A study on the effect of fiber tenacity on the pressure drop and filtration efficiency and to examine the interdependency of pressure drop and filtration efficiency of needlepunched nonwoven filter fabric

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Abstract: The present study has been made to examine the effect of fiber tenacity on pressure drop and filtration efficiency. Three fibers low tenacity polyester (LTP), recycled polyester (RCP) and high tenacity polyester (HTP) have been used for the preparation of needle-punched nonwoven filter fabric. The study has shown that the increase in fiber tenacity exhibit higher pressure drop and filtration efficiency (%). Filtration efficiency (%) for low tenacity polyester (FLTP) increases with the increase in pressure drop and the trend holds a linear relationship. Filtration efficiency (%) for recycled polyester fabric (FRCP) and virgin polyester fabric (FHTP) increases with increase in pressure drop but the trend does not hold linear relationship. The results have shown that pressure drop and filtration efficiency hold high relationship between each other. The comparison of filtration efficiency of different tenacity fiber fabrics has shown insignificant difference between filtration efficiency of recycled polyester fabric (FRCP) and virgin polyester fabric (FHTP) both at 95% and 99% confidence limit.

Keywords: Needle-punched nonwoven filter fabric, pressure drop, filtration efficiency, recycled polyester

INTRODUCTION

Nonwoven fabrics have distinct advantages over woven fabrics for dry filtration applications due to their unique characteristics such as random and multi dimensional orientation of fibres, fullness of fabric, higher fluid rate, etc. Needle-punched nonwovens are used as dust filters in large quantity in fertilizer and cement industries, coal mines, etc. Research work in this area is therefore required to enable manufacturers to make filters to meet the desired specification.

Nonwoven filter fabric should be prepared from a judicious combination of finer and coarser fibres [1]. Kothari et al. [2] from his studies concluded that increase in fiber fineness results in higher filtration efficiency of needle-punched nonwoven air filters. With the increase in proportion of finer fibre content in the needle-punched fabrics the air permeability decreases while filtration efficiency increases from coarser fibre fabric to finer fibre fabric.

Study made by Atwal [3] has shown that fineness of fibers plays an important role to determine pressure drop across nonwoven fabric. It was also reported that the magnitude of pressure drop depends on the amount of exposed fibre surface area, thus finer fibers provide higher pressure drop. From the study made by Gervais et al. [4] it has been concluded that the most of the nonwovens used as air filters are made from blend of fibers; however, the scientific details of manufacturing those nonwovens have been kept as trade secret by the filter companies.

In order to improve the extent and quality of filtration, several separate filtration fabrics are made from coarse to fine fibers with different fabric thicknesses and densities are employed in tandem [5, 6]. Thus, enormous increase in the surface area together with the reduction in pore size due to the use of finer fibers improves the extent and quality of filtration.

Study made by Gador [7] concluded that as the diameter of fibres in a nonwoven fabric increases then pressure drop decreases. Nonwoven fabric built out of thinner fibres has smaller porosity than that produced out of thicker fibres.

Most of the researchers have made study on needle-punched nonwoven fabric using different denier and type of fibers but none has made study using different tenacity fibers and examined the interdependency of pressure drop and filtration efficiency. In the present work all the three polyester fibers of same denier have been used with the thinking that it will not affect directly much on the porosity as well as pressure drop and filtration efficiency.

MATERIAL AND METHODS

Materials

The three fibers namely low tenacity polyester fiber (LTP), recycled polyester fiber (RCP) and high tenacity polyester fiber (HTP) had same nominal denier (1.5), staple length (42 mm) and crimps (10 crimps/cm) to study the effect of pressure drop and filtration efficiency. The recycled polyester fiber is the fiber manufactured using post consumer bottle flakes.

METHOD USED FOR NONWOVEN FABRIC DEVELOPMENT

Three fabric samples were prepared using three different fibers keeping GSM (grams/sq mtr) 550, needling density (punches/sq cm) 250 and depth of penetration (mm) 1.50.
The sequence for manufacturing all needle punched nonwoven filter fabrics were as follows:
Web preparation
Webs each of GSM (250) were prepared on the Carding machine (EK 150-0-5-A2) using all the three different fibers separately.

Fabric preparation

Three needle-punched non woven filter fabrics each of RCP, LTP and HTP fibers were prepared one by one using webs on the Erko needle loom type ENL-1 and type ENL-2. In between two webs each of GSM (250), scrim fabric of GSM (50) was sandwiched as reinforcing material. Thus three different fabric samples each of GSM (550) were obtained.
The details of the scrim fabric used as reinforcing material are as follows:
Material: 100% polyester
GSM: 50 (grams/sq mtr)
Ends per inch (EPI) = 26, Pics per inch (PPI) = 22
Elongation: Machine direction (MD) = 45 %, Cross direction (CD) = 47 %
Tensile strength: Warp way 25 kgf, Weft way 20 kgf

Finishing of samples

The needle-punched nonwoven filter fabrics were singed prior to calendering on a 3 roller pair calendering machine at pressure of 1.0 bar and temperature maintained at 230 ^{o}C for upper roller and 180 ^{o}C for lower roller.

