# Permeability properties of dry-laid mechanical bonded nonwovens for filter

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## ABSTRACT – REZUMAT

### Permeability properties of dry-laid mechanical bonded nonwovens for filter

*The present study aimed to investigate the permeability of dry-laid, mechanically bonded nonwoven fabrics for filters of five different samples. Various permeability properties were investigated in the experimental part, such as water vapour permeability, air permeability, thermal conductivity, porosity parameters, and surface openness, which affect the permeability properties. The results of the study and statistical confirmation showed that the nonwoven structure has a great influence on filtration performance.*

*It was found that the sample with the largest mass and thickness had the optimal filtration properties, as it had the smallest open area and thus the lowest water vapour permeability, average air permeability, and highest thermal conductivity.*

*Statistical analysis confirmed that water vapour permeability correlates strongly with fibre diameter and bubble point, air permeability correlates strongly with thickness and mass, and thermal conductivity correlates strongly with fibre diameter, thickness, and mass of the nonwovens studied.*

***Keywords:*** *nonwovens, water vapour permeability, air permeability, thermal conductivity, porosity parameters, surface openness*

### Proprietăți de permeabilitate ale nețesutelor obținute prin consolidare uscată mecanică pentru realizarea filtrelor

*Scopul prezentului studiu a fost de a investiga permeabilitatea nețesutelor obținute prin consolidare uscată mecanică, pentru realizarea a cinci probe diferite de filtre. În partea experimentală, au fost investigate proprietățile de permeabilitate, cum ar fi: permeabilitatea la vapori de apă, permeabilitatea la aer, conductivitatea termică, cât și porozitatea și structura suprafeței, care afectează permeabilitatea. Rezultatele studiului și confirmării statistice au arătat că structura nețesută are o mare influență asupra performanței de filtrare.*

*S-a constatat că proba cu valorile cele mai ridicate ale masei și grosimii a avut proprietăți optime de filtrare, întrucât avea cea mai mică zonă deschisă și astfel cea mai scăzută permeabilitate la vapori de apă și permeabilitate medie la aer, precum și cea mai mare conductivitate termică.*

*Analiza statistică a confirmat că permeabilitatea la vapori de apă se corelează cu diametrul fibrei și punctul de barbotare, permeabilitatea la aer se corelează cu grosimea și masa, iar conductivitatea termică se corelează cu diametrul fibrei, grosimea și masa materialelor nețesute studiate.*

***Cuvinte-cheie:*** *nețesute, permeabilitate la vapori de apă, permeabilitate la aer, conductivitate termică, parametri de porozitate, structura suprafeței*

## INTRODUCTION

Nonwovens belong to the group of unconventional textiles. Nonwovens are produced directly from fibres or continuous filaments. The term nonwovens are often used as a general description for textiles made by a process other than weaving and knitting, or more generally for textiles other than traditional textiles, paper rods, or plastic films. They are used in medicine, hygiene products, construction, household products, as various fillers, and for various types of filters. Nonwovens are innovative, versatile and indispensable. Nowadays it is impossible to live without them [1–4]. According to EDANA [5], around 2,774 million tons of nonwovens were produced in the EU in 2018. The production growth was 4.8% compared to 2017, and the estimated total turnover of the European nonwovens industry is around 8852 million euros [1–6].

In 2018, the main market segments in terms of volume for nonwovens roll goods, were hygiene (27.9%), wipes for personal care (12.8%), construction (9.6%), automotive (6.5%) civil engineering (5.6%), filtration (3.6%), food & beverage (3.0%). In volumes, total nonwoven exports from EU28 countries to the rest of the world increased by only 3.8% in 2018, amounting to 386,563 tons (as compared to 372,297 tons in 2017) for a value of € 1,849 million (a +2.1% increase in value) [6, 7].

The study aimed to investigate the permeability or filtration capacity of dry-laid mechanically bonded nonwovens for filters and to find out and prove which of them is most suitable for filters.

The EDANA definition of filtration is that filtration is a mechanism or device to separate one substance from another. Filtration can be used to separate impurities from a liquid or to separate valuable substances such as minerals, chemicals, or food in a process operation. Separations can be broadly classified into six categories: Solid-Gas Separations; Solid-Liquid Separations, Solid-Solid Separations; Liquid-Liquid Separations; Gas-Liquid Separations; and Gas-Gas Separations [5]. Nonwovens are ideal for filtration because they can be modified and engineered to meet demanding specifications and complex regulatory requirements. This is the reason why they have displaced many traditional materials and have become the medium of choice in filtration [2].

