Chapter 4

Effect of Fibre Cross-Sectional Shape, Fabric Weight and Reinforcing Material on the Filtration and Mechanical Properties of Nonwoven Needle-Punched Polyester Filter Fabrics
CHAPTER 4

EFFECT OF FIBRE CROSS-SECTIONAL SHAPE, FABRIC WEIGHT AND REINFORCING MATERIAL ON THE FILTRATION AND MECHANICAL PROPERTIES OF NONWOVEN NEEDLE-PUNCHED POLYESTER FILTER FABRICS

The present chapter deals with the assessment of the influence of fabric weight and reinforcing material of three different fibre cross-sectional shapes on the characteristics of needle-punched nonwoven polyester filter fabrics.

4.1 Introduction

In order to bring out some desirable characteristics in synthetic fibres, manufacturers have been paying much attention in recent years to chemical and physical modifications of the structure of the existing popular fibres. As a result, many more variants, such as conjugate fibres, low-and-high shrink fibres, hollow fibres, split fibres and fibres with trilobal, multilobal and other profiled cross-sections, micro fibres are available for use in textiles as well as for other applications including filtration purposes.

It was observed that trilobal fibre filter fabrics give higher filtration efficiency than normal round filter fabrics owing to the greater projected area available for surface filtration. During filtration, if the number of particles captured by depth filtration is high, cleaning became more difficult, and repeated use of filter fabric became restricted due to blinding of the filter fabric as a result of particle residue in the filter.

Hollow fibres have tubular cross-section which results in increased bulkiness. Greater surface area is also responsible for lower effective density thus providing a higher cover power. Hollow fibres made from cellulose acetate, acrylic, Nomex etc. are generally used as membranes in reverse-osmosis for desalination, separation of gases and ultra filtration. Industrial applications of hollow polyester fibres such as insulated tents, geo textiles, air filters, carpets, etc. are also claimed. Having assessed the specialty in fibre properties, it was
anticipated that useful filter fabrics can be made using hollow polyester fibres. In that case, the more important positive aspects expected to be derived in the filter fabric over the normal nonwoven filter fabric constructed from regular fibres are as follows: i) Since the fibre has greater bulk, fabrics will also be of greater surface area resulting in better fabric cover, ii) Due to its tubular structure, the fibre is more stiff and thus ensures better quality characteristics namely of durability, etc., iii) Because of its increased surface area, hollow polyester fibre can capture fine particles as compared to regular round fibres, iv) Due to tubular structure, it will have better air flow.

Filtration and mechanical characteristics of a filter fabric for dusty and gas filtration are greatly influenced by the type of fibres, fibre cross-sectional shape, lobe number, lobe depth, fibre crimp, fibre fineness, etc.

In the present study, nonwoven needle-punched filter fabrics produced from three different fibre shapes were studied for filtration and mechanical properties in terms of air permeability, filtration efficiency, pressure drop, tenacity, breaking elongation, abrasion resistance and bursting strength. Effect of fabric weight and presence of scrim were also studied for the filtration and mechanical properties.

4.2 Materials and Methods

4.2.1 Materials

100% polyester fibre is used to produce needle felt nonwoven fabric which may be used for dust filtration. The reason for selecting polyester fibre is its good chemical & mechanical properties and also comparatively good resistance to heat, making the fabric useful for hot gas filtration. Although there are different types of filter fabrics available in the market, yet it has not been possible to provide a delimitative specification of filter fabric for a given application. Therefore, in the present work it was decided to manufacture the filter fabric of 100% polyester fibres of three different cross-sectional shapes (Hollow, Trilobal & Round) with varying constructional parameters i.e., weight per unit area of fabric & effect of reinforcing material as follows:

(a) Fibre variables: Cross-sectional shapes
   (Hollow, Trilobal & Round)

(b) Fabric variables:
i) Weight in gms/sq.m. (200, 300, 400, 500, 600) ii) Presence of scrim (with and without)

The fibre specifications are shown in Table 4.1.

A lightweight cotton fabric was used as reinforcing material having the following specifications:

<p>| | |</p>
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<tr>
<td>Warp Count</td>
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</tr>
<tr>
<td>Weft Count</td>
<td>28's</td>
</tr>
<tr>
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<td>36</td>
</tr>
<tr>
<td>Picks/Inch</td>
<td>24</td>
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</table>

**Table 4.1: Fibre Specifications**

<table>
<thead>
<tr>
<th>Cross Sectional Shape</th>
<th>Length (mm)</th>
<th>Fineness (denier)</th>
<th>Tenacity (gms/den)</th>
<th>Breaking Extension (%)</th>
<th>Crimp (%)</th>
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<tr>
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<td>6</td>
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<tr>
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<td>6</td>
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<td>21.05</td>
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**4.2.2 Sample preparation**

Eighteen nonwoven needle punched fabrics were prepared from 100% polyester fibre having different variables (fibre & fabric) as stated above. In order to see the effect of fibre cross-sectional shapes, five fabrics of different wt/sq.m from each fibre shapes were prepared. The effect of presence of scrim was studied by placing a cotton scrim centrally between two webs in such way that the resulting fabric weight becomes 400 gms/sq.in. Nonwoven needle-punched fabrics were prepared at JTRL, Calcutta. The fabric specifications are given in Table 4.2. The fabrics were made from parallel laid web which was obtained by feeding opened fibres in the 'TAIRO' Laboratory Model Stationary Flat Card. The fine web emerging out of the card was built up into several layers in order to get the desired fabric weight. After preparing the web the bonding was carried out in 'James Hunter Laboratory Fibre Locker'. The needling was done alternately on each side of the fabric. The machine speed and needle density on the board was chosen in such a way that in a single passage, the needling density that can be obtained on the fabric was 50 p/sq.cm. Needle dimension: 15 x 18 x 36 x R/SP x 3.5” x ¼” x 9
<table>
<thead>
<tr>
<th>Fab. ref. no.</th>
<th>Fibre Shape</th>
<th>Fabric Weight (gsm)</th>
<th>Needle Density (P/sq.cm)</th>
<th>Needle Penetration (mm)</th>
<th>Presence of Scrim</th>
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<tr>
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<td>200</td>
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<td>12</td>
<td>NO</td>
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<td>600</td>
<td>&quot;</td>
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<tr>
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</tr>
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<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>F12</td>
<td>&quot;</td>
<td>300</td>
<td>&quot;</td>
<td>&quot;</td>
<td>&quot;</td>
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<td>YES</td>
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<td>Round</td>
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</table>
4.2.3 Methods