PHYSICAL PROPERTIES OF FIBERS

Fineness (denier), tenacity and elongation of fiber were measured on instrument Lenzing Vibrodyn 500.
The test report for the fibers is as shown in Table 1.

Table 1. Results for fineness and tenacity.

Fiber	Actual Denier	Tenacity (gpd)
LTP	1.50	4.7
RCP	1.51	6.0
HTP	1.53	6.8

PHYSICAL PROPERTIES OF FABRICS

Web weight (GSM)

IS: 1964-2001 standard was used to measure the mass per unit area of nonwoven fabrics. The specimens of the size 10.0×10.0 cm were cut randomly from different places of conditioned sample and weighed in electronic balance with an accuracy of 0.005 g. For each fabric five samples were taken and their mean was entered in the Table 2. Prior to test, the samples were conditioned to moisture equilibrium in the standard atmosphere of 65 ± 2 percent relative humidity and 27 ± 2°C temperature.

Air Permeability

For the determination of air permeability of samples standard prescribed method as given in IS: 11056-1984 was used. Kurps electronic air permeability tester was used for measuring air permeability of different fabric samples. Five readings of each fabric samples were taken. Their mean was entered in the Table 2.

Prior to test, the specimens were conditioned to moisture equilibrium in the standard atmosphere of 65 ± 2 percent relative humidity and 27 ± 2°C temperature.

Filtration Efficiency %

ISO 5011 method was used for testing filtration efficiency of nonwoven fabrics. The filter fabrics were tested by feeding test dust at a constant airflow of 350 CFM. The amount of dust passed through the filter - *Accumulative Gain* - was measured. Dirt passing through the filter was captured in the Test Station's *Post Filter.* The exact amount of dirt passed was determined by measuring before and after weight of the *Post Filter*. Similarly, the amount of dirt retained by the Filter under test - *Accumulative Capacity* – was measured by taking the difference between the before and after weights of the filter.

$$\text{Filtration efficiency (\%)} = \frac{\text{(mass of dust collected by fabric)} \times 100}{\text{(mass of dust feed)}}$$

Pressure drop

Pressure drop values for different samples were directly noted from the dial fitted on the machine.

Pore size determination

ASTM E 1294 standard method was used to determine Pore size distribution on Capillary flow porometer using liquid extrusion technique. In this technique a wetting liquid (Galwik) having surface tension of 15.9 dynes/cm2 fills the pores of fabric sample and pressurized gas removes the liquid from the pores.

Dust Specifications

ISO 12103-1 Arizona test dust contaminants A3 medium grades was used for this study.

RESULTS AND DISCUSSION

Fabric codes, as used for LTP, RCP and HTP fibers are named as FLTP, FRCP and FHTP.
The results have been indicated in Table 2.

Table 2. Results of fabric weight, air permeability and filtration efficiency for fabrics FLTP, FRCP and FHTP.

Fabric Code	Fabric weight (gsm)	Air permeability (cm3/cm2/sec)	Filtration efficiency (%)
FLTP	551	211	88.33
FRCP	549	197	92.50
FHTP	553	180	95.15

In order to examine statistically three terms have been employed:
- Regression line equation
- Correlation coefficient
- Test of significance between filtration efficiency of three kinds of fabrics

REGRESSION STUDY OF FILTRATION EFFICIENCY FOR THE FABRICS FLTP, FRCP AND FHTP

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Regression study of filtration efficiency for fabric FLTP

Table 3. Time wise values of pressure drop, mean pore size and filtration efficiency for fabric FLTP.

Time (min)	Pressure drop (X_1) (Pa)	Mean pore size (μ)	Filtration efficiency (Y_1) (%)
10	32	124	85.35
20	153	122	86.45
30	384	119	87.60
40	569	117	88.51
50	708	115	89.23
60	820	114	90.05
70	875	113	91.15

