The filtration behaviour of woven and nonwoven fabrics at different air flow rate, dust feed rate, dust loading, time intervals and dust particles has been studied. It is observed that the pressure drop increases with the increase in airflow rate for both the woven and nonwoven filters. In general, the pressure drop in case of woven filter is found to be higher than that in case of nonwoven filter. In case of woven fabric, in general, the filtration efficiency and the pressure drop increase with the time interval, but the rate of increase is found to be different for different types of dust particles, i.e. the distribution of size of dust particles. The cleaning efficiency of woven filter in case of clay is found to be lowest followed by sand and Sipernat mixture. The outlet dust concentration in case of woven filter reduces with the time and in case of clay it is highest as compared to the other dust particles. In case of nonwoven filter, with the increase in air flow rate the increase in pressure drop is found to be more at constant dust loading than that at constant dust feed rate. The filtration and cleaning efficiencies of nonwoven fabric, for a certain type of dust particle, are found to be affected by the dust feed rate and the air flow rate.

**Keywords:** Air flow rate, Cleaning efficiency, Dust feed rate, Filtration efficiency, Nonwoven fabric, Pressure drop, Sipernat mixture

**IPC Code:** Int. Cl. D04H

### 1 Introduction

A filter medium is defined as the permeable material used for a filter that separates particles from a fluid passing through it. Textile filter fabrics are essential part of countless industrial processes, contributing to product purity, savings in energy/production costs and a cleaner environment. Till the beginning of 1950, textiles used in filtration were based on woven fabrics of cotton, wool and glass fibres. The development of synthetic fibres and nonwoven fabric technology substantially modified the use of textiles in filtration. Main importance of textile filter media in air filtration is to control air pollution. Air filtration plays an important role in improving air quality and hygiene at work. The demands on air quality and hygiene at work places have increased greatly due to new regulations, new scientific knowledge and also a change in health consciousness. Apart from temperature and relative humidity, primarily the concentration of gaseous and solid contaminants is an important parameter to evaluate the air quality at work places. There exists a multitude of possibilities to improve the air quality. Filter fabrics made of woven and nonwoven structures are suitable to effectively collect particles (dust) from intake or exhaust air and have therefore been used for this purpose. Practically, all dry filtration is the filtration of air and has conventionally been split into two divisions, namely gas filtration and air filtration. Gas filtration, using textile filter media, deals with air with high solid loads and often at very high temperatures, for instance, collecting fly ash from coal fired boilers or collecting carbon black as a part of the production process. A number of filter media are used for separating solid particles from gases. But, in terms of efficiency, the other filter medias rarely surpass the fabric filter, particularly when the particles are of the order of 1 micron or less in size. The particles in the environment are typically in the range of 0.1-25 μm and may be collected by one of the several techniques, viz. setting chambers, cyclones, granulate filters, electrostatic precipitators and fabric collectors. Fabric collectors are most efficient and versatile in separating out very fine particles, which settle down very slowly.\(^1\)

Textile filter media can be divided broadly in two groups, i.e. woven and nonwoven. The nonwoven filters have advantages over woven counterpart in many aspects, like higher permeability of the media or more readily available pores per unit area, higher filtration efficiency, no chance of yarn slippage as that

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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. 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 which provide 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, viz woven monofilaments, woven multifilament and woven staple fibre fabrics. In filtration, nonwoven fabrics can be generally described as a random fibrous web, formed by either mechanical, wet or air laid means and having interconnecting open area throughout the cross-section and able to remove a percentage of particulate from liquid or gaseous fluids streams flowing through it. Typically, nonwoven fabric filtration media have 1 to 500 micron mean flow pore (MFP) ratings. Below 10-15 micron, the fabrics must be calendared in order to achieve the finer micron ratings.

A large number of studies has been reported on various aspects of filtration of nonwoven and woven filter fabrics. The objective of the present study was to understand the filtration related behaviour of woven and nonwoven filter fabrics at different levels of air flow rate, dust feed rate, dust particle size and time intervals.

