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Effect of Nylon-6 Concentration on Morphology and Efficiency of Nanofibrous Media

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ABSTRACT: Electrospinning is a method of nanofiber filter media production. By this method, it is possible to produce media with nanofiber in the range of nanometer to micrometer. Nanofibrous media provide a large specific surface area in a finite volume thus they are suitable for filtration applications. In this study, nanofiber non-woven membranes production of Nylon-6 by electrospinning method is investigated. It is demonstrated that the total filter efficiency and pressure drop increases by increasing the thickness of filer media. The objective of this experimental study was to find out the effect nylon concentration and thickness of nanofilter media.Samples by different Nylon-6 concentrations and time of electrospinning were made. The filtration characterizations of these media were investigated in different laboratory conditions. The SEM micrographs of specimens treated by ImageJ software reveal that the porosity passes by a minimum at 10% concentration. The diameter of nanofiber varied in the range of 47 to 89 nm when the nylon concentration varied from 7.5% to 15% respectively. The efficiency was improved more than three times by electrospinning operation for all three concentration samples. Our results showed that the highest efficiency obtained in this study was 99.96% belonging to 10% Nylon-6 concentration for 45 minutes electrospinning time.

Key words: Electrospinning, Nanofibers, Porosity, Pressure drop

INTRODUCTION

Fibrous filters media widely used to separate solid matter from the air flow streams. Suspended particulate matters from industrial processes are generally dangerous for human health and causes equipment amortization. Aerosols are exist in the atmosphere by nature or through human activities. They come in many forms such as dust, mist, fume, smoke and fog (Chuanfang, 2012). Consequently, the use of preferment filtration system in industry is a method of financial and human resources saving. Electrospinning is a simple and cost-effective method of producing polymeric fibers with diameters ranging from few nanometers to micrometers (Huang *et al*., 2003 ; Yin, 2010 ; Ki *et al*., 2007 ; Subbiah *et al*., 2005). The basic principles of this technique concern with application of an intense electrostatic field to a polymer solution across a finite distance. Nylone-6 has a good resistance to many commercial solvents and can be only dissolved in a few solvents such as formic acid (Deitzel *et al*., 2001).

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Although numerous studies on the production and specification of polymeric nanofiber successfully done, a systematic study on optimization of electrospinning parameters for Nylon-6 is yet to be achieved (Chowdhury and Stylios, 2010). Nylon has a good resistance to many commercial solvents and can be only dissolved in a few solvents such as formic acid. Nylon 6 electrospun into nanofibers easily, which provide the application basis for the electrospinning nylon 6 nanofibers media (Mit-uppatham *et at*., 2004; Renuga *et at*., 2006).

The morphology of electrospun fibers are affected by the polymers concentration and electrospinning parameters (Pirjo and Ali, 2008; Kang *et al*., 2006; Krishnappa, 2003). Tae Kim was concluded that the concentration of nylon in the formic acid is the most important factor in the structure of produced fibers (Kim *et al*., 2008). H. Park and Y. Park showed that the high electric field strength makes thinner fibers by increasing repulsive force on the polymer surface (S. Park and O. Park, 2005).

Ki Myoung Yun prepared Polyacrylonitrile fibers with mean diameters in 270-400 nm range by electrospinning for use as a filter media, and found electrospun filters had nanoparticle penetration values comparable to commercial filters (Yun *et al*., 2007).

C. Shin produced polystyrene fibers from recycled expanded polystyrene through electrospinning. They found that adding nanofibers to conventional micron sized fibrous filter media improved the separation efficiency of the filter media, the separation efficiency was improved from 61% to 91% (Shin, 2006). Sadigzadeh showed that the total filtration efficiency is proportional to the thickness of the media (Sadigzadeh, 1991).

The objective of this experimental study was to find out the impact of Nylon-6 concentration and thickness of filter media in order to obtain a media with suitable filtration quality factor.

