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DEVELOPMENT OF POLYURETHANE/NON-WOVEN FABRIC COMPOSITE AS A PROTECTIVE DEVICE FOR FILTERING ULTRAFINE PARTICLES IN AIR AND ABSORPTION OF CO_2

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In this study we proposed a processing method for improving the filtering capacity of conventional non-woven fabric used in air mask filters by electrospinning polyurethane nanofibers onto the surface of the non-woven fabric. We used FGM technology in controlling different electrospinning parameters to test which is the optimal process method for manufacturing. The morphology of the nanofiber in the non-woven fabric surface was investigated using FESEM. The filter test is done using an air filter chamber device that we constructed and fitted with CO_2 and dust sensors. We tested the influence of the parameters (Distance from tip to collector, Electrospinning Time) in UFP filtration effectivity and CO2 absorbance.

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1. Introduction

Recently, ultrafine particle (yellow dust) poses big problems in Asia. Yellow dust is made up 10μm size particle and 2.5μm size ultrafine particle (UFP) it can't be shielded by the human body's natural defenses and it could go directly into the respiratory system. Prolonged exposure to these particles can cause severe respiratory responses and can cause harm or damage to individuals, especially infants dwelling in urban cities are highly vulnerable to these UFP's because their immune system is not yet fully developed [1]. Also volatile organic compounds (VOCs) are one of the problems like yellow dust. VOCs are emitted in to the air by vehicles, aircraft, industrial plants and many other sources and also pose a great deal of problem for the population [2, 3]. Making an air filter that can shield UFP, VOCs and Heavy metals particles can compromise air circulation and that can lead to reduced oxygen intake and quality of air being inhaled by people. In order for us to solve this problem we used electrospinning as a post processing method to effectively filter UFPs and VOCs without compromising air circulation.

These nonwoven fabrics have recently emerged as effective membrane for moving harmful air-borne contaminants from the environment [4-7]. To supplement the functionality of nonwoven fabric, we used electrospinning. Electrospinning is a widely used electrostatic fiber fabrication technology using polymer solutions; it has been thoroughly studied for commercial

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applications over the past decade [8]. Electro-spinning technique is a simple and flexible way to make nanofibers such as pristine or composite fiber, organic or inorganic composite fiber etc. [9-12]. Scholten et al. reported that polyurethane (PU) micro fibers can be effectively used to absorb VOCs from air [16]. We choose the nonwoven fabric to combine with the device due to its durability. With the use of Electro-spinning, we can control the parameters and reduce the pore size on the felt to emit nano fibers. In order for us to effectively filter UFPs,VOCs and Heavy metal particles an adequate pore sized material must be made. To shield this particles, filter have a 1~2μm pore size to shield the UFP. After the making the filter, we test its capacity to shield the UFP. We made a special chamber to test which parameter has the optimal filtering capacity.

2. Experimental

2.1 Materials and Method

Polyurethane and the non-woven fabric were obtained from Estane Thermoplastics, Librizol Corp (MW=110,000) and Sunjin Glotech respectively. The solvents N,N-Dimethylformamide (DMF), 99.5% and Tetrahydrofuran (THF), 99.5% were obtained from Samchun Chemicals.

2.2 Electrospinning Method

10 wt % (w/w) of Polyurethane was dissolved using DMF/THF 1:1 solvent on a 100 ml glass container using a magnetic stirrer for 4 hours. The parameters for the electrospinning can be seen in Table 1. Figure 1 shows the electrospinning schematics; we loaded the PU solution on a 10 ml syringe. A4 sized non-woven fiber was then prepared and taped onto the barrel collector. The electrospun PU is then collected on the non-woven fabrics surface. To see the optimal electrospinning processing method parameter; Time and Y-axis parameters were fixed at 10 mins and 100 mm respectively. Under fixed time parameter we try to investigate the filtering capacity at different Y-axis distances; 50 mm, 100 mm, 150 mm and 200 mm. We also did the same thing under the fixed Y-axis parameter, by changing the electrospinning time at 5 mins, 10 mins, 15 mins and 20 mins as seen on table II.

