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THE INFLUENCE OF CONSTRUCTION OF NON-WOVEN TEXTILES ON AIR PERMEABILITY FOR THEIR APPLICATION IN THE COMMUNITY FACE MASKS

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ABSTRACT

The article is aimed at evaluating the air permeability of various types of non-woven fabrics prepared by Spunbond, Spunbond-Meltblown-Spunbond technology and non-woven fabrics reinforced mechanically by needling and thermal calendering. These are commercially available non-woven fabrics with various mass per unit area and thickness made of 100 % polypropylene, without special surface finish. By combining individual types of non-woven fabrics, three-layer and four-layer textile materials were prepared, meeting the minimum requirement of technical standardization information TNI CWA 17553 for air permeability, intended for application in the community face masks. As part of the experimental works, the effect of increased humidity on the air permeability of three-layer non-woven fabrics was verified as well.

KEYWORDS

Non-woven fabric; Spunbond; Meltblown; Air permeability; Community face masks.

INTRODUCTION

The pandemic of a new type of human coronavirus (SARS-CoV-2), causing a serious infectious disease of the upper respiratory tract, COVID-19, is an ongoing threat to public health worldwide [1]. It is transmitted by droplet infection up to a distance of approximately 1 m, especially when sneezing, coughing, or talking, by releasing aerosol droplets with a diameter greater than 5 μm, contaminated with pathogens [2].

Determining the quality and effectiveness of face masks is a comprehensive topic which is still an active research area. Face masks are one of the most powerful public health tools we can use to slow and stop the spread of the virus, especially when used in places where social distancing cannot be maintained [3]. The community face masks cover part of the face in the area of the mouth, nose, chin and do not contain any inhalation and exhalation valves. The inhaled air penetrates through the material of the face mask directly into the area of the nose and mouth, the exhaled air penetrates through the material of the face mask in the opposite direction directly into the surrounding atmosphere. The community face masks are suitable for ordinary people who do not have clinical symptoms of viral infection and who are not in direct contact with people with this viral disease. In fact, they act as a temporary filter that, depending on time, reduces the rate of transmission of droplets of saliva, mucus or respiratory secretions of the user when communicating, coughing or sneezing. In addition, they can also prevent these droplets from entering the nose and mouth from the outside environment. Face masks also have a protective function preventing the user from accidental touch of the covered face areas with potentially contaminated hands.

Currently, the community face masks are produced with a very high diversity in terms of material quality, level of protection, but also the potential group of their users. The main part of a disposable face mask is a filter able to filter liquids and/or particles of specific size according to the purpose the face mask is intended for. It enables trouble-free breathing and provides long-term comfort to its user. The filtration component can consist of several layers of filtration material with different configurations [4]. Main part of disposable face mask consists of three layers of nonwoven fabric with a structure SMS spunbond – meltblown – spunbond. The outer layer does not pass droplets, the middle layer fulfils function of a filter and the inner layer absorbs humidity. Medical face masks N95 consist of 5 layers with a structure spunbond – meltblown – meltblown – meltblown – spunbond. Two the most important source materials for manufacture of the medical face masks are spunbond and meltblown type nonwovens. The outer and inner layer

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of the spunbond type nonwovens is made of polyester and polypropylene, while the middle layer is meltblown type nonwoven made of high-melting polypropylene [5]. It is ideal when the face mask has maximum filtration efficiency and at the same time also high breathability. A solution can be also a filtration web filtering bacteria from humid air with a high efficiency, preserving it for a long time and still having a sufficient breathability [6].

As part of our own research focused on the quality of commercially available alternative face masks, 21 types of masks were analyzed in terms of construction, material composition and air permeability parameter. A survey showed that the masks were made of different types of materials (woven knitted and, non-woven fabrics), most often of cotton and blended fabrics, made of one, two or more textile layers, coated, with a membrane, or with surface treatment, disposable or reusable types. The protective masks, which were constructed in three layers of woven and knitted materials with an intermediate membrane layer, achieved air permeability at the level of 0 l/s/m^2. The highest air permeability was achieved by single-layer protective masks made of non-woven fabric at the level of approx. 700 l/s/m^2. The three-layer protective masks made of non-woven fabric achieved air permeability at the level of 100-250 l/s/m^2. In the case of cotton protective masks, the air permeability was influenced by the weave and sett of the woven fabric. With a single-layer cotton mask with satin weave and with a higher density of threads, the air permeability was achieved at the level of approx. 60 l/s/m^2, with a 2-layer mask of the same quality, the air permeability was at the level of approx. 40 l/s/m^2. It follows from the above that performance of the face masks from a viewpoint of air permeability influences mainly kind of textile material used (woven fabric, knitted fabric, nonwoven fabric), its construction parameters (e.g. weave, sett) as well as construction solution of the face mask itself (one-layer, more-layer one) [7]. This knowledge was used, among other things, to co-ordinate course of the experiment, result of which are a subject of this article.