2 Materials and Methods

Two commercially available filter fabrics (one woven and other nonwoven) have been used in the study. The constructional details of woven filter fabric are: weave, 2/2 twill; warp, 135 tex polyester yarn; weft, 165 tex polyester yarn; warps/dm, 205; weft/dm, 106; thickness, 1.35 mm; and fabric area density, 588 g/m². The nonwoven fabric is polyester needle-punched with thermobonded surface with an area density of 540 g/m² and thickness of 4.11 mm. For testing the filtration related characteristics, three different types of dust particles, namely 100% sand, 100% clay and Sipernat mixture (sand 50%, clay 30% and Sipernat 20%) were used. The sand is least cohesive and adhesive; the clay has high cohesive and adhesive behaviour and the Sipernat is voluminous and free flowing.

2.1 Analysis of Particle Size Distribution of Dust

Dust particle analysis of different types of dust samples was done by CILAS particle size analyzer for particle size distribution and mean diameter. The CILAS particle size analyzer has two main functions, namely blank measurement and sample measurement by UV source. The blank solution is medium of solvent without any particle and is measured by blank measurement function with different UV wavelength sources in glass channel. Disturbance of UV source for the same different wavelength is taken as blank measurement. After addition of sampling particles, the same procedure is followed after uniform mixing with ultrasound vibrator and agitator. With the help of CILAS software the difference in UV observation shows particle size distribution and sizes of sampling particles. Range of particle size measurement is 0.5-2000 micron/100 classes. The particle size distributions of sand, clay and Sipernat are shown in Fig. 1 and Table 1.

2.2 Testing of Filtration and Related Parameters

Air permeability of fabrics was tested by air permeability tester FX 3300 with test area of 5 cm² and also by filtration tester where the test area is 150 cm². An indigenously developed air filtration testing instrument with dust feeder was used for measuring the filtration characteristics of fabrics. The dust loading is defined by the ratio of amount of dust particle to the volume of air. Dust loading is the concentration of dust in air, which is passed through filter fabric. In the present study the dust loading was kept within the range of 2-6 g/m³. The face velocity of air is the ratio of volumetric flow rate through the fabric and the area of fabric, as expressed below:

\[ V = \frac{\text{Volumetric flow rate through the filter (}Q\text{)}}{\text{Area of filter (}A\text{)}} \]

The pressure drop across the filter is defined by the following expression:

\[ \Delta P = P_1 - P_2 \]

where \( P_1 \) and \( P_2 \) are the upstream and downstream absolute pressures respectively. Initially, the difference depends uniquely on the porosity of filter
medium and as the filtration progresses this loss also depends on the properties of particles retained by the filter. The filtration efficiency is defined as the ratio of amount of dust collected by the fabric to the amount of dust fed, as shown below:

\[
\text{Filtration efficiency (\%)} = \frac{\text{Mass of dust collected by fabric}}{\text{Mass of dust fed}} \times 100
\]

The dust particle was fed with the help of a dust feeder at a constant rate and dust concentration. The weight of dust particle collected by the fabric at certain time interval was measured by measuring the mass of dust feed and the mass of dust passed through the filter fabric. The dust particles passed through the filter fabric were collected by an absolute filter paper (thickness 0.20 mm and weight 87 g/m²) placed after the filter fabric. The idea was not to disturb the filter fabric and duct cake formation during the course of testing. The dust particles were fed for 1 min time interval and weights of absolute filter paper were observed to know weight of dust particles passed through filter fabric for the measurement of filtration efficiency. Initial pressure drop and pressure drop after each 1 min time interval was noted for the study of comparative rise in pressure drops. The cleaning efficiency of the filter fabric was determined by giving a reverse flow on the fabric. Cleaning of the filter was done in reverse side of dust loaded filter fabric with air at a face velocity of 28.89 cc/cm²/s (same as that used during filtration) for time duration of 5 min. Mass of dust removed from filter fabric was measured after cleaning for cleaning efficiency. Fabric area density was taken after 5 min time and the cleaning efficiency was calculated by using following relationship:

\[
\text{Cleaning efficiency (\%)} = \frac{\text{Dust removed}}{\text{Total dust retained by fabric}} \times 100
\]

The outlet concentration of dust particles \(C_0\) is the ratio of the mass of dust passed by the filter to the volume of air passed during a given filtration time, as shown below:

\[
C_0 = \frac{m_p}{Qt_t}
\]

where \(m_p\) is the mass of particles in given filtration time; \(t_t\), the filtration time; and \(Q\), the volumetric flow rate through the filter.

