Filtration characteristics of spun-laid nonwoven fabrics

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The filtration behaviour of two types of spun-laid nonwoven fabrics, namely thermobonded and needle-punched, with wide range of physical parameters has been studied. A computerized air filtration apparatus has been designed and developed for measuring the air filtration characteristics of different types of filter fabrics. The developed apparatus measures the filtration parameters following the principle of dry filtration mechanisms. Needle-punched nonwovens show good filtration efficiency with lower pressure drop than the corresponding thermobonded nonwovens. Overall, the needle-punched fabrics perform better as a filter fabric in comparison to thermobonded nonwovens.

Keywords: Filtration efficiency, Needle-punched nonwoven, Spun-laid nonwovens, Thermobonded nonwoven

1 Introduction
In the last two decades, over 100 legal regulations have been introduced in the area of environmental protection, the majority of which are directed towards the control of environmental pollution. Therefore, industry should look to filtration technologies to assist in meeting the increasingly stringent statutory requirements. Textile filter fabrics are the essential part of countless industrial processes, contributing to product purity, savings in energy/production costs and a cleaner environment. The filtration can be defined as “the process of separation of dispersed particles from a dispersing fluid (gas or liquid) by the help of porous medium”. The dispersing medium can be gas or gas mixture, most frequently air or a liquid. It is fundamental unit operation aimed at the separation of suspended solid particles from a process by passing fluid stream through a porous substance referred to as a filter medium. Five decades ago filter media were mainly made of cotton, wool and cellulose. Man-made fibres were, of course, already in use but the changes over these five decades have been quite astonishing. These developments have come at all levels—the basic fibre or filament, the form of the filter medium, and the ways in which the media are used. Textile filter media can be divided broadly into two groups, i.e. woven and nonwoven. The woven filter media dominates in certain cases due to easy estimation of pore size distribution, easy to construct to obtain desired filtration efficiency and easy cleaning of choked filter medium. The woven textile filter medium can be constructed according to a particular size and desirable filtration efficiency by simply changing weave parameters and yarn characteristics. This provides an indication of saving of cost and best results suitable for different industries as their requirements. Woven textile filter media can be divided into three groups, namely woven monofilaments, woven multifilament and woven staple fibre fabrics\textsuperscript{1}. The nonwoven filters have the advantages over woven counterpart in many aspects, like higher permeability of the media, more readily available pores per unit area, higher filtration efficiency, no chance of yarn slippage as that of woven media and good cake discharge property. There have been drastic developments in filter media. The trends of nonwoven filter media in recent years involve lower cost, expansion of applications, improved temperature resistance, improved cake separation, lower pressure drop at a fixed efficiency and global usage. Typically, the nonwoven fabric filtration media have 1-500 µm mean flow pore (MFP) ratings. Below 10-15 µm, the fabrics must be calendared in order to achieve the finer micron ratings\textsuperscript{2}.

Number of studies\textsuperscript{3-11} have been reported on various aspects of filtration of nonwoven and woven filter fabrics. The objective of the present study is to understand the filtration-related behaviours of

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thermobonded and needle-punched nonwoven filter fabrics at different dust particle sizes and time intervals. The present paper deals with the filtration behaviour of spun-laid nonwoven fabrics studied on an instrument having laser-based particle counting.

2 Materials and Methods

2.1 Materials
Two types of nonwoven fabrics, namely 100% polypropylene spun-laid thermobonded and 100% polyester spun-laid needle-punched, were used for the study. Four samples from each type of nonwoven fabrics (total 8 samples) were tested for the filtration efficiency. Spun-laid thermobonded samples were coded as S1, S2, S3 and S4, and spun-laid needle-punched samples as N1, N2, N3 and N4.

2.2 Test Methods

2.2.1 Fabric Parameters
Fabric mass per unit area was measured using electronic weighing balance. The thickness of the fabrics was measured according to ASTM D1777-96 standard with the SDL digital thickness gauge at a pressure of 20 gf/ cm². Standard atmospheric conditions were maintained for all the experiments. The fabric parameters are given in Table 1.

2.2.2 Air Permeability
Air permeability of the fabric was measured using TEXTEST FX 3300 air permeability tester at a pressure of 100Pa as per ASTM D737. The air permeability values for all the fabrics are given in Table 1.

2.2.3 Filtration Characteristics
A computerized air filtration apparatus has been designed and developed for measuring the air filtration characteristics of different types of filter fabrics (Fig. 1). The developed apparatus measures the filtration parameters by following the principle of dry filtration mechanisms. The design of the apparatus ensures that the dust particle loaded air flows across the whole area of the samples.