According to the available studies aimed at evaluating the effectiveness of common commercially available types of face masks, it was found that some types of alternative masks provide very low protection [8]. In a study aimed at evaluating the effectiveness of face masks using the method of optical measurement of the transmission of droplets expressed as relative number of droplets released by breathing and during normal speaking, the researchers compared different types of commonly available face masks (Figure 1, samples 1-13) with a filtering face mask (Figure 1, sample 14).

Figure 1. Commercial types of face masks (samples 1-13) and filtering half mask (sample 14).

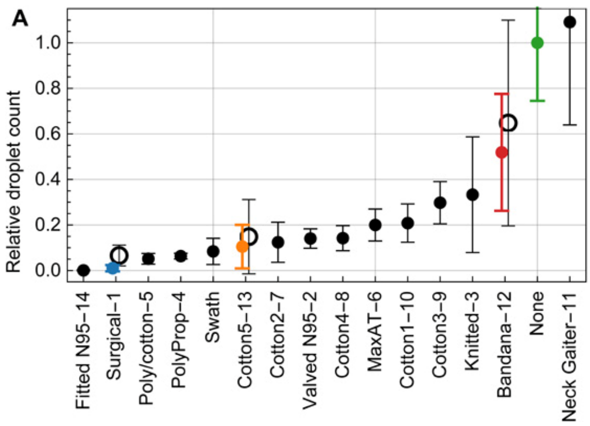

Figure 2. Relative transfer of droplets through the corresponding mask/gown.

Figure 2 shows relative number of droplets transferred through the specific face mask. Each full data point represents an average value of relative number of droplets from 10 measurements performed on the same face mask with calibration on the base of control experiment (without any face mask), while each face mask was tested on the same speaker. The hollow data points represent an average value of relative number of droplets measured on four speakers. Figure 2 shows a diagram with logarithmic scale on y-axis and numbers on x-axis correspond to the numbers of face masks on Figure 1. The results showed that some types of face masks approach the performance of standard surgical masks (Sample 1), while some alternatives to masks, such as neck scarves, provide very low barrier protection.

Table 1. Characteristics of the non-woven fabrics

No.	Designation of the sample	Production technology	Thickness [mm]	Mass per unit area [g/m^2]
1	S20	Spunbond	0,35	20
2	S25	Spunbond	0,26	25
3	S35	Spunbond	0,36	35
4	S40	Spunbond	0,38	40
5	SMS60	Spunbond/Meltblown/Spunbond	0,39	60
6	SMS80	Spunbond/Meltblown/Spunbond	0,52	80
7	VK90	Needled, calendered	0,63	90
8	VK100	Needled, calendered	0,68	100
9	VK150	Needled, calendered	0,98	150
10	VK200	Needled, calendered	1,28	200
11	VK250	Needled, calendered	1,48	250
12	VK300	Needled, calendered	1,74	300

The results of measuring the actual number of droplets released by breathing showed that the mask actually acts as a temporary low-pass filter [8]. An important recommendation in the selection of materials suitable for the construction of face masks was to improve the characteristics of virus capture by reducing the openings in the fabric while simultaneously ensuring the comfort of the user's breathing. The above-mentioned recommendation was taken into account on designing optimum material construction for use of the face masks, meeting the requirement of the Technical Standardization Information TNI CWA 17553 concerning air permeability, which guarantees the required breathing comfort with simultaneous provision of filtering efficiency. The subject of the article is to compare the protective effect of selected types of non-woven fabrics of different construction prepared by various technological procedures, potentially suitable for the production of face masks from a viewpoint of the air permeability parameter. The goal of the paper is to get as close as possible to the air permeability value required by the Technical Standardization Information TNI CWA 17553, as there is a high probability of meeting also the other minimum requirements for filtration efficiency and breathing resistance when it is achieved.

EXPERIMENTAL PART

Technical requirements and test methods

Technical parameters of the community face masks are specified in the Technical Standardization Information TNI CWA 17553 "Community face masks. Guide to minimum requirements, methods of testing and use' (hereafter 'TNI'). Basic functional parameters of the community face masks include filtration efficiency of the material, respiratory resistance and air permeability [9]. These parameters depend on each other and are mainly influenced by the construction of the material used. When choosing material intended for production of the face masks, its ability to absorb moisture and health safety are equally important.

Air permeability *R*, as one of the above-mentioned properties determining quality of the face masks, is defined as the speed of air flow passing perpendicularly through the test fabric under specific test conditions (area, pressure drop, time). According to TNI, materials intended for the production of the community face masks must not exceed the limit requirement $R \geq 96$ l/s/m^2 at a pressure drop of 100 Pa. Our effort was to achieve air permeability just above the required minimum limit value, in order to come as close as possible to meeting other functional requirements related to the quality of the material used (filtration efficiency, breathing resistance).

The method for measuring permeability of fabrics to air is defined by the EN ISO 9237 standard. Principle of the test is determination of the speed of air flow passing perpendicularly through a given surface of a textile material at a specified pressure difference between two sides of the test surface during a specified time interval. The source materials were tested and conditioned for 24 hours in standard atmosphere with a temperature of 20 °C and a relative humidity of 65 %. The conditioned materials were tested under the same conditions at a pressure drop of 100 Pa and a test area of 20 cm^2 at 10 different locations. The arithmetic mean of air permeability *R* expressed in millimeters per second (mm/s) [10] is calculated from the individual results, which corresponds to the unit liter per square meter per second (l/s/m^2).