MATERIALS & METHODS

The electrospinning device used in this experiment was a horizontal type (Model ES1000) produced by Fanavaran Nano Meghyas Co. The high voltage supplement source of this device was in the range of 0 to 30 KV. In this study, the Nylon 6 polymer was used for producing non-woven nanofiber filter media. In order to obtain a suitable filter media (high efficiency and low pressure drop), three different nylon concentrations 7.5,10, and 15 weight percent per volume were used. To prepare the polymer solution Nylon 6 pellets were dissolved in formic acid with 98% purity. The electrospinning parameters used in this work are shown in Table 1. All the experiments were carried out at room temperature.

In this experimental study, nanofibers media with different thickness were made by changing the time of electrospinning process from 15 to 45 minutes. Due to the poor mechanical property of nylon nanofibers, a polyester based fabric was selected as a substrate.

The schematic diagram of the experimental set-up is shown in Fig.1. Atmospheric aerosol was used for the experimental tests. A homogenizer system (H) was used so as to have a uniform aerosol concentration in the entire tunnel test. An air compressor (Model DING HWA Co., LTD SPARMAX) assures the air circulation in the device. The upstream and downstream aerosol concentration was determined by a condensation particle counter (Model 5.412, GRIMM Co). The media pressure drop was obtained by a pressure manometer device (Model 202, KIMO Co).At the beginning of all tests the air in the system is filtered by a high efficiency particle air (HEPA) filter in order to ensure from no leakage in the system.

Table 1. Experimental electrospinning Parameters

Parameters	Values
Polymer	Nylon6
Solvent	Formic acid
Concentration (%)	7.5, 10, 15
Collector	Polyester substrate
Needle length (mm)	40
Electric voltage (KV)	20
Tip to collector distance (mm)	100
Feed rate (ml/hr)	0.25
Relative humidity (%)	24
Temperature (°C)	25
Drum velocity (rpm)	325
diameter of the needle tip (mm)	0.6

RESULTS & DISCUSSION

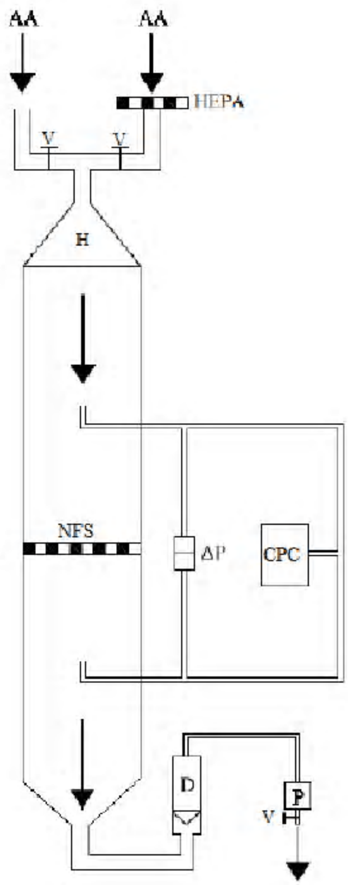
The morphologies of the electrospun fibers were observed by SEM micrograph. The fiber diameters and media porosity were calculated by ImageJ software.

Fig. 2 to 4 show the morphology of Nylon-6 nanofiber at 7.5%, 10%, and 15% concentrations, respectively. The SEM images are taken at the same magnifications in order to be comparable with each other. It was observed that the length of nanofibers in the 7.5% specimens were thin. The SEM image of nanofibers at this concentration shows that many of nanofibers were scraped; this is due to the low surface tension of polymer solution. Furthermore, there were observed drops in place of fibers' break, in the 7.5% sample.

Fig. 3 and 4 correspond to 10% and 15% nylon concentration nanofiber media. It was observed a uniform nanofiber shape in these two specimens. In these images scraps were not observed. That means, by increasing the concentration from 7.5% to more than 10% the number of scraps decreased rapidly.

The nanofiber diameters were varied with nylon concentration. The nanofibers average diameter were 47, 71, 89 nm for 7.5%, 10%, 15% concentration, respectively. The concentration of nylon influences on pore size in the filter media. The average pores size were 2154, 2187, 3583 nm^2 for 7.5%, 10%, and 15% concentration, respectively.

