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An analysis on air permeability of polyester/viscose blended needle-punched nonwovens

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Abstract

Air permeability is one of the important properties which affect the performance of nonwovens used for filtration, insulation and drainage applications. In this study, an analysis on the air permeability of the polyester/viscose blended needle-punched nonwovens has been carried out. In addition, a mixture-process crossed regression model with two mixture components (polyester and viscose blend ratios) and two process variables (fabric mass per unit area and needling density) is developed to analyze the air permeability of polyester/viscose blended needled nonwovens. For this purpose, five different blend ratios of polyester/viscose webs were produced, cross lapped and needled in four different mass per unit areas and three different punching densities. Air permeability of sixty nonwovens was determined by performing standard test method and the data obtained from tests were statistically analyzed with the Design Expert software. In conclusion, blend ratio of polyester-viscose fibers in web, fabric mass per unit area and needling density have major effects on the air permeability of nonwovens and the generated statistical model has given satisfactory predictions about air permeability.

Keywords

Needle-punched nonwovens, air permeability, blend ratio, punching density, simplex lattice design

Introduction

The nonwoven fabrics are increasingly used in many technical applications rather than woven and knitted fabrics due to their simple production stages, high efficiency of production, lower cost and disposability. Filtration, insulation and drainage are some of these applications. Air permeability which can be described as the transportation of air through a porous material under a pressure gradient is one of the important properties for these applications. The air permeability of nonwovens depends on geometrical and structural properties of fabrics.

Various studies have been reported about air permeability and filtration properties of nonwovens.[1–4] These studies have addressed the relationship between air permeability, filtration performance and structural characteristics of nonwovens containing fabric mass per unit area, fabric thickness, fabric density, fiber diameter, fiber cross-section, and fiber crimp frequency. Generally, it was shown that air permeability decreases as mass per unit area, thickness, and density of fabric, increase and diameter of fiber constituting the fabric decreases.

The needle-punched nonwovens are commonly preferred in filtration applications especially for dry filtration, owing to their loftiness, distinctive porous structure and lower cost of manufacturing. Needle punching is a mechanical bonding method for producing nonwovens in which a carded web of fibers is subjected to the penetrating action of barbed felting needles through the thickness of web. By carrying the bundles of fibers, barbs of needles provide their

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entanglement in the web when the needles are withdrawn in the web.[5]

For needle-punched nonwovens the parameters which affect air permeability, and consequently filtration properties, are fabric mass per unit area, fabric density, porosity, pore size and distribution, fiber properties, type and size of needles, depth of needle penetration, arrangement and density of needles, and punching density of fabric. There have been various studies carried out on the effects of given parameters on air permeability and filtration performance of needled nonwovens.[6–14] Atwal[6] investigated the effect of fiber fineness, fabric weight per unit area and fabric thickness of parallel-laid nonwovens on air permeability. The theoretical and experimental air permeability of multilayered needle-punched nonwoven samples made from ceramic and glass fiber with varying web layers and number of barbs in felting needles were analyzed by Mohammadi et al.[7,8] and it was shown that air permeability decreased as the number of barbs in needles and the number of layers in the web increased.

The air permeability of polyester based needled and calendered nonwovens manufactured with four different needling stroke frequencies was examined by Young Yeo et al.[9] and it was found that, with the increase in needling stroke frequency, air permeability increased because of an increase in the number of pores.

Rawal[10] developed a model for permeability of needle-punched nonwovens by choosing feeding rate, needle stroke frequency and depth of needle penetration as variables. According to the multiple regression analysis, feed rate and combined effect of feed rate and depth of needle penetration had the greatest effect on permeability characteristics of fabrics. Furthermore, it was determined that permeability characteristics of needled nonwovens decreased with an increase in fabric density and thickness.

The feeding rate, needling stroke frequency and depth of needle penetration changed systematically during needling process for both polyester and flax fibers and effects of these parameters on permeability were examined by Rawal and Anandjiwala.[11] In comparison, permeability features of flax fabrics found to be higher than that of polyester fabrics due to the high bending rigidity and low packing density of polyester in fabric.

The effect of weight per unit area of fabric, punching density and depth of needle penetration on air permeability of jute needled nonwovens was investigated by Sengupta et al.[12] and statistically analyzed results showed that the air permeability was decreased with an increase in weight and depth of needle penetration, which caused high density and compactness of the fabric.

Anandjiwala and Boguslavsky[13] evaluated the air permeability and filtration performance of flax-based needled nonwovens by changing machine variables such as feed rate, stroke frequency and depth of needle penetration.

Yuksekkaya et al.[14] performed an experimental investigation by using needle-punched nonwovens made from recycled polyester fibers and they passed the web through the needling loom two, three, four and five times with and without reinforcement to provide different needling intensities. They evaluated air permeability of the samples and it was found that the pore size of fabrics increased with an increase in needling intensity which caused higher air permeability.

The fiber and process configuration of needled nonwovens can be arranged easily according to the level of air permeability and filtration performance desired in application at a reasonable cost. Changing fiber composition of the fabric is one of the ways to improve the properties of fabric. There are few studies which systematically handle the effect of fiber composition/blend ratio of fabric on air permeability of needled nonwovens. The originality of this study is taking the blend ratio as a factor and investigating the effects of blend ratio, mass per unit areas and needling densities together in a

Table 1. The properties of polyester and viscose fibers

Fiber	Length (mm)	Fineness (dtex)	Strength (cN/tex)	Elongation (%)	Crimp level (crimp/cm)
Polyester	38	1.6	53.9	34.45	4.77
Viscose	40	1.7	26.30	26.98	4.10

Table 2. Blend ratios used for the study

	Blend ratios (%)	
	Polyester	Viscose
A	100	0
B	75	25
C	50	50
D	25	75
E	0	100

Table 3. Levels of process factors changed during sample production

	Mass per unit area (g/m^2)		Punching density (punch/cm^2)
1	50	1	75
2	75	2	150
3	100	3	225
4	125		

