Journal of Electrostatics 83 (2016) 73–77

Contents lists available at ScienceDirect

Journal of Electrostatics

journal homepage: www.elsevier.com/locate/elstat

On the triboelectrically charged nonwoven electrets for air filtration

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ARTICLE INFO

Article history:
Received 1 July 2016
Received in revised form
5 August 2016
Accepted 16 August 2016

Keywords:
Triboelectrification
Needlepunched nonwoven
Electret charge
Air filtration

ABSTRACT

This work deals with development, characterization, and application of triboelectrically charged nonwoven electrets. The electrets were prepared using wool and polypropylene fibers and employing needlepunched nonwoven technology. It was observed that the magnitude and duration of electret charge increased with a decrease in diameter of wool and polypropylene fibers. The charge was found to decay double exponentially, presumably due to quick decay of surface charge and slow decay of bulk charge. The charge in tribocharged electrets was utilized to capture hazardous particles from the air stream very efficiently. The electret media exhibited remarkably higher filtration efficiency than the uncharged media.

1. Introduction

Triboelectrically charged fibrous electrets are dielectric materials exhibiting quasi-permanent electrical charge imparted by contact or frictional electrification between fibers of different chemical entities. When an electron donor fiber comes into frictional contact with an electron acceptor fiber, triboelectric exchange of charges takes place, as a result, the fibrous material gets electrically charged. In the past, a few attempts were made to examine the process of charge generation in triboelectrets. Hersh and Montgomery [1] observed that the direction and length of fiber-to-fiber rubbing played a decisive role in generation of charge in triboelectrets. If two different samples of same material were rubbed over each other in 0–90 direction then negative charges yielded, but when rubbed in 90–0 direction then positive charge generated. Further, the amount of charge generation was found to be proportional to the rubbing length. Liu [2] noticed that the rubbing speed and contact pressure played key roles in generation of charge in triboelectrets. It was observed that higher rubbing speed and higher contact pressure resulted in higher charge generation. Though the process of charge generation was examined in these studies, but the role of fiber geometry in deciding the generation of electret charge was not investigated.

Another interesting topic of study on tribocharged electrets was related to the decay of electret charge. Jasti [3] found that the tribocharged electrets prepared from polyester and polypropylene fibers exhibited slow decay of charge due to high electrical resistivity. Ieda et al. [4] observed that a tribocharged electret with higher charge density exhibited faster charge decay than a tribocharged electret with lower charge density. Ramer and Richards [5] examined the role of relative humidity on charge decay and found that a higher relative humidity helped in quicker conduction of charges, thus resulting in faster charge decay. Onogni et al. [6] studied the dissipation of triboelectric charge from the surface of fibrous materials. It was found that apart from the conduction of charges, the free water molecules present on the surface of fibrous materials helped in charge dissipation during evaporation. In another work, Onogni et al. [7] observed that the rate constant for charge dissipation had a linear relationship with the amount of free water till 20 °C temperature, beyond this no significant effect of temperature was found on charge dissipation.

The application of tribocharged fibrous electrets was one more interesting topic of research. A few attempts were made to find out if the electret charge could have been utilized to capture airborne particles. In this regard, Smith et al. [8] suggested that if the electret charge was required to be useful for air filtration application then a high electric field must be generated in the region between fibers. This meant that both positive and negative charges must be present inside triboelectrets. According to Tsai et al. [9], triboelectrification produced bipolar charges and the electret filter media produced by triboelectrification exhibited highest filtration efficiency among all the three electret filter media prepared by corona charging, tribo charging, and induction charging. Schutz and Humphries [10] examined the air filtration

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http://dx.doi.org/10.1016/j.elstat.2016.08.004
0304-3886/

behavior of tribocharged nonwoven electret filter media prepared from wool and polypropylene fibers. The electret filter media comprising of 60% wool and 40% polypropylene fibers registered highest filtration efficiency (around 60%). Nevertheless, it was not known why the filtration efficiency of the tribocharged nonwoven filter media was so low. As the electrostatic charge of the filter media was not reported and the filtration efficiency of the charged media was not compared to that of uncharged media, the usefulness of triboelectrically charged nonwoven filter media was not established.

It is therefore clear that the state of our knowledge on triboelectrically charged fibrous electrets is presently very unsatisfactory. The role of fiber geometry in determining the magnitude and duration of charge storage in fibrous electrets is not known. The nature of charge decay in triboelectrically charged fibrous materials is not enough well understood. Whether such materials can be found as an excellent air filter media is also questioned. A scholarly research study is therefore called for to improve our understanding on development, characterization and application of triboelectrically charged fibrous materials.

