ABSTRACT

Air pollution is regarded the one of the most grave environmental concerns of the world. Effective air filters are a key component in capturing a wide spectrum of air contaminants. Therefore, requirement for highly complex and efficient air filtration systems has increased. Nonwoven fabrics find wide applications in the field of air filtration. The main objective of the filter medium is to maximise the chance of trapping of the suspended particles in the air stream while minimising the energy loss to the air stream. The arrangement of fibres in a nonwoven filter media plays a significant part in deciding the structure of the media which ultimately governs the filtration properties.

This work begins with an investigatory study on the structure and properties of nonwoven fabrics produced from fibres of different fineness. The image analysis and Lindsley's techniques were employed to analyse the structure of the nonwoven fabric. The porous paths created in the fibrous assembly were quantified by calculating the pore channel tortuosity. A relationship was developed between the structure of nonwoven fabrics and its properties which ultimately helped in designing a suitable nonwoven filter media. An air filtration instrument was also designed and fabricated for the evaluation of filtration performance of nonwoven filter fabrics. An attempt was made to regulate the structure of composite nonwoven fabrics having constituent layers of varying structure influenced by different approaches to improve the filtration performance. The structure of composite nonwoven fabrics was investigated by X-ray computed tomography (XCT) and its relationship with the filtration performance was probed. Interestingly, it was established that an inverse gradient of carded batts having increasing order of fibre fineness in the composite nonwoven fabric provided the lowest pressure drop along with next to highest filtration efficiency.

Subsequently, an attempt was made to highlight the significance of the carding parameters (feeder speed, cylinder speed and doffer speed) required for fibre of different fineness for regulating the orientation of fibres in carded web and ultimately the properties of the nonwoven fabric. Three factor three level Box-Behnken factorial design was employed to analyse and optimise the carding parameters required for fibre of different fineness to improve the fibre orientation in carded web. Orientation of fibres was measured with the help of Lindsley's and image analysis techniques in terms of proportion of curved fibre ends, coefficient of relative fibre parallelisation and anisotropy of inclination angle of fibre and tortuosity factor. A non-

linear regression technique was used to establish a relationship between tortuosity factor and measured values of fibre diameter, proportion of curved fibre ends, coefficient of relative fibre parallelisation, anisotropy of inclination angle of fibres and mean flow pore size. Subsequently, the regression models were developed to establish relationship between specific property of nonwoven fabric and structural indices. The findings of this study demonstrated the significance of fibre fineness specific carding parameters for modulating the orientation of fibres in carded web to improve the physical, functional as well as mechanical properties of needle punched nonwoven fabric. The work further explored the possibility of tuning the structure of composite layered nonwoven fabrics by distinctly placing the layers of batts of differently oriented fibres influenced by carding parameters. X-ray computed tomography technique was used for comprehensive evaluation of the packing densities at incremental thickness of composite nonwoven fabrics. The obtained trends of packing density were found to be in good agreement with the measured properties of nonwoven fabrics. Creation of an inverse gradient having an increasing order of orientation of fibre in composite nonwoven fabric displayed improved filtration efficiency and reduced pressure drop.

After realising the role of fibre fineness and fibre orientation in carded web influenced by carding parameters, emphasis was laid on the punching process for further enhancement of functional properties of needle punched nonwoven fabrics. A unique approach of sequential punching was proposed in which composite nonwoven fabrics having layers of semi punched fabrics of either different punch densities or different needle penetration depths were prepared. Initially, the Box-Behnken factorial design was used to optimise the basis weight, punch density and needle penetration depth. The optimised punching parameters for 100 g/m^2 basis weight were used to prepare composite nonwoven fabrics having layers of semi punched fabrics of either different punch densities or different needle penetration depths. X-ray computed tomography technique was used for evaluation of the packing densities of composite nonwoven fabrics. The obtained trends of packing density were found to be in good agreement with the measured properties of nonwoven fabrics. It was established again that formation of an inverse gradient structure in both the cases possessed high filtration efficiency by simultaneously achieving a low pressure drop. However, composite nonwoven fabrics having different punch densities in layered structure performed better than the composite fabrics having different needle penetration depths.

Lastly, influence of external factors like quantity of dust, operating time, and air velocity on the performance of sequentially punched composite nonwoven fabrics was investigated. The study reconfirmed that inverse gradient structure having layers of increasing order of packing density in composite nonwoven fabric resulted in lower pressure drop and improved filtration efficiency as compared to gradient structure having layers of decreasing order of packing density.