FIBROUS ELECTRET: DEVELOPMENT, CHARACTERISATION AND APPLICATION

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Abstract: *Fibrous electrets are dielectric media that carry quasi permanent charge, which is mostly induced by the process of corona charging. Fibrous electrets are extensively used in air filtration application due to their ability to offer very high filtration efficiency at low pressure drop. The filtration performance of these filter media is related to their charge storage capability. In this study, the magnitude and duration of surface charge generated in corona charged fibrous electret, developed by varying the discharge process parameters, were optimized simultaneously by using desirability function approach in conjunction with design of experiments and response surface methodology of analysis. Further the decay behavior of fibrous electrets has been investigated, in order to develop clear understanding on the decay mechanisms. A double exponential function was used to explain the charge decay behavior. The developed fibrous electrets were then examined for their filtration efficiency and compared with the mechanical fibrous filters.*

Keywords: *Fibrous electrets, corona discharge, charge decay, filtration efficiency, simultaneous optimization.*

1. Introduction

Corona charged electret fibrous media are dielectric media carrying quasi-permanent or polarized electrical charge achieved through the process of corona charging. They are found to be extensively used in air filters and the products include HVAC filters, HEPA filters, air-purifying respirator, and more [1-2]. The process of corona charging is based on the principle of corona discharge. Corona discharge arises when a very high potential difference is maintained between two asymmetrical electrodes, generally in the form of point to plane geometry. This result in ionization of air near the high potential electrode and the ions get driven towards the low potential electrode. Hence the fibrous media kept over the low potential electrode gets charged through ion deposition on it. This results in formation of a corona-charged fibrous electret. These electrets are known to offer higher filtration efficiency with low pressure drop as they carry an additional particle capturing mechanism, that is the electrostatic force of attraction between the particles and the fibers present in the media. But these electret fibrous media have a problem of charge decay over a period of time. Therefore, the charge stability in a fibrous electret is an important attribute to be studied. Longer is the charge stability longer will be the performance of the filter made by these electret fibrous media. A fundamental understanding of the charge decay behavior of such electrets is not yet achieved. Research findings on the nature of charge decay in fibrous electrets are found to be limited [3-6]. A few attempts have been made to study the effect of corona discharge process parameters like applied voltage and charging time on the charge storage capability of fibrous electrets. However, the findings reported by various researchers lead to many conflicting ideas that further need to be investigated. At the same time, the research findings on the optimization of charge storage in fibrous electrets are scarce. Also, the effects of the corona discharge process parameters on the charge decay of electret fibrous media are not yet explored, systematically.

In this work, a series of fibrous electrets was prepared by varying the corona charging process factors, namely applied voltage, time of charging and distance between electrodes in accordance with a 3^3 full factorial design of experiment. The electrets were tested for their initial surface potential and half-decay time. Half-decay time was defined by the time required for the surface potential to fall to one-half of its value as measured initially. The results of experiments were analyzed by using response surface methodology. The single as well as interaction effects of process factors on the initial surface potential and half-decay time were examined. A simultaneous optimization of multiple responses based on desirability function approach was carried out. The predicted results were compared to those obtained experimentally. Further, three sets of fibrous electrets were prepared by varying the aforesaid three process parameters at three different levels in such a manner that while changing the one, the other two were kept at their middle levels. Thus prepared nine electrets were tested for their surface potential decay. Later, the filtration performance of the electret filter media was tested and compared to that of mechanical filter media.

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2. Materials and Methods

Polypropylene meltblown nonwoven fabric having average fiber diameter of 3 µm, thickness of 0.25 mm and basis weight of 33 g/m^2 was used in this work. A series of circular sample of 12 cm in diameter was cut from the fabric roll and made free of any residual charges by treating with isopropanol solution. After drying, fibrous media were kept in a dessicator maintained with 0% relative humidity, overnight for conditioning. An in-house fabricated apparatus, described elsewhere [7], was used to apply electrostatic charge onto the samples of the nonwoven fabric. Two series of fibrous electrets were developed through positive corona charging; first to optimize the process of corona discharge and second to study the decay behavior in fibrous electrets. The first set of fibrous electrets was developed by varying the corona discharge process parameters as per the full factorial design of experiments. The parameters were varied at three different levels, such as applied voltage from 5 kV to 15 kV, charging time from 15 min to 45 min and the distance between electrodes varied from 25 mm to 35 mm. Similarly, the second set fibrous media was developed by varying one process parameters at a time, keeping the other two process parameters at their middle level. The parameters were varied at three levels of applied voltage, from 5 kV to 15 kV; three levels of charging time, ranging from 5 min to 45 min; and three levels of distance between electrodes, between 15 mm and 35 mm. Whole study was carried out in an atmosphere having temperature of 30 $\pm$ 2°C and relative humidity of 40 $\pm$ 2%.

