Development of Needle-Punched Nonwoven Fabrics from Reclaimed Fibers for Air Filtration Applications

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ABSTRACT
This paper reports an investigative study on the fabrication and measurement of the air permeability, mechanical properties, pore size distribution, and filtration efficiency of different nonwoven fabrics produced from reclaimed fibers by analytically changing the machine variables to manipulate the physical parameters of the nonwoven fabrics. Reclaimed fiber of cotton (60%) and polyester (40%) blend was used, so that the prospect of value addition to an inexpensive source of raw material could be explored. The changes in air permeability were interpreted in terms of fabric density profile and pore size distribution. The filtration parameters of filtration efficiency, dust holding capacity, and pressure drop were also calculated. Additionally, the effects of calendering on pore size and filtration properties were evaluated to discover the opportunity of fine-tuning and the performance of the filters. The outcome in this study reflected an overall development in all filtration characteristics due to the calendering operation.

Keywords: Air filtration, Porosity, Tensile strength, Reclaimed fiber, Nonwoven, Needle punched.

INTRODUCTION
The objective of the current study was to compare the properties and characteristics of nonwoven fabrics made from reclaimed fibers with those of ordinary nonwovens.

Modern developments in air filtration media have been in the field of electrostatic filters in which fibers are electrically charged to attract oppositely chargedparticulates, thus improving filtration effectiveness due to decreased pressure drop across the filter and increased particle holding ability. The definition of performance for the purpose of any product is an important factor for the design. The pressure drop is an indication of the resistance to air flow of the filter. It is important, both when the filter is clean and when it is barren due to deposition of particles on the surface which results in the formation of a filter cake. Pressure drop is also a measure of the energy requirement and the cost associated with the filtration operation.

Disadvantages of single-layered needle-punched nonwoven materials for use in air filtration applications include the non-uniformity of the web and distribution of pore size which result in poor serviceability due to inadequate strength in the direction of air flow. Apparently, this approach is low cost due to different fibers and structures employed, besides the heterogeneous behavior of the material in terms of certain mechanical and physical properties. A multi-layered reclaimed nonwoven fabric can be produced cost effectively and may offer a viable solution for such applications.

METHODOLOGY:
Material Preparation
The most widely accepted preparatory method is 'mechanical re-fiberization'. This involves passing cut fabric pieces through two nipped feed rollers, which grip the cut fabric while a rapidly rotating cylinder covered with sharp metallic pins mechanically opens the fabric into smaller fractions. The product of mechanical pulling typically consists of a mixture of individual fibers, yarn segments and smaller fabric pieces. Further separation stages are employed to increase the reduction of the segments and pieces into fiber form. The fiber is then collected on a vacuum assisted drum and fed out of the machine. The structure of the textile being refiberized influences the dimensions, degree of separation, and homogeneity of the fibrous product. More loosely formed structures, such as weft-knitted textiles, tend

to have lower density which yields longer fiber lengths when reprocessed.

Web Formation

We used dry laid web formation in this process. The most common form of dry laid web formation is carding, but heavier weight webs containing waste fibers are also commonly formed into webs using Garnett machines. Immediately after carding, the webs were parallel lapped, which involved laying the webs over one another in the machine direction to improve final web uniformity further without changing the predominant fiber orientation. The resulting web is anisotropic in nature, in that fibers are preferentially aligned in the longitudinal direction. After subsequent bonding, the final fabric tensile strength will tend to be higher in the longitudinal direction. While most air laying techniques designed for waste fiber recycling have traditionally utilized revolving pinned rollers to transport fibers, a second method of web formation involves converting very short fibers (less than 10mm) using an adapted air laying technique of the sifting type. The short fibers and particles that are recovered from the clothing waste which are incompatible with both carding and garneting were found to be particularly suited to conversion using the air lay method. The fibers were separated efficiently during processing and formed a uniform web with isotropic properties.

NEEDLE PUNCHING

Premixing and opening were achieved by a CMC* Rando Cleaner. The fibers were then fed through the chute feed system, which fed the fibers to a 51 cm (20 in) pneumatic card. From the card, the fiber web was fed onto a 61 cm (24 in) Automatex cross lapper conveyor system. The formed and cross-lapped webs were then needle punched on a 53 cm (21 in) Automatex needle loom at a rate of 200 strokes per minute and a delivery speed of one meter per minute to yield nominal 1700 g/m^2 sample fabrics.

