Obtaining bi-layer particulate filters with the participation of a layer of electrospun nanofibers

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Abstract

In the present study was examined the possibility of using a carrier of non-woven fabric obtained by wet process of waste from cotton fibers and dust for the preparation of highly efficient particulate bi-layer filters with the participation of a mat of electrospun nanofibers.

Mattresses were derived from cotton fibers with a length of 1-2 mm by the wet method for nonwovens. Pads were moulded with the addition of a primary binder. The pads were then used for a carrier of nanofibers layer, spun directly onto the surface of the mat. The obtained non-woven products were used as filtering barriers for cleaning dust. Mats were prepared by precipitation from different amounts of fibers while maintaining the amount of the primary binder. It was investigated the influence of the mass, thickness, air permeability and uniformity of the resulting carriers on the parameters of the applied layer from electrospun nanofibers.

Spinning process was performed vertically from 9% solution of polyvinyl alcohol (PVA) for 1 hour at 190 mm distance between the nozzle and the collector, voltage of 15 kV and 27G nozzle size. The flow rate of the polymer solution supply was 0.1 ml / h.

It was found that the distribution of the sediment fibers' mass on the surface of the carrier depended entirely on the conditions of the spinning process and the concentration of the polymers. Similar results, with a small impact of the carrier's properties, were obtained at the same conditions of the spinning process, using the same polymer.

The layer of nanofibers modified the air permeability of the material, as it was important the type of material on which was deposited the fiber mat, the concentration of the solution and the conditions under which it was spun.

The nanolayer modified the wetting ability of liquids with a different surface tension. The longer the spinning process was the more clearly expressed properties of the nanolayer and its impact on the parameters of the obtained nanofilters were.

Keywords: electrospinning, nanofibers, nowovens, particulate filters

Introduction

Nano-composite fiber-based structures can be catalysts, sensors, carriers and transmitters of information, solar cells, heat accumulators, electrical insulators, bio-functional, possessing fire-resistant, non-flammable and healing-cosmetic properties. Particularly, a lot of work is being done on the preparation and application of fiber nano-products for high-class textile filter screens.

The production of nanofiber mats and combinations with their participation involves the need to solve the following three major problems:

1. Production of nanofibers or nanoparticles.
2. Finding a suitable textile carrier and forming a composite material with the participation of a certain type of nanolayer.
3. Quality control of the nanofiber wool depending on the nature of the lap, the polymer used and the composition of the solution / smelt undergoing electrospinning.

The fibrous structures used as mats greatly alleviate the problem of coating the lap of nanofibers due to the formation of a capillary porous structure. Thus, the mat serves as a matrix on and in which nanoparticles or nanofibers are located. In this way, it stabilizes the structure of the nanoparticle and gives to the resulting complex flexibility, elasticity, strength and deformability to a degree that depends on the structure of the mat - fabric, knitwear, nonwoven fabricated by different technologies.

Fibers are a class of materials that can be continuous filaments or discrete elongated elements with a similar geometric structure [1].

For drawing out very thin (on the order of nano or micrometers) fibers from liquid or melt, an electric charge is used. The process has general characteristics with the electrically spray process and the traditional way of spinning from solutions and melts, as it is not complex regarding the used apparatus and does not require the use of coagulation chemistry or high temperatures to produce solids from a solution or a melt [1]. It is particularly suitable for the production of very fine fibers from polymers with different properties. High voltage is used in electrospinning to create electrically charged jet of polymer solution or melt as one of the electrodes is in contact with the solution. The following basic set of parameters is active in the electrospinning / electrospraying process:

Solution parameters - Polymer selection (molecular weight, average degree of polymerization, molecular weight distribution), solution properties (viscosity, conductivity and surface tension, electrical potential, flow type and concentration).

Process parameters - nozzle/collector screen distances, environmental parameters (temperature, air humidity in the chamber and in the room), collector movement.

The properties of the resulting hybrid materials depend much on the nature of the mat on which the nanofibers are applied.

Parameters of the collector or carrier of the nanofiber mat – foil, fabric, nonwoven fabric obtained by different methods.

Applying a layer of nanofibers on a textile mat, including one that is designed for filters changes the class of the base carrier. The type of filtering is retained – it is about Membrane Filtration – pressure is applied to selective barriers, which are three basic types depending on the size of the particles that retain: Macrofiltration – 5 µm and up (Woven Mesh Screens); Microfiltration – 0.05 – 5 µm (Direct Flow and Tangential Flow)and Ultrafiltration (Molecular filtration) – 5 kD to 0.05 µm (Tangential Flow only) (Table 1).

