Joanna Grzybowska-Pietras,
Jadwiga Malkiewicz

Influence of Technologic Parameters on Filtration Characteristics of Nonwoven Fabrics Obtained by Padding

Institute of Textile Engineering and Polymer Materials
University of Bielsko-Biała,
ul. Willowa 2, 43-309 Bielsko-Biała, Poland
e-mail: jpietras@ath.bielsko.pl

Abstract
The influence of the technological parameters of the padding process on the filtration properties of polyester nonwoven fabrics was analyzed. The variables were surface weight and binding agent concentration. The filtration properties were indirectly analyzed by pore size measurements and pore size distribution. The results obtained proved that the surface weight of webs strongly influenced the volumetric air flow of the tested nonwoven fabrics.

Key words: *pore sizes distribution, filtration, nonwovens, padding.*

Introduction

Emerging technologies of nonwoven formation give opportunities to obtain novel modern filters, leading to improved effectiveness of air filtration. The market for filter media is growing together with new filter applications [1 - 3]. Regardless of the final applications, nonwoven filters should posses the following features:

- high air permeability
- high filtration efficiency
- low airflow resistance [4 - 6].

It is rather difficult to combine all of these features in practice.

Generally there are two main groups of tests used for the characterisation of nonwovens for filtration. The first group takes into account the structural measurements of filters like the mean porosity of filtration layers and air permeability. The second one comprises measurements of the dynamic changes in filtration efficiency and airflow resistance during filter loading as well as the determination of retained capacity [7 - 9].

The effect of process parameters on filtration efficiency has been discussed in detail in many papers. Numerous studies have been conducted on needle-punched nonwovens as well as melt-blown, spunlaced and composite structures [10 - 13]. Kothari and Newton assigned the effect of the concentration of the binding agent used for padding and the surface weight of nonwoven to the air permeability of structures obtained [14].

Great interest then arose in the analysis of the coincident effect of surface weight and binding agent concentration on air permeability, pore sizes and their distribution for nonwovens obtained by the padding method, to be used as preliminary filters.
Due to the very selective applications of nonwoven filter media, not only overall permeability, but also pore sizes and pore size distribution are important to obtain the filtration efficiency desired.

Materials and methods

Polyester, orthotropic carded webs of surface weights equal to 50, 100 and 200 g/m^2 were prepared using a Befama 3KA laboratory carding machine. Styrene-butadiene latex LBSK 5545 from Dwory S.A. in form of water dispersion was used as a binding agent. Four concentrations of binding agent were prepared: 10, 20, 30, and 40%. As the prepared carded webs were immersed in polymer dispersion, excess liquid was removed. Temperature of drying was established at 130 °C. After drying, the exact mass of polymer remained on the webs [15].

The surface weights (M) of the nonwovens obtained were analysed according to Standard PN-EN 29073-1:1994 and the thickness based on Standard PN-EN 29073-1:1994. Air permeability measurements were carried out according to Standard PN-EN ISO 9237:1998, using a FX 3300 Labotester III from Textest AG, and the conditions as follows:

- sample surface - 20 cm^2,
- pressure drop - 100 Pa.

A PMI capillary porometer was used to assess information on pore sizes and pore size distribution. The idea of porosity measurements with a capillary porometer is based on the effect of solid wetting by liquid. It should be noted that a capillary porometer enables to determine only those pores which form a channel in all the thickness of material (Figure 1.a.) This results from the fact that the measurement of pore sizes is based on the air flow through material. Closed pores are not determined (Figure 1.b).

The first step in the procedure of obtaining nonwoven fabric porosity character-

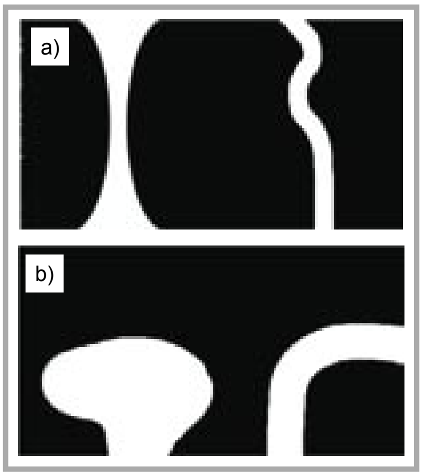

Figure 1. *Schematic picture of opened (a) and closed (b) pores.*

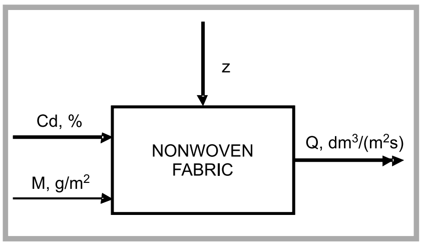

Figure 2. *Scheme of investigations of simultaneous effect of web surface weight and padding dispersion concentration on the air permeability through the filtration nonwoven fabric.*