CALENDERING PROCESS

The needle punched fabrics were squeezed together and thermally molded to comparable thicknesses and densities on a Carver press using 12.7 mm (0.5 in), 6.4 mm (0.25 in) and 3.2 mm (0.125 in) frames. The minimum thickness was achieved by compressing the nonwoven fabrics without a frame at a pressure of 30 tons. The test specimen manufacturing procedure was carried out in the following sequence. The calendaring device was heated to 80°C, and the sample, frames were placed into the device. The samples were then compressed for 6 min at 5 tons of pressure and were cooled under pressure for 6 min. Finally, the pressure was released and the sample was taken out of the calendaring device. After the samples were compressed, they were cut into 30.5 cm by 30.5 cm (12 in by 12 in) test specimens.

SAMPLE PREPARATION

Nonwoven fabric samples were set on a laboratory model card prepared with universal card clothing, cross lapper and a needle-punching loom containing 6000 needles per running meter. The variations in the substantial and structural parameters of the nonwoven fabrics produced were achieved by properly changing process variables, such as the standard feed roller speed, cross-lapping speed, stroke frequency and depth of needle penetration. Groz-Beckert felting needles, with technological condition as 15x18x32x3 R333 G3027, were used for the needling. However, 80 °C was a minimum temperature that enabled us to achieve results in terms of the density, compactness and pore size distribution. The higher temperature could cause damage to cellulose and hemicelluloses in the natural fiber structure and would require higher energy consumption.

EXPERIMENTAL

All fabric samples were habituated under standard atmospheric conditions of 21 ± 1 °C and 65 ± 2 % RH for at least 24 hours before testing. The area weight of the fabrics was measured according to ASTM D 3776. The measurement of fabric thickness was performed according to ASTM D 5729-95, which was adopted using a FAST instrument at a constant pressure of 4.14 ± 0.21 kPa or 422 ± 21 kg/m^2. The fabric tensile strength was measured on an Instron tensile tester according to ASTM D 5034.

The reclaimed nonwoven fabrics were tested for their separation force on an Instron tensile tester according to the Peel or Stripping Strength test method defined in ASTM D 903-98. The force required to separate two single layers was taken as a measure of the bond strength between layers due to the needle-punching process. The air permeability test was carried out on an air permeability testing apparatus according to the ASTM D 737- 96. The air permeability was expressed in ml/s/cm^2 at a prescribed water pressure differential of 98 Pa between the two surfaces of the fabric. The dimension of fabric pore size can be carried out by various techniques, such as projection microscopy, scanning electron microscopy, optical microscopy interfaced with digital image processing, and special purpose techniques, such as extrusion flow porometry. The pore size and its distribution were calculated on the Capillary Flow Porometer according to ASTM E 1294-89. For the dimension of filtration parameters, a standard test method as per American Society of Heating, Refrigeration and Air Conditioning Engineers ASHARE 52.2, was adopted to evaluate filtration efficiency, dust holding capacity and pressure drop.

Air Flow (m^3/sec) = Air Velocity × Filter Area

Dust increment per min (g/min) = total dust/total time.

RESULTS AND DISCUSSION

Air Permeability

Air permeability is the most important property of nonwoven materials for the application in dry filtration. The evaluation of air permeability and its relationship with physical parameters of the fabric, such as weight, thickness and density are reported in the figures below. In general, the air permeability decreases with the increase in fabric weight. While with increase in fabric weight, the fabric becomes thicker as well as denser, resulting in consolidated fabric structure, though the amount of pores increases with the increase in the number of fibers, the pore size becomes smaller. This research reported that the air permeability decreased with the increase in fabric weight in case of reclaimed chemical bonding by calendaring process respectively.