Source materials

One of the materials suitable for production of community face masks are non-woven fabrics, the construction and properties of which depend on the technology of their production and material composition. When choosing non-woven fabrics potentially suitable for the production of community face masks, we mainly took into account compatibility of the structure, the thickness and the weight of the fabric. Commercially available nonwoven fabrics, nonwoven fabrics prepared using Spunbond (designation "S"), Spunbond-Meltblown-Spunbond (designation "SMS") technology and nonwoven fabrics reinforced mechanically by needling and thermal calendering (designation "VK") were procured. All non-woven fabrics are made of 100% polypropylene, without special surface finish. As these are commercially available materials, the non-woven fabrics have different mass per unit area and thickness (Table 1).

RESULTS AND DISCUSSION

The air permeability R of the non-woven fabrics was measured in one, two and three layers of the same non-woven fabric. The resulting average air permeability values, together with the standard deviations (standard deviation "s" and coefficient of variation "v") are listed in Table 2 and shown in Figure 3, in which the minimum limit value of air permeability specified in the TNI at the level of 96 l/s/m^2 is marked as well.

The highest air permeability was achieved with non-woven fabrics in one layer, as the number of layers increased, the air permeability decreased. The most breathable were non-woven fabrics prepared by Spunbond technology and non-woven fabrics reinforced mechanically by needling and thermal calendering with mass per unit area of 90 g/m^2 and 100 g/m^2. The air permeability of these textiles was on average 10 times higher than its minimum limit value set by the standard. As mass per unit area and thickness increased, the air permeability of nonwovens of the VK type decreased. The least breathable were non-woven fabrics prepared by SMS technology, while the lowest air permeability in one layer exhibited the non-woven fabric SMS60. The air permeability of this non-woven fabric was 2.5 times higher than the minimum limit value set by TNI.

By adding the second layer of the same non-woven fabric, the air permeability of the non-woven fabrics, compared to the air permeability of a single layer, was reduced by an average of 30-60 %. Despite such a significant decrease, we consider the measured air permeability values to be high. The exception is the non-woven fabric SMS60, whose air permeability has fallen below the minimum limit value, which is unacceptable from a viewpoint of the potential use of the fabric in the range of facial masks.

By adding the third layer of the same non-woven fabric, the air permeability of the non-woven fabrics, compared to the air permeability of a single layer, was reduced by an average of 50-70 %. The samples SMS80 and VK150 up to VK300, whose air permeability was in the range of 126–167 l/s/m^2, came closest to the required limit value.

On the three-layer non-woven fabrics, except for sample SMS60, the influence of humidity on the change in air permeability of non-woven fabrics was verified. The aim of the experiment was to simulate the conditions of wearing the face masks, when the humidity of the air increases during breathing and talking, which can affect the breathability of the face mask. The air permeability was measured under the same climatic and test conditions, at the same air temperature of 20 °C, but different relative air humidity: 65 %, 75 % and 85 %. The average value of air permeability at individual climatic and test conditions is listed in Table 3 and shown in Figure 4.

The change in air humidity was most pronounced in non-woven textiles of the VK type. Compared to the results measured under the standard conditions (t = 20 °C, Rh = 65 %), the air permeability of these textiles decreased by approx. 1-26% at a relative air humidity of 75 % and by approx. 2- 29 % at a relative air humidity of 85 %. Due to the technology of their production, non-woven fabrics of the VK type have, compared to the non-woven fabrics of the S and SMS types, a higher mass per unit area and thickness, thanks to which they have the ability to capture in their construction a larger amount of water vapor, which can negatively affect the air permeability parameter. In the case of non-woven fabrics of S and SMS type, there was a slight decrease in air permeability by 1-4 % with increasing humidity, which will be further taken into account in the specification of materials.

When looking for a suitable combination of materials intended for application in the construction of face masks, it is important to take into account their mass per unit area and thickness, in addition to their functional properties. It would be undesirable for the face mask to be uncomfortable and distracting for the user due to its high mass per unit area and thickness. It is equally important in the case of increasing the protective function of the mask, e.g. by the surface finish applied on the outer layer of the face mask, to take into account also quality of the non-woven fabric in terms of compatibility and homogeneity of its surface.

Taking into account the above-mentioned requirements, a series of three-layer material constructions was designed. They consist of a combination of individual types of non-woven textiles. When selecting the outer layer, a compromise solution was adopted between air permeability and weight per unit area of the non-woven fabric. The outer layer of each structure is S40 non-woven fabric, which belongs to the thin low weight non-woven fabrics of the Spunbond category, has a compatible structure and a smooth calendered surface. The middle layer always consists of a different sample of non-woven fabric (Table 1, samples No. 1-12). The inner layer (the layer that will be in direct contact with the human skin) of each structure will be the low weight non-woven fabric S20, which is soft, pleasant to touch and, thanks to this, it will ensure wearing comfort of the mask.