Apart from the above facts, many researchers are investigating the filtration performance of dry-laid nonwovens. Roy and Ishtiaque study the optimum design of a filter media by tuning the structure of the needle-punched nonwoven fabric. They also deal with the influence of carding parameters on nonwovens as filter media [8]. Some authors explore the filtration performance of mono-, bi- and multicomponent nonwoven air filter media [9]. In addition to the technological parameters, the authors also address the structural parameters of nonwoven media for filters, such as fibre diameter, fibre combinations, and solids volume fraction, which have a significant effect on the air filtration properties of nonwoven media [10].

In their research, Sakthivel et al. investigate the air permeability, mechanical properties, pore size distribution and filtration efficiency of different nonwovens made from recycled fibres [11]. Some authors also focused their research on composite nonwovens in filters and their application [12].

In the first section – the theoretical part – the production process and the main definition of nonwoven filters and porosity are presented. The studied samples (five dry-laid, needle-bonded nonwovens), methods, image analysis and statistical evaluation are presented in the Materials and Methods section. The Results and Discussion and Conclusions sections present the main findings on the influence of fibre diameter, mass and thickness, mean pore diameter, and openness of the surface of the nonwovens to filters on their permeability properties.

Statistical analysis confirmed that water vapour permeability is strongly correlated with fibre diameter and bubble point. Air permeability correlates strongly with thickness and mass, and thermal conductivity correlates strongly with fibre diameter, thickness and mass of the nonwovens studied.

## THEORETICAL PART

### Nonwoven filters

A nonwoven filter is a porous fabric consisting of a random arrangement of fibres or filaments, the specific function of which is to filter and/or separate phases and components of fluid being transported through the medium or to support the medium performing the separation. The fabric is a web-like structure manufactured in a length long enough to be wound into rolls. Although the random fibre structure is the backbone of the nonwoven fabric, it may contain other components that are part of the forming process, including (but not limited to) particulate fillers (clays, calcium, adsorptive powders, etc.), sizing agents, wet strength agents, antimicrobial additives, plasticizers, dyes and pigments, softeners, and wetting agents.

The definition implies that the fibres and filaments are bonded together in some form or fashion. The formed fabric may be consolidated during its manufacture. Nonwoven fabrics may also be consolidated by a mechanical bonding process of the nonwoven former, either in-line or offline with the production process. The mechanical bonding process may include any of the following methods: Fibre entanglement by needling, hydroentanglement or stitch bonding, water-based latex treatment, solvent-based resin treatment, and thermal bonding. As long as the fabric is a random fibre structure to be used for filtration and/or separation, the specific bonding process is not critical to the definition. The fabric may be subjected to other chemical and mechanical treatments to improve its properties. Examples include coatings and finishes, flame retardants, antimicrobials, water repellents, dyes, and plasticizers. It may also be subjected to downstream mechanical processing, such as creping, corrugating, embossing, slitting and wrapping, folding, pouching, filming, dyeing, and die-cutting, which are required for the final application as a filter and/or separator [1–3, 5, 9–17]. The filter media is responsible for the rapid and effective formation of a cake and can make a significant contribution to the success of filtration. At the beginning of a filtration process, the filter media retains the particles. Later, the particles are retained by the filter cake itself, while the filter medium serves as a carrier for the cake. The filter media affects the filtrate flow, the initial filter resistance, and the clarity of the filtrate in each filtration cycle. At the end of a cycle, the filter media also affects cake release. Cycle time depends on the type of sludge and the concentration of sludge added. In general, the higher the sludge concentration, the shorter the cycle time [18].

Different natural and manmade fibres are used in filter fabric manufacturing. In most cases, polyester filter fabrics are popular today due to their good resistance to chemicals and ease of availability.

Compared with woven fabric structures, nonwoven fabric structures have more voids; because of this, they are considered to be porous media, which contain a relatively high volume of air and very complex pore structure due to the random arrangement of fibres in the fabric [19].