The corona-charged fibrous media were measured for their surface potential by using a non-contacting electrostatic voltmeter having precision of 10 V. The measurements were carried out at a distance of 100 mm from the measuring probe. The measurement was carried for 1800 s with a time interval of 30 sec.

3. Results and Discussions

3.1 Optimization of Initial Surface Potential and Half-decay Time

The fibrous electrets were characterized for their initial surface potential (ISP) and half-decay time (HDT). The observations were used to fit a pair of quadratic response surface models for the ISP and the HDT after taking into account of the main and interaction effects of the corona charging process factors. The best-fitted

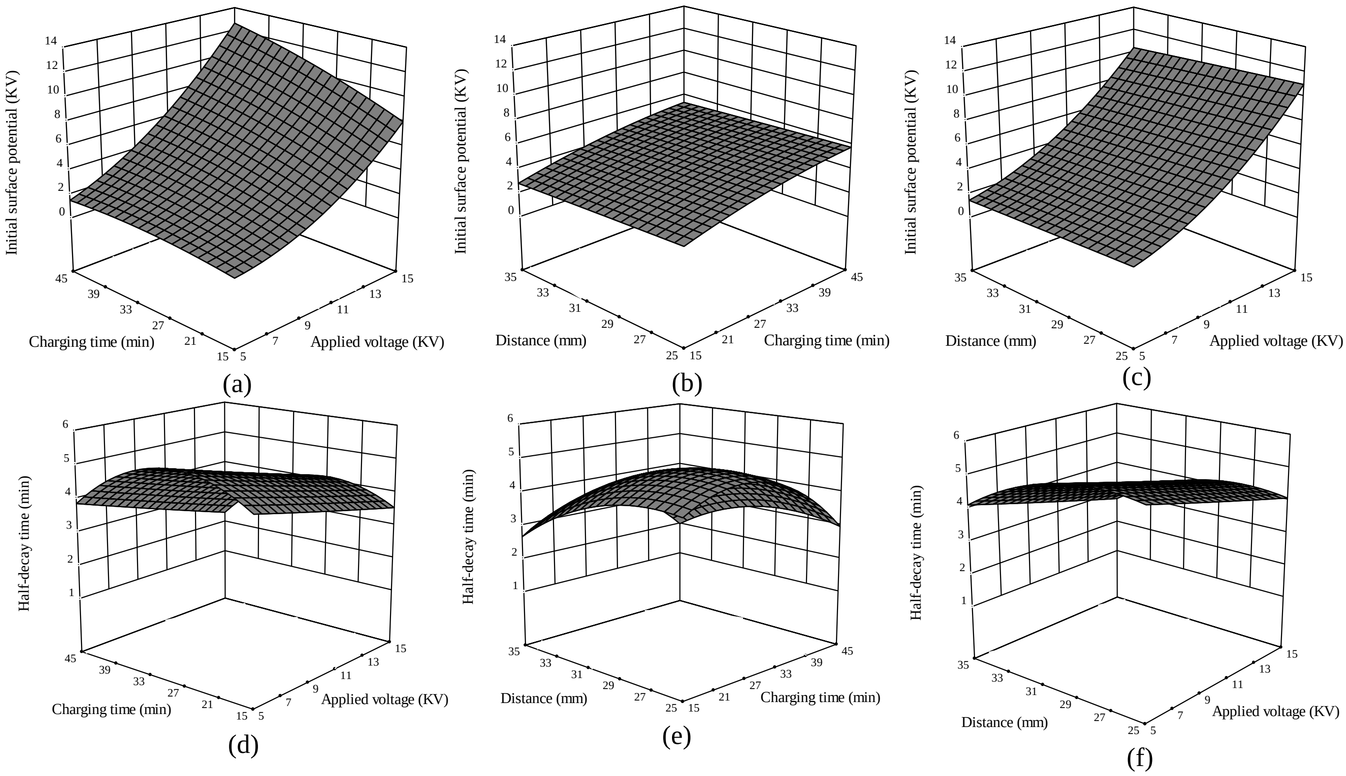

Figure 1: Response surface plots for ISP (a)-(c) and HDT (d)-(f)

response surface models were obtained and which gave three dimensional response surfaces as shown in Figure 1.