The needle-punched nonwoven fabrics produced were studied as follows for their physical, filtration and mechanical characteristics.

a) Physical Characteristics:
   (i) Thickness (mm)
   (ii) Density (gms/cc)
   (iii) Porosity (%)

(b) Filtration Characteristics:
   (i) Air permeability (cc/sq.cm/sec)
   (ii) Filtration efficiency (%)
   (iii) Pressure Drop (mm-WG)

(c) Mechanical Characteristics:
   (i) Tenacity (gms/tex) & Breaking Elongation (%)
   (ii) Abrasion Resistance (no of cycles)
   (iii) Bursting Strength (kg/sq.cm)

Before going to start any test all the samples were conditioned in standard testing temperature (20 ± 2°C) and humidity (65±2 % R.H.) for 24 hours for getting stable and standard results.

Fabric thickness was measured by 'R & B' cloth thickness tester. Thickness values were measured at 10 different places at 20 gms/sq.cm pressure and the average value was taken.

After measuring the average thickness, the density was calculated from thickness and known values of fabric weight in gms/sq.m.

\[
\text{Density (gms/cc) = \frac{\text{Weight in gms/sq.m.} \times 10^3}{\text{Thickness (mm)}}}
\]

Porosity of non-woven fabrics was calculated from the ratio of volume of void present in the fabric to the total volume of the fabric expressed as percentage.

\[
\text{Porosity (\%) = \frac{\text{Volume of voids}}{\text{Volume of fabric}} \times 100}
\]
\[
\text{Volume of fabric} - \frac{\text{Volume of fibres} \times 100}{\text{Volume of fabric}} = 1 - \frac{\text{Fabric density} \times 100}{\text{Fibre density}}
\]

In the experimental setup (Figure 3.1), pressure drop across the orifice meter and across the fabric was measured at different flow rates by controlling the valves. From the orifice meter calibration chart, flow rates in litres/sec can be determined for subsequent pressure head differences across the orifice meter. From these flow rate results, air permeability in cc/sq.cm/sec was calculated by dividing area of fabric. Sectional permeability, which is defined as the product between permeability and thickness of the fabric, was also calculated.

For the measurement of filtration of efficiency cement dust having a particle size range of 3.89 micron to 118 micron was used. The particle size distribution of dust used is given in Table 3.2.

Dust feeding was done at the rate of 0.5 gms/min. The dust laden air was sucked through the fabric by the suction pump. The fabric was weighted after each 10 seconds up to one minute and thereafter after each 60 seconds. It was observed that as the dusty air was fed to the fabric, the reading of both manometers M₁ and M₂ was changing. The Orifice meter reading was adjusted constantly to initial value (2 cm water gauge) in order to keep the face velocity constant at 30 cm/sec and corresponding manometer (M₂) reading, as noted after each 60 second intervals, and the fabric sample was taken out and weighted. The dust concentration was kept constant as 5.25 gms/cum.

From these readings the filtration efficiency and pressure drop were calculated. The tests were carried out for total of 360 seconds for each samples.

The mechanical properties like Tenacity and Breaking Elongation were measured in Intron, Abrasion resistance was measured in C.S.I. Abrasion Tester and Bursting Strength was measured in Mullen Bursting Strength Tester.
4.3 Results and discussion

The physical properties of the fabrics, in terms of fabric thickness, density and porosity, were measured and are given in Table 4.3. The results of the experiments on permeability and sectional permeability are also shown in Table 4.3.

4.3.1 Air permeability

Experiments were conducted with dust free air to estimate the effect of variables on the air permeability and sectional permeability at 10 mm-WG pressure differential. Experiments were also carried out for clean air permeabilities at different pressure drops ranging from 2 mm-WG to 10 mm-WG. The variation of permeability at different pressure drop values for individual fabric are given in Table 4.4 and Figures 4.1-4.3 and 4.5-4.6. From the Figures 4.1-4.3 and 4.5-4.6, it can be observed that with the increase of pressure drop the air permeability increases almost proportionately in all the cases. Sectional air permeability which is a product of air permeability and fabric thickness, was also measured to have permeability values independent of the thickness and are shown in Table 4.3.
<table>
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<th>Fab. ref. no.</th>
<th>Actual Fabric Weight (gsm)</th>
<th>Fabric Thickness (mm)</th>
<th>Fabric Density (gms/cc)</th>
<th>Porosity (%)</th>
<th>Air Permeability (cc/sq.cm/sec)</th>
<th>Sectional Air Permeability (cc/cm/sec)</th>
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</table>
4.3.1.1 Effect of fibre shape on air permeability

Figures 4.1 to 4.3 give the plot of variation of permeability with pressure drop for fabrics with three different fibre shapes i.e., hollow, trilobal & round at five gsm level. Figure 4.6 shows the results of permeability with pressure drop of three different deniers at 400 gsm level. Sectional permeability values of three different fibre shapes at five gsm level are shown in the Figure 4.5.
AIR PERMEABILITY