In the apparatus, different types of contaminated air or smoke, like kerosene oil smoke, wood smoke and exhausts from the vehicle, can be taken and allowed to pass through filter fabric at controlled air flow rate. The specially designed furnace can produce the contaminated air as well as gas and feeds into the apparatus by the tube line at controlled flow rate. Air is sucked from bottom of the apparatus by a vacuum pump. Inside vertical pipe of the apparatus, by principle of pneumatic conveying, a suspension of contaminated gas passes across the filter fabric. The number of particles fed and number of particles passed through the specimen give an idea about filtration efficiency. Two laser-based particle counters measure filtration efficiency by counting the number of particles in both inlet and outlet sides. Pressure drop created across filter fabric and the air flow rate are measured using manometer and anemometer respectively. The fabric samples were tested for filtration efficiency against kerosene oil smoke for 90 min. The filtration efficiency of fabrics for a known particle size was calculated using following formula:

\[
\text{Filtration Efficiency} = \frac{\text{Number of particles fed} - \text{Number of particles passed}}{\text{Number of particles fed}} \times 100
\]

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Areal density g/m²</th>
<th>Air permeability cc/cm²/s</th>
<th>Thickness mm</th>
<th>Porosity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>94</td>
<td>80.73</td>
<td>0.36</td>
<td>71.31</td>
</tr>
<tr>
<td>S2</td>
<td>135</td>
<td>58.89</td>
<td>0.47</td>
<td>68.16</td>
</tr>
<tr>
<td>S3</td>
<td>195</td>
<td>34.29</td>
<td>0.77</td>
<td>72.17</td>
</tr>
<tr>
<td>S4</td>
<td>260</td>
<td>10.96</td>
<td>0.90</td>
<td>68.25</td>
</tr>
<tr>
<td>N1</td>
<td>180</td>
<td>258.60</td>
<td>3.26</td>
<td>96.03</td>
</tr>
<tr>
<td>N2</td>
<td>210</td>
<td>219.00</td>
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<td>93.49</td>
</tr>
<tr>
<td>N3</td>
<td>460</td>
<td>102.66</td>
<td>3.65</td>
<td>90.93</td>
</tr>
<tr>
<td>N4</td>
<td>500</td>
<td>95.88</td>
<td>4.15</td>
<td>91.33</td>
</tr>
</tbody>
</table>

Fig. 1—Layout of laser based air filtration apparatus
Filtration efficiency (%) = \[ \frac{N}{n_1} \times 100 \]
\[ = \frac{(n_1 - n_2)}{n_1} \times 100 \]
where \( N \) is the no. of particles arrested by the filter fabric; \( n_1 \), the no. of inlet particles; and \( n_2 \), the no. of outlet particles.

3 Results and Discussion

3.1 Thermobonded Nonwovens

It can be observed from Fig. 2 that the sample S1 shows lower filtration efficiency for <1 \( \mu \) particle size. This is mainly due to higher pore size which is evident from its higher air permeability and lower fabric weight as compared to samples S2, S3 and S4. But after 50 min, all the samples show almost identical filtration efficiencies. It is also observed that among all samples, S4 shows the highest filtration efficiency for <1 \( \mu \) particle size, because of its lower pore size & air permeability, and higher mass per unit area. Figure 2 also shows that for the particle size >5\( \mu \), samples S2, S3 and S4 give almost identical filtration efficiency values, whereas S1 shows much lower filtration efficiency values till 60 min, because of its higher pore size and air permeability. After 60 min, all the samples show the same filtration efficiency values. The initial rate of increase in filtration efficiency with time in case of S1 fabric is much higher than those in case of S2, S3 and S4 samples. This is mainly due to the fact that the phenomenon of pore blockage with >5\( \mu \) size particles are more prominent in case of S1 than in case of other fabrics. It is clear that the fabric samples S2, S3 and S4 show marked increase in filtration efficiency with time in case of particles size <1\( \mu \), but in case of particles >5\( \mu \) these fabrics show relatively lesser increase in filtration efficiencies with time.

After a period of time for both <1\( \mu \) and >5\( \mu \) particle sizes, all the samples show almost identical efficiencies, because of the cake formation. Cake which is formed on the inlet side of the fabric assists in filtration of particles. At the beginning the filter cake thickness is very less, so initially filtration efficiencies are at lower side.

The change in pressure drop across the thermobonded nonwoven fabrics with time for particle size >5\( \mu \) is shown in Fig. 3. It is evident that the sample S4 has much higher pressure drop from the beginning. Sample S3 has higher pressure drop compared to samples S1 and S2 throughout the test. In the entire samples, pressure drop (pressure difference between inlet side and outlet side) increases because of the formation of cake at the inlet side of the sample. In case of sample S4 the pressure drop is significantly higher; this is because of its very low air-permeability and high areal density.