There is a wide range of needle punch nonwoven filter media with different basis weights used in industrial and residential filtration. Das et al. [7] conducted a comparative study between thermally-bonded and needled nonwovens. They found that needled nonwovens performed better in terms of filtration efficiency and pressure drop. They concluded that needled nonwoven is a better filter media than thermally bonded nonwoven. Kothari et al. [20] carried out a work on the effect of processing parameters on the physical properties of needle-punched nonwoven

Table 1

| THE BASIC PROPERTIES OF THE SAMPLES ANALYZED | | | | | |
|---|---|---|---|---|---|
| **Samples** | **Chemical composition** | **Length of fibres (mm)** | **Diameter of fibres (µm)** | **Thickness (mm)** | **Mass (g/m$^2$)** |
| A | 50% PET + 50% bico PET fibres (PET-core/PET-sheath) | 60 | 13.830 | 0.9491 | 192.50 |
| B | | | 15.654 | 1.1104 | 240.00 |
| C | | | 17.851 | 0.6183 | 121.50 |
| D | | | 16.663 | 0.8325 | 213.00 |
| E | | | 13.799 | 0.9877 | 208.00 |

fabric by changing the machine variables. They concluded that needled nonwoven fabrics have better abrasion-resistant properties and finer fibrous nonwoven fabrics have lower air permeability. They also found that nonwovens have a higher breaking load in the machine direction than in the cross direction and that increasing the punching density reduces the air permeability [21].

Carding and needle punching parameters influence the structure of the nonwoven filters, hence compromising the effectiveness of filtration efficiency of filter media [18–21].

### Porosity

The internal geometric structure (voids of different shapes and sizes inside the product) is a condition for the permeability properties of the nonwoven. If these cavities are interconnected from one side of the product to the other, we are dealing with an air and liquid-permeable body. The hollow internal structure of the product is the porosity (the proportion of the volume of the voids in the total volume of the nonwovens). The voids inside are called pores. From a practical point of view, the pores between the fibres in the fibre are of particular interest. The fibre has such a shape that the pores here have no walls from the beginning to the end of the product, and the shape of the pores is arbitrary. In the case of the fibre, a specific internal surface area is used as an indicator to describe the internal structure. A larger specific surface area per unit volume indicates a less permeable nonwoven structure with smaller pores, which is favourable for both the adsorption and filtration of individual particles. The specific surface area is most influenced by the diameter of the fibres and the shape of the cross-section, and to a lesser extent by their length [2, 6–7, 10].

Porosity is the ratio of the volume of air in the fabric to the total volume of the fabric, expressed as a percentage. This is a calculated value based on the specific volume of the constituent fibres and the volume of the fabric from the measured values of width, length, and thickness of the fabric [2, 14, 16].

## EXPERIMENTAL PART

### Materials and technological parameters

With the presented research, the five dry-laid, needle-bonded nonwovens were analysed. The basic properties of the samples analysed are shown in table 1. The samples were produced on the manufacturer Laroche's process line, which includes a roller carding machine, a pre-needling machine and two needling components. The line also includes a horizontal cross-lapper. The number of needles on the needle board is 8000 needles per meter and the width of the needle board is 200 cm. The needles (manufacturer Groz-Beckert) have a reduced blade with a three-lobed shape and regular teeth. The technological parameters of the tested samples are listed in table 2.

Table 2

| TECHNOLOGICAL PARAMETERS IN THE PRODUCTION PROCESS OF THE SAMPLES ANALYZED | | | |
|---|---|---|---|
| **Samples** | **Web bonding technique** | **The intensity of needling (stitches/cm$^2$)** | **The number of plies on a cross lapper** |
| A | Needling | 230–300 | 16 |
| B | | 500–600 | 30 |
| C | | 230–300 | 14 |
| D | | 230–300 | 24 |
| E | | 230–300 | 24 |

Figure 1 shows images of specimens of different magnifications taken under different microscopes, namely a stereomicroscope 65.560 NOVEX (Euromex – Holland) with a digital camera CMEX 5000 and a magnification of 6.5 (the zoom was 0.65 and 4.5) and a handheld digital microscope (Dino-Lite basic capture, which allows you to take the picture at 50 to a maximum of 250× magnification).

### Methods

*Air permeability*

The air permeability of nonwovens indicates the amount of air that will pass through a given surface of the specimen at a chosen pressure at a given time. This is the amount of air, measured in cubic meters (m$^3$), that passes through 1 m$^2$ of textile in one minute at a pressure of $p$ = 20 mm $H_2O$ ($p$ = 196.2 Pa). By measuring air permeability, the influence of various factors can be determined: Raw materials, textile construction, finishing processes, etc.

