve					
D	1.07	1.064	1.224	1.219	1.109

The fractal etched curves on nanofiber membranes reveal that nanofibers are very sensitive to plasma ions.

Conclusion

This paper shows that the plasma is an effective method to improve the permeability of nanofiber membrane, while it has an inverse effect for non-woven fabrics. Its mechanism has been elucidated, and we conclude that this technology has potential application in surface treatment of nanofiber membranes for practical applications with extremely high filtration efficiency and dramatically low pressure drop.

With a higher power plasma treatment, the surface of bubbfil nanofiber has many "earthworm like" curves with fractal dimensions of about 1.138.

Acknowledgment

The work is supported by Nantong Science and Technology project under grant No. GY12015022, Production and Research Prospective Joint Research Project of Jiangsu Province under grant No. BY2015047-09, and PAPD (A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions).

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Paper submitted: July 15, 2016
Paper revised: August 26, 2016
Paper accepted: December 4, 2016