Research Article

Design of Polymeric Nanofiber Gauze Mask to Prevent Inhaling PM2.5 Particles from Haze Pollution

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Recently, PM2.5 (particulate matter with diameter of 2.5 micron or less) has become a major health hazard from the polluted air in many cities in China. The regular gauze masks are used to prevent inhaling the PM2.5 fine particles; however, those masks are not able to filter out the PM2.5 because of the large porosity of the mask materials. Some well-prevented masks usually have poor breathability, which increases other health risks. In this study, a polysulfone based nanofiber for mask filtration material was synthesized by electrospinning. That nanofiber mask material was characterized by SEM, air permeability test, and PM2.5 trapping experiment. The results indicate that nanofiber mask material can efficiently filter out the PM2.5 particles and simultaneously preserve a good breathability. We attribute such improvement to the nanoscaled fibers, having the same porosity as that of regular gauze mask but with extremely reduced local interfiber space.

1. Introduction

PM2.5 (particulate matter with diameter of 2.5 micron or less) in polluted air can directly go through the lung alveolar to cause many diseases including asthma [1]. Recently, many Chinese cities are covered by haze air. Figure 1 showed the polluted air in Beijing. The heavy metals adhered on PM2.5 particles may even lead to severe chronic health problems such as cancer after long-term exposure under the particles contained environment [2].

In order to prevent inhaling PM2.5 in haze, people wear regular gauze masks. Most of those masks are made of non-woven fabric, activated carbon, or cotton which has fiber diameter of several micrometers [3]. They have significant shortcoming of poor PM2.5 rejection and low air permeability [4].

In this paper, a novel polymeric nanofiber masks were synthesized by electrospinning. Such masks based on nanofibers are expected to well prevent the PM2.5 particles and maintain a good air permeability. These nanofibers can be potentially developed to high efficiency and low cost mask product.

2. Materials and Methods

2.1. Experiment Materials. Polysulfone, acetone, polyethylene oxide, and dimethyl acetamide were purchased from Beijing Chemical Factory, China. Medical clinic masks, medical operating room masks, ITO PM2.5 masks, N95 respirator, and R95 masks were purchased from Tianjin Youkang medical and health care products factory. All chemicals were of analytical grade and were used without further purification.

2.2. Procedure for Electrospinning. Polysulfone solution was prepared at a concentration of 18 wt% by dissolving in DMAc/acetone (9:1) with vigorous stirring. The prepared solution was kept overnight without stirring under room temperature to remove air bubbles. For the electrospinning, the 18 wt% polysulfone solutions were filled into a syringe with a metal needle connected with a high-voltage power supply (Tianjin Dongwen High Voltage Co., China). The voltage is 13 KV and the distance between the needle and the aluminium foil is 13 cm. The polymer solution was fed at a constant rate of 0.4 mL/h by using a syringe pump.

TABLE 1: Electrospinning conditions.

Polymer	Solvent	Humidity	Flow rate	Voltage	Distance	Time
Polysulfone 1.8 g/polyethylene oxide 0.018 g	Dimethylacetamide 9 mL/acetone 1 mL	53%	0.4 mL/h	13 kV	13 cm	15 min
						30 min
						60 min

FIGURE 1: Typical haze in Beijing.

The nanofibers were collected on the surface of a non-woven PP on the grounded aluminium foil. The collective time of nanofibers was 15, 30, and 60 min. More detailed information was shown in Table 1.

2.3. Morphology Observation. The membranes were dried in vacuo and sputtered gold before observation. The morphology of nanofiber membranes was imaged by scanning electron microscopy (SEM, Hitachi T-1000, Japan).

2.4. Permeability Simulation Test. Permeability simulation test device mainly includes a pump, a pressure differential gauge, a meter, and bronchus. The nanofiber matts and the commercial masks as control group were clamped by a well-sealed testing chamber, which was connected with a syringe at top, install a pressure meter at the side exit. The bottom side of the chamber was open to the ambient air. Counterweights were placed on the syringe to adjust the pressure inside the testing chamber. The resulting pressure above the nanofiber matts was measured by the pressure meter.

2.5. Intercept Rate Test. Intercept experimental equipment was conducted in a nuclear particle counter (Model of CPC 3772 made in TSI Company). That counter can measure the concentration of particles (diameter between 10 and 2500 nm) in the air. The particle concentration in air represented the PM2.5 intercept rate of the filtration material.

2.6. Data Analysis. All data were means $\pm$ SD from three independent experiments. Comparisons between multiple groups were performed with the ANOVA test by SPSS. P values less than 0.05 were considered statistically significant.

FIGURE 2: Nanomasks on non-woven fabrics.

3. Results

3.1. Morphology Observation. Figure 2 is the picture of nanofibers on the non-woven fabric. All the masks are white in color and homogeneously distributed on the non-woven fabric. The thickness of the electrospun fiber matts was at the rank of 15 min < 30 min < 60 min.

According to the SEM images, the nanofibers of 15 min electrospinning were about 500–800 μm in diameter with random orientation and high porosity (Figure 2). The interdistance among the nanofibers is about 1–3 μm . The nanofibers with 30 and 60 min electrospinning showed similar morphology to those of 15 min except for their higher thickness (data not shown).

3.2. Permeability Test. The permeability of the nanofiber masks was then compared with the commercial masks of disposable non-woven face mask, non-woven mask for operation room, Ito PM2.5, N95, and R95 (Figure 4). As listed in Table 2, the pressure drop of three nanofiber masks was 15 min < 30 min < 60 min. Compared with the commercial masks, the disposable non-woven face mask showed the lowest pressure drop, while the R95 had the highest barrier to air permeability. The low pressure drop indicated the good permeability.