The aim of the work is to demonstrate the possibility of applying a layer of nanofibers on a layer of waste cotton fibers and powders obtained by the wet method of an installation constructed in Technical University-Sofia under project BG161PO003.1.1.05-0261 "Filter media of non-woven fabric".

Material and methods

For this purpose, a cotton fiber band is used, from which fibers with 1-2 mm length are cut. They are used for laps casting with the addition of a primary binder, and after that as a carrier for a nanofiber layer, directly on its surface. This type of non-woven products is also often used as filtering barriers.

Table 1. Relation between the filter pore parameters and the particle size they retain.

Size	Molecular Weight	Particle Example	Membrane Process
100 000 nm – 100 um		Pollen	MACROFILTRATION
10,000 nm – 10 um		Starch	
		Blood Cells	
		Typical Bacteria	
1,000 nm – 1 um			MICROFILTRATION
		Smallest Bacteria	
100 nm – 1,000 A (0.1 um)		DNA Viruses	
10 nm – 100 A	100,000	Albumin	ULTRAFILTRATION, DIALYSIS
	10,000		
	1,000	Vitamin B12	
1 nm – 10 A		Glucose	REVERSE OSMOSIS, ELECTRODIALYSIS, POLYMERIC MEMBRANE EXTRACTION
	100		
	10	Water	
0.1 nm – 1 A		NaCl	

Results and discussion

The mats are obtained by precipitating different amounts of fiber while the amount of the primary binder remains unchanged. By increasing the amount of fibers in the lap and maintaining the amount of the primary binder, naturally the mass of the nonwoven fabric and its thickness increase. The mass increases linearly, as can be seen from Figure 1.

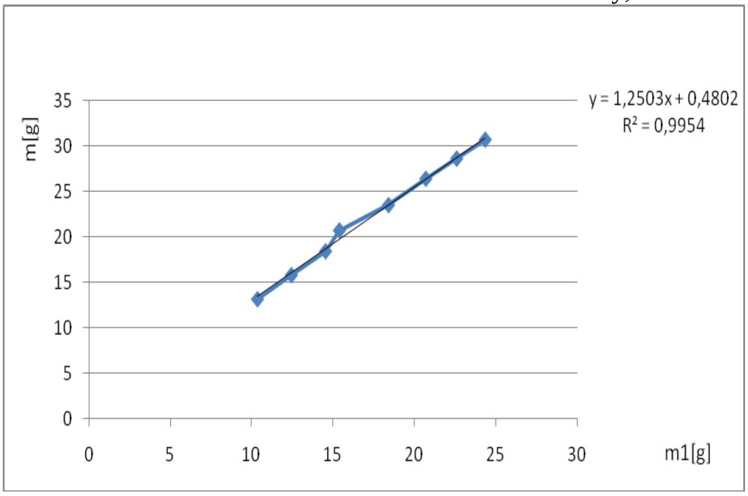

Figure 1. Increasing the mass of the mat (m) when increasing the mass of the fiber during casting (m^1).

The thickness of the same samples depends on the site of measurement due to the specificity of the working area of the apparatus used and this should affect the process of spinning. The thicknesses of the resulting mats measured at the highest load before electrospinning is shown in the circular diagram below (Fig. 2).

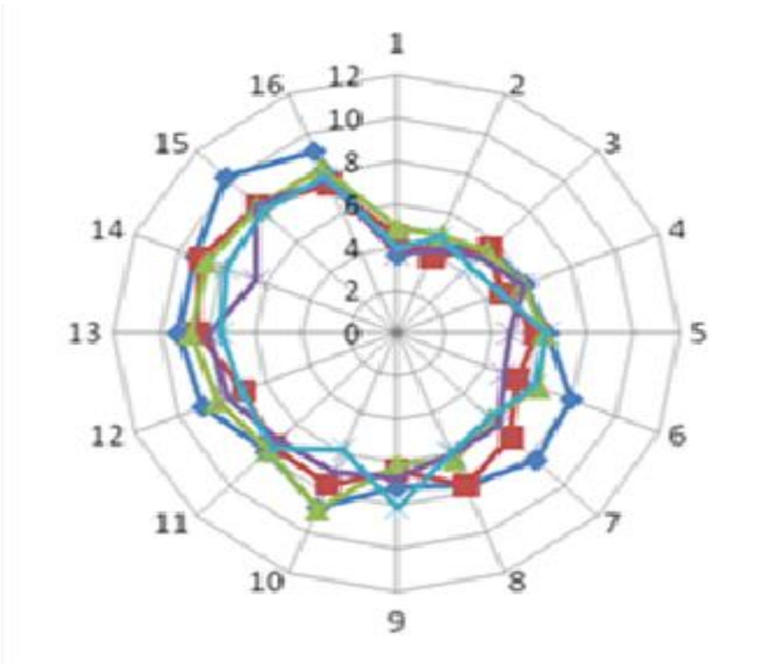

Figure 2. Distribution of the sample thickness in the working area

The measurement is conducted in the center from a pre-labeled mark at 0, 90, 180, 270 degrees. When changing the thickness at different point, the air permeability also changes, as shown in Figure 3. By reducing the mass and thickness, the air permeability increases, and this affects both the electrospinning process and the parameters of the bi-layer material. After electrospinning on a mat, obtained by the wet method, no change in the mass of the bi-layered article was observed for one hour because of the measurement uncertainty and the significantly smaller area mass of the nanofibers applied than the total fiber mass in the sample.