Table 1. Electrospinning Fixed values and raw CO2 absorption and Dust filtration data

Fixed value		CO2 [L] (ppm)	CO2 [R] (ppm)	Dust [L] (mg/m^3)	Dust [R] (mg/m^3)
10 min	Felt	1424.109	819.0887	0.006	0.004571
	50mm	1296.832	946.0026	0.0052	0.003333
	100mm	1497.822	881.6907	0.005167	0.0023
	150mm	1822.517	928.9021	0.005833	0.001167
	200mm	1805.341	892.7403	0.005167	0.000667
		CO2 [L]	CO2 [R]	Dust [L]	Dust [R]
Y-axis Distance 100mm	Felt	1424.109	819.0887	0.006	0.004571
	5min	1610.537	927.7612	0.0053	0.002333
	10min	1497.822	881.6907	0.00516	0.002167
	15min	1475.904	888.0881	0.0055	0.0025
	20min	1695.748	862.4973	0.005143	0.002429

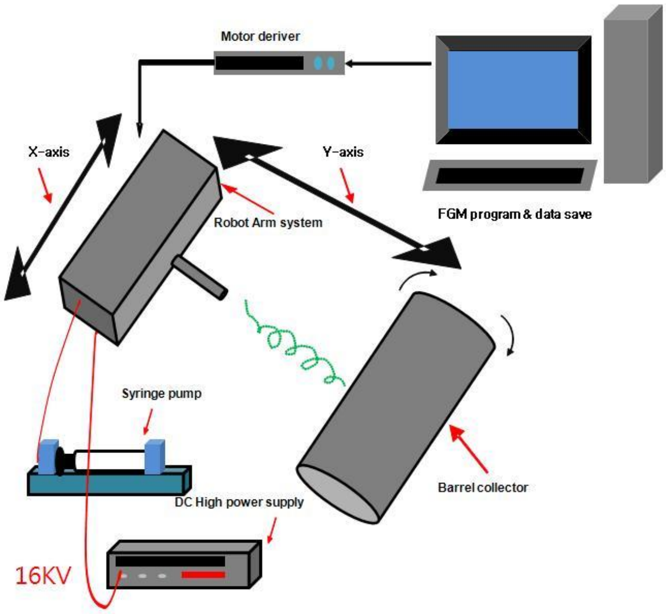

Fig. 1 Electrospinning system FGM technology mimetic diagram.

2.3 UFP and CO_2 Filtration Test

To test the effectivity of the composite air filter, we constructed a chamber using a transparent fiber glass. We divided the chamber into two sections; the right side is where the UFP and CO_2 Inlet were placed. The UFP is made out of calcium carbonate ($CaCO_3$) dust with a mean diameter of 1.55 μm, four standard computer fans pointed at different locations were fitted on the right side of the chamber to circulate the UFP and CO_2. Pressure (Solid State Pressure Sensor 33A series), Dust (Sharp GP2Y1010AU0F) and CO_2 (Infrared Carbon Dioxide Module, Wuhan Cubic Optoelectronics Corp.) sensors were also placed at both sides of the chamber and connected into Labview program to accurately measure the amount of UFP and CO_2 as seen on Figure 2. The difference between the amount on the left side and the right side of the chamber is the filtering capacity of the composite air filter.