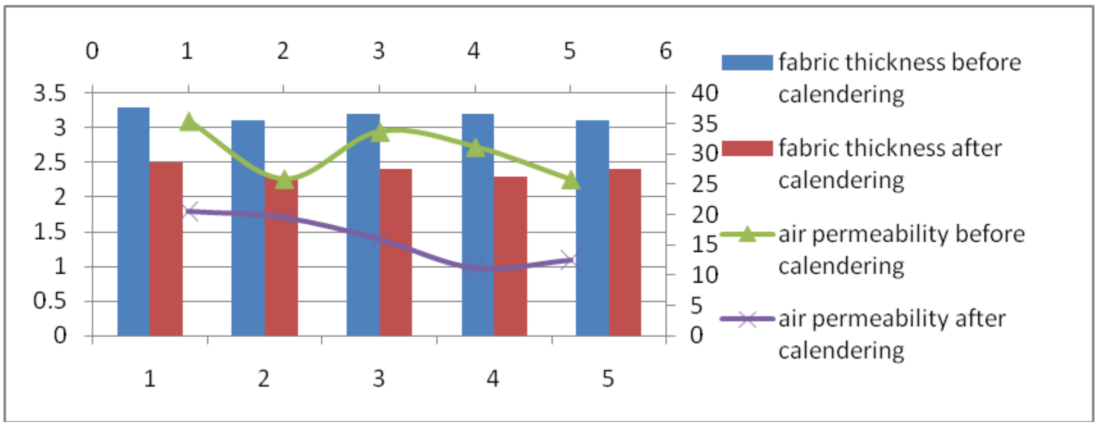

FIGURE 1. Relationship between fabric thickness and air permeability.

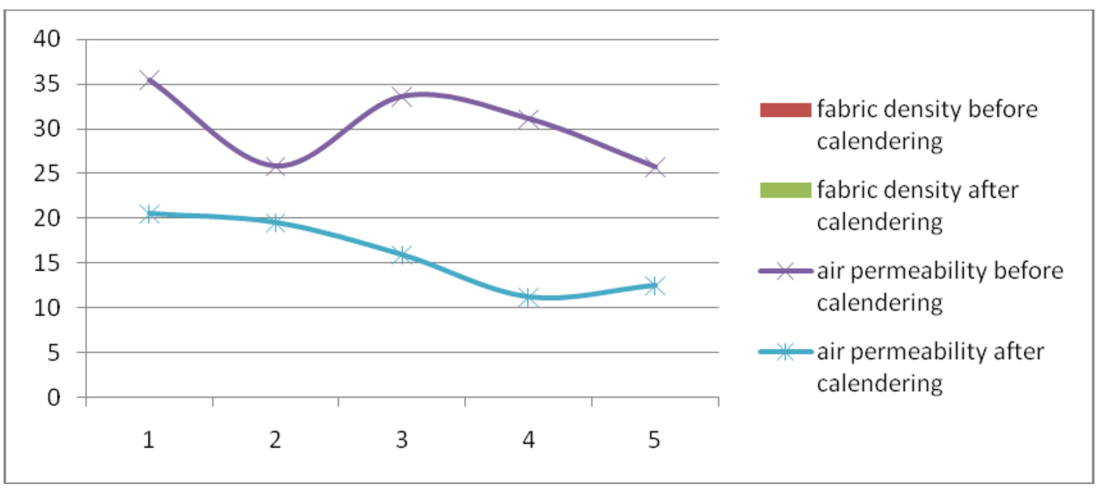

FIGURE 2. Relationship between fabric density and air permeability.

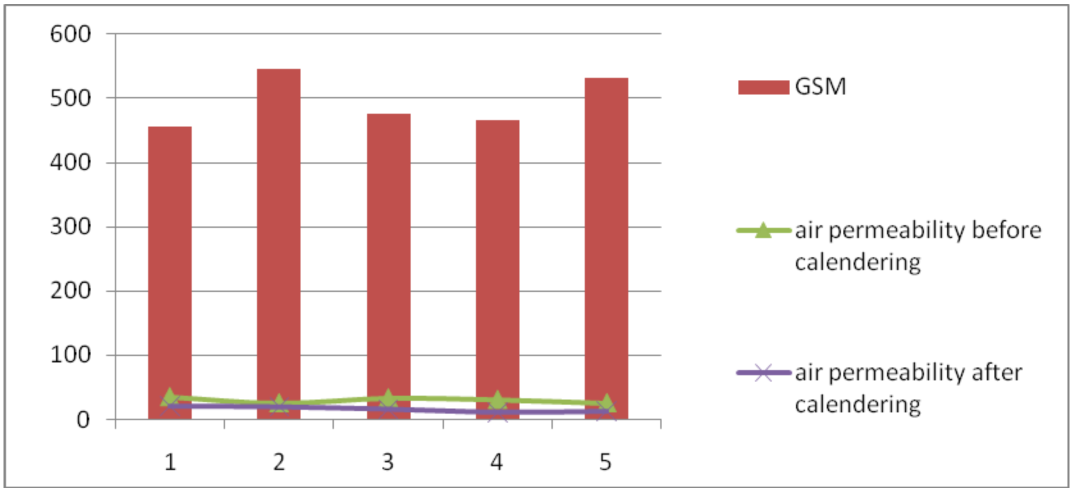

FIGURE 3. Relationship between GSM and air permeability.