Fig. 4.1: Effect of Pressure Drop

AIR PERMEABILITY (cc/sq.cm/sec)

Pressure Drop (mm-wg)

Fabric Weight

- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P./F.S. = 400 pscm/12 mm/HOLLOW
AIR PERMEABILITY

Fig. 4.2: Effect of Pressure Drop

AIR PERMEABILITY (cc/sq.cm/sec)

PRESSURE DROP (mm-wg)

Fabric Weight

- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P/F.S.= 400 pscm/12 mm/TRILOBAL
AIR PERMEABILITY

Fig. 4.3: Effect of Pressure Drop

AIR PERMEABILITY (cc/sq.cm/sec)

PRESSURE DROP (mm-wg)

Fabric Weight
- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P/F.S.= 400 pscm/12 mm/ROUND

95
It can be seen from the Tables 4.3 & 4.4 and Figures 4.1 to 4.6 that, in all the cases, at any level of fabric weight, the hollow fibre fabric shows higher air permeability, followed by trilobal & round fibre fabrics.

The above phenomenon may be attributed to the two factors. Firstly, in case of hollow fibre fabric total surface area exposed to air is more, thus more resistance to air flow. This should cause a decrease in air permeability, however, the density of hollow fibre fabric is less. Within the range of air pressure studied, density factor is predominating, therefore, resulted in higher air permeability for hollow fibre fabrics as compared to other two variety of fibres. Trilobal has less density than normal round, thus shows more permeability as compared to round fibre fabrics.

It is concluded from the studies made with clean air that hollow fibre filter fabric has higher permeability at a particular pressure drop for all level of fabric weight followed by trilobal and round fibre fabrics.
AIR PERMEABILITY
(At 1 cm P.D.)

Fig. 4.4: Effect of Fabric Weight

AIR PERMEABILITY (cc/sq.cm/sec)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape
- Hollow
- Trilobal
- Round

N.D / N.P = 400 pscm / 12 mm
SECTIONAL AIR PERMEABILITY
(At 1 cm P.D.)
Fig. 4.5: Effect of Fabric Weight

SECTIONAL AIR PERMEABILITY (cc/cm/sec)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape
- Hollow  - Trilobal  * Round

N.D / N.P = 400 pscm / 12 mm
4.3.1.2 Effect of fabric weight on air permeability

Figures 4.1 to 4.3 give the plot of pressure drop on air permeability for five different fabric weights i.e., 200 gsm, 300 gsm, 400 gsm, 500 gsm & 600 gsm respectively of each type of fibre shapes. Figures 4.4 and 4.5 depict the effect of fabric weight on air permeability & sectional air permeability at 1 cm pressure drop for three different fibre shapes i.e., hollow, trilobal & round respectively.

From the Figures 4.1- 4.4, it is found that for all the fabrics, the air permeability decreases with the increase in fabric weight. Sectional air permeability' also found to be decreased with the increase of fabric weight as may be seen from Figure 4.5.

The decrease of permeability with the increase of fabric weight is due to the fact that increase in fabric weight causes more number of fibres per area. Therefore, total surface area exposed is more, resulting in less air permeability. Secondly, increase in fabric weight causes the fabric density to increase which in turn increases the resistance to air flow, which is in agreement with the findings of Kothari and Newton [14]. It may be concluded from the Figures 4.1-4.5 that although higher gsm (500-600) gives reduced permeability, however, higher gsm may be selected for the filtration purposes as higher gsm values would provide stable filter structure.

4.3.1.3 Effect of reinforcing material (scrim) on air permeability

Table 4.3 & Figure 4.7 show the effect of reinforcing material (scrim) on the permeability values for three different fibre shapes at 400 gsm level.

As seen from the Table 4.3 & Figures 4.6-4.7 that the presence of scrim causes reduction in air permeability as compared to non-woven fabric without scrim.

The reduction in permeability is due to better consolidation of fibres with the presence of scrim. The woven fabric scrim itself restricts the air flow leading to less air permeability. Further, it is also clear that this decrease in air permeability is more for circular hollow fibre fabric. Normal round and trilobal fibre fabric have almost same amount of decrease. This is due to the increase in fabric density in case of hollow fibre fabric. Although, with the presence of scrim, the permeability reduces, but from the durability point of view, scrim should be used as a reinforcing material to stabilize the loose nonwoven structure.
Fig. 4.6: Effect of Pressure Drop

AIR PERMEABILITY (cc/sq.cm/sec)

PRESsure DROP (mm-wg)

Fibre Type

- HOLLOW
- TRILOBAL
- ROUND

N.D/N.P/F.W. = 400 pscm/12 mm/400 gsm
AIR PERMEABILITY (with scrim)

Fig. 4.7: Effect of Pressure Drop

AIR PERMEABILITY (cc/sq.cm/sec)

PRESURE DROP (mm-wg)

Fibre Type
- HOLLOW
- TRILOBAL
- ROUND

N.D/N.P/F.W.= 400 pscm/12 mm/400 gsm
4.3.2 Filtration properties

Experiments were conducted with dusty air using cement dust, keeping face velocity constant as 30 cm/sec. The filtration properties in terms of filtration efficiency and pressure drop were measured. The experimental values of filtration efficiency and pressure drop are summarized in Tables 4.5 and 4.6.