The measurement conditions and the resulting average value of the air permeability of the three-layer combination of the non-woven fabrics with the basic Spunbond non-woven fabric (sample No. 4: S40) are listed in Table 4 and shown in Figures 5 and

6, in which weight per unit area and total thickness of the individual combinations is also shown for a comprehensive assessment.

The combinations 4/5/1 and 4/6/1 show the lowest air permeability. The middle layer of the combinations consists of non-woven fabrics produced by Spunbond-Meltblown-Spunbond (SMS) technology. These are non-woven fabrics made by laminating of Spunbond (technology based on spinning from the melt) and Meltblown (technology based on melt blowing) layers, thanks to which the SMSs have better filtration, insulating and barrier properties than non-woven fabrics prepared only by Spunbond technology (combinations 4/1/1 to 4/4/1). Compared to combinations including the non-woven fabrics reinforced mechanically by needling and thermal calendering (combinations 4/7/1 up to 4/12/1), their additional advantage is a lower overall weight per unit area and thickness. Despite the fact that air permeability of the 4/5/1 combination is higher only by 36 $l/s/m^2$ than the minimum limit value set by the standard, we consider this value to be high even after taking into account the effect of humidity on air permeability (min. 4% decrease).

The solution how to reduce the air permeability of combinations 4/5/1 and 4/6/1 was addition of the fourth layer, which consists of the non-woven fabric SMS60 (sample No. 5), or SMS80 (sample No. 6). The non-woven fabrics were inserted into the existing combinations between the original second and third layer. The measurement conditions and the resulting average value of air permeability of the four-layer combination of non-woven fabrics with the basic Spunbond non-woven fabric (sample No. 4: S40) are listed in Table 5 and shown in Figures 7 and 8.

The four-layer combinations brought the expected shift of the air permeability parameter to lower values. While the air permeability of the 4/5/5/1 combination is below the limit value and does not meet the requirement of the standard, the 4/6/6/1 combination can still be considered less risky. The combinations 4/5/6/1 and 4/6/5/1 meet requirement of the standard, but after taking into account the influence of humidity, only sample 4/5/6/1 was evaluated as a satisfactory one. From the results, achieved so far, it follows that the construction of a community face mask should consist of at least three or more layers of non-woven fabrics, the appropriate combination of which would meet the minimum limit requirement of the standard regarding air permeability.

Since our goal is to achieve not only satisfactory functional properties, but also the lowest possible mass per unit area and thickness of the combination of materials intended for application in the face mask, a new series of three-layer material constructions was prepared. Their outer layer is SMS60 non-woven fabric, the middle layer always consists of a different sample of non-woven fabric (Table 1, samples No. 1 -12) and the inner layer is the low weight non-woven fabric S20. The measurement conditions and the resulting average air permeability value of the three-layer combination of non-woven fabrics with the basic SMS non-woven fabric (sample No. 5: SMS60) are listed in Table 6 and shown in Figures 9 and 10.

Compared to the three-layer combinations with the basic Spunbond non-woven fabric (sample No. 4: S40), the air permeability of the three-layer combinations with the basic SMS non-woven fabric (sample No. 5: SMS60) was significantly reduced by changing the outer layer. It has been repeatedly confirmed that by a combination of min. two SMS60 (Figures 3, 9 and 10 - sample 5/5/1) the air permeability falls below the minimum limit value required by the standard and this combination is not suitable for preparation of the face masks. From the series of above-mentioned three-layer combinations, we consider the most suitable 5/1/1 and 5/6/1 combinations whose air permeability as well as weight per unit area and thickness are acceptable for application in the construction of the community face masks.

CONCLUSION

Air permeability is only one of three qualitative parameters to be met by the community face masks. For the formulation of definitive recommendations, it is therefore necessary to continue the experiment by determining the filtration efficiency and breathing resistance of the specified types of material combinations and verifying the wearing comfort of the face mask by the user. Based on the achieved results, it is possible to formulate the following partial recommendations and conclusions:

- construction of the face mask made of non-woven fabrics should consist of at least three or more layers. This conclusion corresponds to the requirement of TNI CWA 17553, which recommends to make the community face masks from two or three layers;

Table 2. Air permeability of the non-woven fabrics in 1, 2 and 3 layers

No.	Designation of the sample	Air permeability								
		1 layer			2 layers			3 layers		
		***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]	***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]	***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]
1	S20	**623**	16,9	2,7	**321**	8,0	2,5	**228**	3,9	1,7
2	S25	**1 053**	24,2	2,3	**728**	9,3	1,3	**544**	6,5	1,2
3	S35	**957**	4,4	0,5	**646**	2,2	0,4	**427**	2,1	0,5
4	S40	**873**	16,6	1,9	**564**	9,6	1,7	**363**	6,0	1,7
5	SMS60	**228**	7,3	3,2	**89**	1,3	1,5	**0** [1)]	0,0	0,0
6	SMS80	**442**	9,7	2,2	**242**	5,1	2,1	**137**	2,6	1,9

7	VK90	**1 000**	31,0	3,1	**633**	19,0	3,0	**420**	12,3	2,9
8	VK100	**950**	28,5	3,0	**425**	12,4	2,9	**271**	6,8	2,5
9	VK150	**371**	10,8	2,9	**247**	7,4	3,0	**164**	4,7	2,8
10	VK200	**374**	10,1	2,7	**249**	6,7	2,7	**156**	3,9	2,5
11	VK250	**425**	13,2	3,1	**230**	6,7	2,9	**133**	3,5	2,6
12	VK300	**383**	11,1	2,9	**220**	6,2	2,8	**126**	3,5	2,8

Note: [1)] At a pressure drop of 100 Pa, it was not possible to measure air permeability on the sample.