a) Regression equation of line (as calculated) is: Y1 = 0.006119 X1 + 85.23

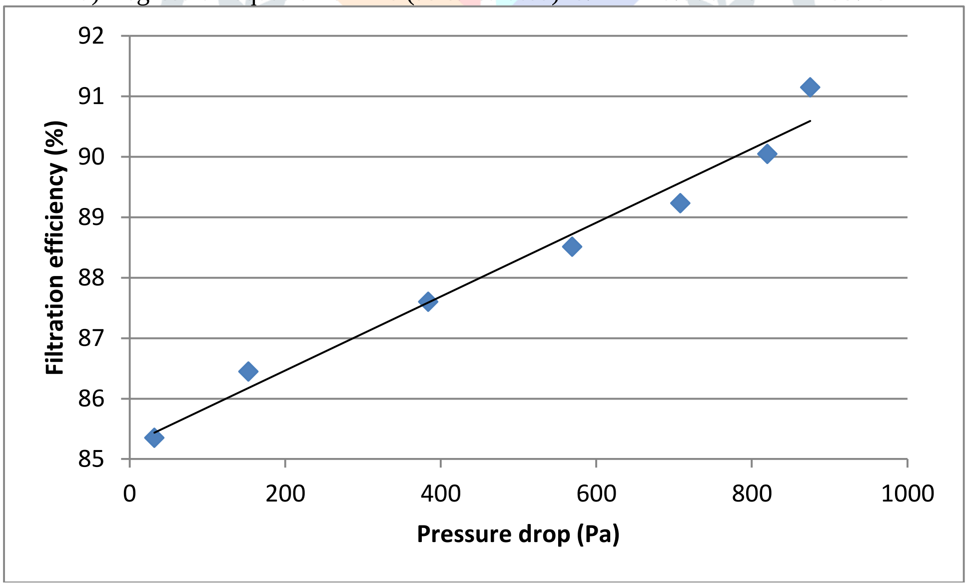

Figure 1. Graph plotted between pressure drop and filtration efficiency for fabric FLTP

From Figure 1 it is observed that filtration efficiency (%) increases with increase in pressure drop and the trend holds a linear relationship.

Regression study of filtration efficiency for fabric FRCP

Table 4. Time wise values of pressure drop, mean pore size and filtration efficiency for fabric FRCP.

Time (min)	Pressure drop (X_2) (Pa)	Mean pore size (μ)	Filtration efficiency (Y_2) (%)
10	61	122	88.72
20	396	120	89.29
30	652	118	90.08
40	789	115	91.24
50	880	113	92.74
60	969	112	93.74
70	1020	110	95.14

b) Regression equation of line (as calculated) is: $Y2 = 0.006277X2 + 87.29$

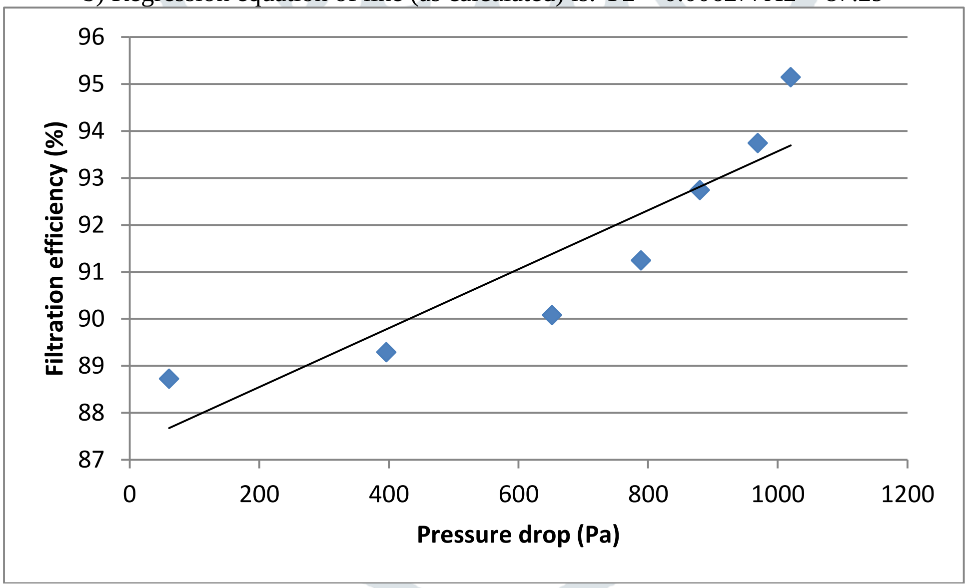

Figure 2. Graph plotted between pressure drop and filtration efficiency for fabric FRCP.

From Figure 2 it is observed that filtration efficiency (%) increases with increase in pressure drop but the trend does not hold linear relationship.

Regression study of filtration efficiency for fabric FHTP

Table 5. Time wise values of pressure drop, mean pore size and filtration efficiency for fabric FHTP.

