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Study on the preparation of Nylon 6 nanofibers by electrospinning on particle removal

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Abstract. In order to investigate the filterability of artificial fiber, salts were added to the fiber for particulate removal. In addition, nanofibers were prepared for particle filtration efficiency assessment, and Nylon 6 nanofibers were prepared by electrospinning. Scanning electron microscopy (SEM) was used for analyzing the fiber characteristics. Furthermore, the single-factor experimental method was used to study the optimal material preparation method and operating parameters, including content of different salts (NaCl and KCl), with Nylon 6 nanofibers for particle removal. The particle removal efficiency of pure Nylon 6 nanofibers was about 95%. The removal efficiencies of Nylon 6 nanofibers containing NaCl and KCl were 99% and 98%, respectively. It was found that the removal efficiency of nanofibers was decreased with increasing content of salts in Nylon 6 nanofibers.

1. Introduction
The industrial revolution made our lives easier. An impact on the environment while improving the living standards has unbalanced economic development and increased the greater difficulties towards the protection of the environment. Granular pollutants are the crucial pollution in the air, and their formation is inextricably linked to human activities. Due to the increase in human activities and the application of nanotechnology, the opportunities for exposure to nano and sub-micron particles have increased. Recently, many studies have begun to focus on the filtration of nano-sized particles by using polymers nanofiber-coated basic material of containing metal salts. It can provide excellent air filtration efficiency and low pressure drop.

2. Experimental methods
Initially, dissolve nylon 6 (nylon 6, N6) in formic acid solvent, and latter add 5, 10, 15 and 20 wt% of salt (NaCl, KCl), which is magnetically stirred for 6 hours, then homogenized with the ultrasonic source for 1 hour to obtain a homogeneous 20 wt% nylon 6 polymer solution as a precursor solution. The prepared precursor solution was added into 10 mL syringe. The needle tube and the needle were connected with a Teflon tube to set the propulsive flow rate of 0.1 mL h⁻¹. In addition, the distance between the collector and the needle was set to 15 cm, and the electric field voltage was controlled at 19-25 KV. Furthermore, the rotation of the rotary collector was covered by template material (PET) and speed of rotation was controlled to 250 rpm. Finally, the electrospun nylon 6 was collected after 6 hrs. The collected fibers were placed in a drying oven.
3. Results and Discussion

3.1 Electrospun fiber filter material characteristics
There are many factors affecting the diameter and shape of electrospinning. It includes the conductivity, molecular weight, viscosity, surface tension, collection distance, and operating voltage that can affect the diameter and shape of the fiber (Bhardwaj and Kundu, 2010). Therefore, the morphology and average diameter of PET, 5% KCl-N6 and 5% NaCl-N6 fibers were observed by SEM. It can be observed from Figure 1 that the surface of the PET fiber is basically smooth and flat, and the average fiber diameter of PET is 39.8 ± 20.0 μm. From Figure 2 and Figure 3, the formation of fibers with 5% KCl-N6 and 5% NaCl-N6 can be seen. Due to loading of the salt, finer fibers were produced between the fibers, which increases fine fibers on the whole. The average fiber diameters of the 5% KCl-N6 and 5% NaCl-N6 filters were 152 ± 32 nm and 130 ± 20 nm, respectively.

![Figure 1. PET substrate fiber.](image1)

![Figure 2. 5% KCl-N6 fiber](image2)

![Figure 3. 5% NaCl-N6 fiber](image3)

3.2 Filter performance test results

3.2.1 Particle size distribution
For this study, constant Output Atomizer was used to generate sodium chloride particles as a source of test the particles by controlling the total number and particle size distribution with dilution air. In addition, the total number and particle size were measured by SMPS (Scanning Mobility Particle Sizer). As shown in Figure 4, the filtration experiment stabilized the total number of particles between $3.20 \times 10^6$ ~ $3.70 \times 10^6$ # cm$^3$. 
3.2.2 Filtering efficiency of salt-containing fibers