### 3 Results and Discussion

#### 3.1 Filtration Behaviour of Woven Fabric

The change in pressure drop across the woven fabric at different levels of air flow rate was studied without dust particles by air permeability tester as
well as by filtration tester. The filtration behaviour was studied at different time intervals with different types of dust particles.

### 3.1.1 Effect of Air Flow Rates on Pressure Drop

Effect of air flow rate on the pressure drop created across woven filter fabric was studied on air filtration apparatus and compared with air permeability tester and the test results are shown in Fig. 2. It is clear that the pressure drop increases with the increase in airflow rate due to more resistance created by fabric at higher flow rate. Pressure drops measured at lower flow rate by air filtration apparatus are found to be close to those measured by air permeability tester. At higher flow rate, the increase in pressure drop difference may be due to the fact that at higher flow rates more resistance is offered by smaller filter test area in case of air permeability tester.

### 3.1.2 Filtration Behaviour for Different Types of Dusts

Filtration behaviour of woven filter fabric was studied for different types of dusts (sand, clay and Sipernat mixture) at constant face velocity, dust feed rate and dust loading of 28.89 cc/cm²/s, 1.02 g/min and 3.92 g/m³ respectively. Table 2 shows the filtration efficiency and the pressure drop of woven filter for different types of dust particles at different time intervals. Figures 3 and 4 show the filtration efficiency and the pressure drop respectively of woven filter for different types of dust particles at different time intervals. It can be observed from Table 2 and Figs 3 and 4 that, in general, the filtration efficiency and the pressure drop increase with the time interval, but the increase is different for different types of dust particles, i.e. the distribution of size of dust particles. The proportion of larger size of particles in case of sand being high, the filtration efficiency of sand is relatively higher than the other particles and reached 100 % at 3 min. But, on the other hand, the pressure drop is always lower than that observed in case of other particles. This is mainly due to the fact that in case of sand the dust cake, which was formed on the filter surface, is porous in

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Filtration efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
</tr>
<tr>
<td>0</td>
<td>- (20.8)</td>
</tr>
<tr>
<td>1</td>
<td>97.80 (27.6)</td>
</tr>
<tr>
<td>2</td>
<td>99.27 (31.6)</td>
</tr>
<tr>
<td>3</td>
<td>100.0 (35.6)</td>
</tr>
<tr>
<td>4</td>
<td>100.0 (38.8)</td>
</tr>
</tbody>
</table>

PD — Filtration process was terminated for high pressure drop. Values in parentheses indicate pressure drop (mm water gauge).
structure and results in lower pressure drop even at 100 % filtration efficiency. On the other hand, the clay and Sipernat mixture show lower filtration efficiency and higher pressure drop than that of sand and at 4 min the pressure drop is so high that the filtration process had to be terminated. This behaviour is mainly due to the smaller size of particles in these two dusts, which initially pass through the filter and after cake formation block the pores completely.

The cleaning efficiencies in case of sand, clay and Sipernat mixture were found to be 79.77, 52.47 and 84.42% respectively. The lowest cleaning efficiency in case of clay may be due to the highest cohesive and adhesive behaviour of particles. Sipernat mixture shows highest cleaning efficiency in spite of clay contribution in mixture. This may be due to voluminous and free flowing behaviour of Sipernat. Sipernat shows very low density than other dusts and hence volumetric contribution is higher.

