Nonwoven filtration mat production by electrospinning method

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Abstract. The filtration of nanoparticles and submicron particles is an important problem in industry and health protection. One of the methods which can be used to solve this problem is to use nonwoven nanofibrous filters. The process of producing filtration mats of different thickness by electrospinning is presented in the paper. The experimental results on filtration properties of nanofibrous filter mat, including the efficiency of removal of cigarette smoke particles from a gas are also presented.

1. Introduction
The filtration of submicron particles, including nanoparticles, is an important problem in industry, environment and health protection. One of the methods which can be used to solve this problem is that which uses the nonwoven nanofibrous filtration mat. The most effective method of the nanofibrous mat production is electrospinning [1, 2]. Mats produced by electrospinning are of uniform density and built from fibers of nearly the same diameter. Most of the papers published in the subject of electrospinning are intended for the production of nanofibers for various nanotechnology applications, with increasing number of applications in biotechnology [3], and recently, explore the problems of fabrication of nanocomposite membranes for gas cleaning applications [4 - 8].

The physical background of electrospinning lies in the utilization of electrical forces for generating shear stress on the surface of a viscous liquid, usually a polymer solution, flowing from a capillary nozzle. Under this stress, the jet becomes thinner, and finally a thin fiber is formed after solvent evaporation. The method has been applied for the production of nanofibrous mats made from polymer material. The goals of this paper are to determine the morphology of the mats produced by the developed technology and study the efficiency of removal of micro and nanoparticles. This type of mat could be used for the production of masks and filters.

In this paper, we demonstrate the electrospinning technology used for the production of nanofibrous filtration mat in the form of non-woven fabric, and the efficiency of removal of cigarette smoke particles from a gas.

2. Experimental set-up
A photograph of the experimental set up is shown in Figure 1. A thin metal nozzle made from a hypodermic needle of outer diameter 0.45 mm was designed for the production of nanofibers. During
the process of electrospinning, the polymer jet flowing out from the capillary nozzle is elongated, forming a thin thread, which becomes thinner due to the solvent evaporation. By this method, a nanofibrous, polymer filtration mat can be produced. In the experiments, the electrospun fibers were deposited onto a horizontally rotating grounded plate with a thin metal grid stretched on metal frames (dimensions 15 mm x 15 mm). The distance between the nozzle tip and the table was about 120 mm. The electrospinning of nanofibers was carried out for the poly(vinyl chloride) (PVC) and poly(vinylidene fluoride) (PVDF) polymers. The PVC was dissolved in 1:1 dimethylformamide (DMF) and tetrahydrofuran (THF) mixture by stirring at room temperature to obtain 9% solution. The 15% PVDF solution was obtained by dissolving 0.9 g PVDF in 2.48 g DMAC (N, N Dimethylacetamide) and 2.84 g acetone. These polymers were chosen as the mat material because they are chemically resistant and have good mechanical properties. The spinning was carried out at room temperature and humidity of 45-50%. The flow rate of the polymer solutions was 1 ml/h, and the voltage was: 12 kV for PVC, and 14 kV for PVDF.

The morphology of the nanofibrous filtration mat produced by electrospinning was tested under a scanning electron microscope Zeiss Evo 40. The diameter of the PVC fibers was in the range of 600 to 800 nm, and PVDF 400 to 600 nm.

The fibers were deposited on the grid substrate for times of 8, 16, and 24 min in order to produce mats of various thicknesses. After the electrospinning process was completed, each electrospun mat was dried in a vacuum chamber.

![Figure 1](image1.png)

**Figure 1.** Stand for the production of nonwoven filtration mat.

![Figure 2](image2.png)

**Figure 2.** Schematic diagram of experimental stand.
In the paper, the investigations of mechanical properties of nanofabrics were carried out by the optical method. Deformation of nanofibrous mat mounted in a small channel with cross section of 15mm x 15mm, under the air flowing through the channel was observed using microscope NIKON Eclipse TS-100F (Figure 2). The pressure drop on the nanofibrous mat filter of different thicknesses was measured for different air flow rates. The face velocity of the air was measured by hot-wire anemometer TSI 8455.

The efficiency of removal of nanoparticles was measured in a small laboratory channel. The method of measurement of collection efficiency was based on the determination of concentration of particles in the channel before and after the filtration mat by the optical microscope technique. This method was based on light extinction measurement by microscope camera DS1 produced by NIKON. Cigarette smoke was used for testing the removal efficiency of smoke particles. Before and after the experiment, the filtration mat was tested under scanning electron microscope ZEISS EVO 40 in order to estimate qualitatively the effect of particles deposited onto the fibrous filter morphology.

3. Results

The SEM micrographs of PVC polymer mats produced by electrospinning method are shown in Figure 3. Figure 3 (a) presents an image of a clean fibrous filter, and Figure 3 (b) an image of the filter after cigarette smoke treatment. Because the smoke particles are mainly composed of tar matter, the fibers are covered by a thin film of tar which wetted the fiber material. Some thin membranes, which bridge the fibers can also be observed.

![SEM micrographs of PVC polymer mats](image)

Figure 3. PVC nanofibrous polymer mats. (a) Clean filter, (b) Filter after cigarette smoke treatment

![Pressure drop and cigarette smoke removal efficiency](image)

Figure 4. Pressure drop (a) and cigarette smoke removal efficiency (b) measured by the optical method. PVC nanofibrous polymer mats. Sample 1: 8 min deposited on the grid substrate, Sample 2: 16 min, and Sample 3: 24 min.
The pressure drop on the filter is a linear function of gas velocity that indicates the viscous flow of air through the filtration mat. The collection efficiency of the nanofibrous mat is higher than for a HEPA filter (Figure 4b) by similar pressure drop that is very important in air conditioning systems. The difference in collection efficiency between nanofibrous filter and HEPA filter increases with increasing face velocity.

4. Summary
The experimental results on filtration properties of nanofibrous filter mat, including the efficiency of removal of cigarette smoke particles from a gas are presented in the paper.

The nanofibrous filtration mat produced by electrospinning method has fibers of diameter in the range from 400 to 800 nm and is of high porosity. Mats produced by electrospinning are of uniform density and built from fibers of nearly the same diameter that allows a uniform pressure drop distribution to be obtained over the entire surface of the filter.

The experimental results presented have shown that a nonwoven nanofibrous filtration mat has a good filtration efficiency for nano and submicron particles, better than HEPA filters. Pressure drop on the nanofibrous filtration mat is similar to HEPA filters

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