Table 4. Experimental test results

Fabric type	Measured mass per unit area (g/m^2)		Thickness (mm)		Bulk density (g/cm^3)	Air permeability (m/s)	
	Average	CV (%)	Average	CV (%)		Average	CV (%)
A11	50.40	4.319	1.730	3.901	0.0291	2.361	5.025
A21	76.77	3.546	2.250	5.229	0.0341	1.710	4.009
A31	100.49	3.263	2.710	4.935	0.0371	1.364	2.462
A41	124.21	3.094	3.121	8.251	0.0398	1.061	5.201
A12	50.51	3.527	1.670	6.632	0.0302	2.693	6.694
A22	74.78	3.140	2.097	3.548	0.0357	1.913	5.588
A32	99.87	2.578	2.340	4.187	0.0427	1.554	2.193
A42	125.09	2.074	3.000	2.160	0.0417	0.950	2.105
A13	50.63	3.240	1.562	5.173	0.0324	2.757	4.591
A23	74.13	3.224	1.868	3.649	0.0397	2.131	4.454
A33	100.7	3.388	2.091	2.978	0.0482	1.670	4.134
A43	125.04	1.679	2.589	2.439	0.0483	0.970	4.166
B11	50.7	2.912	1.497	4.225	0.0339	2.359	3.196
B21	75.73	2.122	2.051	2.762	0.0369	1.706	1.214
B31	101.01	2.240	2.552	2.726	0.0396	1.359	1.921
B41	126.33	3.857	3.311	4.798	0.0382	0.899	3.240
B12	50.41	2.536	1.540	3.076	0.0327	2.386	6.793
B22	75.48	2.033	2.041	2.135	0.0370	1.777	2.148
B32	99.76	2.765	2.422	2.011	0.0412	1.387	2.590
B42	125.17	2.122	2.598	3.3555	0.0482	1.029	2.474
B13	50.07	4.194	1.461	6.481	0.0343	2.654	3.872
B23	74.21	3.958	1.839	4.231	0.0404	2.060	1.838
B33	99.20	3.086	2.188	4.680	0.0453	1.480	5.263
B43	123.2	2.278	2.412	2.700	0.0511	1.146	3.375
C11	51.11	6.674	1.469	6.673	0.0348	2.330	6.185
C21	76.1	3.160	2.000	3.916	0.0381	1.766	2.064
C31	99.91	4.004	2.250	4.537	0.0444	1.520	3.397
C41	125.33	3.295	3.011	5.231	0.0416	1.000	6.164
C12	50.19	4.149	1.560	4.956	0.0322	2.456	4.016
C22	74.86	5.524	2.059	9.904	0.0364	1.940	4.881
C32	100.62	2.453	2.232	4.034	0.0451	1.451	4.236
C42	125.13	2.386	2.860	2.622	0.0438	1.019	3.277
C13	50.10	5.136	1.160	0.068	0.0432	2.913	3.075
C23	73.97	2.603	1.692	0.050	0.0437	2.143	2.757
C33	98.71	2.135	2.092	0.073	0.0472	1.503	2.022
C43	124.67	2.612	2.431	0.070	0.0513	1.507	2.088
D11	50.42	5.140	1.430	6.114	0.0353	2.391	7.281
D21	76.93	4.366	1.879	5.784	0.0409	1.859	2.871
D31	100.32	3.733	2.491	4.867	0.0403	1.169	4.513
D41	127.22	2.766	3.048	3.912	0.0417	0.949	2.751
D12	50.72	4.175	1.361	5.037	0.0373	2.596	5.542
D22	76.02	3.410	1.783	4.796	0.0426	1.749	7.989
D32	101.15	4.022	2.152	5.297	0.0470	1.493	2.938
D42	124.84	2.364	2.717	3.849	0.0459	0.904	4.729
D13	49.85	3.297	1.317	4.251	0.0379	2.809	2.293

(continued)

Table 4. Continued

Fabric type	Measured mass per unit area (g/m^2)		Thickness (mm)		Bulk density (g/cm^3)	Air permeability (m/s)	
	Average	CV (%)	Average	CV (%)		Average	CV (%)
D23	75.03	3.176	1.746	3.704	0.0430	1.809	3.646
D33	99.39	2.305	2.051	3.027	0.0485	1.391	3.252
D43	124.86	3.867	2.319	4.834	0.0538	1.09	5.922
E11	50.89	3.316	1.315	5.415	0.0387	2.160	6.799
E21	77.13	2.813	1.792	3.566	0.0430	1.473	1.868
E31	100.87	2.698	2.303	3.668	0.0438	1.080	2.507
E41	125.07	1.859	2.600	4.576	0.0481	1.037	4.042
E12	49.34	5.355	1.482	6.618	0.0333	2.130	6.932
E22	75.72	3.735	1.733	4.495	0.0437	1.659	7.461
E32	100.71	3.274	1.982	3.445	0.0508	1.351	3.831
E42	124.90	2.360	2.252	5.381	0.0555	1.389	2.178
E13	50.06	3.270	1.269	3.915	0.0394	2.187	4.950
E23	74.38	4.615	1.460	5.226	0.0509	1.957	4.127
E33	100.67	4.385	1.909	7.807	0.0527	1.326	9.737
E43	125.05	2.462	1.932	5.169	0.0647	1.249	4.634

Table 5. ANOVA for [Linear]*[Quadratic] regression model

Source	Sum of squares	Degrees of freedom	Mean square	F value	*p*-value	Significance
Model	17.460	6	2.91006	148.0133	< 0.0001	Significant
Linear mixture	5.683	1	5.68312	289.0582	< 0.0001	Significant
PM	7.048	1	7.04849	358.5047	< 0.0001	Significant
PPd	0.263	1	0.26255	13.35387	0.0006	Significant
VM	3.905	1	3.90523	198.63035	< 0.0001	Significant
VPd	0.191	1	0.19112	9.72091	0.0029	Significant
VM^2	0.370	1	0.36986	18.81188	< 0.0001	Significant
Residual	1.042	53	0.01966			
Cor Total	18.502	59				

P, blend ratio of polyester in the mixture; V, blend ratio of viscose in mixture; M, fabric mass per unit area; Pd, needling density.

statistical analysis. In the present study, the effect of blend ratio, mass per unit area, and needling density on air permeability of polyester-viscose blended nonwovens, are investigated. A statistical model was developed by using a mixture-process crossed regression model with two mixture components (polyester-viscose blend ratios) and two process variables (fabric mass per unit area, needling density) to analyze the air permeability of polyester/viscose blended needled nonwovens.