4.3.2.1 Filtration efficiency

Filtration efficiency experiments with cement dust were carried out up to 6 minutes. The fabric was weighted after each 10 seconds interval up to one minute, thereafter, 60 seconds interval up to 6 minute for the measurement of filtration efficiency. Figures 4.8 - 4.12 give the plot of time interval versus filtration efficiency for five different fabric weights of each type of fibres,

It may be seen from the Table 4.5 and Figures 4.8-4.12 that with the passage of time, the filtration efficiency increases and after some time, it almost reaches a steady state. The increase of efficiency with time can be explained that as the dust particles reach the fabric surface along with air, deposition of dust particles occur. As the dust deposition continues, cake formation takes place which will act as a filter medium than fabric itself. It is important that filter cake should be formed immediately so that filtration takes place due to resistance offered by the cake than by fabric. This demands a fabric to have high filtration rate and maximum collection efficiency should be achieved at the shortest possible time. The slow filtration rate of 200 gsm fabric indicates that dust is getting lost with time. It can also be seen that the collection efficiency of 100% is reached in a much shorter time for trilobal fibre fabric compared to round and hollow fibre fabric. It can be concluded that the fabric which attains maximum collection efficiency (100%) at a shorter time should be selected for the tested dust.

4.3.2.1.1 Effect of fibre shape on filtration efficiency

Figures 4.8 to 4.10 and Table 4.5 give the results of filtration efficiency at different time interval for three variety of fibres at each level of fabric weight. Figure 4.11 plots the filtration efficiency with filtration time for three different fibre shapes i.e., Hollow, Trilobal and Round at 400 gsm level.
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FILTRATION EFFICIENCY

Fig. 4.8: Effect of Time Interval

FILTRATION EFFICIENCY (%)

TIME INTERVAL (sec)

Fabric Weight

- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P/F.S. = 400 pscm/12 mm/HOLLOW
FILTRATION EFFICIENCY

Fig. 4.9: Effect of Time Interval

FILTRATION EFFICIENCY (%)

TIME INTERVAL (sec)

Fabric Weight

- 200 gsm  +  300 gsm  *  400 gsm

□ 500 gsm  X  600 gsm

N.D/N.P/F.S.* 400 pscm/12 mm/TRILOBAL
FILTRATION EFFICIENCY

Fig. 4.10: Effect of Time Interval

FILTRATION EFFICIENCY (%)

TIME INTERVAL (sec)

Fabric Weight
- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P/F.S.* 400 pscm/12 mm/ROUND
It can be observed that initially filtration efficiency is less for hollow fibres at each level of gsm. Trilobal fibre fabric gives higher filtration efficiency followed by round fibres at each level of gsm. However after some time, filtration efficiency approaches to 100% for each type of fibres. It is also found from the Figure 4.1 that filter fabrics with trilobal fibres take less time to reach 100% efficiency, followed by hollow & round fibres.

Initial decrease in filtration efficiency with the hollow fibres may be attributed to the fact that hollow fibre filter fabrics show lower fabric density & hence chances of surface filtration is less as compared to normal round filter fabrics. Trilobal fibres because of its peculiar structure with projected area can capture particles more effectively as compared to round & hollow- fibre fabrics. Another reason may be due to the lodging of particles in the concave region of the trilobal fibre. This is in agreement with the findings of Lamb et al [1].

The plot of filtration efficiency versus time interval would be useful in deciding the type of filter fabrics which can reach 100% efficiency at minimum possible time. It may be concluded from the Figures 4.8-4.11 that trilobal fabric shows better filtration efficiency as compared to hollow and round fibres. Trilobal fabric also reaches 100% efficiency within 3 minutes of filtration time. However, one should see the acceptable pressure drop level before selecting the fibre shapes.

4.3.2.1.2 Effect of fabric weight on filtration efficiency

Figures 4.8-4.10 plot between the filtration efficiency and filtration time for five different fabric weights of each type of fibre shapes.

From the Table 4.5 and Figures 4.8 to 4.10, it is observed that in case of all the three variety of fibres, fabrics with higher weight per unit area shows higher filtration efficiency. It is also seen from the figures that for hollow fibre fabrics, 400-600 gsm are giving almost 100% efficiency in 3-4 minutes, whereas 200 gsm takes 6 minutes & more to approach 100% mark and 300 gsm comes in between. In case of trilobal fibre fabrics, within one minute, 100 % efficiency is achieved for 500-600 gsm, whereas it takes 4-5 minutes to achieve the above mark for 200-300 gsm and 400 gsm gives intermediate results. Similarly, for round fibres 400-600 gsm give 100% collection efficiency in between 2-3 minutes, 300 gsm takes 4-5 minutes to achieve the same and 200 gsm does not achieve 100% mark even at 6 minutes filtration time.
The reason may be attributed to the fact that with the increase in fabric weight both the fabric thickness and density increases. Increase in fabric thickness means a dust particle will have to travel more distance through the fabric i.e., greater chance of dust particles being separated from air stream. The increased fabric density gives rise to air resistance which in turn enables retention of higher amount of dust particles but at the same time increases pressure drop. Another reason may be due to the increased number of fibres per unit area with higher gsm. Higher the number of fibres, more will be the probability of capturing dust particles.
FILTRATION EFFICIENCY

Fig. 4.11: Effect of Time Interval

FILTRATION EFFICIENCY (%)

0 60 120 180 240 300 360

TIME INTERVAL (sec)

Fibre Type

--- HOLLOW  + TRIOBAL  * ROUND

N.D/N.P/F.W. = 400 pscm/12 mm/400 gsm
FILTRATION EFFICIENCY
(With Scrim)
Fig. 4.12: Effect of Time Interval

FILTRATION EFFICIENCY (%)

TIME INTERVAL (sec)

Fibre Type

HOLLOW  TRIOBAL  ROUND

N.D/N.P/F.W.= 400 pscm/12 mm/400 gsm
From the Figures 4.8-4.10, it is clear that fabrics with higher gsm for each type of fibres are approaching to 100% filtration efficiency very quickly. In the Industry, it is preferable to use those filter fabrics which can capture dust particles as quickly as possible so as to save the costly cement dust. Therefore, from the filtration point of view one should select 600 gsm filter fabrics. On the other hand, higher gsm will also increase the pressure drop which in turn would increase the fan-power consumption. Hence, before deciding the usefulness of higher gsm filter fabrics, one should see the acceptable pressure drop limit. Moreover, with the higher gsm, cost of the filter fabrics would also expected to be increased. However, life of filter fabrics would be increased with the increase of number of fibres in the cross-section with higher gsm.