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The three-dimensional response surface plots displaying the roles of corona charging process factors on the initial surface potential of fibrous electrets are shown in Figure 1a-1c. It can be observed that the initial surface potential was increased with the increase in applied voltage. Also, with the increase in charging time, there was a slight increase in initial surface potential. It can be seen in Figure 1b that there was a slight decrease in the initial surface potential with the increase in distance between electrodes. Overall, it was inferred that a higher applied voltage in combination with a higher charging time and a lower distance between electrodes was favorable to higher initial surface potential of fibrous electrets. The three-dimensional response surface plots demonstrating the effects of corona charging process factors on HDT of fibrous electrets are given in Figures 1d-1f. It can be observed that the half-decay time was increased almost linearly with the decrease in applied voltage. Further, it can be observed that with the increase in charging time, the half-decay time was increased till it achieved the maximum value and then decreased. As shown in Figure 1e, an increase in half-decay time was initially observed with an increase in charging time and distance between electrodes. However, an increase in both parameters beyond the optimum region resulted in a decrease in half-decay time. Overall, it was inferred that a higher half-decay time can be achieved at lower applied voltage in combination with an optimum charging time and an optimum distance between electrodes.

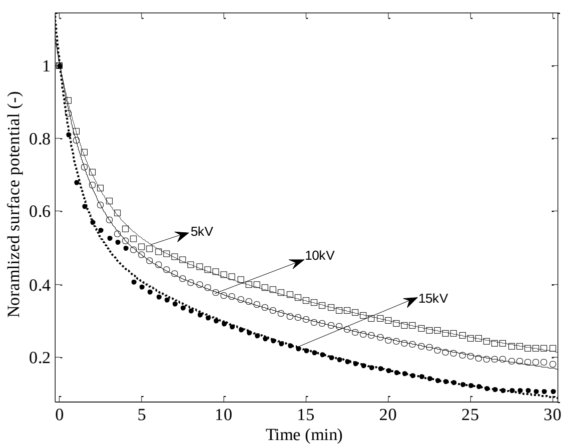
Finally, simultaneous optimization of ISP and HDT was carried out through desirability function approach. The best solution was found at an applied voltage of 15 kV, a charging time of 29.4 min, and a distance between electrodes of 26.35 mm. The initial surface potential and half-decay time were predicted as 10.56 KV and 4.22 min, respectively. The overall desirability was found to be 0.7064. In order to verify the predicted results, a fibrous electret was prepared by keeping applied voltage at 15 KV, time of charging at 30 min and distance between electrodes at 27 mm. The initial surface potential and the half-decay time were recorded as 10.84 KV and 4.24 min, respectively. A satisfactory agreement between experimental and predicted results was thus observed.

3.2 Examination of Charge Decay Behaviour

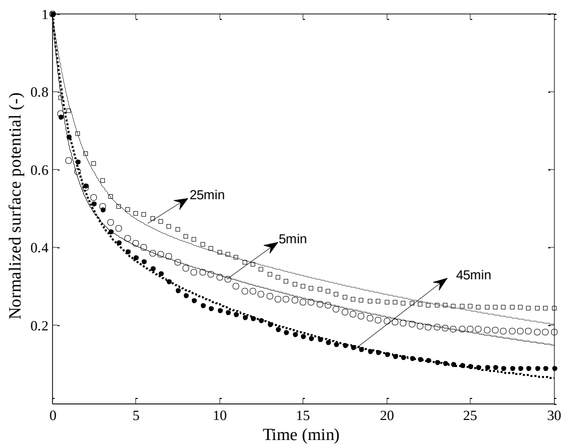
The charge decay profile of corona-charged electret fibrous media prepared by varying the levels of applied voltage, charging time and distance between electrodes was examined. The double exponential function given in Equation 1 was attempted to fit with all the experimental results.

$$z(t) = \alpha_1 e^{-\beta_1 t} + \alpha_2 e^{-\beta_2 t} \quad (1)$$

where z(t) refers to the non-dimensional normalized surface potential (ratio of surface potential at time t to initial surface potential at time 0); t denotes the time, which is expressed in min; α_1 and α_2 denote the dimensionless coefficients and β_1 and β_2 indicate the exponents, which are expressed in min^{-1}. The decay curves for varied applied voltage, charging time and distance between electrodes along with the experimental data and the fit have been given in Figure 2a- 2c. It is evident that the double exponential function fitted very well with the experimental results obtained at all levels of applied voltage, charging time and distance between electrodes.