Materials and methods

Preparation of nonwovens

The present study focuses on nonwovens produced with different blend ratios of polyester and viscose fibers, with different fabric mass per unit areas and needling densities. The end use of the samples used for this experimental study was considered as dry filtration. Since, polyester and viscose fiber can be used for dry filtration applications,[15] the raw material of nonwovens produced during this study has been chosen as polyester and viscose fiber. In addition, the effects such as widespread presence in market, cheap price and conformity of fibers to production method were the other factors affecting the material choice. The properties of polyester and viscose fibers used for preparing webs are illustrated in Table 1.

The needle-punched nonwoven samples were produced at the Nonwoven Research Group Laboratories in University of Leeds. The fibers were opened and blended by hand by using a sandwich

Table 6. Predictions made by statistical model and its prediction performance

Fabric type	Actual air permeability (m/s)	Predicted values	APE	Fabric type	Actual air permeability (m/s)	Predicted values	APE
A11	2.361	2.429	2.911	C32	1.452	1.406	3.154
A21	1.710	1.899	11.038	C42	1.019	1.071	5.134
A31	1.364	1.368	0.276	C13	2.913	2.590	11.066
A41	1.060	0.837	21.058	C23	2.143	1.999	6.704
A12	2.692	2.570	4.530	C33	1.503	1.536	2.212
A22	1.913	2.039	6.590	C43	1.507	1.201	20.283
A32	1.554	1.508	2.954	D11	2.390	2.281	4.559
A42	0.950	0.977	2.854	D21	1.858	1.660	10.680
A13	2.757	2.710	1.691	D31	1.168	1.230	5.342
A23	2.132	2.179	2.223	D41	0.949	0.994	4.693
A33	1.670	1.648	1.292	D12	2.595	2.406	7.286
A43	0.970	1.117	15.199	D22	1.748	1.784	2.084
B11	2.358	2.380	0.940	D32	1.492	1.355	9.165
B21	1.705	1.819	6.687	D42	0.905	1.118	23.581
B31	1.358	1.322	2.652	D13	2.808	2.531	9.872
B41	0.899	0.889	1.108	D23	1.808	1.909	5.603
B12	2.385	2.515	5.465	D33	1.392	1.480	6.332
B22	1.777	1.954	9.972	D43	1.090	1.243	14.063
B32	1.387	1.457	5.058	E11	2.160	2.231	3.310
B42	1.028	1.024	0.368	E21	1.472	1.580	7.325
B13	2.648	2.651	0.095	E31	1.080	1.185	9.685
B23	2.060	2.089	1.426	E41	1.037	1.046	0.847
B33	1.480	1.592	7.590	E12	2.130	2.351	10.386
B43	1.147	1.159	1.080	E22	1.659	1.699	2.445
C11	2.33	2.331	0.026	E32	1.352	1.304	3.526
C21	1.765	1.739	1.457	E42	1.388	1.166	16.029
C31	1.520	1.276	16.041	E13	2.188	2.471	12.931
C41	1.001	0.941	5.965	E23	1.957	1.819	7.037
C12	2.455	2.461	0.229	E33	1.325	1.424	7.475
C22	1.940	1.869	3.644	E43	1.248	1.285	2.984
MAPE (%)				6.30			
R (%)				97.14			

technique and then mixed by blender with five different blend ratios as given in Table 2. The blended fiber mass was fed onto the laboratory model card and the webs formed were oriented in a cross-machine direction using a cross-lapper to provide web of the required fabric weight per unit area.

The webs were then fed onto the laboratory model needling loom containing 2000 needles on the needle board. The feed speed, stroke frequency and the other parameters of the needle loom were arranged to get a punch density of 75 punch/cm^2 accordingly. The depth of needle penetration was kept at 10 mm and the type of needles were Foster $15 \times 18 \times 36 \times 3RB \times F20\text{-}9\text{-}4NK$ for all samples. The webs were passed through the loom one, two, and three times separately to get three different punching densities (75, 150, 225 punch/cm^2) for each fabric mass per unit area as shown in Table 3.

In order to investigate only the effect of needling density, the weights of fabrics were tried to be kept constant after one, two or three passes through needling loom for fabrics with identical mass per unit areas. For this purpose, the weights of webs produced by card for identical mass per unit area intervals were gradually reduced by adjusting the feeding rollers of card to get the same mass per unit area after each needling process. Sixty different samples were produced by taking into consideration the number of blend ratios (5), the number of weight per unit areas (4) and

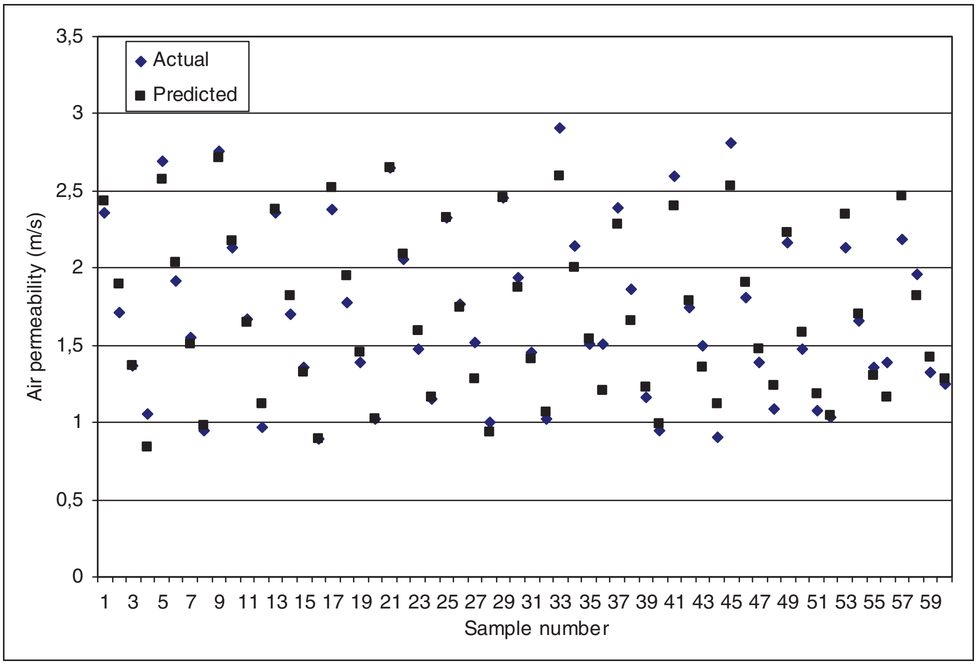

Figure 1. The comparative diagram of the actual and predicted air permeability (m/s) values by the statistical model.