Measurements were made according to ISO 9237 [22] on the air permeability tester (MESDAN S. p. A.,

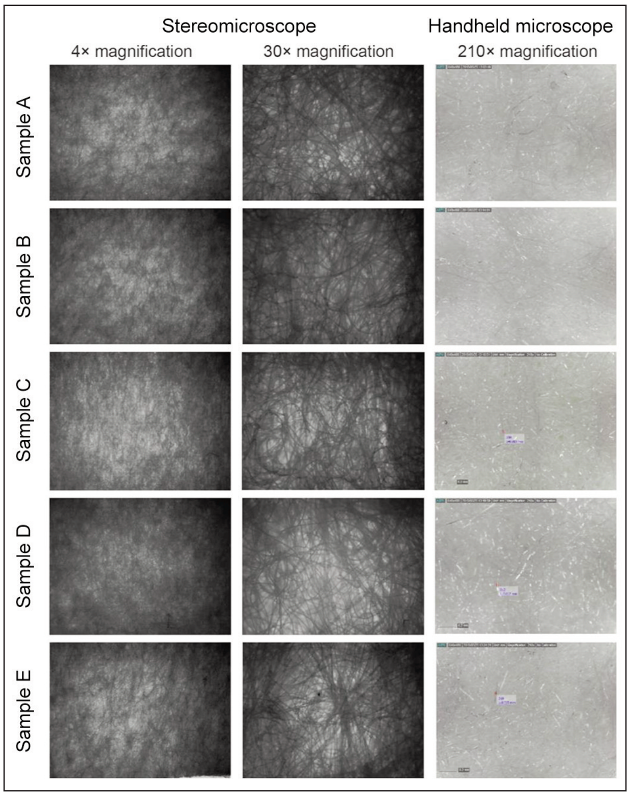

Fig. 1. Visually displayed images in the light transmission function under different magnification

Puegnago del Garda, Italy). For the air permeability measurements, ten test specimens of approx. 15 × 20 cm were cut per sample.

*Water vapour permeability*

The measurements were carried out according to the ASTME96:E96M standard [23]. Two test specimens were prepared for each sample. We placed the sample in the metal lid with an opening of 3 cm in diameter and covered the glass container with it and fixed it with a metal holder.

The prepared dishes with lids were weighed on a precision balance and then left at room conditions for one hour before being placed in the chamber for 24 hours. The conditions in the chamber are as follows: humidity 55% and temperature 23°C.

The water vapour permeability, WVT was calculated with equation 1:

$$WVT = \frac{\Delta m}{s \times t} \qquad (1)$$

where $WVT$ is water vapour permeability (g/m$^2$h), $\Delta m$ – the difference in the mass of the water cup with water and sample immediately and after 24 hours (g), $S$ is the surface of the lid open (m$^2$), and $t$ is time (h) [23–26].

*Thermal conductivity*

The thermal conductivity of the samples was measured using the comparative method, like DIN 52612-2 [23]. The measurement of thermal conductivity is based on the transport of heat flow from a warmer to a colder region, from the bottom of the apparatus to the top. Both blocks and three measuring plates are connected to the temperature-measuring device (ALMEMO 2590, Ahlborn Mess, Holzkirchen, Germany). The whole system is insulated [27–29].

The thermal conductivity was calculated with equation 2:

$$\lambda_x = \lambda_n \times \frac{d_x}{d_n} \times \frac{T_4 - T_3}{T_3 - T_2} \qquad (2)$$

where $\lambda_x$ represents the thermal conductivity of the samples (W/mK), $\lambda_n$ – thermal conductivity of a reference glass sample ($\lambda_n$ = 1.0319 W/mK), $d_x$ – thickness of the sample (mm), $d_n$ – thickness of reference glass sample ($d_n$ = 4 mm).

*Porosity*

The size and distribution of the pores between the fibres were determined using the Jakšić [29, 30] air flow method also called the fluid flow methods where the changes in the flow are measured concerning the opening of the pores under increasing pressure drop. This involves measuring the volumetric flow of air through a given area of dry sample on a rotameter at different pressure differentials. The sample is then immersed in a liquid of known density and surface tension. When it is completely wetted, it is inserted into the measuring head of the rotameter, slowly increasing the pressure difference until the first air bubble appears. The difference is read, and the hydraulic diameter of the largest pore is calculated. The pressure is then increased, and the pressure value is read at preselected volume flows. The measurement is finished when the volume is squeezed out of even the smallest pores. With the mentioned method we can get a distribution of the minimal diameter of the pore channels in the samples and the highest pore diameter [30–33]. For the study and analysis of some parameters of nonwoven porosity, we have used the bubble point and mean pore diameter from the above method.