Figure 5 shows the outlet concentrations of different types of dusts at different time intervals. It is clear that for all the dust particles the outlet dust concentration reduces with the time, which is due to the formation of dust cake and increase in filtration efficiency with time. The outlet concentration in case of clay is highest; this may be due to the fact that at same dust feed rate clay shows the lowest filtration efficiency, i.e. larger amounts of dusts pass through the filter.

3.2 Filtration Behaviour of Nonwoven Fabric

The change in pressure drop across the nonwoven fabric was studied without and with dust particles. When studied without dust particle, the change in pressure drop was observed at different levels of air flow rate. However, with dust particles, the change in pressure drop was studied at different levels of time intervals for various experimental combinations. The filtration and cleaning efficiencies were studied after 5 min of dust feeding with one type of dust particles, i.e. Sipernat mixture.

3.2.1 Effect of Air Flow Rates on Pressure Drop

3.2.1.1 Without Dust

Figure 6 shows the impact of air flow rate (without dust) on the pressure drop created across nonwoven filter tested on air filtration apparatus and compared with air permeability tester. It is clear that the pressure drop increases with the increase in airflow rate due to more resistance created by fabric at higher flow rate. The results obtained by air filtration apparatus are found to be closely related to the results obtained by air permeability tester. The rate of increase in pressure drop with the increase in air flow rate is lower in case of nonwoven fabric than the woven fabric. This is due to the more porous structure.

<table>
<thead>
<tr>
<th>Experimental combination</th>
<th>Air flow rate (cc/cm²/s)</th>
<th>Dust feed rate (g/min)</th>
<th>Dust loading (g/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁</td>
<td>22.2</td>
<td>0.85</td>
<td>4.25</td>
</tr>
<tr>
<td>A₂</td>
<td>22.2</td>
<td>1.1</td>
<td>5.50</td>
</tr>
<tr>
<td>B₂</td>
<td>28.9</td>
<td>1.1</td>
<td>4.25</td>
</tr>
<tr>
<td>C₂</td>
<td>35.6</td>
<td>1.1</td>
<td>3.43</td>
</tr>
<tr>
<td>C₃</td>
<td>35.6</td>
<td>1.35</td>
<td>4.25</td>
</tr>
</tbody>
</table>

*Alphabets A, B & C show three different air flow rates and numbers 1, 2 & 3 show three different dust feed rate.*

Fig. 5 — Outlet concentrations for different types of dusts in case of woven filter

Fig. 6 — Effect of air flow rates on pressure drop in nonwoven filter (without dust)
Table 4 — Impact of different process parameters on filtration and cleaning efficiencies of nonwoven filter fabric

<table>
<thead>
<tr>
<th>Experimental combination</th>
<th>Avg. initial mass of fabric specimen g</th>
<th>Avg. final mass of fabric specimen g</th>
<th>Mass of dust retained on filter fabric g</th>
<th>Mass of dust retained on filter paper g</th>
<th>Total dust supplied g</th>
<th>Mass of fabric specimen after cleaning g</th>
<th>Filtration efficiency %</th>
<th>Cleaning efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>13.92</td>
<td>17.69</td>
<td>3.77</td>
<td>0.28</td>
<td>4.05</td>
<td>15.37</td>
<td>93.1</td>
<td>61.5</td>
</tr>
<tr>
<td>A2</td>
<td>13.10</td>
<td>18.41</td>
<td>5.31</td>
<td>0.25</td>
<td>5.56</td>
<td>14.94</td>
<td>95.5</td>
<td>65.3</td>
</tr>
<tr>
<td>B2</td>
<td>13.61</td>
<td>18.47</td>
<td>4.86</td>
<td>0.28</td>
<td>5.14</td>
<td>15.36</td>
<td>94.6</td>
<td>64.0</td>
</tr>
<tr>
<td>C2</td>
<td>12.93</td>
<td>17.90</td>
<td>4.97</td>
<td>0.32</td>
<td>5.29</td>
<td>15.14</td>
<td>93.9</td>
<td>55.5</td>
</tr>
<tr>
<td>C3</td>
<td>14.06</td>
<td>20.30</td>
<td>6.24</td>
<td>0.34</td>
<td>6.58</td>
<td>14.92</td>
<td>94.83</td>
<td>86.2</td>
</tr>
</tbody>
</table>