number of needling densities (3) for the experimental study ($5 \times 4 \times 3 = 60$).[16]

Testing of nonwovens

All the fabrics were conditioned 24 hours at standard atmospheric conditions (20±2°C temperature and 65±2% relative humidity) prior to testing. The standard tests were performed to determine the mass per unit area, thickness and air permeability of fabrics at standard atmospheric conditions. Mass per unit area was determined according to EDANA test standards, ERT 40.3-1990, by testing 30 cm × 30 cm of ten samples. The mean of the results was calculated for mean mass per unit area. SDL Atlas M034A Digital Thickness Gauge with pressure 1 kPa was used to measure the thickness of ten samples for each fabric according to the EDANA standard, ERT 30.5-1999. The air permeability test of nonwovens was conducted on an SDL Atlas M021A Digital Air Permeability tester using the EDANA standard, ERT 140.2-1999. The results were expressed as m/s by taking into consideration the unit volume of air (m^3/s) that passed through 1 m^2 of fabric at a pressure difference of 100 Pa. Seven pieces of 10 cm × 10 cm size samples were cut from different parts of each fabric and measurement was done using a test area of 20 cm^2. The mean air permeability of each fabric was reported. The fabric density was calculated by using a mean of measured mass per unit area and thickness. All the experimental results were represented in Table 4. The letters in fabric type indicate the kinds of blend ratio (as in Table 2), the first number shows the mass per unit area and second number represents the needling density of each sample (as in Table 3). For instance; for fabric A21, A means that the blend ratio of fabric is 100% polyester, 2 means that the mass per unit area is 75 g/m^2 and 1 shows that the needling density is 75 punch/cm^2.

Statistical analyses

For this experimental study, variables were chosen as blend ratios of polyester and viscose in fabric, mass per unit area and needling density of fabrics. The blend ratio contains a component of the ingredients of the mixture (blend ratio of polyester and viscose fiber) and their levels are not independent. For example, if $x_1, x_2, \ldots, x_p$ denote the proportions of p components of a mixture; it should be as

$$0 \leq x_i \leq 1, \; i = 1, 2, \ldots, p \tag{1}$$

and

$$x_1 + x_2 + x_3 + \ldots\ldots + x_p = 1 \tag{2}$$

In the present study, p = 2 (two components: polyester, x_p, and viscose, x_v)

$$x_p + x_v = 1 \tag{3}$$

and the blend ratio parameter should be a mixture factor and it is required to consider using simplex

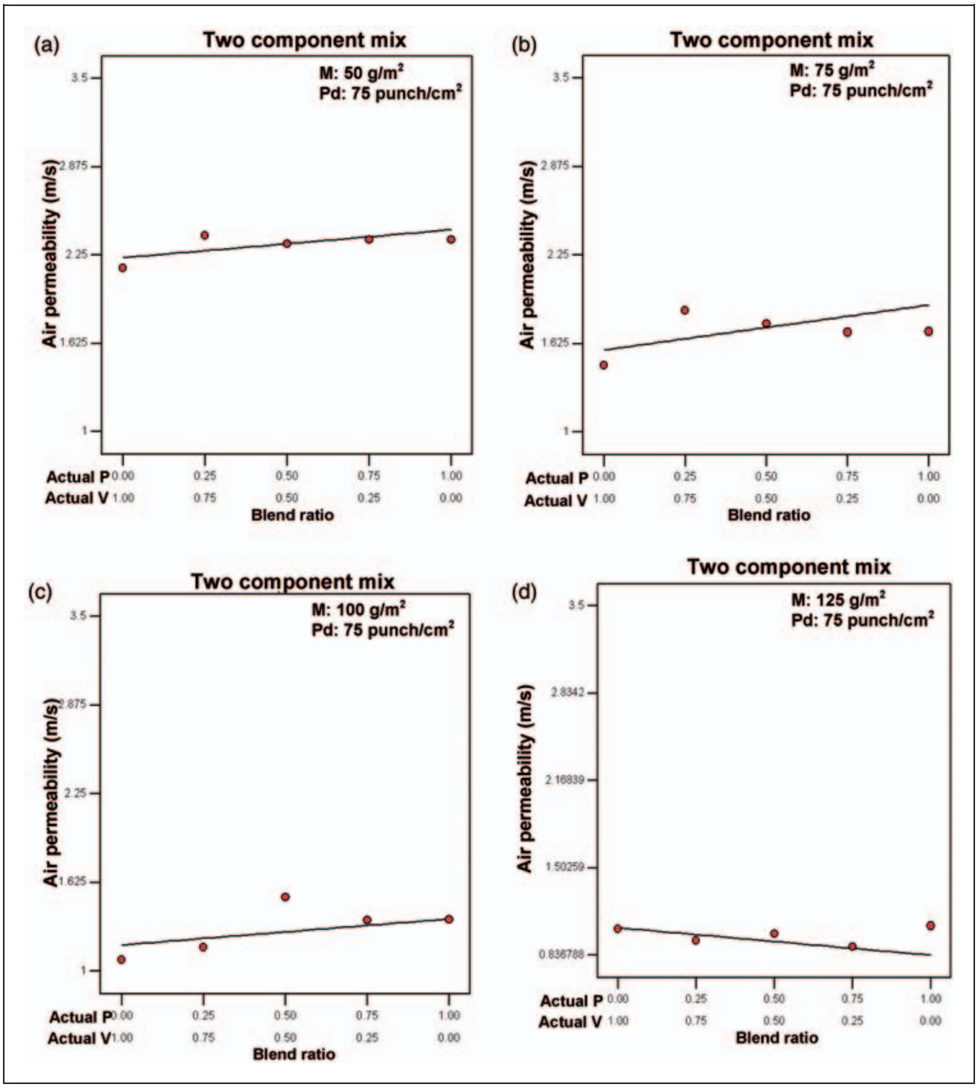

Figure 2. Relationship between blend ratio and air permeability for different fabric mass per unit areas and for 75 punch/cm^2 punching density: a) for 50 g/m^2 fabrics, b) for 75 g/m^2 fabrics, c) for 100 g/m^2 fabrics, d) for 125 g/m^2 fabrics.

lattice design. Simplex designs are used to investigate the effect of mixture components on the response variable where all components must have the same range.[17] The factor space is explored at points of composition corresponding to an ordered arrangement known as a lattice. The method has two key features: (1) properties or responses are measured at lattice composition points; and (2) polynomial equations having a special correspondence to the lattice points are then used to represent the responses.[18]

The mass per unit area and needling density are process variables used in this study and they are independent from the mixture. Since, the experimental design of this research consists of two process variables (as mass per unit area and needling density) besides mixture components, the mixture-process crossed regression model was developed to predict the air permeability of polyester/viscose blended needle-punched nonwoven fabrics.