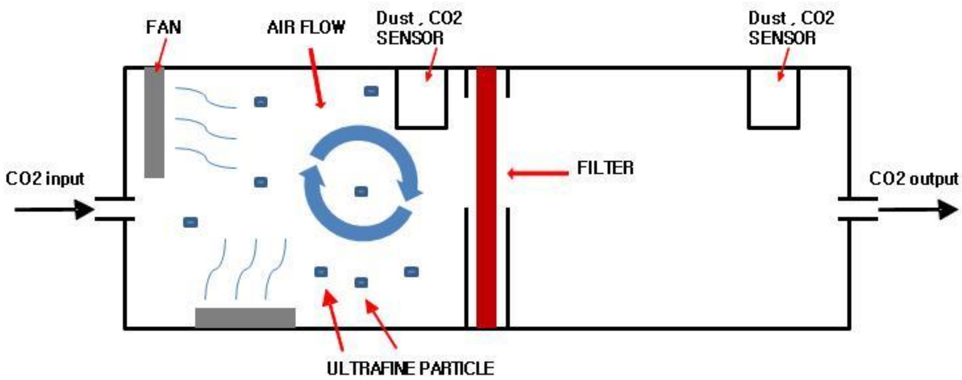

Fig. 2 Air Filtration Test Chamber Schematics

2.4 Characterization

After the filtration test, the morphology of the composite filters was then observed using Field emission scanning electron microscope (Carl Zeiss Supra 40VP). Before the images were taken, the samples were sputter coated under argon to make them electrically conductive. The excitation voltage used to take the images was set at 2 kV. The average fiber diameter of about 50 points was surveyed using imageJ software (NIH, USA).