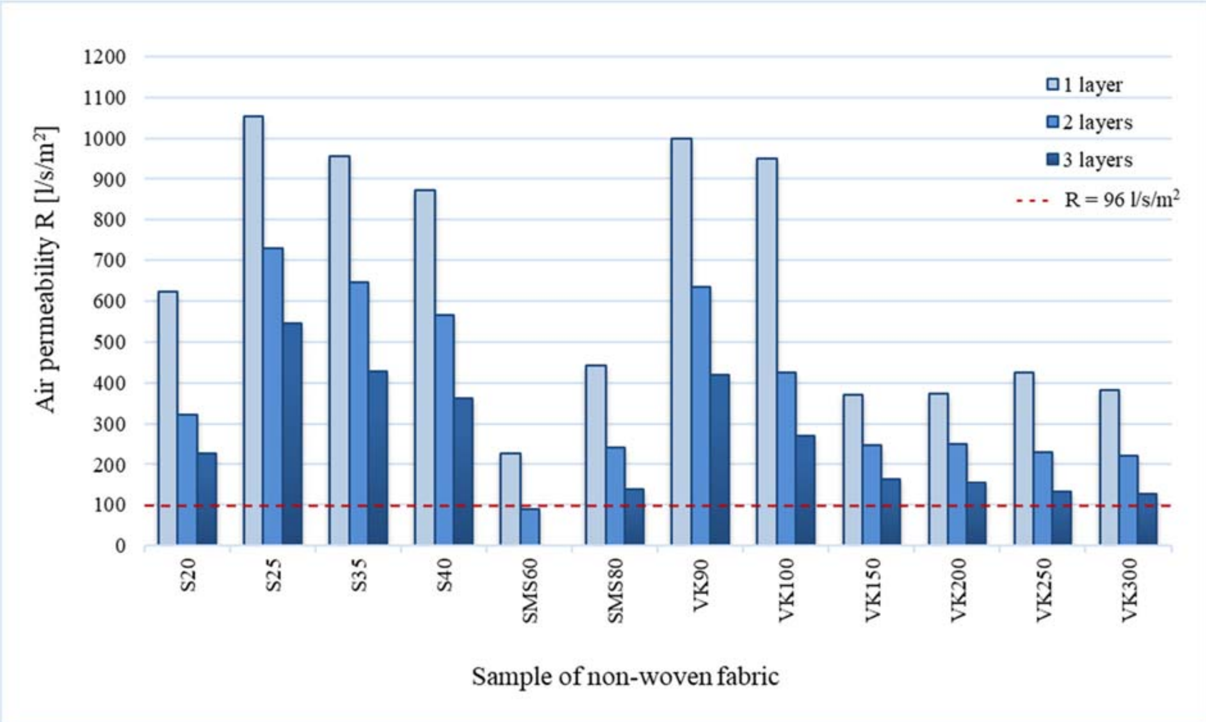

Figure 3. Air permeability of the non-woven fabrics in 1, 2 and 3 layers.

Table 3. Air permeability of non-woven fabrics in **3 layers** under different climatic and test conditions

No.	**Designation of the sample**	**Climatic and test conditions**								
		***t* = 20 °C, *RH* = 65 %**			***t* = 20 °C, *RH* = 75 %**			***t* = 20 °C, *RH* = 85 %**		
		Air permeability								
		***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]	***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]	***R* [l/s/m²]**	*s* [l/s/m²]	*v* [%]
1	S20	**228**	3,9	1,7	**229**	7,3	3,2	**226**	6,3	2,8
2	S25	**544**	6,5	1,2	**544**	15,8	2,9	**543**	16,3	3,0
3	S35	**427**	2,1	0,5	**418**	14,6	3,5	**411**	13,6	3,3
4	S40	**363**	6,0	1,7	**358**	11,1	3,1	**354**	8,8	2,5
6	SMS80	**137**	2,6	1,9	**140**	4,3	3,1	**131**	3,7	2,8
7	VK90	**420**	12,3	2,9	**416**	14,1	3,4	**412**	7,8	1,9
8	VK100	**271**	6,8	2,5	**233**	6,5	2,8	**226**	7,0	3,1
,9	VK150	**164**	4,7	2,8	**143**	4,4	3,1	**141**	3,4	2,4
10	VK200	**156**	3,9	2,5	**116**	2,6	2,2	**111**	2,1	1,9
11	VK250	**133**	3,5	2,6	**107**	1,6	1,5	**102**	3,0	2,9
12	VK300	**126**	3,5	2,8	**103**	2,1	2,0	**98**	2,6	2,7