In statistical analysis in the study, 'Design Expert' software was used. After introduction of the test results of air permeability to the software, analyses were conducted applying the mixture-process crossed design. A [Linear]*[Quadratic], [Mixture]*[Process] design was suggested by the software for air permeability of fabrics by evaluating residual analyses. Consequently, the regression equation of determined model was found as:

$$\begin{aligned} \text{Air permeability} &= 3.351363\text{P} + 4.184339\text{V} \\ &- 0.02124\text{PM} + 0.001871\text{PPd} - 0.05171\text{VM} \\ &+ 0.001596\text{VPd} + 0.000205\text{VM}^2 \end{aligned} \tag{4}$$

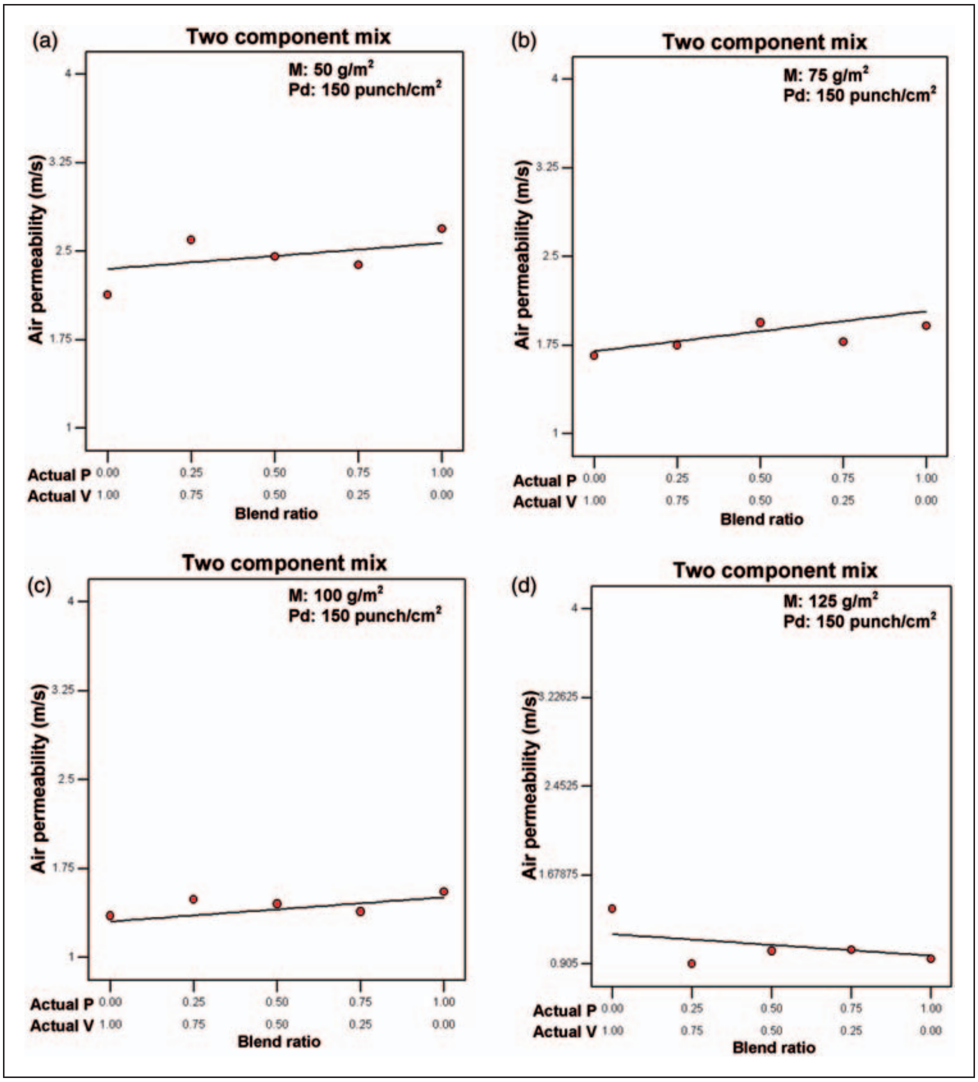

Figure 3. Relationship between blend ratio and air permeability for different fabric mass per unit areas and for 150 punch/cm^2 punching density: a) for 50 g/m^2 fabrics, b) for 75 g/m^2 fabrics, c) for 100 g/m^2 fabrics, d) for 125 g/m^2 fabrics.

where P and V are the proportions of polyester and viscose in the blend, respectively, and change as 0, 0.25, 0.50, 0.75 and 1 according to the blend ratio. M expresses the mass per unit area and Pd shows the punching density of fabrics in the equation. It should be noted that since the '[Mixture]*[Process]' model was selected as [Linear]*[Quadratic], blend components are linear while the process parameters are second order (quadratic) in the regression equation.

The Analysis of Variance (ANOVA) table of this model is also given in Table 5. The model parameters having p-values lower than 0.05 is expected to be significant in this table. It also shows that there is significant interaction between the blend components. This means that interaction of process parameters and blend ratios for the air permeability of the fabrics manufactured are meaningful or the effects of related parameters are significant. Since, Linear*Quadratic mixture-process crossed regression model has been constituted, the ANOVA table includes mixture factors in linear form and the quadratic interactions of process parameters with mixture factors. As seen from the table, the parameter which has the highest effect on the air permeability is PM (interaction/combined effect of polyester blend ratio and mass per unit area) by having 358.5047 F-value.