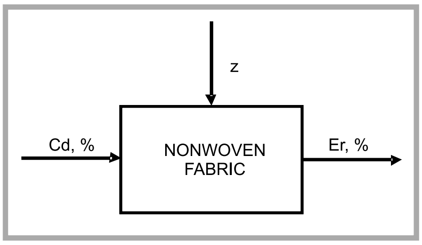

Figure 3. *Scheme of investigations of the effect of the concentration of padding dispersion on fractional distribution and size of pores in the nonwoven fabric (basis weight 100 g/m²).*

istics is the definition of “bubble point”, which relates to pores of the largest sizes. During the measurement the air pressure grows progressively until the first bubble occurs (bubble point). It is proved that the differential pressure required to remove liquid from a pore is related to the pore diameter [17]:

$$D = 4\,\gamma \cos\theta / p \qquad (1)$$

where:
D - pore diameter,
γ - surface tension of wetting liquid,
θ - contact angle of the wetting liquid with the sample,
p - differential pressure.

The pore size distribution curve is plotted automatically according to a computer program, on the basis of measurements of volumetric air flow through the wet and dry sample. Measurements are based on the assumption of the cylindrical shape of pores.

Results and discussion

The experiment comprised the establishment of the effect of the surface weight of nonwoven (M) and concentration of the binding agent dispersion (Cb) on volumetric air flow (Q). The dispersion concentration influenced the fractional distribution of pores (Er) in the padded nonwoven fabric selected, and of surface weight 100 g/m² was also defined. Figures 2 and 3 illustrate this schematically.

The main structural parameters of the nonwovens obtained are presented in Table 1. A typical nonwoven structure obtained by the padding method is presented in Figure 4.

In order to establish the effect of the surface weight of nonwoven (M) and concentration of the binding agent dispersion (Cb) on the air permeability represented by volumetric air flow (Q), the following regression function expressed by linearly-quadratic polynomial was determined.

$$Q = B_0 + B_1 \cdot M + B_2 \cdot Cb + B_{11} \cdot M^2 + B_{22} \cdot Cb^2 + B_{12} \cdot M \cdot Cb \qquad (2)$$

Moreover, the statistic parameters of the mathematical model proposed were calculated, among them regression equation coefficients (B), squares of multidimensional correlation coefficients – R^2, and analytical and critical values of F-Fisher-Snedecor-F test statistics (K,N-K-1). The statistic parameters of the mathematical model of air permeability through the padded nonwoven fabrics are presented in Table 2. The regression functions are statistically essential at a confidence level of $\alpha = 0{,}05$ and have very high values of F statistics and values of correlation coefficient squares. A mathematical model of regression function was determined in the form of a superficial diagram. The effect of web surface weight and binding agent concentration on the volumetric air flow at defined pressures is presented graphically in Figure 5.

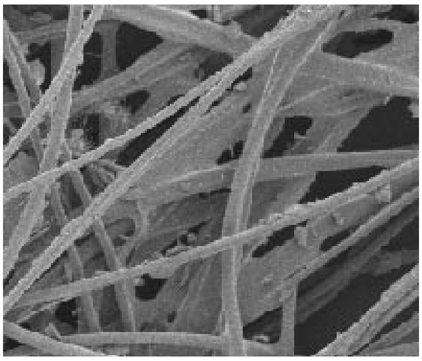

Figure 4. *Typical nonwoven structure obtained by padding method.*

It can be noted that there was a distinct influence of web surface weight on the volumetric air flow. With the growth of surface weight, air permeability through the padded nonwoven fabrics increases independently of the concentration of binding dispersion. Hence, the influence of binding agent concentration on filtration characteristics is not significant.

