STUDIES ON MULTI-CONSTITUENT NONWOVEN AIR FILTER MEDIA

by

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CERTIFICATE

This is to certify that the thesis titled '**Studies on Multi-constituent Nonwoven Air Filter Media',** being submitted by **Mr. Arun Kumar Pradhan** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy,** is a record of bonafide research work carried out by him. He has worked under our guidance and supervision and fulfilled the requirements for submission of the thesis which has attained the standard required for a Ph.D. degree of this Institute.

The results contained in this thesis have not been submitted, in part or in full, to any other university or institute for the award of any degree or diploma.

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ABSTRACT

A driving force for rising demand in cost-effective efficient air filtration media is a growing necessity for pure air required by all around the world. The air has become extremely polluted due to the presence of various contaminants such as dust, sand, lint, mist, spores, pollen, bacteria, smoke, smog, diesel soot, virus, carbon black, to name a few. Needless to say, these particles are needed to be removed from the air and filtration is the only way to do this. There are numerous filter media available today that are capable of removing these particles from a polluted air stream. The nonwoven fibrous filter media are known to be one of the most efficient and cost-effective filter media that are continuously being used in air filtration.

It is always desirable for a filter medium to possess high filtration efficiency, low pressure drop and high mechanical durability. As known, the finer fibres enhance the filtration efficiency but result in higher pressure drop. On the other hand, the coarser fibres result in lower pressure drop, but offer lower filtration efficiency. Further, the filter media made from finer fibres are stronger than those made from coarser fibres. Therefore, the nonwoven filter media consisting of either coarser fibres or finer fibres – known as mono-constituent filters showing unimodal fibre diameter distribution − cannot offer enhanced filtration efficiency, lower pressure drop and higher mechanical durability simultaneously. To derive the best from the both, a large proportion of nonwoven filter media is found to be prepared from a combination of finer and coarser fibres − known as bi-constituent filters showing bi-modal fibre diameter distribution or multi-constituent filters displaying multi-modal fibre diameter distribution. In literature, a significant amount of analytical, numerical, and experimental research work has been published on mono-constituent nonwoven filters. The same on bi-constituent nonwoven filters is limited. Research findings on multi-constituent nonwoven filters are scarce.

In this work, a series of multi-, bi-, and mono-constituent nonwoven fabrics was prepared by using polypropylene fibres of different finenesses and employing a laboratory-based nonwoven needle-punching line. The air flow and particle filtration behaviours of the nonwoven fabrics were determined by using an air filter test rig, which was designed and developed in house. The measurement reliability of the test rig was estimated in terms of repeatability and reproducibility. The test rig was found to be good enough for measurement of air velocity, pressure drop, and filtration efficiency. The same test rig was used to examine the compression-induced air permeability and filtration efficiency of the multi-, bi-, and mono-constituent nonwoven fabrics. The mechanical strength of the multi-constituent nonwoven fabrics was determined and compared to that of the bi- and mono-constituent nonwoven fabrics. Further, a series of virtual three-dimensional multi-, bi- and mono-constituent fibrous structures were generated on computer. Stokes flow simulations were performed to obtain the air permeability and Lagrangian formulation of particle transport was used to simulate the filtration efficiency of the modelled geometries. The simulation results were compared to the experimental ones. Furthermore, attempts were also made to explain the results in light of theoretical models.

The air permeability of the multi-constituent nonwoven fabrics was evaluated and compared with that of the bi- and mono-constituent nonwoven fabrics. The multi-constituent nonwoven fabrics exhibited highest air permeability, followed by the bi- and mono-constituent nonwoven fabrics for the same mean fibre diameter. This behaviour was explained in terms of pore diameter of the nonwoven fabrics. An analytical expression for the mean fibre diameter of the multi-constituent nonwovens was proposed. The expression for mean fibre diameter coupled with the Kozeny-Carman equation was found to predict the air permeability of the multi-, bi-, and mono-constituent nonwovens very well. Also, the simulated results of air permeability were found to be in good agreement with the experimental results of air permeability. The compression induced experiments revealed that the *in situ* compressed structures exhibited higher permeability as compared to the *ex situ* compressed structures.

The particle filtration efficiency of multi-constituent nonwoven fabrics was determined and compared with that of bi- and mono-constituent nonwoven fabrics. The mono-constituent nonwovens exhibited highest filtration efficiency, followed by the bi- and multi-constituent nonwovens, respectively. It was found that the mean fibre diameter in conjunction with an existing model of particle filtration predicted the filtration efficiency of the nonwovens reasonably well. Though the experimental and theoretical results showed good agreement between them, the simulation results were observed to overpredict the filtration efficiency. The multi-constituent nonwovens, however, displayed the highest quality factor, followed by the bi- and mono-constituent nonwovens. The study on compression induced filtration efficiency showed that the *ex situ* compressed nonwovens performed better towards higher filtration efficiency that the *in situ* compressed nonwovens..

The mechanical durability of the multi-constitute nonwoven fabrics was examined and compared with that of the bi- and mono-constituent nonwoven fabrics. It was observed that the mono-constituent nonwoven fabrics exhibited highest bursting strength, followed by the multi- and bi-constituent nonwoven fabrics, respectively, at the same mean fibre diameter. A similar trend was observed in case of tensile strength of the nonwoven fabrics. It was found that for a given tensile strength, the bursting strength of the multi- and bi-constituent nonwoven fabrics was higher than that of the mono-constituent nonwoven fabrics.

The composition of the constituent fibres in nonwoven fabrics was optimized by using an augmented simplex lattice design in conjunction with response surface methodology of analysis. The fibres of different finenesses registered a synergistic effect on the filtration efficiency. Also, a binary or ternary blending of fibres of different finenesses resulted in lower pressure drop than would have expected just by averaging the pressure drops of the corresponding pure blends. A set of expressions was obtained for predicting the filtration efficiency, pressure drop and bursting strength of the nonwovens as a function of proportion of fibres of different finenesses. The predicted results were found to correlate well with the experimental ones. An optimal design of nonwoven filter media corresponded to a ternary blend in order to achieve higher filtration efficiency, lower pressure drop and higher mechanical strength simultaneously.

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