The prediction performance of the generated regression model has been evaluated in Table 6. In the table, actual values of air permeability obtained from experimental test results and the predictions made by the statistical model are demonstrated. The table includes Absolute Percentage Error (APE-%) values of each prediction and MAPE (Mean Absolute Percentage Error-%) value in order to see the prediction capability of the model. APE of each prediction can be calculated as

$$APE = \left(\left|\frac{A_i - P_i}{A_i}\right| \times 100\right) \quad (5)$$

Here A_i is actual value, P_i is predicted value, i is the number of the experimental point.[17] For instance, selecting the fabric type A11, blend ratio of polyester and viscose is 100% and 0%, respectively; fabric mass per unit area is 50 g/m^2, and needling density is 75 punch/cm^2; the actual air permeability result obtained for these real production parameters is 2.361 m/s. The predicted air permeability by the statistical model developed is 2.429 m/s. The APE is calculated as 2.911%. The MAPE value, which is an important parameter in assessing the prediction performance of the model, is also given in the table. It is calculated as 6.30% for the generated statistical model and this means that the air permeability of the investigated fabrics can be predicted with 93.7% (1–6.30) confidence by using the developed model. In addition, the correlation coefficient of the statistical model for evaluating the air permeability of chosen fabrics is also illustrated in Table 6. The correlation coefficient of the model was found as 97.14% and this shows that the parameters chosen as blend ratio, fabric mass per unit area and needling density explain the 97.14% of the variability in air permeability.

The prediction performance of the model developed can be seen more clearly in Figure 1. This figure demonstrates comparative diagrams between the real air permeability (m/s) data and the predictions made by

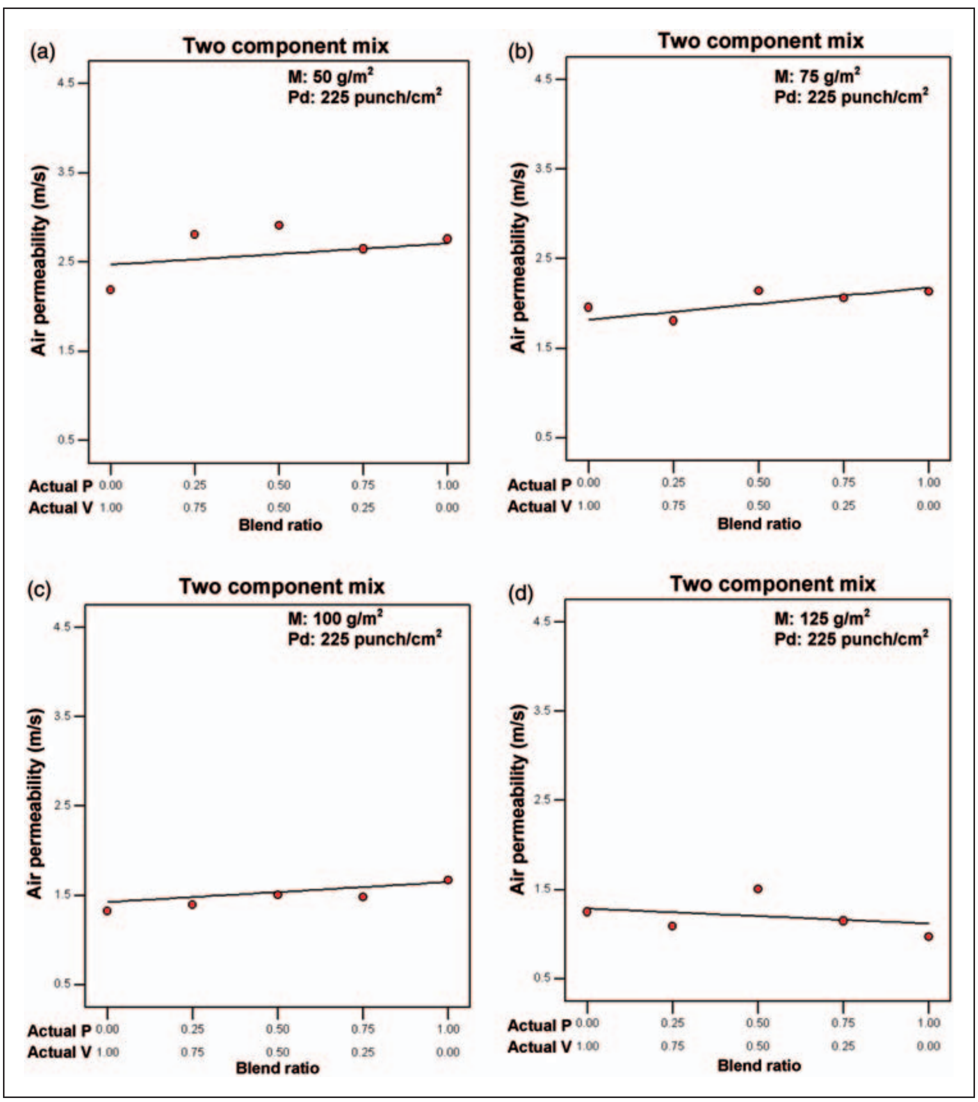

Figure 4. Relationship between blend ratio and air permeability for different fabric mass per unit areas and for 225 punch/cm^2 punching density; a) for 50 g/m^2 fabrics, b) for 75 g/m^2 fabrics, c) for 100 g/m^2 fabrics, d) for 125 g/m^2 fabrics.

the statistical model successively. Here, the air permeability (m/s) results and predictions made by the model are marked on the figure according to the sequence in Table 6. The predictions made by the statistical model are closer to the actual air permeability values, as seen from figure.

Results and discussion

Five different blend ratios of polyester/viscose nonwoven fabrics were produced by changing the fabric mass per unit area in four levels, and the needling density in three levels, in this study. A mixture-process crossed design (simplex lattice design) was developed by introducing the blend ratio, fabric mass per unit area and needling density as input variables and the air permeability of fabrics as output variables. The best model for prediction was selected and explained here. In order to clarify the relationship between input factors and air permeability, regression curves generated according to regression equation by software are demonstrated in this part.