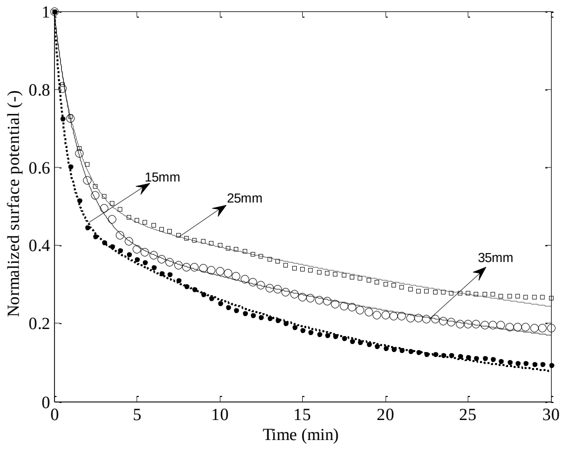


a.



b.

Figure 2: Charge decay curves of fibrous electrets for: a. varying applied voltage, and b. varying charging time



c.

Figure 2 (c): Charge decay curve of fibrous electrets for varying distance between electrodes

The decay behavior of the fibrous electret can be explained through the nature of curve observed. It was noticeable that with the increase in applied voltage the rate charge decay increased as indicating that the contribution of slow-decay component decreased and the contribution of quick-decay component increased. For the case of varying charging time, it was noted that, as the charging time was increased, initially from 5 min to 25 min, the charge decay was slowed down but the decay was more with further increase of charging time from 25 min to 45 min. This suggested that the charge stability of the electret fibrous media could be highest for an optimum level of charging time. The distance between electrodes also affected the charge decay similar to charging time. It was observed that as the distance between electrodes was increased initially from 15 mm to 25 mm, the charge decay decreased initially, but increased while moving further apart from 25 mm to 35 mm. This gave an insight that there exists an optimum distance between the electrodes for which the electret fibrous medium could give highest charge stability.

3.3 Analysis of Filtration Performance

Two (meltblown and spunbond) sets, of polypropylene fibrous electrets were developed at optimized process parameters and tested for their filtration efficiency and pressure drop, at an air flow velocity of 0.1 m/sec, by an in-house developed filter test rig. The filtration performance of these fibrous media was also tested in their uncharged state. The comparison of their filtration behaviour with electret fibrous filters is shown in Figure 3. The filtration efficiency of the fibrous media was found to enhance upon charging with no observed increase in their pressure drop.

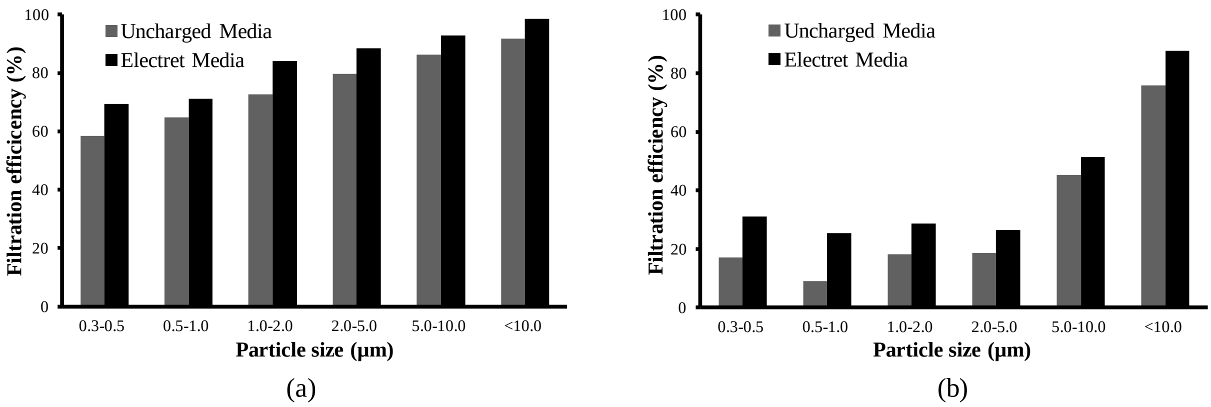


Figure 3: Filtration performance of electret and mechanical: a. meltblown, and b. spunbond fibrous media

4. Conclusions

The electret fibrous media yield highest magnitude and duration of charge at the optimized parameters, with applied voltage at 15 kV for a charging time of 29.4 min and distance between electrodes as 26.35 mm. The charge stored in fibrous electrtes was found to decay double exponentially. Further, the filtration efficiency of the electret media was found to enhance upon charging without any increase in pressure drop as compared to mechanical filters.

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