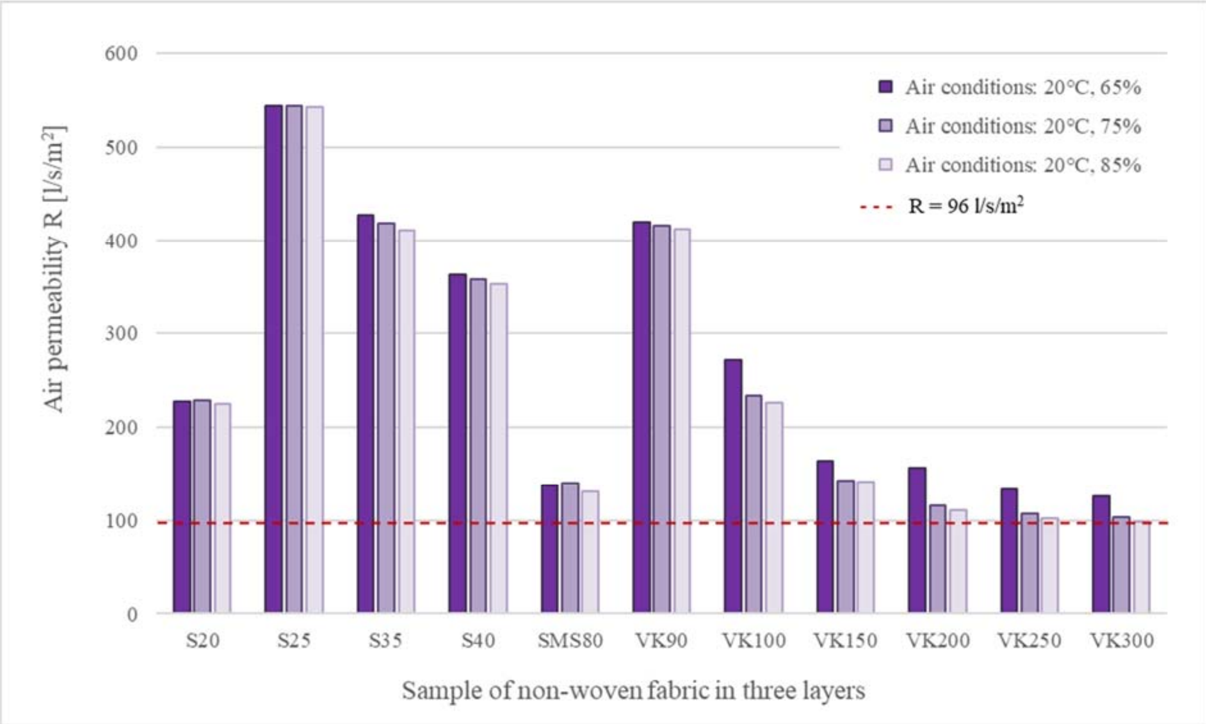

Figure 4. Air permeability of non-woven fabrics in 3 layers under different climatic and test conditions.

Table 4. Parameters of the three-layer combination with the basic Spunbond non-woven fabric (sample No. 4: S40)

Designation of the sample	Three-layer combination of non-woven fabrics	Air permeability			Thickness [mm]	Weight per unit area [g/m²]
		R [l/s/m²]	*s* [l/s/m²]	*v* [%]		
4/1/1	S40 / S20 / S20	263	5,4	2,0	1,09	80
4/2/1	S40 / S25 / S20	329	9,9	3,0	1,00	85
4/3/1	S40 / S35 / S20	326	8,9	2,7	1,06	95
4/4/1	S40 / S40 / S20	309	5,0	1,6	1,14	100
4/5/1	S40 / SMS60 / S20	132	4,5	3,4	1,14	120
4/6/1	S40 / SMS80 / S20	211	5,7	2,7	1,24	140
4/7/1	S40 / VK90 / S20	297	7,7	2,6	1,33	150
4/8/1	S40 / VK100 / S20	277	6,9	2,5	1,43	160
4/9/1	S40 / VK150 / S20	250	3,5	1,4	1,64	210
4/10/1	S40 / VK200 / S20	245	7,1	2,9	1,98	260
4/11/1	S40 / VK250 / S20	264	6,8	2,6	2,17	310
4/12/1	S40 / VK300 / S20	240	6,7	2,8	2,31	360

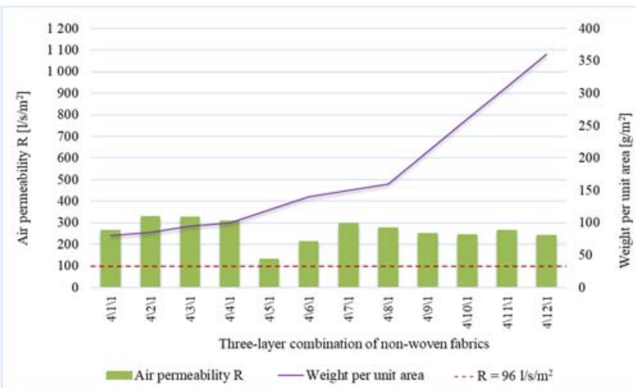

Figure 5. Air permeability and weight per unit area of the three-layer combination with the Spunbond non-woven base fabric (sample No. 4: S40).