4.3.2.1.3 Effect of reinforcing material \{scrim\} on filtration efficiency

Table 4.5 gives the filtration efficiency values for the nonwoven filter fabrics using reinforcing material in the central layer. Figure 4.11 and 4.12 show the variation of filtration efficiency with the filtration time for three different fibre shapes for fabrics of without and with scrim.

As seen from the Figures 4.11 and 4.12 that the use of reinforcing material gives increased filtration efficiency at all interval of time. Trilobal fabric with scrim shows higher efficiency followed by round and hollow fibre fabrics.

The increased filtration efficiency may be due to the increase in fabric compactness and density with the use of reinforcing material.

It may be concluded from the above study that fabrics with reinforcing material not only reaches 100% efficiency faster but also supposed to increase the life of filter fabrics. Trilobal fabrics reinforced with scrim takes 1-2 minutes to reach 100% efficiency, whereas round and hollow fibre fabrics take 3-4 minutes to reach 100% mark.

4.3.2.2 Pressure drop

Pressure drop (mm-WG) is measured after each 10 seconds up to one minute, followed by 60 seconds interval up to 6 minutes filtration time. Figures 4.13 to 4.16 show the pressure drop variation with the filtration time. It is observed that with the increase of filtration time,
### Table 4.6: Pressure Drop (mm-WG)

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pressure drop increases in all the cases. The increase of pressure drop is due to the increase in resistance offered by the cake of dust particles deposited on the fabric surface. The pressure drop study is a very useful for determining the time for cleaning cycle. The filter fabrics can be operated as long as the system can take maximum pressure drop. The time, in which the maximum pressure drop is reached, is known from Figures 4.13-4.16. This time can be adjusted for reverse cleaning.
PRESSURE DROP

Fig. 4.13: Effect of Time Interval

![Graph showing the effect of time interval on pressure drop for different fabric weights.](image)

**Fabric Weight**
- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D/N.P./F.S. = 400 pscm / 12 mm/HOLLOW
Fig. 4.14: Effect of Time Interval

PRESSURE DROP (mm-WG)

TIME INTERVAL (sec)

Fabric Weight
- 200 gsm
- 300 gsm
* 400 gsm
- 500 gsm
* 600 gsm

N.D/N.P/F.S.* 400 pscm /12 mm/TRILOBAL
Fig. 4.15: Effect of Time Interval

PRESsure Drop (mm-WG)

TIME INTERVAL (sec)

Fabric Weight
- 200 gsm
- 300 gsm
- 400 gsm
- 500 gsm
- 600 gsm

N.D./N.P/F.S.= 400 pscm/12 mm/ROUND
4.3.2.2.1 Effect of fibre shape on pressure drop

Table 4.6 and Figures 4.13 to 4.15 show that the pressure drop variation of fabrics made of different fibre shapes with the filtration time at each gsm ranging from 200 to 600 gsm. Figure 4.16 gives the plot of pressure drop and filtration time for three different fibres at 400 gsm level.

It is observed from the Figures 4.13-4.16 that pressure drop is increasing with the filtration time for all the fabrics. Pressure drop does not show any significant increase at the initial stages followed by abruptly increase at the later stages for most of the fabrics. It is also seen from the Figure 4.16 that pressure drop is more for normal round fibre fabrics followed by trilobal and hollow fibre fabrics.

The low variation of pressure drop with time for the hollow filter fabric may be due to the lower fabric density as compared to trilobal and round filter fabrics.

It is concluded from the study that hollow fibre filter fabric performs better than other type of fabrics. This is inferred from the low variation of pressure drop with filtration time. The plot of filtration time versus pressure drop is very much useful in determining the time of cleaning the filter fabrics. It is usually observed in the plant practice that the adjustment of the timer is left to the discretion of the plant operator. The operator with intention of running the plant and with frustration in trying to avoid the choking of the fabric, tries to increase the pressure of the reverse jet air and increases the frequency of cleaning. It results in decrease in life of the fabric. The development of fabric characteristics such as given in Figures 4.13 to 4.16 will be useful in minimizing the above problem by knowing the time for cleaning after attaining the acceptable pressure drop level from the graphs.

4.3.2.2.2 Effect of fabric weight on pressure drop

The effect of time interval on pressure drop are shown in the Figures 4.13 to 4.15 for five different fabric weights of individual fibres.

It can be seen from the Figures 4.13 to 4.15 that with the increase in fabric weight pressure drop increases. However, fabric with lower weight (200 gsm) shows low pressure variation with time.
Fig. 4.16: Effect of Time Interval

N.D./N.P./F.W. = 400 pscm / 12 mm/400 gsm
The increase in pressure drop with the increase of fabric weight is due to the fact that with the increase in fabric weight the total number of fibres increases and thus the total surface area exposed is increased, resulting in increased pressure drop. Secondly, fabric density increases with the increase of fabric weight resulting in an increased pressure drop [14].

From the above study, the fabric with 200 gsm should be used for showing lower pressure drop values which in turn will reduce the fan-power consumption. However, life of the fabric will be less as compared to higher gsm fabrics. Therefore, an optimum level of gsm (400-500) should be used in producing filter fabrics.
PRESSURE DROP
(With Scrim)
Fig. 4.17: Effect of Time Interval

PRESSURE DROP (mm-WG)

TIME INTERVAL (sec)

Fibre Type

- HOLLOW
- X TRILOBAL
- ROUND

N.D/N.P/F.W.= 400 pscm / 12 mm/400 gsm
4.3.3.2.3 Effect of reinforcing material on pressure drop

Table 4.6 shows the effect of reinforcing material (scrim) on the pressure drop. Figure 4.17 gives the variation of pressure drop values with the time for three different fibre shapes at 400 gsm level.