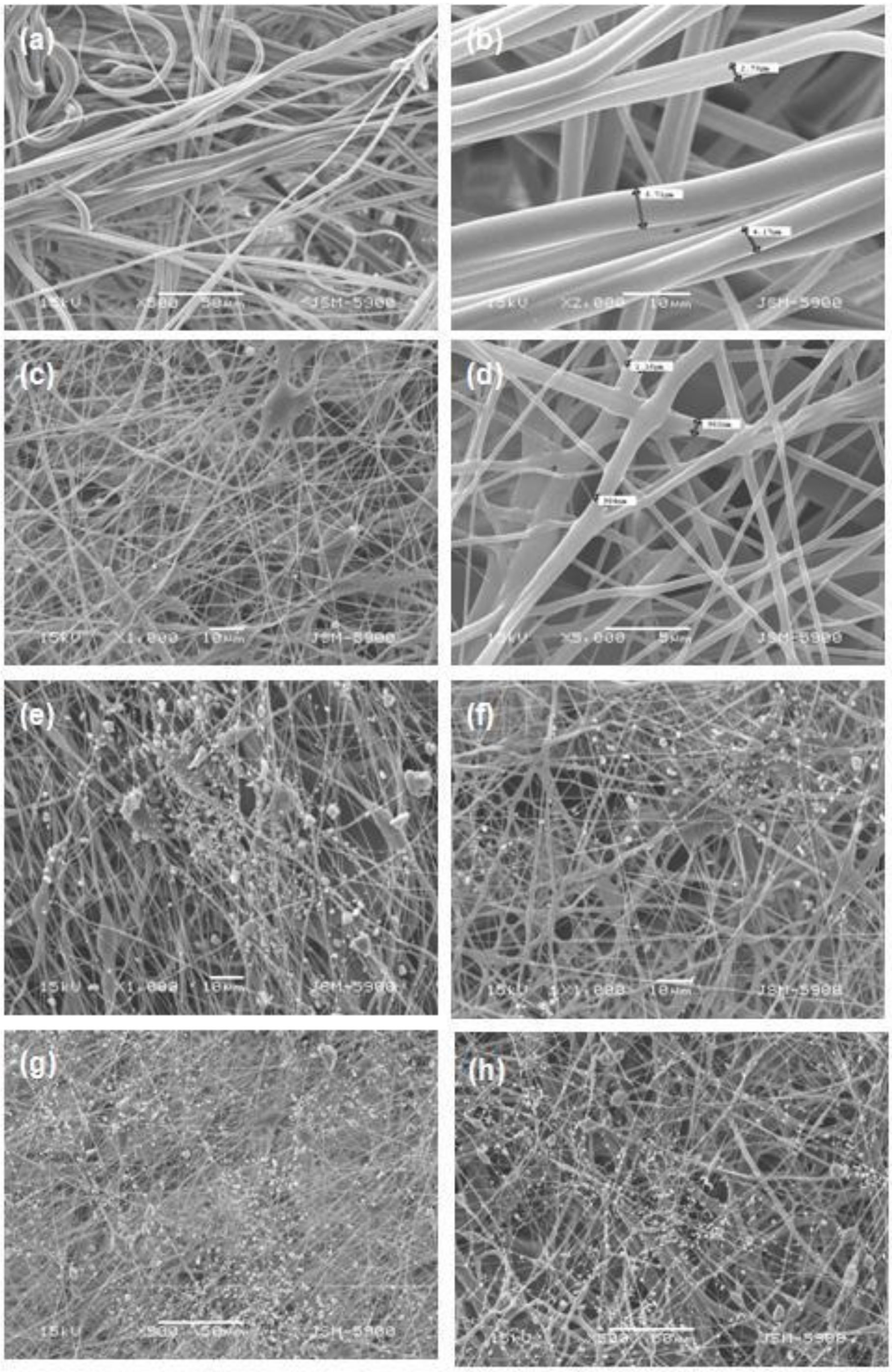

Fig. 3 FESEM images (a)(b) nonwoven fabric (c)(d) Air filter composite T-5min (e) Air filter composite T-10min (f) 15min (g) Air filter composite Y-axis-150 mm (h) Air filter composite Y-axis-200 mm

3. Results

3.1 Morphology of the fibers in the composite air filter

The morphology of the electrospun fibers was uniformed and some crosslinking were noted. The non-woven fabric fiber diameter on average is 6 μm as surveyed while the electrospun PU nanofiber diameter varies depending on the Y-axis value and the time of the electrospinning. As seen on Figure 4, the fiber diameter of t-5mins, t-10 mins, t-15mins, t-20mins, were at 994.0 nm, 1181.48 nm, and 1314.71 nm respectively. While the average diameter of the electrospun fibers at Y-axis-150 mm is 1129.67 nm and Y-axis-200 mm is 694.66 nm. On Figure 3 we can see the FESEM images of the airfilter composites after filtering with the UFP attached onto the surface of the fibers.

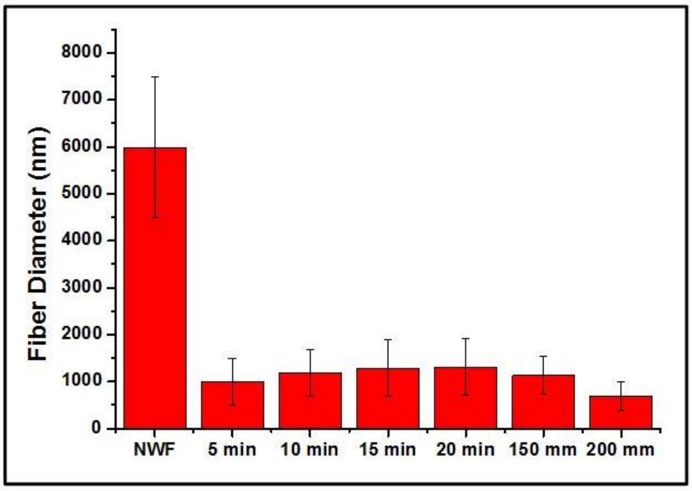

Fig. 4 Surveyed average fiber diameter

3.2 CO_2 Absorption Behavior the Composite Air filter

The CO_2 reduction efficiency varies depending on the parameter of the electrospinning used. The most efficient in mitigating CO_2 under fixed Y-axis value is the air filter composite with 10 mins running time. The CO_2 reduction was measured in at 58 %, while the other air filter composite under fixed Y-axis parameter showed 56 %, 54.5 % and 52.8 % for 5 mins, 15 mins, and 20 mins respectively. On the other hand the results under fixed time parameter shows that the most efficient in CO_2 reduction is the 200 mm Y-axis value with 67.5 % CO_2 reduction as shown in Figure 5.