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**Fig. 2**—Filtration efficiency of thermobonded fabrics for particle sizes (a) <1\( \mu \) and (b) >5\( \mu \) at different intervals of time

**Fig. 3**—Change in pressure drop with time in case of (a) thermobonded and (b) needle-punched fabrics for particle sizes >5\( \mu \) at different intervals of time
Even though for sample S4, pressure drop is much higher than those for other thermobonded samples, it is observed that in all the thermobonded fabrics pressure drop increases sharply at quick intervals of time right from the beginning of the test. Hence, this sample is not recommended for filtration of air having >5µ particles size.

3.2 Needle-punched Nonwovens

The change in filtration efficiency of needle-punched nonwoven fabrics for particle size <1µ with time is shown in Fig. 4. Samples N1 and N2 have lesser filtration efficiencies for <1µ particle size than samples N3 and N4. Between N1 and N2, sample N1 shows still lesser values of efficiencies than sample N2. The reason for the lower values of N1 and N2 is that both the fabrics have high air permeability values that indicate higher pore size. Lower GSM, high porosity and high air permeability values cause lower values of filtration efficiencies for samples N1 and N2. It is also clear from Fig. 4 that filtration efficiency values for all needle-punched fabrics come close at 70 min and remain as such for the rest of the time interval.

Figure 4 also shows the change in filtration efficiency of needle-punched nonwoven fabrics for particle size >5µ with time. It can be observed that sample N1 behaves differently from rest of the samples for particles >5µ. The nature of the curves is almost similar to that of thermobonded nonwovens (Fig. 2) for particles size >5µ. The rate of increase in filtration efficiency for lower GSM fabric (sample N1) is very high initially and after 20 s the filtration efficiency of all the fabrics becomes almost same. This may be due to the fact that initially the larger pores in N1 sample are blocked by the particles size >5µ.

It can be concluded from Fig. 3 that the pressure drops over the complete period of testing time are same for N1 and N2 samples and also for the samples N3 and N4, because of the similarities in their air permeability values. But, the rates of increase in pressure drop in case of fabrics N1 and N2 are relatively slower initially as compared to fabrics N3 and N4. This may be due to the fact that the blockage of pores in needle-punched fabrics with lower GSM is slower. Throughout the experiment it is noticed that in needle-punched samples the pressure drops are lesser than the corresponding thermobonded fabrics, which is due to higher porosity of needle-punched fabrics. Getting good filtration efficiencies with less pressure drops is very important requirement in filtration. Overall in needle-punched samples, N2 and N3 show good results.

3.3 Comparative Filtration Behaviour

Overall filtration efficiency for a fabric sample with a particle size <1µ or >5µ has been calculated based on total number of particles of that size fed to the system and total number of particles allowed to pass through the system for the complete duration of the experiment. For particles of the size <1 µ (from Fig. 5) it is found that sample N1 shows significantly lesser efficiency than rest of the samples. This is mainly due to the fact that higher air permeability, lower GSM and higher porosity values of this fabric help the particles of <1µ size to escape through than in any other sample.

It is also observed from Fig. 5 that except N1, remaining needle-punched samples show slightly better results for <1µ particles size. This is because of their bulky characteristic. This is very clear when GSM and thickness values of S3 and N2 samples are compared (Table 1). Since needle-punched fabrics are bulky, there is higher probability of catching particles of any size than equivalent thermobonded fabrics. Thermobonded fabrics have straight pores since they are thin as compared to needle-punched samples for the identical GSM. Due to these straight pores,
sample S3 shows lower filtration efficiency than N2 sample. In case of >5 μm particles of size, the needle-punched fabrics show good results (Fig. 5).

Bulkiness of needle-punched fabrics also reflects in less pressure drop build-up throughout the experiment. It is evident from Fig. 3 that fabric sample S3 shows much higher values of pressure drops right from the beginning to the end of experiment as compared to equivalent needle-punched sample (N2), which is having similar areal density.

4 Conclusions

4.1 Needle-punched nonwovens show good filtration efficiency with lower pressure drop than the corresponding thermobonded nonwovens.

4.2 Thermobonded nonwovens are having compact structure and lower air permeability with equivalent GSM, which results in higher pressure drop. High areal density of thermobonded fabrics causes more pressure drop because of rapid cake formation on its surface.

4.3 In thermobonded fabrics with low areal density, there is high probability of escaping the particles because of their lower thickness and straight pore structure.

4.4 Overall, the needle-punched fabrics perform better as filter fabric as compared to thermobonded nonwovens.

Industrial Importance: Spun-laid nonwoven fabrics are extensively used in various technical applications. The present study deals with the applications of these fabrics in filtration. From this study one can get idea about the applicability of a specific nonwoven fabric for a particular size of particle. The industry can get some clue in selection of a particular type of nonwoven fabric to achieve targeted filtration characteristics for a given condition.

References