In order to obtain more insight into the effect of process parameters on the prop-

Table 1. *Parameters of obtained nonwovens.*

Surface weight of web M, g/m²	Concentration of binding dispersion (w/w) Cd, %	Surface weight of nonwoven, g/m²	Thickness, mm	Density, kg/m³	Airflow Q, dm³/m²/s	Binding agent content in nonwoven, %
50	10	74.94	2.5	29.98	2478	14.05
	20	83.75	2.6	32.21	2277	11.48
	30	106.13	2.9	36.60	2115	22.71
	40	127.86	3.1	41.25	2058	34.22
100	10	124.31	4.3	28.91	1374	19.76
	20	136.58	4.4	31.04	1395	21.06
	30	148.25	4.5	32.94	1305	26.36
	40	189.62	4.7	40.00	1266	29.49
200	10	204.25	10.7	19.04	948	15.33
	20	214.73	6.4	33.71	834	37.15
	30	224.34	7.0	32.05	822	36.09
	40	236.04	7.4	32.07	792	44.51

Table 2. *The statistic parameters of mathematical models of air permeability through the nonwoven fabric.*

Function	Values of regression function coefficients						Values of statistics		
Regression functions	B_o	B_1	B_2	B_{11}	B_{22}	B_{12}	R_w^2	F^5_6	F_{kr}
Regression function Q wl=f(M, Cd)$_{5545}$	1326.17	6.798	-10.781	0.044	0.017	0.029	0.99	209.88	2.97
Values of partial test		F_1	F_2	F_{11}	F_{22}	F_{12}			$F_{kr\ cz.}$
		-2.125	-15.292	0.738	11.245	2.031			4.23

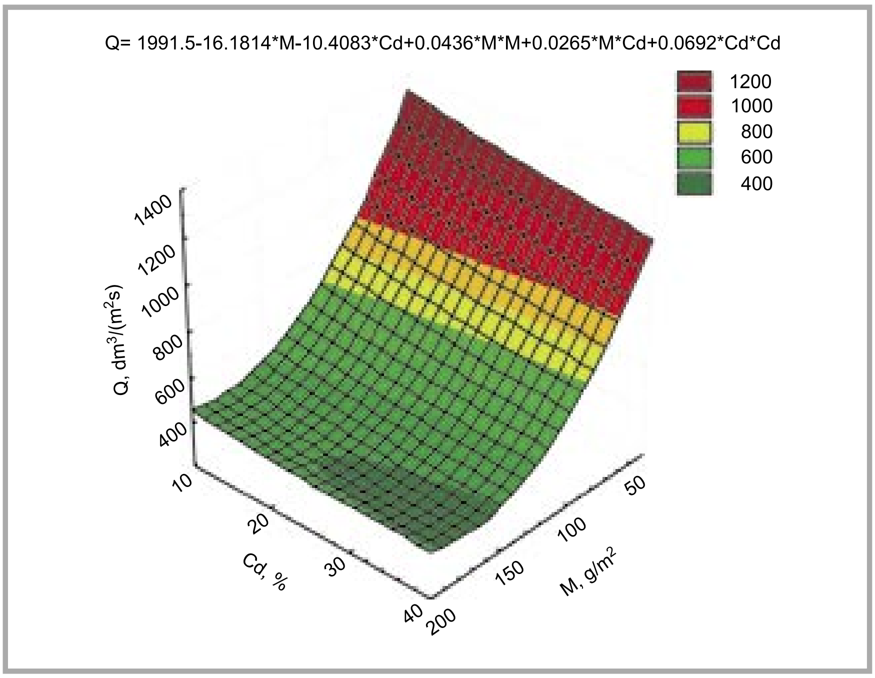

Figure 5. The web surface weight (M) and dispersion concentration (Cd) versus the air permeability.

erties of the structures obtained, mainly filtration efficiency and measurements of the pore size distribution were done for a group of nonwovens of 100g/m^2 surface weight. The results are presented in Figures 6 and 7 and in Tables 3 and 4.

The starting air flow resistance values for all of the nonwoven samples analysed do not exceed 50 Pa. Significant differences in pores size distribution were observed. Both from Capillary Flow Analysis data as well as from the diagrams of fraction distribution, it was evident that in the case of padded nonwoven fabric obtained from 10% dispersion (samples A and B) the so called substitute diameter of the main fraction of pores was similar 234.8 µm (A) and 258.7 µm (B), respectively. In the case of nonwoven A we observed the second important fraction of smaller pores at ranges of approx. 90 µm. Analysing sample B, we also noted two other fractions of larger and smaller pore sizes than the main fraciton (242.2 µm and 87.9 µm). The presence of additional fractions of smaller and larger pores neagatively affects the efficiency of filtrations. Due to an uneven structure it would be difficult to define the final application of such filters.