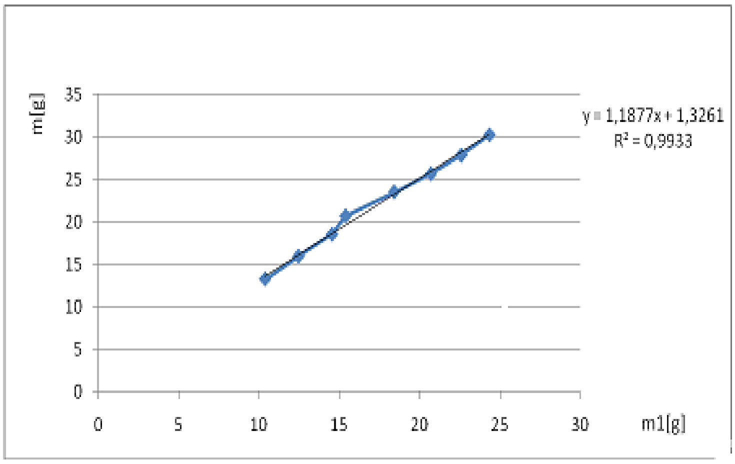

Figure 3. Increasing of the mat's mass (m) after applying a nanofibers layer depending on the quantity of fibers in the lap (m^1).

The thickness of the composite product follows the thickness change of the pad. This is due to the volume of the mat and the large amount of fiber oriented vertically. These initial studies have shown that in order to successfully define the nanofibers layer, it is necessary to work in two directions: changing the parameters of the carrier - hardness, porosity, thickness and increasing the duration of the electrospinning process on it.

Spinning was performed vertically from a 9% solution of polyvinyl alcohol (PVA) for 1 hour at 190 mm distance between the nozzle and the collector, 15 kV voltage and 27G nozzle size. The flow rate of the polymer solution is 0.1 ml/h. A picture of a material before and after application of the nanolayer is given on Figure 4.


a.

b.

Figure 4. Picture of a material prepared by the wet method before (a) and after electrospinning.

Fiber line and pore distribution are represented by scanned electron microscopy (SEM) images of the nanofibers layer (Fig. 5).

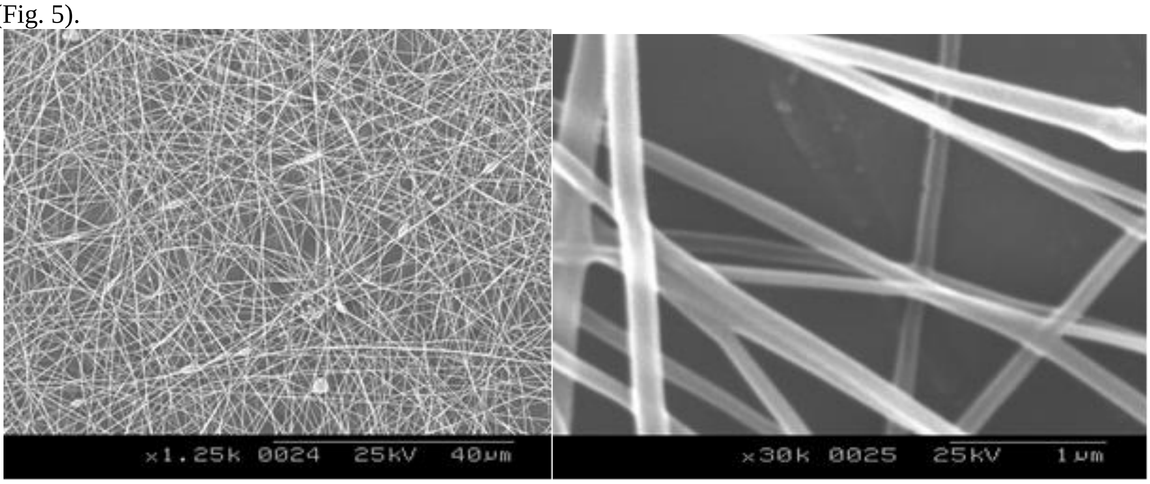

Figure 5. SEM picture of a mat of nanofibers applied on nonwoven fabric obtained by the wet method.