Fig. 5 shows the relation between the porosity of filter media as a function of electrospinning times. From this figure it is observed that the lowest porosity obtained was belonged to 10% nylon concentrationwas19.6% and 17.8% for 15 and 30 minutes electrospinning time, respectively.



HEPA High Efficiency Particle Air
AA Atmospheric Aerosol
H Homogenizer
ΔP Pressure Manometer
CPC Condensation Particle Counter
D Flow-meter
P Pump
V Valve
NFS Sample

Fig. 1. Experimental device

The relations between pressure drop and the time of electrospinning for three different Nylon-6 concentrations is shown in Fig. 6. According to this figure, it is concluded that by increasing the time of electrospinning from 15 to 45 minutes, the pressure drop increases linearly in all of concentrations.

From Fig. 5 and 6 it can be concluded that the specimen containing 10% nylon concentration has highest pressure drop, 101.5 Pa, as well as lowest porosity, 17.8%,for 30 minutes electrospinning in comparison with other samples.

The total experimental collection efficiency (E_{exp}) of the nanofibers media is calculated by equation (1):

$$E_{exp} = [1 - \frac{N_t}{N_i}] \times 100 \qquad (1)$$

Where N_i and N_f are the number concentration of particles counted in upstream and downstream of filter media, correspondingly.

The results of the experimental efficiency tests for 7.5%, 10%, and15% nylon concentration and also plain substrate without any electrospun nanofibers are shown in Fig. 7. The efficiency for 7.5%, 10%, and 15% nylon concentration was found out 93.10%, 99.96%, and 92.13%, respectively. Specimens with 10% nylon concentration have higher efficiency and pressure drop compared to 7.5% and 15% specimens.

It was assumed that at this experimental condition only one nanofiber ejects from the polymer droplets, consequently six layers per minute will be coat on the substrate media. Therefore by increasing the time of electrospinning process from 15 to 45 minutes, the number of layers electrospun will be 90 to 270 layers, respectively. Fig. 8, show the theoretical efficiency of two granular bed with different thickness.

The theoretical total efficiency and pressure drop of media are computed with the equations 2 and 3 (Baron and Willeke, 2001). It is observed that the total efficiency as well as pressure drop is directly proportional to the thickness (L) of media.