In the case of increasing padding bath concentration, significant displacement of the pore main fraction in the direction of smaller sizes (sample C – 79.2 µm and sample D – 97.5 µm) was observed. Moreover, another "bubble point" value was noted. Such a significant spread of "bubble point" values can be evidence of the heterogeneity of pore sizes in nonwoven fabric, with the main fraction remaining at the same level of the pore sizes.

Summary

It is possible to optimise the structure of nonwovens obtained by padding in a wide variety of parameters. Not only the desired air permeability of nonwoven, but also appropriate pore sizes can be obtained by using a web of selected surface weights and dispersions of binding agent. This enables the adjustment of nonwoven fabric structure to the properties of the filtered medium.

Analysis of the results obtained enabled to establish a hierarchy of importance

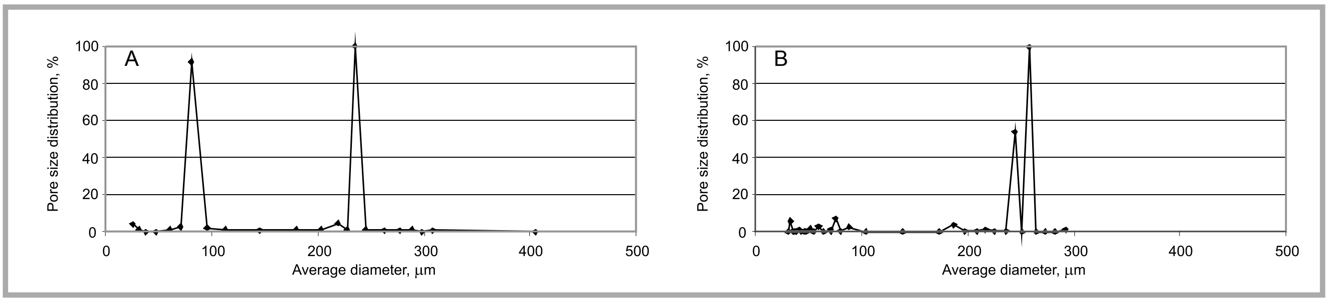

Figure 6. Pore size distribution of nonwoven fabric (10% of binding agent in dispersion).

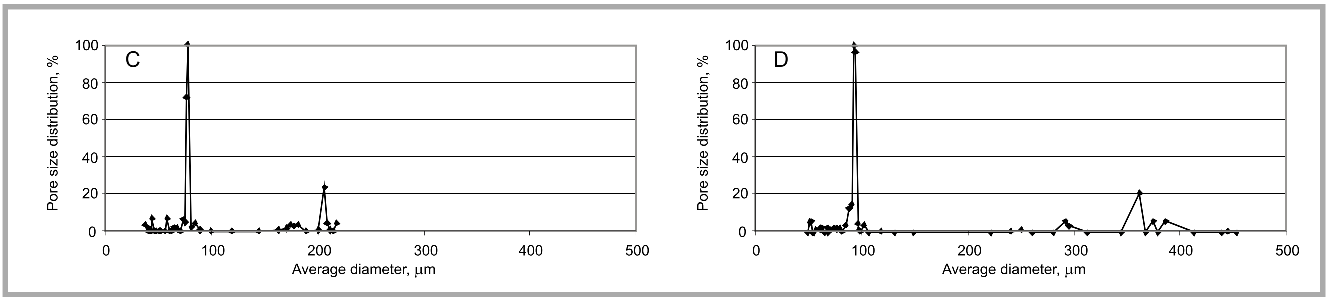

Figure 7. Pore size distribution of nonwoven fabric (40% of binding agent in dispersion).