2. Materials and methods

2.1. Materials

In this study, angora wool fibers of 11 μm diameter and 70 mm length, merino wool fibers of 25 μm diameter and 60 mm length, and polypropylene fibers of 2.5 denier and 15 denier linear density and 51 mm length were used. The diameters of 2.5 denier and 15 denier polypropylene fibers were calculated as 19.7 μm and 48.3 μm, respectively, using the following formula: $d = 12.47\sqrt{t}$, where d stands for fiber diameter (μm) and t refers to fiber fineness (denier) [11].

2.2. Methods

2.2.1. Development of triboelectrically charged nonwoven electrets

The wool-polypropylene tribocharged nonwoven electrets were prepared on a small scale manufacturing set-up comprising of different processes including fiber cleaning, fiber opening, fiber drying, fiber blending, fiberweb making and fiberweb bonding. In order to remove spin finish from polypropylene fibers, scouring was done with 0.05% sodium carbonate and a wetting agent at 60 °C temperature for 30 min. The fibers were then dried and opened manually. But, as the wool fibers were procured as scoured ones, no additional scouring was followed. In this work, one-half of electrets were prepared with dried wool fibers, in such cases, wool fibers were dried in an oven at 90 °C temperature for 24 h. The other half of electrets were prepared using wool fibers as procured (undried wool fibers). Afterwards, wool and polypropylene fibers were blended manually. Two sets of blends were prepared. In the first set, coarser wool fibers (25 μm diameter) were blended with coarser polypropylene fibers (48.3 μm diameter). In the second set, finer wool fibers (11 μm diameter) were blended with finer polypropylene fibers (19.7 μm diameter). In each set, wool and polypropylene fibers were blended according to five different weight percentages (0/100, 25/75, 50/50, 75/25, 100/0). The fiber blends were fed to a laboratory-based carding machine and the resulting fiberwebs were processed through a laboratory-based needlepunching machine in order to ultimately prepare needlepunched nonwoven electrets.

2.2.2. Determination of electrical charge in tribocharged nonwoven electrets

The surface potential measurements were carried out keeping the electrostatically charged nonwovens in a sealed enclosure under controlled environmental condition of 27 °C temperature and 65% relative humidity. The temperature was maintained by the air conditioning plant and the humidity was controlled by the help of hydrating agent (chemicals) and dehumidifier attached to the enclosure. A non-contacting electrostatic voltmeter was used for measurement of surface potential. The distance between the measurement probe of voltmeter and the electret was kept constant at 50 mm. The readings of surface potential were noted in kilovolt with a resolution of 10 V. The readings were noted at a time interval of 30 s and plotted as a function of time over a period of 900 s. The very first reading was considered as the initial surface potential and the time required for the surface potential to fall to one-half of its initial value was considered as half-decay time. The initial surface potential and the half-decay time were the measures of magnitude and duration, respectively, of electret charge.

2.2.3. Determination of filtration efficiency of nonwoven filter media

The tribocharged as well as uncharged nonwoven filter media were tested for filtration efficiency. The uncharged media was prepared by treating the charged media with isopropanol and ensuring that there was practically no charge present on the uncharged media. The filtration test was carried out in accordance with ISO-5011 standard. The experimental setup for measurement of filtration efficiency is displayed in Fig. 1. ISO 12103 A2 fine dust particles having diameters ranging from 1 μm to 120 μm were used as test dust. The dust particles were fed to the filter tester at a

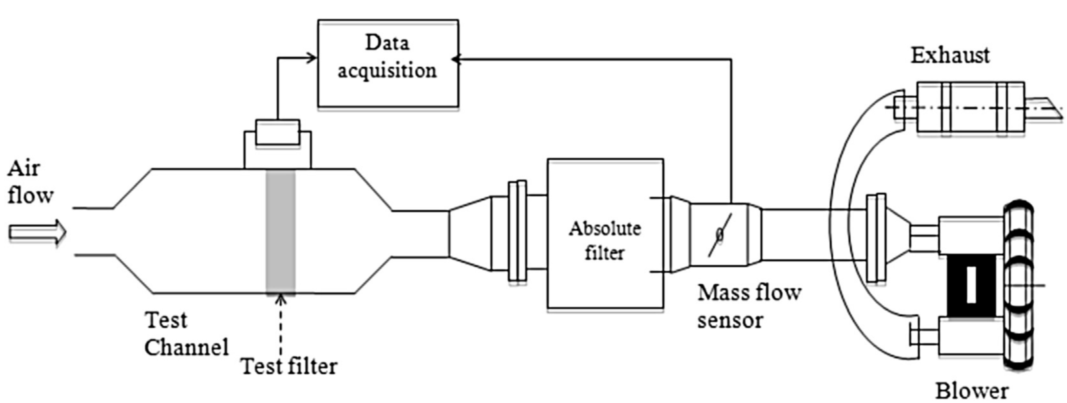

Fig. 1. Schematic diagram of air filter tester.