$$E = 1 - \exp(\frac{-4\eta\alpha L}{\pi d_f (1-\alpha)}) \qquad (2)$$

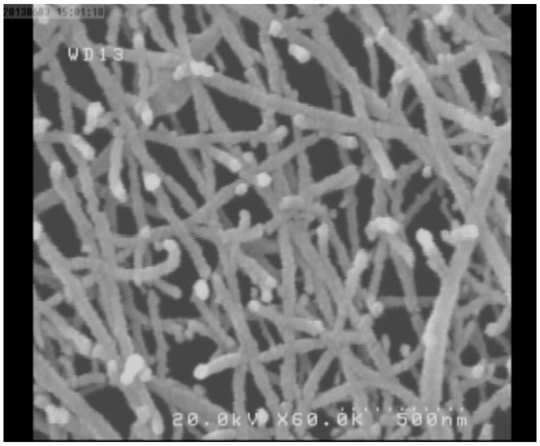


Fig. 2. SEM Image of 7.5%nylon concentration

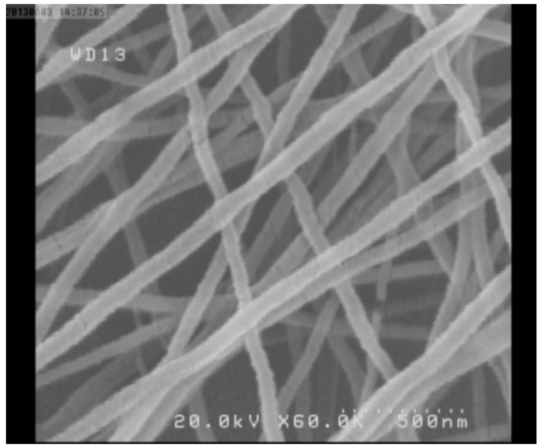


Fig. 3. SEM Image of 10% nylon concentration

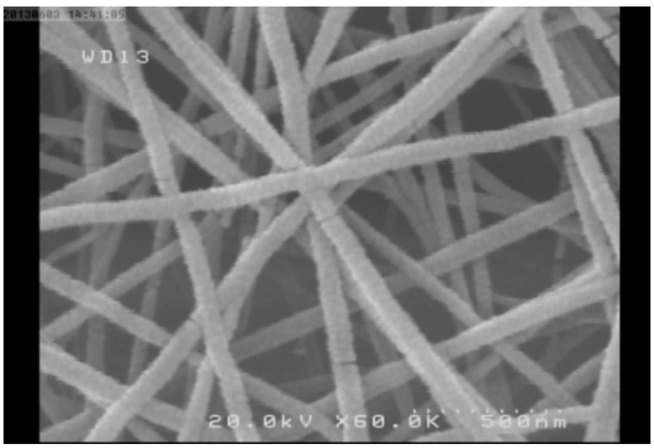


Fig. 4. SEM Image of 15% nylon concentration

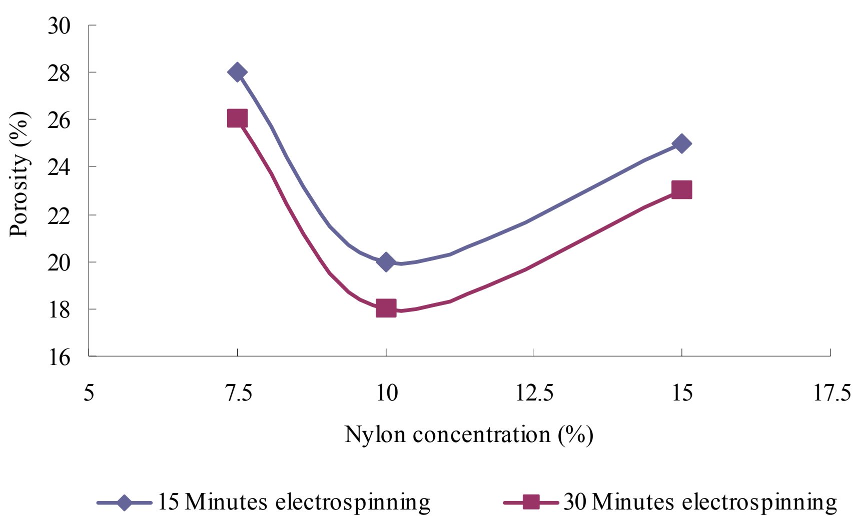


Fig. 5. Porosity versus time of electrospinning

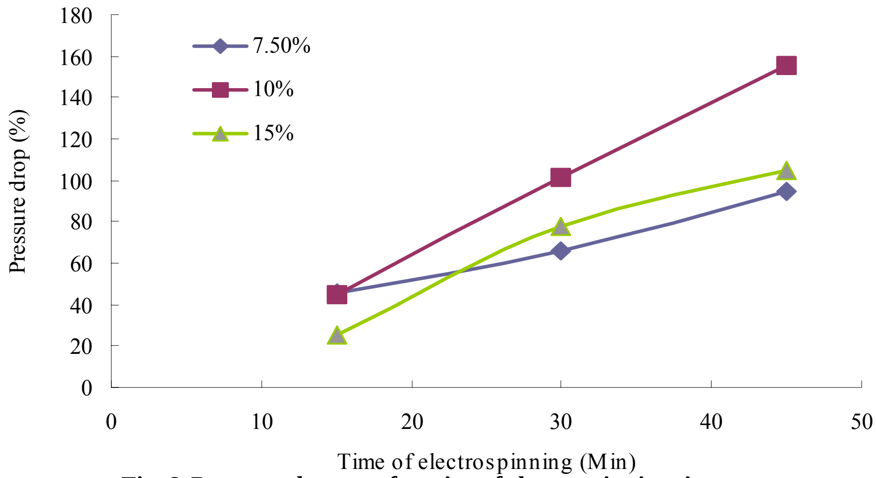


Fig. 6. Pressure drop as a function of electrospinning time

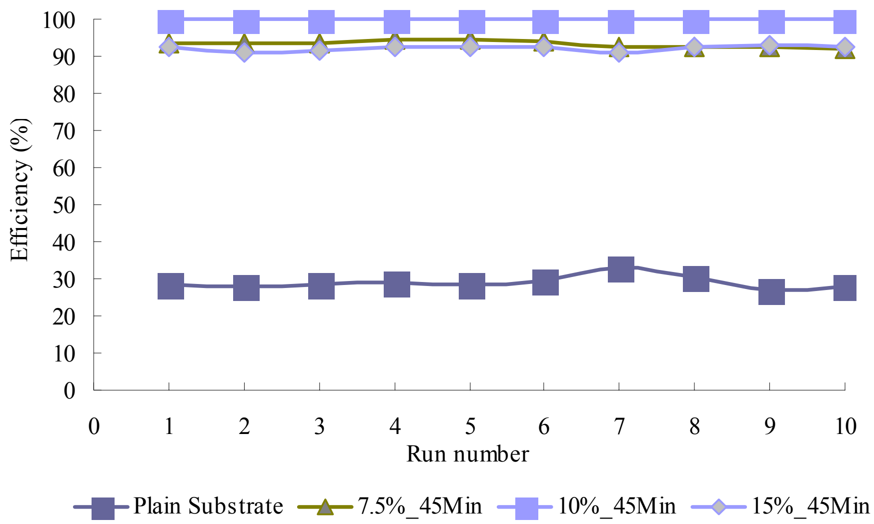


Fig. 7. Efficiencies of media with and without nanofiber coating

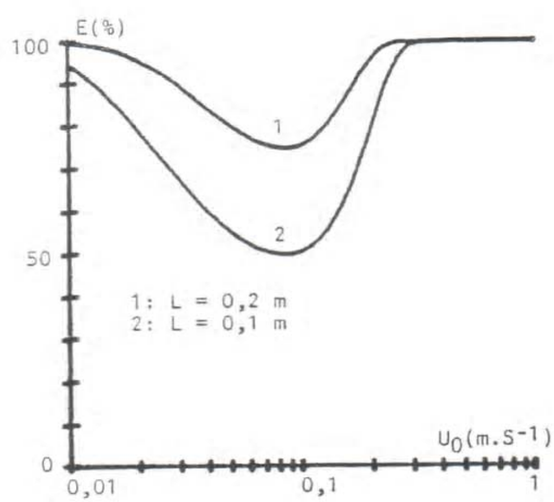


Fig. 8. Efficiency of two granular beds with different thickness

Where E is the total efficiency, α is the solidity, η is the single-fiber efficiency, L is the filter thickness, and d_f is the fiber diameter.

$$\Delta P = \frac{16\eta \alpha UL}{K d_f^2} \tag{3}$$

Where ΔP is media pressure drop and U is the air velocity, and K is the Boltzmann constant.

CONCLUSIONS

In this study, the Nylon-6 polymer solution was used for producing non-woven nanofiber filter media. Three different concentrations of nylon 7.5%, 10%, and 15% were used. It was found out that the higher concentration of the polymer solution leads to form thicker fibers by preventing the fibers from stretching. The experimental tests revealed that in 7.5% concentration media sample there were many scrap fibers and also nanofibers were not uniform in shape. Also, 7.5% concentration samples were not appropriate for using in filtration industries because the nanofibers had short length, and there were many scarps. The SEM micrographs showed that the average diameter of Nylon-6 electrospun fibers were 47, 71, and 89nm for 7.5%, 10%, and 15% nylon concentrations, respectively. In order to obtain the efficiencies for produced filter media, the atmospheric aerosols were used for the experimental tests. By increasing the time of electrospinning from 15 to 45 minutes, the pressure drop increased linearly from 45 to 95, 45 to 155, and 25 to 104 Pa for 7.5%, 10%, and 15% concentration, respectively. Finally, in this study, it is demonstrated that by coating 18.75 milligrams Nylon-6 on a plain substrate the efficiency raised from 30% to 99.96% where the pressure drop increased from 0 to 155 Pa

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