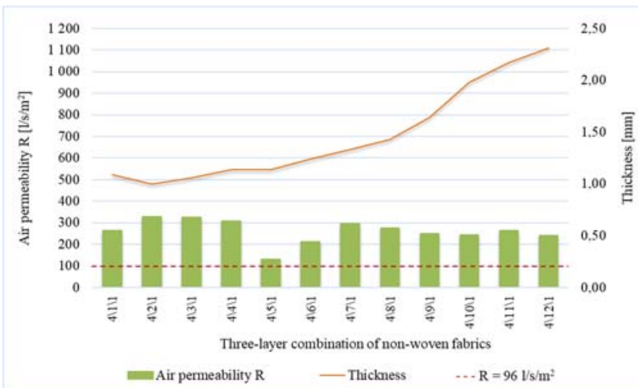

Figure 6. Air permeability and thickness of the three-layer combination with the Spunbond non-woven base fabric (sample No. 4: S40).

Table 5. Parameters of the four-layer combination with the base Spunbond non-woven fabric (sample No. 4: S40)

Designation of the sample	Four-layer combination of non-woven fabrics	Air permeability			Thickness [mm]	Weight per unit area [g/m²]
		R [l/s/m²]	*s* [l/s/m²]	*v* [%]		
4/5/5/1	S40 / SMS60 / SMS60 / S20	81	2,1	2,6	1,54	180
4/5/6/1	S40 / SMS60 / SMS80 / S20	102	2,4	2,3	1,66	200
4/6/5/1	S40 / SMS80 / SMS60 / S20	96	1,9	2,0	1,67	200
4/6/6/1	S40 / SMS80 / SMS80 / S20	132	2,3	1,7	1,76	220

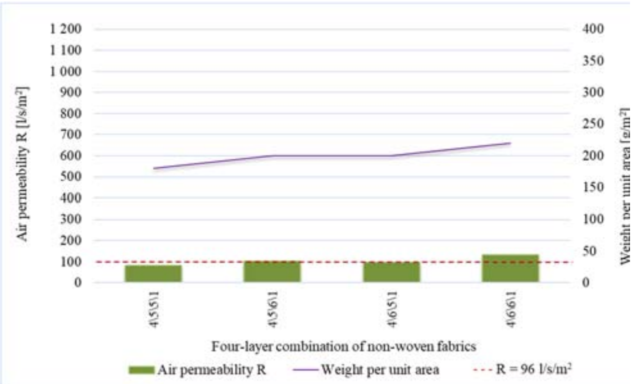

Figure 7. Air permeability and weight per unit area of the four-layer combination with the basic Spunbond non-woven fabric (sample No. 4: S40).

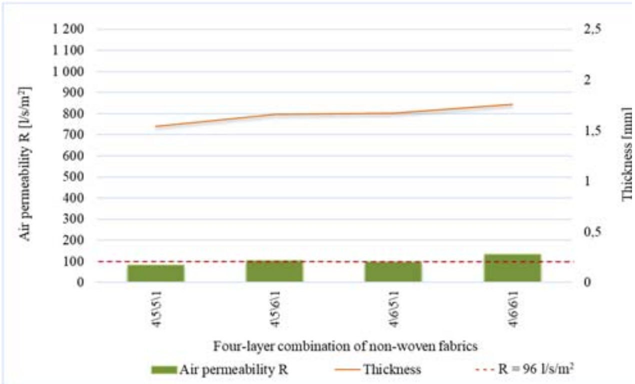

Figure 8. Air permeability and thickness of the four-layer combination with the basic Spunbond non-woven fabric (sample No. 4: S40).

Table 6. Parameters of the three-layer combination with the base Spunbond-Meltblown-Spunbond non-woven fabric (sample No. 5: SMS60)

Designation of the sample	Three-layer combination of non-woven fabrics	Air permeability			Thickness [mm]	Weight per unit area [g/m²]
		R [l/s/m²]	*s* [l/s/m²]	*v* [%]		
5/1/1	SMS60 / S20 / S20	117	2,7	2,3	1,12	100
5/2/1	SMS60 / S25 / S20	129	3,0	2,3	1,05	105
5/3/1	SMS60 / S35 / S20	131	1,3	1,0	1,09	115
5/4/1	SMS60 / S40 / S20	127	2,6	2,1	1,15	120
5/5/1	SMS60 / SMS60 / S20	86	2,5	2,9	1,16	140
5/6/1	SMS60 / SMS80 / S20	105	3,0	2,9	1,26	160
5/7/1	SMS60 / VK90 / S20	127	3,2	2,5	1,35	170
5/8/1	SMS60 / VK100 / S20	127	2,6	2,0	1,45	180
5/9/1	SMS60 / VK150 / S20	108	1,6	1,5	1,69	230
5/10/1	SMS60 / VK200 / S20	112	2,5	2,2	2,06	280
5/11/1	SMS60 / VK250 / S20	98	2,1	2,1	2,22	330
5/12/1	SMS60 / VK300 / S20	97	1,4	1,5	2,34	380