Fig. 7 — Effect of air flow rate, dust feed rate and dust loading on pressure drop of nonwoven filter fabric

3.2.1.2 With Dust

Effect of increase in air flow rates on pressure drop of nonwoven fabric was studied for constant dust feed rate of 1.1 g/min and constant dust loading of 4.25 g/m³ at three different air flow rates (22.2, 28.9 and 35.6 cc/cm²/s). The dust used in this study was Sipernat mixture. Table 3 shows the details of experimental parameters used during the study and Fig. 7 shows the impact of these parameters on pressure drop. It is clear from Fig. 7 that the pressure drop increases with time for all the experimental combinations. The reason for this has been explained earlier. The experimental combinations A₂, B₂ and C₂ show that the increase in air flow rate at constant dust feed rate increases the pressure drop, even when the dust loading drops. The reduction in dust loading should reduce the pressure drop. But the extent of increase in pressure drop due to increase in air flow rate dominates over the extent of reduction in the pressure drop due to drop in dust loading, resulting the net increase in pressure drop. The experimental combinations A₁, B₂ and C₃ show the increase in air flow rate at constant dust loading. It is found that at constant dust loading the increase in pressure drop is more than that at constant dust feed rate. This fact may be due to more rapid blinding of the pores of fabric.

3.2.2 Filtration and Cleaning Efficiencies

The filtration study of nonwoven filter fabric was carried out with Sipernat mixture, and the filtration and cleaning efficiencies were calculated after 5 min time interval for different experimental combinations as indicated in section 3.2.1.2. The details of filtration and cleaning efficiencies are given in Table 4. The filtration efficiency, in general, is found to be lower than that of woven fabric, which is due to the structure and size of pores in the filter fabrics. It can be observed that for experimental combinations A₂, B₂ and C₂, i.e. keeping the dust feed rate constant when the air flow rate increases, the filtration efficiency reduces. This may be due to the fact that at higher speed of air the dust particles also travel at higher speed and strike the filter fabric with higher energy, which may result more particles to pass through the pores of nonwoven filter. It has also been observed that with the increase in dust feed rate for a constant air flow rate (experimental combinations A₁, A₂ and C₂, C₃), the filtration efficiency after 5 min time interval increases. This may be due to quick dust cake formation at higher dust feed rate.

It can also be observed from Table 4 that as the air flow rate increases, keeping the dust feed rate constant (A₂, B₂ and C₂), the cleaning efficiency drops. This may be due to the fact that at higher air flow rate the dust particles have chances of penetrating within the porous structure of nonwoven
fabric and it became difficult for those particles to come out during cleaning by reverse flow of air. It is also observed that as the dust feed rate increases keeping the air flow rate constant (A1, A2 and C2, C3), the cleaning efficiency increases. This is due to more surface cake deposition at higher dust feed rate.

4 Conclusions

The pressure drop increases with the increase in airflow rate for both the woven and nonwoven filters. In general, the pressure drop in case of woven filter is higher than that of nonwoven filter. In case of woven fabric, in general, the filtration efficiency and the pressure drop increase with the time interval, but the rate of increase is found to be different for different types of dust particles, i.e. the distribution of size of dust particles. The cleaning efficiency of woven filter in case of clay is found to be lowest followed by sand and the Sipernat mixture. The outlet dust concentration, in case of woven filter, reduces with the time and in case of clay it is highest as compared to the other dust particles. In case of nonwoven filter, with the increase in air flow rate the increase in pressure drop is more at constant dust loading than that at constant dust feed rate. Keeping the dust feed rate constant when the air flow rate increases, the filtration efficiency reduces in case of nonwoven filter. With the increase in dust feed rate for a constant air flow rate, the filtration efficiency of nonwoven filter increases. The increase in air flow rate, keeping the dust feed rate constant, decreases the cleaning of nonwoven filter and the increase in dust feed rate, keeping the air flow rate constant, increases the cleaning efficiency.

References