Table 3. *Results of porosity measurements of nonwovens (10% binding agent in dispersion).*

Item number	Sample	Substitute diameter of the largest pores, µm (bubble point)	Main fraction of pores, µm	Average value of pores main fraction sizes, µm	Other significant fractions, µm
1.	A	404.4	227.9 – 244.4	234.8	70.5 – 95.3
2.	B	292.7	251.4 -265.3	258.7	236.4 – 251.4 80.2 – 104.9

Table 4. *Results of porosity measurements of nonwovens (40% binding agent in dispersion).*

Item number	Sample	Substitute diameter of the largest pores, µm (bubble point)	Main fraction of pores, µm	Average value of pores main fraction sizes, µm	Other significant fractions, µm
3.	C	219.5	78.2 – 82.5	79.2	-
4.	D	455.0	95.9 – 98.7	97.5	-

for the technological parameters tested, which affect the structure and characteristics of padded nonwoven fabrics used in preliminary filtration processes.

The results obtained proved that the surface weight of webs strongly influenced the volumetric air flow of tested nonwoven fabrics, although the content of binding agent in nonwoven increases the density and other physical parameters of such structures.

Measurements of porosity with the use of a capillary porometer enabled direct confirmation that the increasing concentration of binding agent dispersion influences the porosity of nonwoven, i.e. decreased the sizes of the main pore fraction by 2.5 times and improved structure homogeneity.

The measurement of the pore fraction in nonwoven fabrics enables the control of material structure, which can depend on the technology and also the condition of the equipment used for production. Therefore, the measurement of pore fractional distribution can potentially be used as a good instrument for filtration nonwoven quality control.

References

1. *Earley S., Cox R., Nonwoven Filter Media Market in North America, Filtration & Separation, Vol. 40, Issue 9, November 2003, pp. 24-25.*
2. *United States Patent 6669761.*
3. *Wierzbowska T., Włókniny techniczne w służbie ochrony środowiska, Przegląd Włókienniczy 1992, pp. 217-273.*
4. *Lisowski A., Jankowska E., Thorpe A., Brown R. C. Performance of textile fibre material measured with monodisperse and standard aerosols, Powder Technology, Vol. 118(2001) (1-2) pp. 149-159.*
5. *Polish Standard PN-EN 779:2004. Przeciwpyłowe filtry powietrza do wentylacji ogólnej. Wymagania, badania, oznaczenie*
6. *Polish Standard PN-EN 1822-1:2001 Wysokoskuteczne filtry powietrza (HEPA i ULPA) Cześć 1: Klasyfikacja, badanie parametrów, znakowanie*
7. *Jankowski T., Skuteczność filtracji cząstek aerozoli, Bezpieczeństwo pracy, Vol. 10/2006, pp. 28-31.*
8. *Scrivener T. F.; "The Differential-Pressure Air Permeability Test for Use in the Nonwovens, Filter and Paper Industries," TAPPI Journal, Vol. 76(1993) No. 11, pp. 221-224.*
9. *www.sfm filtry, Metody badań filtrów powietrza*
10. *Lee Y., Wadsworth L. C.; Structure and filtration properties of melt blown polypropylene webs, Polymer Engineering and Science, Vol. 30(2004), pp. 1413-1419.*
11. *Jackiewicz A., Zaręba A., Podgórski A.; Wpływ niehomogeniczności struktury na skuteczność działania filtrów włókninowych, Przegląd Techniczny Vol. 22(2007) pp. XV-XVIII.*
12. *Brochocka A., Characteristics of Melt-Blown Filter Materials Produced by Simultaneous Blowing of Polymer Melt from Two Extruders, Fibres & Textiles in Eastern Europe, Vol. 9(2001) No. 4(35), pp. 66-69.*
13. *Berkalp O. B., Air Permeability & Porosity in Spun- laced Fabrics, Fibres & Textiles in Eastern Europe, Vol. 14(2006) No. 3(57), pp. 81-85.*
14. *Kothari V. K., Newton A.; The Air Permeability of Nonwovens Fabrics, Journal of the Textile Institute, Vol. 65(1974) No. 8, pp.525-531.*
15. *Albrecht W., Fuchs H., Kittelmann W. Nonwoven fabrics: Raw Materials, Manufacture, Applications, Characteristics, Testing Processes. Wiley-VCH, Veinheim 2002.*
16. *Jena A., Gupta K.; Analyse der Porendurchmesser von Mehrschichtfiltermitteln, F&S Filtrieren und Separieren, Jahrgang Vol. 16(2002) No.1, pp. 13-17.*
17. *Jena A., Gupta K.; Characterization of Pore Structure of Filtration Media, Fluid Particle Separation Journal, Vol. 14(2002) No. 3, pp.227-241.*

Received 15.11.2007 Reviewed 15.01.2008