Effect of blend ratio and fabric mass per unit area

The effects of both blend ratio and fabric mass per unit area on air permeability of nonwovens are demonstrated with the regression curves given in Figure 2, Figure 3 and Figure 4. In these figures, the design points indicate the experimental results obtained and the curve is fitted by the regression equation. The air permeability results against the changing blend ratio of actual polyester (Actual P) and viscose fibers (Actual V) in the mixture from 0.0 to 1.0 for four different mass per unit areas, can be seen in the group of graphs illustrated in each figure. For instance; in Figure 2, the needling density of fabrics is fixed to 75 punch/cm^2 and fabric mass per unit areas are determined as 50 g/m^2 (a), 75 g/m^2 (b), 100 g/m^2 (c) and 125 g/m^2 (d). The needling densities are fixed to 150 punch/cm^2 and 225 punch/cm^2 respectively for Figure 3 and 4.

Since the trend of air permeability is the same for Figure 2, 3 and 4; Figure 2 is explained here in detail as an example. As seen from Figure 2; for all fabric mass per unit areas, the air permeability of the fabrics increases with the increase in blend ratio of the polyester in the blend, except for the 125 g/m^2 fabrics. As the density of polyester fiber is lower than that of viscose fiber, the thicknesses of polyester rich fabrics are higher than that of viscose rich fabrics for identical fabric mass per unit areas. Thus, increasing the proportion of polyester in the mixture causes bulkier fabrics. In addition; because of high bending rigidity and low packing density of polyester, viscose rich fabrics have a more compact structure than the polyester ones with identical needling densities. For 125 g/m^2 fabrics, since the number of fibers in the fabric increases, the fibers get closer to each other in the fabric. It is thought that the bulky effect of polyester may be decreased because

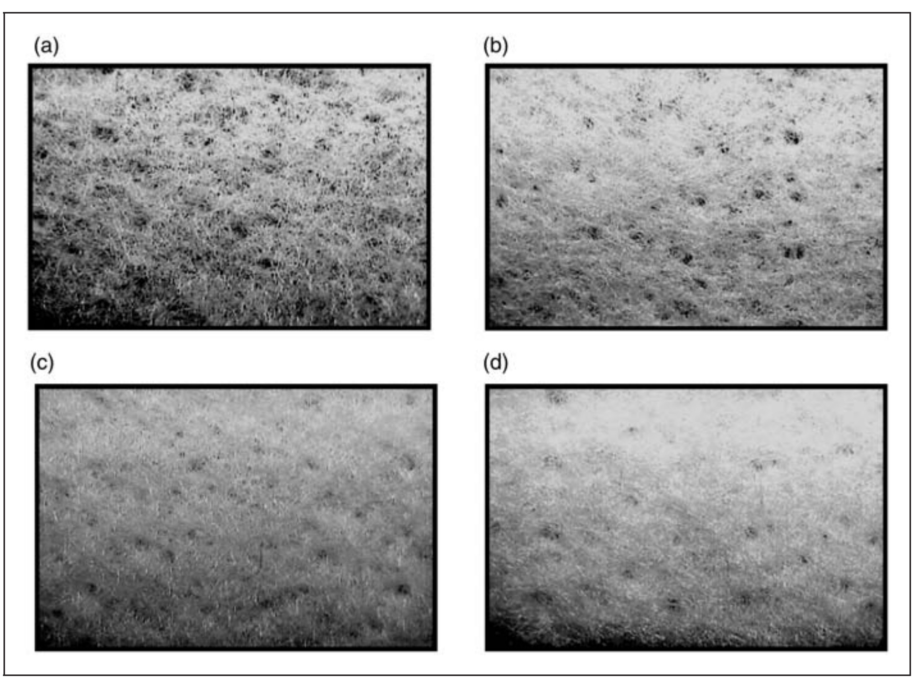

Figure 5. Image of chosen 100% polyester and 100% viscose fabrics with changing mass per unit area: a) 100% polyester, 50 g/m^2, 75 punch/cm^2; b) 100% viscose, 50 g/m^2, 75 punch/cm^2; c) 100% polyester, 125 g/m^2, 75 punch/cm^2; d) 100% viscose, 125 g/m^2, 75 punch/cm^2.

of the lack of space between each fiber in the fabric and the curve changes its trend. This effect can be seen obviously from surface images of chosen fabrics demonstrated in Figure 5. The images have been taken by using computer-connected digital stereo microscope. Here, ten times magnified images of 100% polyester and 100% viscose fabrics with different mass per unit areas (50 g/m^2 and 125 g/m^2) and fixed needling density (75 punch/cm^2) have been given in order to indicate the different behavior of 125 g/m^2 fabrics. In identical mass per unit areas and needling density polyester rich fabrics have a more open structure for 50 g/m^2 fabrics as seen from the figure. However; for fabrics with 125 g/m^2 weight, the structural differences caused by varying fiber properties disappear with the effect of high numbers of fibers in the fabric.

As seen from the Figure 2, 3 and 4; when the needling density kept constant, the increase in fabric mass per unit area causes a reduction in air permeability. By increasing the fabric mass per unit area, the number of fibers in the cross direction increases which resists the air flow through the fabric. Also, an increased number of fibers leads to an increase in thickness and path length of the air flow. The same effect can also be seen clearly in Figure 5.

Effect of blend ratio and punching density

In order to indicate the effects of both blend ratio and punching density on air permeability of nonwovens, graphs in Figure 2a, 3 a and 4 a are given all together in Figure 6. Here, the fabric mass per unit area is fixed to 50 g/m^2 and needling density is changed to 75 punch/cm^2 (a), 150 punch/cm^2 (b) and 225 punch/cm^2 (c). For other masses per unit area and needling densities; the graphs given in parts (b), (c), (d) of Figure 2, 3 and 4 can