*Image analysis*

Image analysis stands for computer-aided processing and is an important tool for process control. It is based on the transmission of visible light through the material. For image analysis, we mostly use the ImageJ program nowadays. ImageJ is a free Java-based image processing and analysis software It consists of a program window that contains various tool collections. For example, tools for lines, markers, magnifications, colour changes, etc. are available. One can measure distances and angles, create histograms, allows automatic thresholding, displays results in tables, and provides graphs [34, 35]. The program supports 8-bit, 16-bit, 32-bit grayscale, 8-bit and RGB colour images. With the program, we can change the colours to black and white or grey.

We took the images of the nonwoven fabric samples using a stereo microscope (65.560 NOVEX (Euromex – Holland) under 30× magnification and transformed the image into binary form by thresholding with default settings and evaluated the openness of the surface.

*Statistical analysis*

The correlation between the independent factors (diameter of fibres, the thickness of nonwoven, mass, porosity) and the dependent factors (air permeability, water vapour permeability, and thermal conductivity) is determined using a correlation matrix.

Also, multiple regression is used as an extension of simple linear regression. It is used when we want to predict the value of one variable based on the value of two or more other variables. The variable we want to predict is called the dependent variable (air permeability, water vapour permeability, and thermal conductivity). The variables we use to predict the value of the dependent variable are called independent variables (diameter of fibres, the thickness of nonwoven, mass, porosity factors). Regression analysis uses a selected estimation method, a dependent variable, and one or more explanatory variables to create an equation that estimates values for the dependent variable. The regression model includes outcomes, such as $R^2$ and p-values, that provide information about how well the model estimates the dependent variable. The correlation matrix and multiple regression were also created using the program Statgraphics [31, 35].

## RESULTS AND DISCUSSION

The results of air permeability and water vapour permeability are shown in figure 2 and thermal conductivity is shown in figure 3. Results of porosity parameters are presented in figure 4 and visually displayed image processing of samples with the program ImageJ in figure 5.

Figure 5 shows the preparation of captured photographs of samples for image analysis using the ImageJ program.

Sample D has the lowest air permeability, a thickness greater than 0.83 mm, a surface mass of 213 g/m$^2$, a maximum pore diameter of 95 µm, and the second lowest open area of 3.10%. Sample C has the highest air permeability, with a large variation compared to the other samples. It also has the lowest thickness, mass, and fibre diameter (17.85 µm), one of the largest pore diameters of 104 µm, and the second largest open area 4.2%, which affects the maximum air permeability of sample C. The air permeability of samples A, B, and E range from 526.5 m$^3$/m$^2$/min to 676.75 m$^3$/m$^2$/min. Samples A, B, and E have fibre diameters of about 13 µm to 15 µm and thicknesses of 0.9 mm to 1.1 mm. Besides the fibre diameter, which is about 17 µm for samples C and D, the thickness and mass are the most important parameters for air permeability and filtration properties, less so the fibre diameter and average pore diameter. The air

