

Performance Characterization of Nanofibers on Fuel Filtration Media in Automotive Filters

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ABSTRACT

In automotive components, filter serves as one of the most significant part of any vehicle. The efficiency and life of the filter plays an important role in determining the optimum wear protection of the engines. Currently, the cellulose media made on the wetlaid nonwoven process is used for this study and the experiments are carried out by depositing the nanofibers over this media using electrospinning process. The preliminary studies were carried out by varying the process parameters such as Voltage, Needle diameter, Electrode spacing distance and concentration.

In order to minimize the number of trials and time, design of experiments was conducted by varying the process parameters at three levels using Taguchi's L9 orthogonal array experimentation. The influence of process parameters on nanofiber diameter is also investigated by using ANOVA analysis. From this approach, it was found that the efficiency of 3 micron particles is close to 99.9% without compromising on the dust holding capacity of the filter. Finally, an empirical model based on the mean analysis was developed for the prediction of nanofiber diameter in filtration media with enhanced performance in both life and efficiency. This model shows the percentage deviation of 10 – 15 % in comparison to the experimental values of fiber diameter (nm).

INTRODUCTION

In the current manufacturing scenario, new development of filters in the automotive industry has been growing in view of technological challenges. The performance of filter in terms of efficiency and life plays an important role in determining the optimum wear protection of the injection systems. The demand for new development of engine management systems has been increased and to

prevent the injection systems from untimely failure, filters with increased filter efficiency and life is needed. In automotive sector, the emission norms are more stringent and due to that the working tolerance between the moving parts in the engine are reduced. Engines are subjected to contaminant from two different sources such as contaminants produced from combustion and outside environment. Contaminants are produced when the engine is in operating condition. This needs very high efficiency of filtration of finer particles in automotive filtration, especially fuel filtration to reduce wear of the engine and also it requires longer change over of filters. Hence, the development of filtration media with gradient density layers became very important and need for development of finer and finer fibers such as meltblown fibers and nanofibers are essential.

Among the technologies including template method, vapor grown, phase separation and electrospinning, electrospinning process is the most effective method for the development of nanofibers. Electrospinning is a process by which a charged liquid polymer solution is introduced into an electric field [1,2,3,4,5,6]. In this electrostatic technique, a high electric field is generated between a polymer liquid contained in a spinning dope reservoir with a capillary tip or spinneret and a metallic fiber collection ground surface. When the voltage reaches a critical value, the charge overcomes the surface tension of the deformed drop of the suspended polymer solution formed on the tip of the spinneret and a jet is produced. This stretching process is accompanied by the rapid evaporation of the solvent molecules that reduces the diameter of the jet, in a cone shaped volume called the "envelope cone". The liquid polymer solution is dispensed via a needle attached to a syringe at certain voltage and is deposited on a conductive material at ground (0V) located at a certain distance from the needle location.

The polymer is ejected from a needle with an inner diameter between 0.4-1.0 mm. The ejected polymer solution forms a continuous nanofiber when the electrical force overcomes the surface tension. At this point the pendant droplet of the polymer solution at the tip of the needle is deformed into conical shape, typically referred as Taylor cone. After the jet flows away from the droplet in a nearly straight line, it bends into a complex path and other changes in shape occur, during which electrical forces stretch and thin it in the range of nanofiber diameter [7, 8]. The resulting nanofiber collects on an electrically grounded metal sheet or on the substrate over grounded metal sheet. These nanofibers cause dramatic increase in filtration efficiency at relatively small decrease in permeability. Nanofiber filter media improves filter life by employing higher dust holding capacity.

This paper covers the electrospinning studies in fuel filtration media that examine nanofiber diameter on the cellulose media treated using PAN polymer solution. It presents the approach adopted for conducting the experiments with polymer solution treated over the cellulose media. Taguchi's design of experiments was used for conducting the experiments. The target parameter nanofiber diameter on the filter media was measured after electrospinning and the performance on fuel filtration media deposited with nanofibers in terms of efficiency, pressure drop and dust holding capacity was carried out in this study.