In this study, SMPS was used to measure the concentration and distribution of particles to calculate the penetration efficiency of particles in the fiber before and after filtration. When the basic material weight was 1 g m$^{-2}$ and the surface velocity was 1 cm s$^{-1}$, the particle concentration measured was $3.20 \times 10^6 \sim 3.70 \times 10^6$ cm$^{-3}$ which was used to investigate the variation of permeability and pressure drop of distinct salt content filters. The performance test done with the pure nylon 6 filters are shown in Figure 5. It is found that the average penetration efficiency of the particle size in the range of 12 to 500 nm was 6.3%. However, when the particle size was 90 to 110 nm, the penetration efficiency was 13.5%. In contrast, the penetration efficiency increased from 0.4% to 12.5% for finer particles (particle size in the range of 12 ~ 90 nm). In addition, the larger particles (particle size in the range of 110 ~ 500 nm) the penetration efficiency decreased from 12.5% to 1.6%. When the finer particles gradually increase from 12 nm to 90 nm, the main mechanism of particle trapping was to gradually reduce the Brownian diffusion force, which results in decrease of particle removal efficiency as the particle size increases. When the larger particles gradually increase from 110 nm to 500 nm, the main mechanism of particle trapping was the direct interception and inertial impact force, which leads to increase in particle removal efficiency with increasing particle size. The results of this study were similar to those of Wilcox et al. (2010). Wilcox et al. (2010) have explained that that a smooth surface will have a lower pressure drop than a rough surface, and the penetration efficiency of the coarse fiber is lower than that of the fine fiber. Since the fibers were intertwined with each other during the electrospinning process, it decreased in the gap between the fibers, which in turn increases the material pressure drop.

In this study, the penetration efficiency of the particles containing KCl fibers was higher than that of the particles containing NaCl. The reason was the NaCl molecules were smaller than the KCl molecules, and the diameter of the KCl-containing fibers was larger than that of the NaCl-containing fibers. The efficiency of particle removal with NaCl-containing fibers is higher than that of KCl-containing fibers (about 2% higher), as shown in Figure 5 (Hung and Leung, 2011).

The pure N6 fiber was tested for particle removal performance. After calculation, the fiber material filtration quality could be obtained, as shown in Figure 6. Although the penetration efficiency of pure N6 was higher, and the pressure drop was lower due to smoother fibers, resulting in the difference in filtration quality from the removal efficiency was smaller.
The content of the salt was 5.0, 10, 15 and 20%; the basic material weight was 1 g m\(^{-2}\), the surface velocity was 1 cm s\(^{-1}\), and the particle concentration was 3.20\(\times\)10\(^{6}\) ~ 3.70\(\times\)10\(^{6}\) cm\(^{-3}\). When the NaCl content was from 5% to 20%, the particle penetration efficiency increased as the content increased. For example, the NaCl content in the fiber was 5, 10, 15 and 20%, and the penetration efficiency was 2.5, 2.9, 3.4 and 4.1%, respectively when the particle size was 100 nm. The reason was that the increase of NaCl content would cause the fiber diameter to become thicker. Therefore, the gap between fibers and fibers, penetration efficiency and treatment efficiency would decrease as the NaCl content increased, as shown in Figure 7.

The filtration quality of the different fiber materials was calculated in this study, as shown in Figure 8. When the salt content was increased from 5% to 20%, the filtration quality was 0.021, 0.02, 0.018 and 0.17 Pa\(^{-1}\), respectively.

**Figure 5.** Comparison of penetration efficiency.

**Figure 6.** Comparison of filtration quality.

**Figure 7.** Permeability of NaCl-containing fiber.

**Figure 8.** Filter quality of NaCl-containing fiber.
4. Conclusion

- This study successfully used electrospinning technology to develop fiber materials, such as N6, 5% NaCl-N6 and 5% KCl-N6.
- It could be seen from SEM analysis that 5% NaCl-N6 and 5% KCl-N6 fibers produced finer fibers between fibers and fibers due to loading of salt.
- 5% NaCl-N6 filter material has the lowest penetration efficiency and the highest filtration quality. In addition, it would cause fibers to become thicker with adding too much salt.

References

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