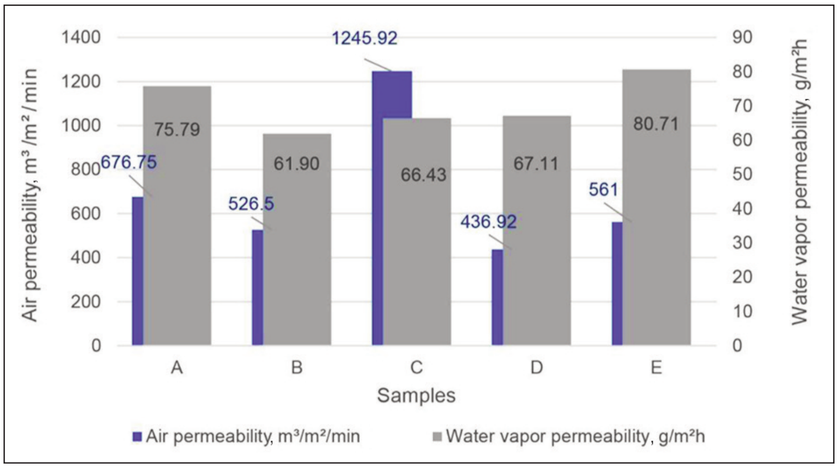

Fig. 2. Air and water vapour permeability values of samples

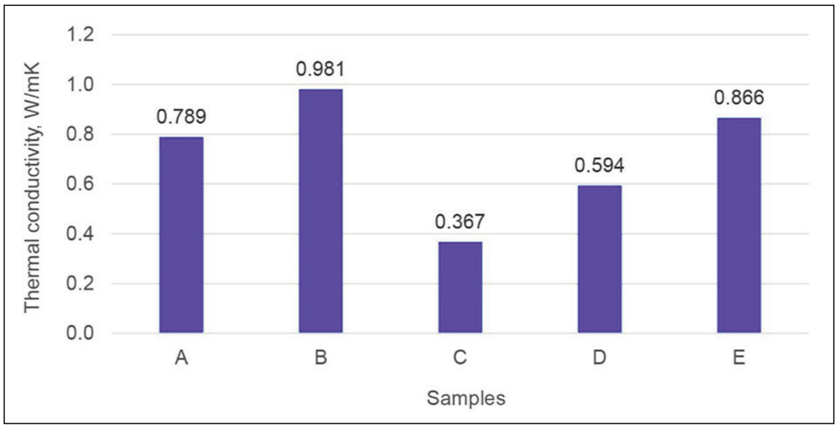

Fig. 3. Thermal conductivity values of samples

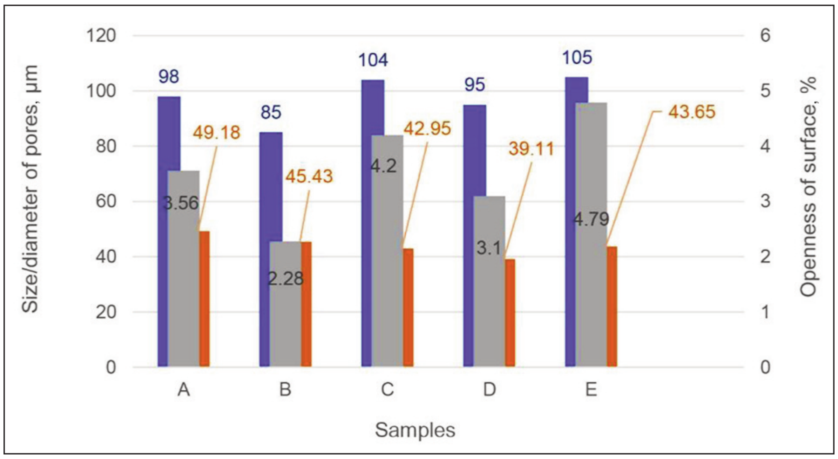

Fig. 4. Porosity parameters of the samples

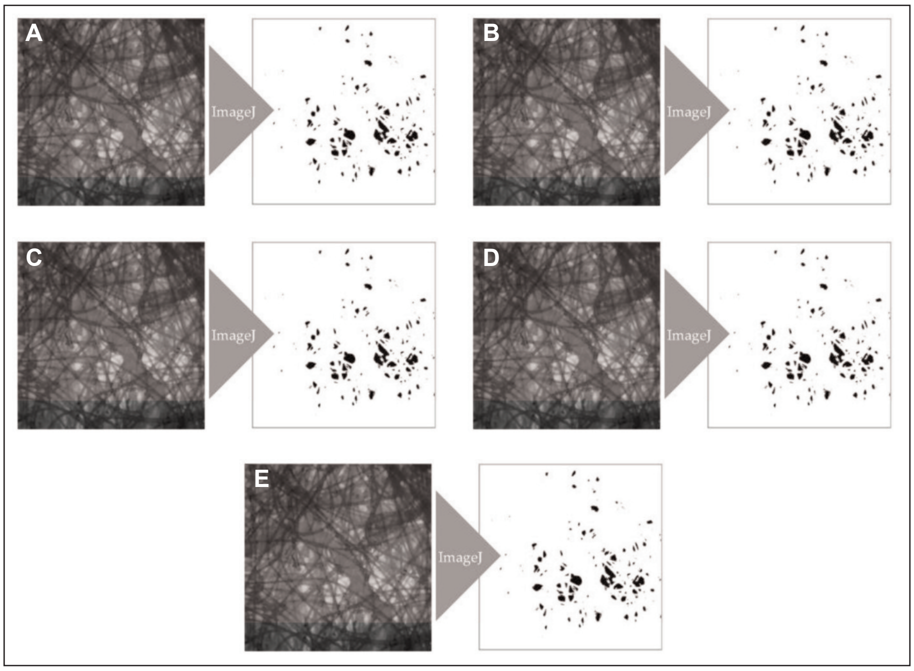

Fig. 5. Visually displayed image processing of samples with the program ImageJ

permeability of the studied samples correlates strongly with the thickness and mass of the studied nonwovens, while the correlation between the air permeability and the diameter of the fibres and the bubble point is moderate.