DEPTH OF NEEDLE PENETRATION

In the case of a multi-layered nonwoven structure, where two or more nonwoven fabrics are needle-punched together to form a fabric, the delamination (division) strength is a significant property which determines its serviceability. In general, the delamination strength was higher at higher depths of diffusion; this was due to more intensive inter-mingling of the two single layers. Almost certainly the fibers from the top fabric layer became more entangled with the fibers from the bottom layer at a greater lowest point of needle penetration, thus requiring a higher force to divide them. At a lower depth of penetration, as the needles had to penetrate across the whole depth of the top fabric, less intensive binding occurred and the two individual layers were bound only at the surface, thus resulting in their easy separation. Also, a much higher needling force will be required in forming multi-layered fabrics and special needles, which cause a minimum disturbance to the top fabric layer when the needles are withdrawn from the fabrics, will be needed.

PORE SIZE AND THEIR DISTRIBUTION

The function of needle punched nonwoven fabrics in dry and wet filtration is mainly determined by the pore size and its distribution. The design consideration for filter fabrics for a particular application begins from the selection of the fibers to achieve the appropriate pore size to filter out the desired size of the particulates. The micro-pores should be smaller than the minimum particle size to ensure the desired filtration efficiency. This should be achieved with the minimum pressure drop across the filter and without causing any disturbance to the pore geometry.

Pore size data are presented in *Table I* and *Figures 3 and 4.*

TABLE I. Minimum, mean and maximum pore size.

Sl no	Minimum pore diameter (µm)			Mean pore diameter (µm)			Maximum pore diameter (µm)		
	uncalendered	calendered	Decrease (%)	uncalendered	calendered	Decrease (%)	uncalendered	calendered	Decrease (%)
1	7.8	2.4	54.5	127.5	35.6	78.8	245.4	49.5	84.5
2	3.8	3.56	5.03	56	39.3	26.1	226.4	112.4	49.4
3	2.78	2.74	0.7	32	17	15.7	85.9	28.5	27.8

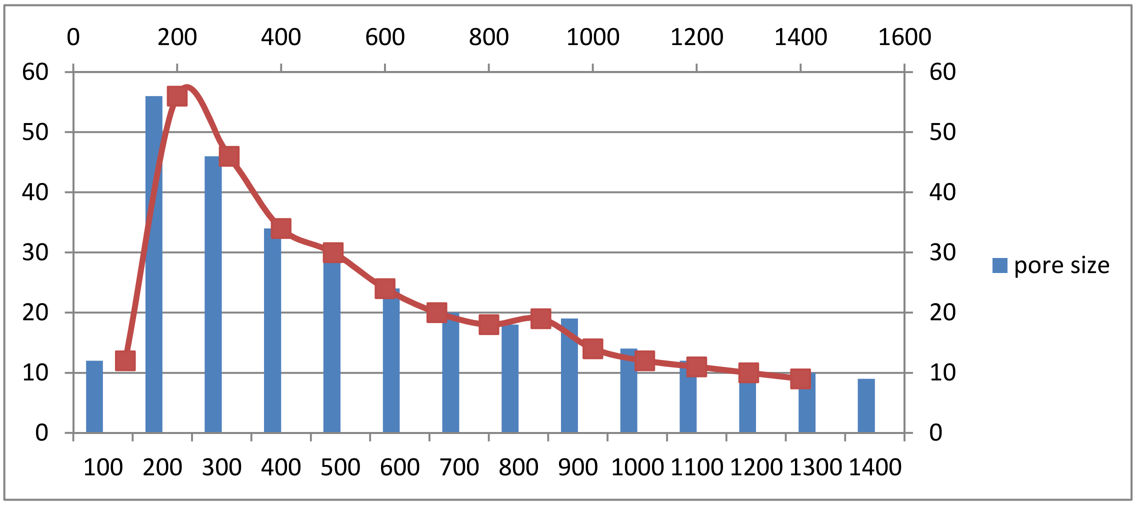

FIGURE 4. Sample 1 pore size and its distribution.