It can be observed from the Table 4.6 that filter fabrics with reinforcing material show higher pressure drop as compared to filter fabrics of without scrim.

The increase of pressure drop with the use of scrim is due to increased fabric density with the consolidation of fibres. Woven fabric in the centre layer may also cause to increase the compactness of the nonwoven fabric, which in turn cause the rise in the pressure drop.

It may be concluded from the above study that, though, the use of reinforcing material causes increased drag, it may help in increasing the life of the filter fabric by consolidating the nonwoven structure. Therefore, reinforced filter fabric is preferable.

4.3.2.3 Effect of pressure drop on filtration efficiency

Figure 4.18 shows the filtration efficiency variation with the pressure drop for three different fibre shapes of 400 gsm fabrics. It is observed that with the increase of pressure drop, filtration efficiency increases in all the variety of fibres. The hollow fibre fabric shows higher filtration efficiency for a given pressure drop level followed by trilobal and round fibre fabrics.

It is also seen that there is a steep increase in efficiency with increase in pressure drop for hollow fibre fabrics and gradual increase for round fibre fabrics.

It is always desirable to have steep increase in efficiency so that 100% efficiency is achieved at minimum pressure drop. Therefore, from the study of filtration efficiency and pressure drop, it may be concluded that hollow fibre fabric will be suitable for long-term filtration purposes.
FILTRATION EFFICIENCY

Fig. 4.18: Effect of Pressure Drop

FILTRATION EFFICIENCY (%)

PRESSURE DROP (mm-WG)

Fibre Type
- HOLLOW + TRILOBAL * ROUND

N.D/N.P/F.W. = 400 pscm/12 mm/400 gsm
4.3.3 Mechanical properties

Mechanical properties like tenacity, breaking elongation, abrasion resistance and bursting strength were measured. The experimental values are summarized in Table 4.7. Figures 4.19 and 4.20 give the values of tenacity at break in machine and cross direction. The breaking elongation values are shown in Figures 4.21 and 4.22. The results of abrasion resistance and bursting strength are given in Figures 4.23 and 4.24 respectively.

4.3.3.1 Tenacity

The Tenacity was measured in machine and cross direction using an Instron Tensile Tester, Model 1185. For testing tenacity, the sample size and rate of straining were chosen according to ASTM standard D2905-72 (Sample size 10 cm 2.5 cm, cross-head speed 10 cm/min, chart speed 5 cm/min, full scale load 100 kg for machine direction and 20 kg in cross direction).
Table 4.7: Tenacity, Breaking Elongation, Abrasion Resistance
and Bursting strength

<table>
<thead>
<tr>
<th>Fab. ref. no.</th>
<th>Machine Direction</th>
<th>Cross Direction</th>
<th>Abrasion Resistance (No. of Cycles)</th>
<th>Bursting Strength (kg/sq.cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tenacity (gm/tex)</td>
<td>Breaking Elongation (%)</td>
<td>Tenacity (gm/tex)</td>
<td>Breaking Elongation (%)</td>
</tr>
<tr>
<td>F1</td>
<td>3.980</td>
<td>135.60</td>
<td>1.095</td>
<td>222.3</td>
</tr>
<tr>
<td>F2</td>
<td>5.144</td>
<td>129.52</td>
<td>1.395</td>
<td>217.0</td>
</tr>
<tr>
<td>F3</td>
<td>6.330</td>
<td>113.75</td>
<td>1.531</td>
<td>214.8</td>
</tr>
<tr>
<td>F4</td>
<td>6.947</td>
<td>100.58</td>
<td>1.606</td>
<td>200.0</td>
</tr>
<tr>
<td>F5</td>
<td>7.146</td>
<td>99.53</td>
<td>1.581</td>
<td>189.0</td>
</tr>
<tr>
<td>F6</td>
<td>3.225</td>
<td>120.08</td>
<td>0.682</td>
<td>197.6</td>
</tr>
<tr>
<td>F7</td>
<td>4.857</td>
<td>107.26</td>
<td>0.783</td>
<td>193.0</td>
</tr>
<tr>
<td>F8</td>
<td>5.907</td>
<td>104.54</td>
<td>1.015</td>
<td>192.0</td>
</tr>
<tr>
<td>F9</td>
<td>6.640</td>
<td>100.28</td>
<td>1.265</td>
<td>188.0</td>
</tr>
<tr>
<td>F10</td>
<td>6.700</td>
<td>90.42</td>
<td>1.375</td>
<td>177.0</td>
</tr>
<tr>
<td>F11</td>
<td>2.322</td>
<td>98.40</td>
<td>0.688</td>
<td>184.9</td>
</tr>
<tr>
<td>F12</td>
<td>3.784</td>
<td>91.68</td>
<td>0.756</td>
<td>180.0</td>
</tr>
<tr>
<td>F13</td>
<td>4.920</td>
<td>86.45</td>
<td>0.904</td>
<td>176.6</td>
</tr>
<tr>
<td>F14</td>
<td>5.088</td>
<td>77.50</td>
<td>1.032</td>
<td>165.2</td>
</tr>
<tr>
<td>F15</td>
<td>5.120</td>
<td>71.82</td>
<td>0.987</td>
<td>156.5</td>
</tr>
<tr>
<td>F16</td>
<td>6.980</td>
<td>89.22</td>
<td>1.505</td>
<td>193.0</td>
</tr>
<tr>
<td>F17</td>
<td>6.620</td>
<td>81.06</td>
<td>1.213</td>
<td>188.4</td>
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<tr>
<td>F18</td>
<td>5.860</td>
<td>75.44</td>
<td>1.100</td>
<td>167.5</td>
</tr>
</tbody>
</table>
4.3.3.1.1 Effect of fibre shape on tenacity

It is observed from the Table 4.7 & Figures 4.19-4.20 that in both direction, hollow fibre fabric shows higher tenacity at each level of fabric weight followed by trilobal and normal round fibre fabrics.