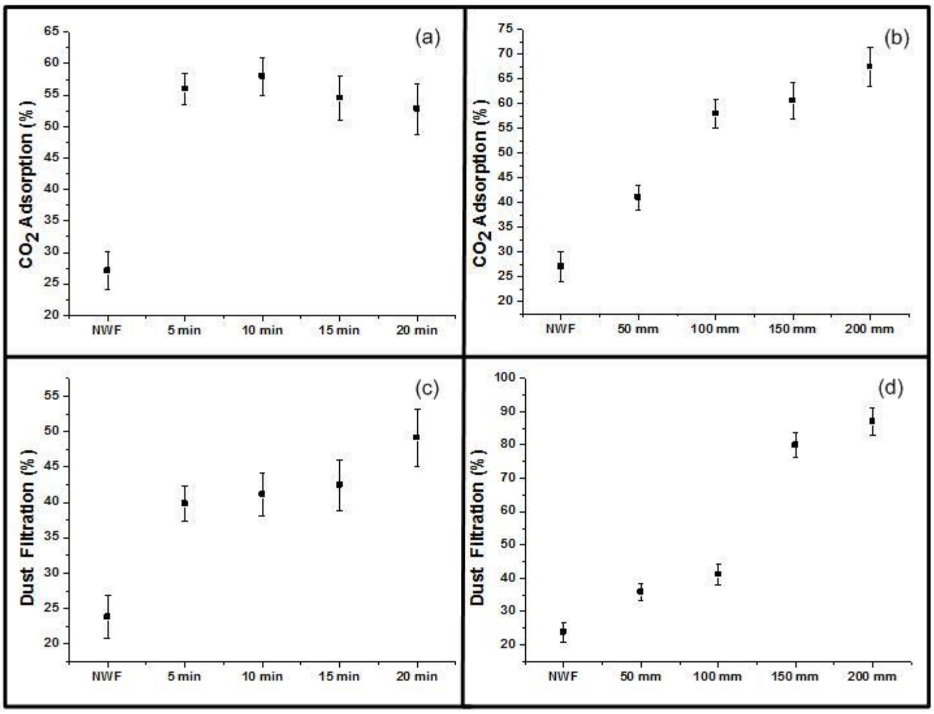

Fig. 5 CO2 adsorption and dust filtration test result:
(a) CO2 adsorption in fixed Y-axis value *(b) CO2 adsorption in fixed time value*
(c) Dust filtration at fixed Y-axis value *(d) Dust Filtration at fixed time value*

3.3 Dust Reduction Behavior of the Composite Air Filter

For the dust reduction result shows that the parameter with the longest electrospinning time at 20 mins and Y-axis value of 200 mm has the highest dust reduction value at 49.1 % and 87.1 % respectively. All other air filter composites also shown better results than the pure non-woven fabric with 35.9 %, 41.1 %, 80 % under the fixed t-value with 50 mm, 100 mm, 150 mm respectively and 39.8 %, 41.1 %, 42.4% under fixed Y-axis value with 5 mins, 10 mins, 15 mins correspondingly.

4. Discussion

The morphology of the non-woven fiber although it is fibrous and porous in nature deemed to be less efficient in filtering UFP's lower than 2.5 μm in size; this is primarily due to the low surface area of the fibers on the non-woven fabric. Small sized particles such as UFP can easily pass thru these fibers. While with nanofibers on the other hand we had increased the surface area of the filter and UFP's can adhere more by virtue of van der Waals forces. With more surface area to attract the UFP therefore the composite airfilter with the lesser fiber diameter is the most efficient in filtering it. The influence of the fiber diameter is coherent with the dust reduction results of the air filter chamber experiment. The composite air filter with the smallest fiber diameter has the most effective reduction of ultrafine particles. The distance of the collector drum to the tip of the nozzle plays a role on the fiber diameter of the nanofibers, with longer elongation time, the Taylor cone of the PU solution can be stretched and thinner fiber diameter can be produced. Polyurethane plays a good role in adsorbing CO2 and the amount of polyurethane on the surface of the non-woven fiber has direct correlation to the amount of CO2 reduction. The interaction of the PU building blocks with the CO2 in the air determines their adsorption capacity. With higher amounts of PU on the non-woven fiber more CO2 can be easily mitigated. Compared to just pure non-woven fabric, CO2 reduction is vastly improved. And also with the reduction of the fiber diameter, the surface area increases, The CO2 reduction is improved as shown in the experimental results.

5. Conclusion

We have successfully made improvements on the filtering capacity of the commercially available non-woven fabric by electrospinning PU onto the surface of the material. We have determined the optimal electrospinning parameters for filtering UFP and adsorption of CO2, at 10 mins with Y-axis value of 200 mm. The electrospun PU nanofibers exhibited uniformed morphology, with the UFP adhering on to the surface of the nanofibers.

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