The lowest thermal conductivity of sample C compared to the other studied samples could be due to the maximum fibre diameter, even considering the open area and the maximum pore diameter. Sample B is the sample with the largest thickness and mass and has the highest thermal conductivity, the lowest water vapour permeability, and the second lowest air permeability. It also contains the smallest pore diameter of 85 µm and the smallest open area of 2.3% (figures 4 and 5), which justifies the results. We assume that the maximum value of thermal conductivity of sample B is influenced by the diameter of the fibres and the average pore diameter (45.43 µm), which is very high compared to the other samples. Sample E has the second largest thickness (more than 0.83 mm), a mass of 208 g/m$^2$, the highest water vapour permeability, a maximum pore diameter of 105 µm and a maximum open area of 4.8% (figures 4 and 5), and the lowest fibre diameter (13.799 µm). A much higher water vapour permeability has samples A and E compared to the other samples. The reason for this is probably the smaller diameter of the fibres (about 13.8 µm) and the higher bubble formation point than the other samples studied. The samples with smaller fibre diameter and higher average pore diameter (from 43 to 49 µm) let through a larger amount of water vapour in the environment. The openness of the surface of the studied nonwovens depends on the method of nonwoven bonding, the length of the fibres, the diameter of the fibres, and the orientation of the fibres in the nonwoven web. The samples were bonded using a mechanical bonding method – the needle bonding method. Sample E is followed by sample A, which has a water vapour transmission rate of 75.79 g/m$^2$h. Sample A has a slightly higher fibre diameter (i.e., 18.83 µm) and a maximum pore diameter (49.18 µm). The highest pore diameter (bubble point) ranges from about 105 to 85 µm (figure 4). There is a high correlation between the values of the measurements of the highest pore diameter and the open area (the correlation coefficient is 0.97). Sample A has the smallest mass (192.5 g/m$^2$), the third largest thickness (0.9491 mm), and the second largest air and water vapour permeability. There were large differences in thermal conductivity between the tested samples, on average the differences in thermal conductivity between samples A, B, C, D and E are about 34%. A very low thermal conductivity has the studied samples C, and D compared to the other samples (less than 0.6 W/mK). The reason for this is probably the higher diameter of the fibres (about 17 µm) and the smaller average pore diameter (about 41 µm). The latter probably affects a large air content in the pores and thus a lower thermal conductivity.

### Statistical analysis

*Statistical analysis of air permeability results*

Statistical analysis shows that the air permeability strongly correlates with the thickness and mass of the nonwovens analysed, while the correlation between air permeability and the diameter of fibres and bubble point is moderate ($R^2 = 0.51$). The analysis also shows a very weak correlation between air permeability and openness of the surface (figure 6). The correlation matrix shows a strong negative correlation between thickness, mass and air permeability and a moderate positive correlation between the diameter of fibres and air permeability. Multiple regression is used to predict air permeability based on the thickness, mass, and diameter of fibres (table 3).

*Statistical analysis of water vapour permeability results*

Statistical analysis shows that the water vapour permeability (WVT) strongly correlates with the diameter of fibres and bubble point of the nonwovens analysed, while the correlation between WVT and the openness of the surface is moderate ($R^2 = 0.50$). The analysis also shows a very weak correlation between water vapour permeability and mean pore diameter