The observation may be attributed to two reasons, firstly the higher bulk of hollow and trilobal fibres provides higher surface area which in turn increases the fibre cohesiveness, and secondly higher tenacity, of hollow and trilobal fibres than round fibres gives less breakage of fibres during needling resulting corresponding increase in strength.

It may be concluded from the above study that hollow fibre filter fabric gives higher tenacity values. The round filter fabric shows lower tenacity values.

4.3.3.1.2 Effect of fabric weight on tenacity

It is seen from the Table 4.7 & Figures 4.19-4.20 that almost all cases, the tenacity at break increases with the fabric weight in both machine and cross direction. However, the rate of increase is more pronounced at the initial stages and after certain level it approaches a steady state.

The increased tenacity with the increase of fabric weight may be attributed to the following reasons: The initial rise may be due to the increase in the number of fibres in the web with fabric weight. This in turn increases the number of vertical loops and increases the density and entanglement, causing less freedom of fibre movement and greater frictional restraints. The reduction in rate of increase of tenacity beyond some fabric weight may be due to fibre breakage during the needling of a consolidated fabric.

It may be concluded from the above study that higher fabric weight (in this case 500-600 gsm) gives better performance as far as tenacity is concerned. Therefore, from the filter fabric life point of view, one should choose 500-600 gsm fabric.
TENACITY
(Machine Direction)
Fig. 4.19: Effect of Fabric Weight

TENACITY (gms/tex)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape

Hollow  Trilobal  Round

N.D / N.P = 400 pscm / 12 mm
TENACITY
(Cross Direction)
Fig. 4.20: Effect of Fabric Weight

FABRIC WEIGHT (gms/sq.m)

Fibre Shape
- Hollow  - Trilobal  - Round

N.D / N.P = 400 pscm / 12 mm
4.3.3.1.3 Effect of reinforcing material on tenacity

As observed from Table 4.7 that the use of reinforcing material causes an increase in fabric tenacity at break in all the cases in machine and cross direction.

The above observation may be due to the fact that the base woven fabric (scrim) do contribute effectively when the final breakage takes place. The results are in agreement with the findings of Hearle and Sultan [24].

It may be concluded from the above study that base woven fabric in the form of reinforcing material (scrim) may be helpful in increasing strength of nonwoven fabric.

4.3.3.2 Breaking elongation

The Breaking elongation was measured in machine and cross direction using an Instron Tensile Tester, Model 1185. For testing elongation, the sample size and rate of straining were chosen according to ASTM standard D2905-72 (Sample size 10 cm x 2.5 cm, cross-head speed 10 cm/min, chart speed 5 cm/ min, full scale load 100 kg for machine direction and 20 kg in cross direction).

4.3.3.2.1 Effect of fibre shape on breaking elongation

It is observed from the Table 4.7 and the Figures 4.21-4.22 that hollow fibre filter fabric shows higher breaking elongation for both directions, followed by trilobal fibre fabric. Round fibre fabric shows lower elongation in both directions.

The reduced breaking elongation for round fibre fabrics are due to the increased fabric consolidation, which reduces the mobility of the fibres in the fabric [30].

It may be concluded from the above study that hollow fibre fabric shows better performance as compared to the other two types of fabrics, because more is the breaking elongation, more will be durability.
4.3.3.2.2 Effect of fabric weight on breaking elongation

The breaking elongation in almost all the cases are found to be decreased gradually in both machine and cross direction with increase in fabric weight, as observed from the Table 4.7 and Figures 4.21-4.22.

The initial fall may be due to the better compactness of fibres causing reduced slippage and further decrease may be attributed to the fibre breakage which reduce the fibre length and hence fibre to fibre cohesion. These results are in agreement with the finding of Hearle and Sultan [16].
BREAKING ELONGATION
(Machine Direction)
Fig. 4.21: Effect of Fabric Weight

BREAKING ELONGATION (%)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape

- Hollow  - Trilobal  * Round

N.D / N.P = 400 pscm / 12 mm
BREAKING ELONGATION
(Cross Direction)
Fig. 4.22: Effect of Fabric Weight

BREAKING ELONGATION (%)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape
- Hollow  - Trilobal  * Round

N.D / N.P = 400 pscm / 12 mm
It may be concluded from the above study that lower fabric weight (200 gsm) gives better performance as far as breaking elongation is concerned. However, higher gsm (400-500) is necessary to achieve optimum strength for desirable performance in the long run.

4.3.3.2.3 Effect of reinforcing material on breaking elongation

It is observed from the Table 4.7 that the breaking elongation of reinforced fabric is marginally reduced to that of fabric without reinforcing material.

The reason may be attributed to the fact that on the one hand increased fabric density should cause reduced breaking elongation for the nonwoven fabrics with scrim but on the other hand presence of woven fabric should bear some load before breaking takes place. Therefore, a marginal decrease in breaking elongation is observed with the reinforced nonwoven fabrics.

From the above study, it may be concluded that presence of reinforcing material (scrim) will be useful for producing nonwoven filter fabric, as it gives better strength and elongation properties.