EXPERIMENTAL PROCEDURE

Figures 1 and 2 show the schematic diagram and photograph of electrospinning process developed and executed in the lab. It consists of motor with a gear to drive the lead screw and variable frequency drive which is connected for controlling the motor speed. The purpose of the lead screw is to control the dispensing rate through the needle. This arrangement is based on mechanical displacement for fixing a set of needles between the plates connected to the lead screw and a fixed plate which moves towards syringes. The collector plate which is a fixed plate is grounded and kept normal to the syringe needles. High voltage panel is provided besides the syringe to supply voltage to the solution through the needle. When the high voltage is applied to the syringe needle having solution, the solution gets charged and ejects a charged jet which generates nanofiber and collects on the substrate over electrically grounded metal sheet.

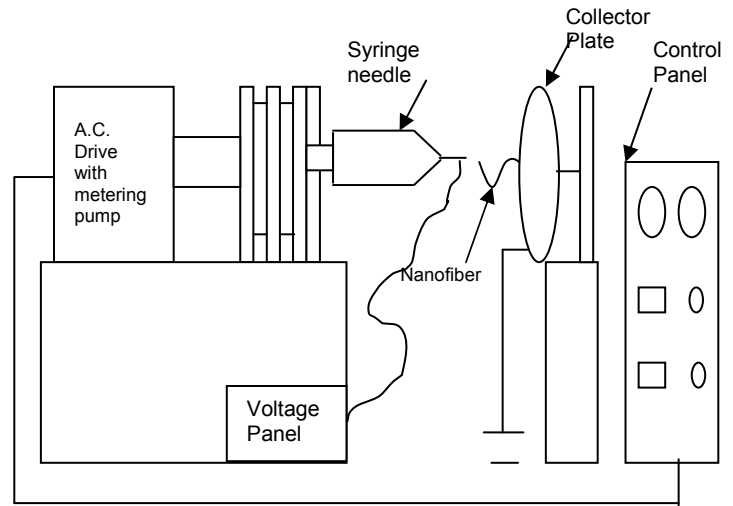


Figure 1: Schematic diagram of Electrospinning process

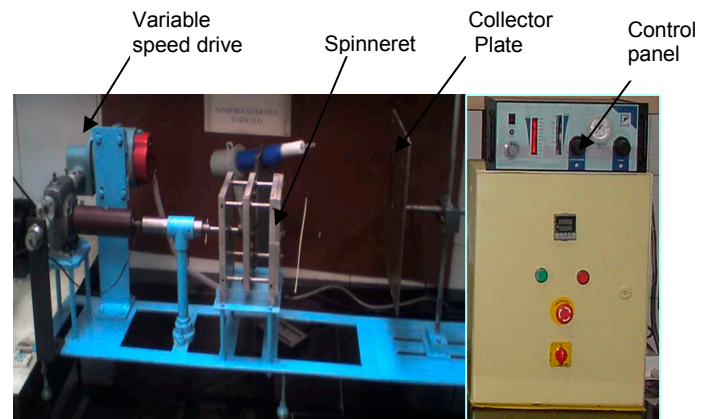


Figure 2: Photograph of electrospinning setup at Mahle Filter Systems India Ltd.

The polymer used for generating nanofibers is in the form of acrylic solution. The media used for the experiments was cellulose media. The characteristics of electrospinning were examined on rectangular media of 297 mm x 210 mm with a thickness of 0.6 mm. Nine samples were considered for electrospinning experiments. Input parameters of electrospinning such as Voltage, Electrode spacing distance, Syringe diameter and Solid concentration were varied to examine their effect on electrospinning results. To analyze the influence of various process parameters on the media surface treated with PAN polymer solution, nanofiber diameter was measured after electrospinning. The nanofiber diameter was measured on the surface using Scanning Electron Microscope (SEM).

TAGUCHI'S DESIGN OF EXPERIMENTS

Design of Experiments (DOE) is the process of planning the experiments considering different parameters influencing the process and different levels for these parameters so as to acquire the necessary data for building statistical models that can aid in predicting the performance of any process [12, 13].