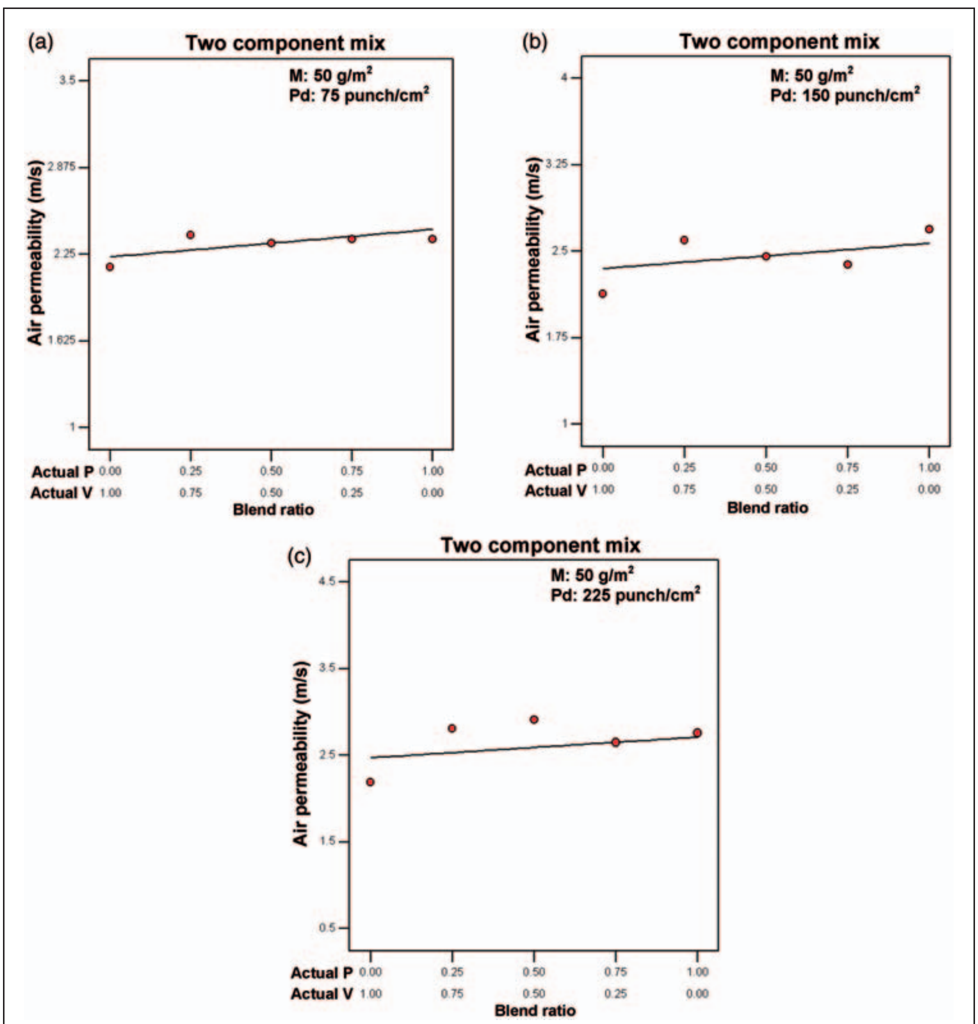

Figure 6. Relationship between blend ratio and air permeability for different needling densities: a) for 50 g/m^2 and 75 punch/cm^2 fabrics, b) for 50 g/m^2 and 150 punch/cm^2 fabrics, c) for 50 g/m^2 and 225 punch/cm^2 fabrics.

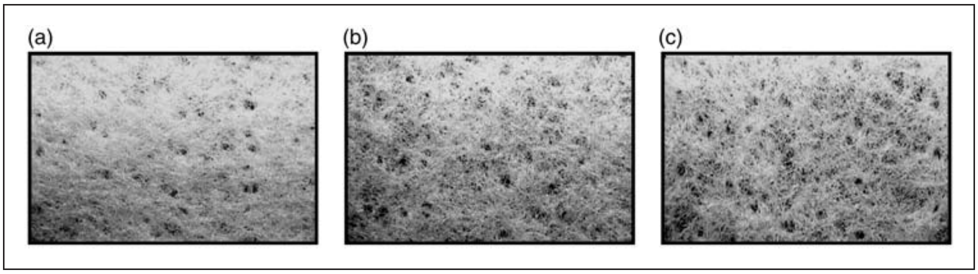

Figure 7. 100% viscose fabric with 50 g/m^2 mass per unit area; a) 75 punch/cm^2, b) 150 punch/cm^2, c)225 punch/cm^2.

be grouped as done for part (a) in Figure 6. If these groups of graphs are investigated, it will be easily seen that the trend of effect of blend ratio and needling density is same as in Figure 6. According to the graphs in Figure 6, there is a small increase in air permeability caused by the increase in needling density. Since the mass per unit area was attempted to be kept constant for different needling densities by adjusting the weight of webs separately in the card, the number of fibers in the fabric is also constant. By increasing the needling density, the entanglement of fibers increases but the spaces around the entangled fiber tufts increases as well. Also, the number of pores formed by the effect of needles may be increased with the increase in passage number of the needling process. In order to explain these effects evidently, the ten times magnified surface images of chosen fabrics are demonstrated in Figure 7. In the figure, an image of 100% viscose blended fabrics with 50 g/m^2 mass per unit area, the changing needling densities of 75 punch/cm^2 (a), 150 punch/cm^2 (b), 225 punch/cm^2 (c) are illustrated. It can be seen that the number of bonded fibers with the effect of needling is increased by increasing needling density. Since the latest mass per unit area and the number of fibers in the structure is the same, the pores around the entangled fibers are higher for higher needled fabrics. This causes higher air permeability with increasing punching density for fabrics with identical mass per unit areas.

Conclusion

As a result of experimental study on the statistical investigation into the analysis of the air permeability of polyester/viscose blended needle-punched nonwoven fabrics, a mixture-process crossed regression model (simplex lattice design) with two mixture components (polyester and viscose blend ratios) and two process variables (fabric mass per unit area and needling density) was developed. Considering the overall performance of the model (correlation coefficient and MAPE), it is determined that the equation derived from this study can be used to predict the air permeability satisfactorily. It is concluded that the model generated is practical and useful for needle-punched nonwoven manufacturers in order to predict the air permeability value of polyester/viscose blended nonwovens before the fabric production.

According to the study; when the blend ratio of polyester in fabrics is increased, the air permeability of fabrics decreases for all fabrics, except the 125 g/m^2 ones. For 125 g/m^2 fabrics, with the combined effect of blend ratio and mass per unit area; the air permeability of polyester rich fabrics is lower than that of viscose rich ones. In addition, the air permeability of the fabrics decreases with the increase in mass per unit area and increase in needling density causes an increase in air permeability.

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