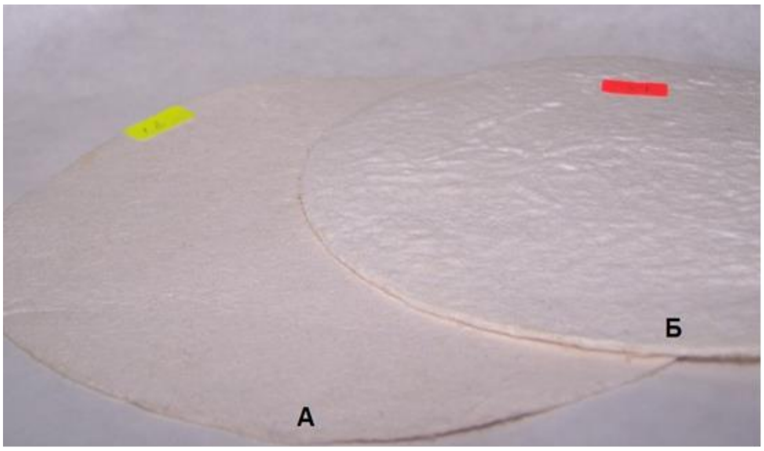

Figure 6. Appearance of the resulting filter barriers.

Obtained results from the air permeability of the bi-layer materials, compared to that of the mat, show greater uniformity and a significant reduction in the air permeability coefficient (Fig. 7). It is interesting the established improved uniformity in air permeability after electrospinning a nanolayer, which is most likely due to penetration of the fibers with nano-sized volume into the pores and the coating with a net of nanofibers.

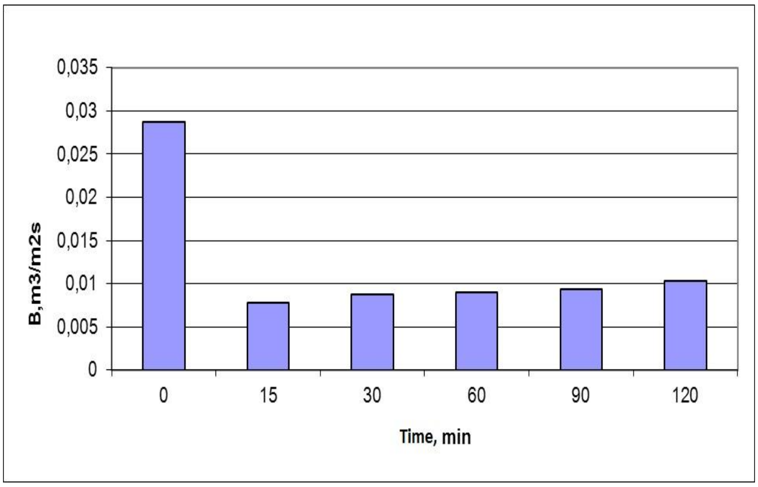

Figure 7. Change of air permeability after application of a nanofibers layer with the electrospinning time.

This is also confirmed by the determination of the pore size change of the hybrid material (Fig. 8).

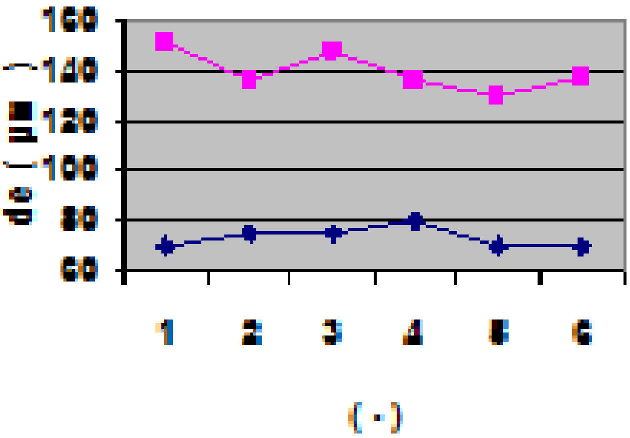

Figure 8. Pore size change after laying a mat of nanofibers before (■) and after electrospinning (◆).

The data confirm the possibility of moving the hybrid filter into a higher class and its application for specialized small size particle retention.

Conclusion

It has been decided to continue working with powders of varying particle size and determining the efficiency of the hybrid bi-layer. The resulting mats by the wet process from cotton waste powders may be used as carriers of nanofibers layer. The technology for their preparation has been determined so as to allow laying of a second layer of nanofibers and obtaining of filters for micro- and nanoparticle retention.

Acknowledgements

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