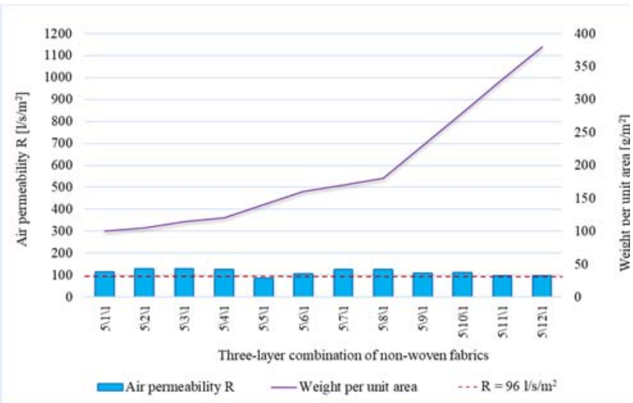

Figure 9. Air permeability and weight per unit area of the three-layer combination with the basic Spunbond-Meltblown-Spunbond non-woven fabric (sample No. 5: SMS60).

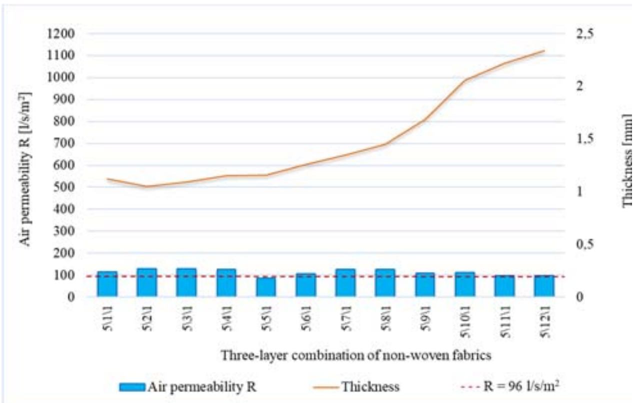

Figure 10. Air permeability and thicness of the three-layer combination with the basic Spunbond-Meltblown-Spunbond non-woven fabric (sample No. 5: SMS60).

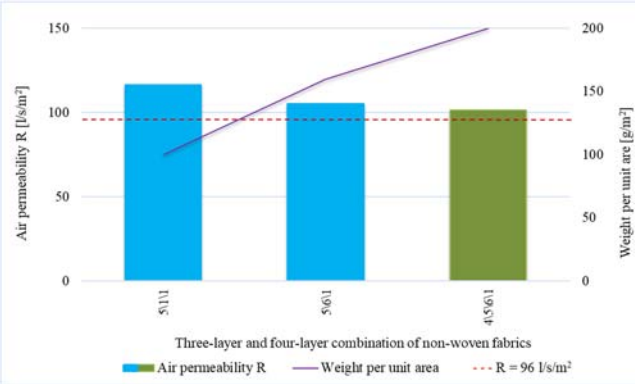

Figure 11. Air permeability and weight per unit area of the recommended three-layer and four-layer combinations of non-woven fabrics.

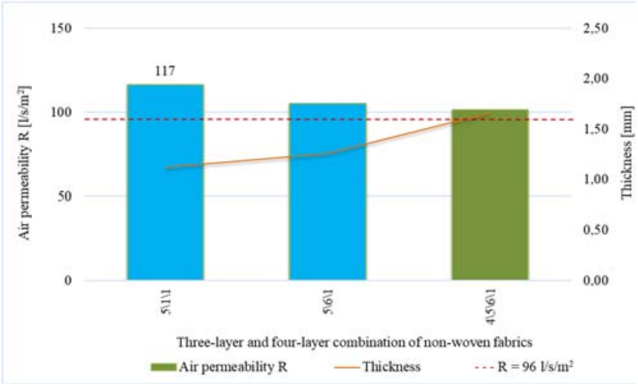

Figure 12. Air permeability and thickness of the recommended three-layer and four-layer combinations of non-woven fabrics.

- it is recommended to use a layer of non-woven fabric prepared by SMS technology in the construction of the face mask. The use of two or more layers of SMS60 non-woven fabric reduces air permeability below the minimum limit value required by TNI;
- it is recommended to make the inner layer of the face mask from a non-woven fabric prepared using Spunbond technology, which will ensure wearing comfort of the face mask;
- it is recommended, when designing the face mask structure, to take into account weight per unit area and thickness of the non-woven fabrics, which affects the resulting weight as well as wearing comfort of the face mask;
- recommended combination of non-woven fabrics for application in the face mask construction are the three-layer combinations 5/1/1 and 5/6/1 and the four-layer combination 4/5/6/1 (Figures 11 and 12), whose air permeability value is even after taking into account the effect of an increase in humidity up to 85%, at the level of the minimum limit value required by TNI.

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