FRACTIONAL FACTORIAL DESIGN

An Orthogonal Array (OA) is a fractional factorial matrix which assures a balance comparison of levels of any factor or interaction of factors. Frequently used orthogonal arrays in design of experiments are two levels and three levels OA. In this work, four parameters are chosen. Since L9 OA considers four parameters at three levels, it is used to select each parameter value for conducting the experiments. The parameter levels are fixed based on the preliminary experiments. In Table 1, the parameters used following L9 OA are shown. The allocation of parameters is shown in Table 2.

Table 1 Parameters used for electrospinning

SL. No.	Variable Parameters	Low	Medium	High
1	Voltage [kV]	20	30	40
2	Needle diameter [mm]	0.45	0.68	0.8
3	Electrode spacing distance [mm]	15	20	25
4	Solid Concentration[%]	8	10	12

Table 2: Allocation of parameters for electrospinning of cellulose media

Expt. No.	Voltage [kV]	Needle diameter [mm]	Electrode Spacing distance [mm]	Solid Concentration [%]
1	20	0.45	15	8
2	20	0.68	20	10
3	20	0.8	25	12
4	30	0.45	20	12
5	30	0.68	25	8
6	30	0.8	15	10
7	40	0.45	25	10
8	40	0.68	15	12
9	40	0.8	20	8

TESTING OF FUEL FILTRATION MEDIA

Testing of filtration media has been conducted for measuring the life and efficiency as per test standard ISO TR 13353 [19]. For testing the filtration media, a fixture was developed to hold the flat sheet of the filter media. The performance characteristics were examined on the circular media of 78.5 sq. cm. area with different thickness. The test stand is also equipped with online particle counters for measuring the size and number of particles at upstream and downstream of the filter during the test. The schematic diagram of the test rig is shown in Figure 3. The test fluid used for this test is MIL H 5606 and ISO fine dust.

Test Specifications

Test standard: ISO TR 13353

Upstream concentration: 5 mg/l

Test flow rate: 1lpm

Test fluid: MILH 5606

Fluid temperature: 30 deg C

Initial cleanliness: 3 micron particles- 230 particles

Dust used: ISO fine test dust

Initial Pressure drop: 1.7 PSI

Injected mass during 50 min: 250 mg

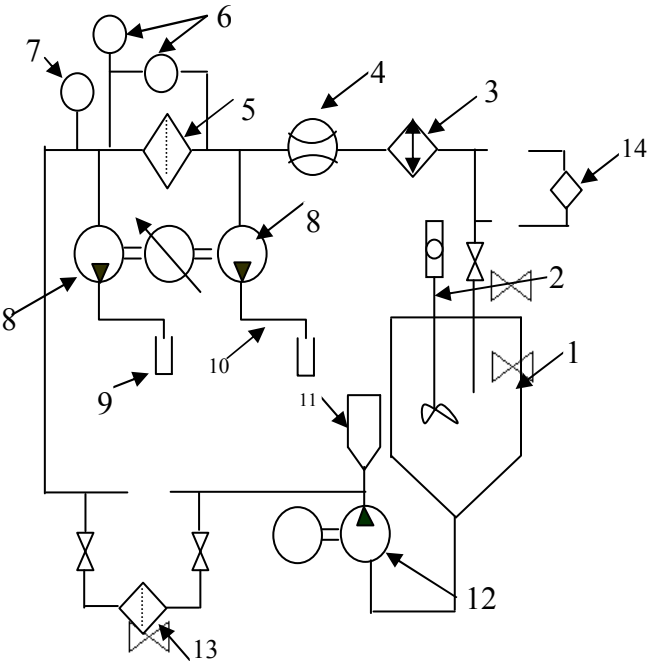


Figure 3: Schematic diagram of test rig as per ISO TR 13353 [19]

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|-----------------------------|--------------------------|
| 1 Reservoir | 11 Damper |
| 2 Mechanical mixer | 12 Dosing Pump |
| 3 Heat control system | 13 Main cleanup filter |
| 4 Flow meter | 14 Return cleanup filter |
| 5 Test filter | |
| 6 Pressure Indicator | |
| 7 Temperature indicator | |
| 8 Sampling pumps | |
| 9 Upstream sampling line | |
| 10 Downstream sampling line | |