3.3. Intercept Rate Test of PM2.5 by Nanofiber Masks. Table 3 showed the PM2.5 rejection capability of each mask in the intercept rate test. The rejecting ratio was calculated by the rejected particles/total particles in air. All the three nanofiber masks performed a high rejected effect of >90%, at the rank of 60 min > 30 min > 15 min. For the commercial available masks, the disposable non-woven face mask showed the poorest effect on PM2.5 rejection of 32.9%, which could not match the requirement of daily use. By contrast, the R95 mask for medical use in preventing virus permeability had

TABLE 2: The pressure drop statistics in permeability test.

Masks	Import (KP)	Export (KP)	Pressure drop (KPa)
Disposable non-woven face mask	1.23	1.52	$\Delta 0.29$
Non-woven mask for operation room	1.05	1.695	$\Delta 0.645$
Ito PM2.5	1.045	1.7	$\Delta 0.655$
N95	1.125	1.635	$\Delta 0.51$
R95	1.06	1.685	$\Delta 0.625$
Nanomask (15 minutes)	1.43	1.84	$\Delta 0.41$
Nanomask (30 minutes)	1.19	2.06	$\Delta 0.87$
Nanomask (60 minutes)	0.915	2.023	$\Delta 1.108$

TABLE 3: PM2.5 rejection by selected masks.

Sample	Average particle number	Rejection ratio
Indoor air (negative control)	14452.9 ± 320.6	—
Disposable non-woven face mask	9695.3 ± 57.0	32.9%
Non-woven mask for operation room	499.2 ± 7.8	96.5%
ITO PM2.5	2480.3 ± 31.1	82.8%
N95	739.0 ± 11.6	94.9%
R95	12.4 ± 1.2	99.9%
Nanomask (15 minutes)	1318.8 ± 23.6	90.9%
Nanomask (30 minutes)	476.7 ± 8.5	96.7%
Nanomask (60 minutes)	82.2 ± 3.5	99.4%
Cellulose microfiltration membrane (positive control)	0.3 ± 0.1	100.0%

an extremely high rejection of 99.9%, which is the highest one among the selected masks in our study.

4. Discussion

In this study, a novel nanofiber mask was synthesized by electrospinning for preventing the PM2.5 from haze air. That nanofiber mask showed better performance than the commercial masks in both air permeability and PM2.5 rejection.

To make a clear comparison, the advantages and disadvantages of commercial masks have been summarized in Table 4. Most of these masks were made of non-woven fabric microfibers with large diameters of several micrometers [5]. The thin microfiber mask such as the disposable non-woven mask, though showed excellent air permeability, performed poor rejection on PM2.5 due to the insufficient thickness

of fibers and larger interfiber space. In contrast, the thick microfiber masks of Ito PM2.5 and N95 improved the rejecting ratio of PM2.5 to >80% which is enough for daily use. But they both had high resistance on air permeability which led to uncomfortable breathability in use. The R95 mask, which is commonly used in medical purpose, could well protect the doctors from virus infection. However, it was not suitable for preventing air pollution in daily use because of the extremely poor air permeability. The nanofiber mask with 15 min electrospinning had a high PM2.5 rejection of 90% and acceptable air permeability (Tables 2 and 3). Therefore, it is a good mask raw material for preventing haze air pollution.

The requirement on air permeability and PM2.5 rejection is a contradiction [6]. That means the high air permeability usually reduces the particle rejection of PM2.5 and vice versa. As shown in Figure 3, the nanofiber mask (15 min) displayed the largest difference between air permeability and PM2.5 rejection among these masks. We attribute that unique feature to the nanoscaled fiber size. At the same porosity, which indicates air permeability, the smaller fiber required higher quantity to achieve the same coverage as that of the bigger fiber. More fibers in the same area result in smaller interfiber space. From the SEM image in Figure 3, when the fiber scale is down to submicron, the interfiber space between the nanofibers is also reduced to micron scale, which is smaller than the PM2.5 size, consequently rejecting the PM2.5 passing efficiently.

5. Conclusion

This study synthesized a polysulfone nanofiber for mask filtration material by electrospinning. The nanofiber mask material was characterized by SEM, air permeability test, and PM2.5 trapping experiment. This nanofiber mask material can efficiently filter out the PM2.5 particles and simultaneously preserve a good breathability. In this regard, this nanofiber based material would be made into the comfortable and effective mask to prevent inhaling the harmful particles in haze air pollution. The nanofiber masks could be developed to commercial available masks in the future.

TABLE 4: Comparison of different masks.

Name	Material	The scope of use and effect	Problem
Medical masks	Non-woven fabric	For hospital outpatient, disposable, good sanitary conditions	Interception effect of fine particles is poor
	Blended material	For the operation room, disposable, good sanitary conditions	Water vapor is poor, respiratory resistance is high
ItoPM2.5 masks	Thickened non-woven fabric	Dedicated to filter PM2.5	Respiratory resistance
N95 masks	Thickened non-woven fabric	Protection of professional occupation, preventing a flow HINI and microbial particles	Respiratory resistance, poor comfort
R95	Activated carbon	Used for industrial dust and trace organic gas entrapment	Respiratory resistance, poor comfort

FIGURE 3: SEM images of masks after 15 min electrospinning. (a) $\times 1000$ and (b) $\times 5000$.

FIGURE 4: Permeability and intercept rate comprehensive comparison.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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