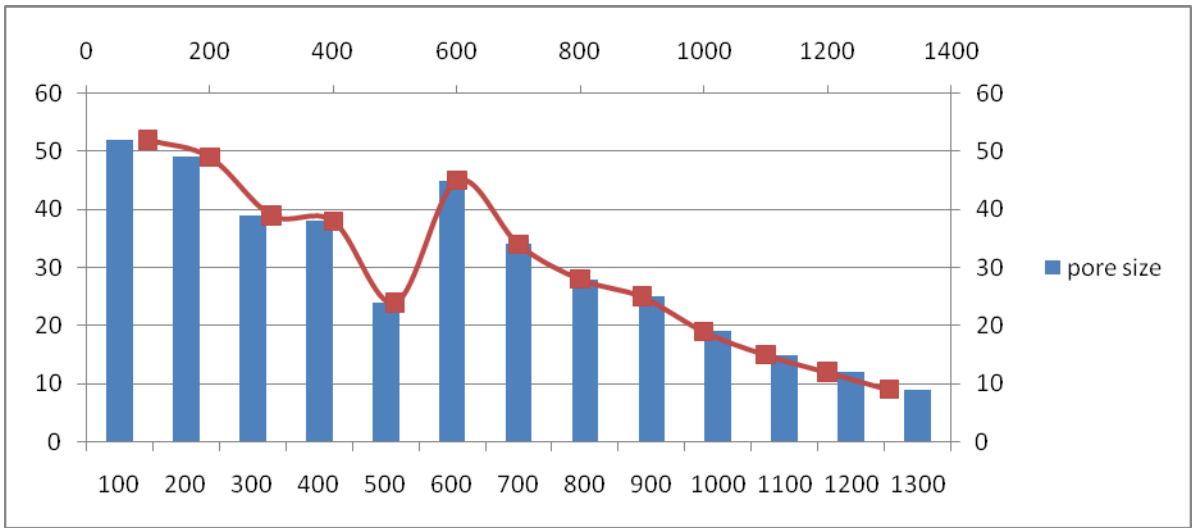

FIGURE 5. Sample 2 pore size and its distribution.

TABLE II. Evaluation of filtration properties.

SAMPLE NO/ PROPERTIES	1		2		3	
	Uncalendered	calendered	Uncalendered	calendered	Uncalendered	calendered
Air flow rate (m^3/sec)	0.44	0.44	0.38	0.38	0.42	0.42
Initial pressure drop (Pa)	0.0	30.0	0.0	30.0	10.0	30.0
Final pressure drop (Pa)	73	83.5	77	84.5	45	78
Dust arrestance (%)	85	90	89	94	92	97
Dust holding capacity(g/m^2)	54.5	85.5	65.5	93.5	89.3	112.3
Dust specifications: ISO 12103-1, A4 Coarse Test Dust, nominal particle size 0-180 µm.						

EVALUATION OF FILTRATION PROPERTIES

Filtration properties provide information about the serviceability of the material in addition to its functional performance. The dust retention capacity of the nonwoven and formation of a "block" retard its purposeful capacity due to an increased pressure drop across the fabric. Three samples of reclaimed needle-punched nonwovens were tested to calculate filtration properties on a dust filtration device, both before and after a calendering operation. The filtration properties, such as dust arrestance, dust holding capacity and resistance to air flow (pressure drop) were evaluated and the results are shown in *Table II*. The results indicate an improvement in filtration properties, such as dust weight arrestance and dust holding capacity, which supports our assumption that the post-needle- punching calendering operation can impart beneficial properties to the fabric. *Table II* compares the filtration parameters of un-calendered and calendered samples of reclaimed needle-punched nonwovens.

The results in this study show overall improvement of all filtration characteristics due to the calendering operation.

CONCLUSION

This was an investigative study proposed for utilizing reclaimed waste fibers for developing inexpensive disposable filtration media for air and dust filtration, mainly for household and industrial air-conditioning. The production of reclaimed samples by combining different nonwoven fabrics through the needle-punching process was also explored. The strength and permeability results obtained for these fabrics were promising and consistent for the intended end-uses. Calendering was found to increase the filtration efficiency of the fabrics by regulating their density and permeability. As a result, the fibers became more tightly packed, thus making it more difficult for particles to pass through the body of the fabric. With the increase in fabric density, the consolidation of the web increased with the resultant increase in dust weight arrestance and dust holding capacity. The results in this study show overall improvement of all filtration characteristics due to the calendaring operation.

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