Time (min)	Pressure drop (X_3) (Pa)	Mean pore size (μ)	Filtration efficiency (Y_3) (%)
10	71	120	92.0

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20	451	117	93.38
30	734	115	94.23
40	879	112	95.03
50	996	110	96.38
60	1081	109	97.13
70	1126	106	97.88

c) Regression equation of line (as calculated) is: Y3 = 0.005219X3 + 91.17

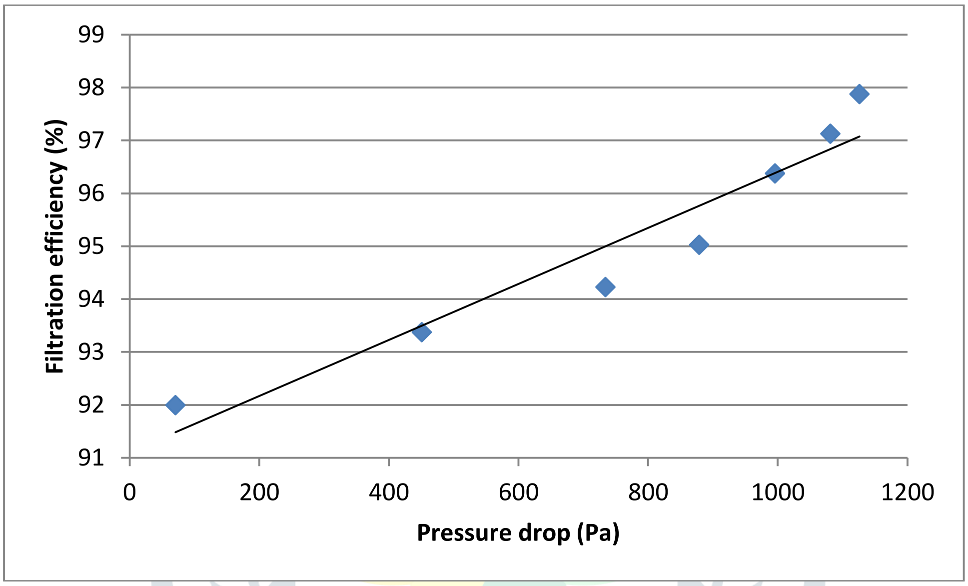

Figure 3. Graph plotted between pressure drop and filtration efficiency for fabric FHTP.

From Figure 3 it is observed that filtration efficiency (%) increases with increase in pressure drop but the trend does not hold linear relationship.

Coefficient of correlation between pressure drop and filtration efficiency for fabrics FLTP, FRCP and FHTP

Formula used for finding out coefficient of correlation between pressure drop and filtration efficiency:

$$\boldsymbol{r = \sqrt{b_{xy} \times b_{yx}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (1)$$

where, r = coefficient of correlation
b_{xy} = regression coefficient of x on y line
b_{yx} = regression coefficient $of\ y$ on x line
a) coefficient of correlation (for fabric FLTP as calculated is): $r_1 = 0.870$

b) coefficient of correlation (for fabric FRCP as calculated is):$r_2 = 0.818$

c) coefficient of correlation (for fabric FHTP as calculated is): r_3= 0.906
High relationship between pressure drop and filtration efficiency is seen in all the three cases as coefficient of correlation is more than 0.8.

SIGNIFICANCE TEST BETWEEN FILTRATION EFFICIENCIES FOR FABRICS FLTP, FRCP AND FHTP

For significance test between filtration efficiency of fabrics FLTP and FRCP fabrics, calculated value of ‘t12’ is 2.65
For significance test between filtration efficiency of fabrics FLTP and FHTP fabrics, calculated value of ‘t13’ is 5.99
For significance test between filtration efficiency of fabrics FRCP and FHTP fabrics, calculated value of ‘t23’ is 1.08
Critical value of ‘t’ at 12 degree of freedom and 95 % confidence limit is 3.06 and at 99 % confidence limit is 2.18 respectively (from ‘t’ Table).
t12= 2.65, *t13* = 5.99, *t23* = 1.08

Comparison of filtration efficiencies of fabrics FLTP and FRCP it is found that at 95 % confidence limit they have insignificant difference but 99 % confidence limit they have significant difference.
Comparison of filtration efficiencies of fabrics FLTP and FHTP it is found that at 95 % and at 99 % confidence limit they have significant difference.

Comparison of filtration efficiencies of fabrics FRCP and FHTP it is found that at 95 % and at 99 % confidence limit they have insignificant difference.

CONCLUSIONS

The comparison of pressure drop and filtration efficiency (%) of needle-punched nonwoven fabrics made from three different tenacity fibers have shown that the increase in fiber tenacity exhibit higher pressure drop and filtration efficiency (%) and the reason behind this may be that higher tenacity fiber shows smaller pore size. Filtration efficiency (%) for fabric FLTP increases with the increase in pressure drop and the trend holds a linear relationship. Filtration efficiency (%) for fabric FRCP and FHTP increases with increase in pressure drop but the trend does not hold linear relationship. The relationship in between pressure drop and filtration efficiency stands at high level in case of all the three fabric samples.

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