4.3.3.3 Abrasion resistance

The Abrasion Resistance was measured by using C.S.I. Abrasion Tester. The sample size and rate of specifications were chosen as per follows: Sample size 4.4" dia, Abradent used: C-320, P 027, Pressure on abrasion head: 2.0 lbs, Air pressure = 3.0 psi.

4.3.3.3.1 Effect of fibre shape on abrasion resistance

It is observed from the Table 4.7 and Figure 4.23 that at any level of fabric weight trilobal fibre fabric shows higher abrasion resistance (number of cycles) followed by normal round and hollow fibre fabrics.

Because of its peculiar three-lobed structure, the trilobal fibre fabric can resist more as compared to round and hollow fibre fabrics. Hollow fibre fabrics, because of its tubular structure, can be easily deformed as far as abrasion cycles are concerned.

From the abrasion resistance results, it may be concluded that trilobal fibre fabric gives better performance, followed by round and hollow fibre fabrics.
ABRASION RESISTANCE

Fig. 4.23: Effect of Fabric Weight

ABRASION RESISTANCE (No. of Cycles)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape

- Hollow  -----  Trilobal  * Round

N.D / N.P = 400 ps/cm / 12 mm
4.3.3.2 Effect of Fabric weight on abrasion resistance

As observed from the Figure 4.23 that increase in fabric weight increases the total number of abrasion cycles required for destruction of sample. The same trend is observed for all the three variety of fibres.

The reason may be the increase in compactness and density of fabric with the increase in fabric weight.

It may be concluded from the above study that higher fabric weight (500-600 gsm) will be useful for better abrasion resistance point of view.

4.3.3.3 Effect of reinforcing material on abrasion resistance

It is seen from the Table 4.7 that the use of reinforcing material causes an increase in abrasion resistance in all the three variety of fibres.

The reason for the increase in abrasion resistance when reinforcing material is used may be due to the same reason as explained earlier i.e., better compactness and higher fabric density. Also the woven base cloth gives higher abrasion resistance.

From the above study, it is clear that the scrim should be used to reinforce the nonwoven structure so that longer life of filter fabrics in terms of abrasion resistance would result.

4.3.3.4 Bursting strength

Bursting Strength is more important for filter cloths, where fabrics are stressed in all directions. The Bursting strength was measured by Mullen Diaphragm Burst Tester according to BS standard 4768 -1972.

4.3.3.4.1 Effect of fibre shape on bursting strength

It is observed from the Table 4.7 and Figure 4.24 that hollow fibre fabric shows higher bursting strength, followed by trilobal and round fibre fabrics.
Hollow fibre, because of its more surface area covering capacity, can resist bursting pressure. Also, fibre tenacity of hollow fibres is higher as compared to trilobal and round fibres thus resulting in more bursting strength.

It may be concluded from the above study that hollow fibre fabric gives better performance as far as bursting strength is concerned as compared to trilobal and round filter fabrics.
BURSTING STRENGTH

Fig. 4.24: Effect of Fabric Weight

BURSTING STRENGTH (Kg/sq.cm)

FABRIC WEIGHT (gms/sq.m)

Fibre Shape
- Hollow
- Trilobal
* Round

N.D / N.P = 400 pscm / 12 mm
4.3.3.4.2 Effect of fabric weight on bursting strength

It is observed from the Table 4.7 and Figure 4.24 that as the fabric weight increases, the bursting strength increases. The same trend is observed for all three variety of fibres.

The above observation is as expected that with the increase of gsm, number of fibres are increased which play an important role in resisting the bursting pressure.

It may be concluded from the above study that higher fabric weight (500-600 gsm) will be useful in producing filter fabrics to achieve better bursting strength.

4.3.3.4.3 Effect of reinforcing material on bursting strength

From the Table 4.7, it is observed that reinforced filter fabrics show higher bursting strength as compared to the filter fabrics without reinforced material.

The increased bursting strength of reinforced nonwoven fabric is because of woven fabric, which also resists some bursting pressure and hence causing more bursting strength. As in the previous case, hollow fibre fabric shows higher bursting strength, followed by trilobal and round filter fabrics.

From the above study, it may be concluded that use of reinforcing material (scrim) is essential to achieve better bursting strength and hence, durable filter fabric.

4.4 Conclusions

4.4.1 Filtration properties

4.4.1.1 Air permeability

Hollow fibre fabrics show higher air permeability values followed by trilobal and normal round fibre fabric. Air permeability decreases with increase in fabric weight. With the use of reinforcing material air permeability reduces.
4.4.1.2 Filtration efficiency

Trilobal fibre fabrics show higher filtration efficiency. Hollow fibre fabric gives lower filtration efficiency. However, for a given pressure drop level, higher filtration efficiency is achieved by hollow fabrics. Increased fabric weight causes increased filtration efficiency. Use of reinforcing material shows higher filtration efficiency.

4.4.1.3 Pressure drop

Fabrics made of round fibres show higher pressure drop as compared to the fabrics made with trilobal and hollow fibre fabrics. Increase in fabric weight increases pressure drop. The use of reinforcing material also increases the pressure drop across the fabric.

4.4.2 Mechanical properties

The hollow filter fabric give higher tenacity (in both direction) and bursting strength. It is observed at all level of fabric weight. Breaking elongation is found to be more in case of hollow fibre fabrics, whereas round fibre fabrics show lower breaking elongation. However, abrasion resistance is found to be higher in case of trilobal, followed by round and hollow fibre fabrics. Increase in fabric weight increases the fabric tenacity at break in machine and cross direction. The rate of increase is more initially but afterwards it falls down. The abrasion resistance and bursting strength increases with the increase in fabric weight. However, breaking elongation is found to be reduced with the increase of fabric weight. Reinforced nonwoven fabrics show higher tenacity (in both direction), abrasion resistance and bursting strength but lower breaking elongation.