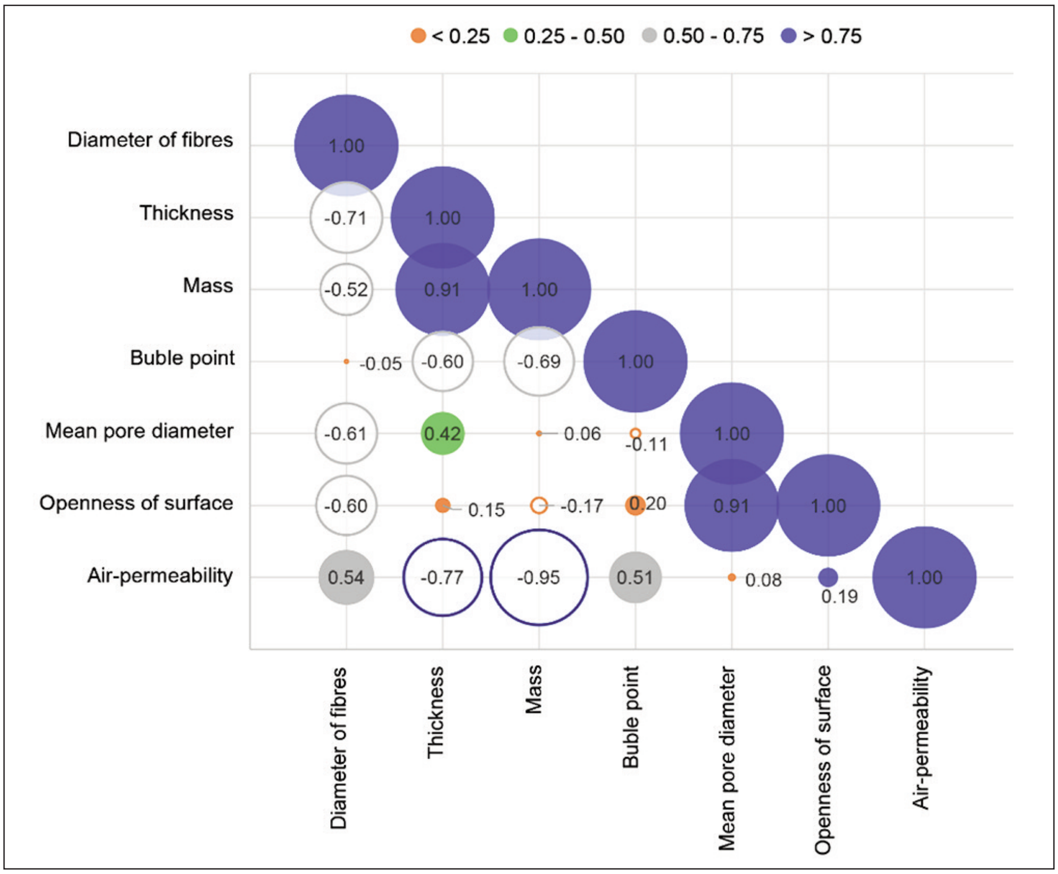

Fig. 6. Correlation analysis between the diameter of fibres, thickness, mass of the sample, bubble point, mean pore diameter, the openness of surface and air-permeability

Table 3

SUMMARY OUTPUT OF MULTIPLE REGRESSION ANALYSIS TO PREDICT AIR-PERMEABILITY

| Regression Statistics | | | Coefficients | Standard Error | t Stat | P-value |
|---|---|---|---|---|---|---|
| **Multiple R** | 0.999987 | **Intercept** | 305.006 | 32.87719 | 9.277131 | 0.068358543 |
| **R Square** | 0.999974 | **Diameter of fibres, DF** | 73.53688 | 1.470254 | 50.01645 | 0.012726512 |
| **Adjusted R Square** | 0.999896 | **Thickness, T** | 1752.929 | 28.28009 | 61.98457 | 0.010269727 |
| **Standard Error** | 3.294982 | **Mass, M** | –11.9831 | 0.096744 | –123.865 | 0.005139531 |
| **Observations** | 5 | | | | | |
| Equation to predict air-permeability: $y = 305 + 73.54\,DF + 1752.93\,T - 11.98\,M$ | | | | | | |

(figure 7). The correlation matrix shows a strong negative correlation between the diameter of fibres and water vapour permeability and strong positive correlation between bubble point and water vapour permeability and a moderate positive correlation between thickness, mean pore diameter, the openness of surface and water vapour permeability. Multiple regression is used to predict water vapour permeability based on the diameter of fibres, bubble point and openness of the surface (table 4).

*Statistical analysis of thermal conductivity results*

Statistical analysis shows that the thermal conductivity strongly correlates with the diameter of fibres, thickness and mass of the nonwovens analysed, while the correlation between thermal conductivity, bubble point and mean pore diameter and openness of surface is moderate ($R^2 = 0.50$). The analysis also shows a very weak correlation between thermal conductivity and the openness of the surface (figure 8). The correlation matrix shows a strong negative correlation between the diameter of fibres and thermal conductivity and strong positive correlation between mass and thickness and thermal conductivity and a moderate positive correlation between mean pore diameter and thermal conductivity. Further correlation results show a moderate negative correlation between bubble point and thermal conductivity. Multiple regression is used to predict thermal conductivity based on the diameter of fibres, thickness, and mass (table 5).

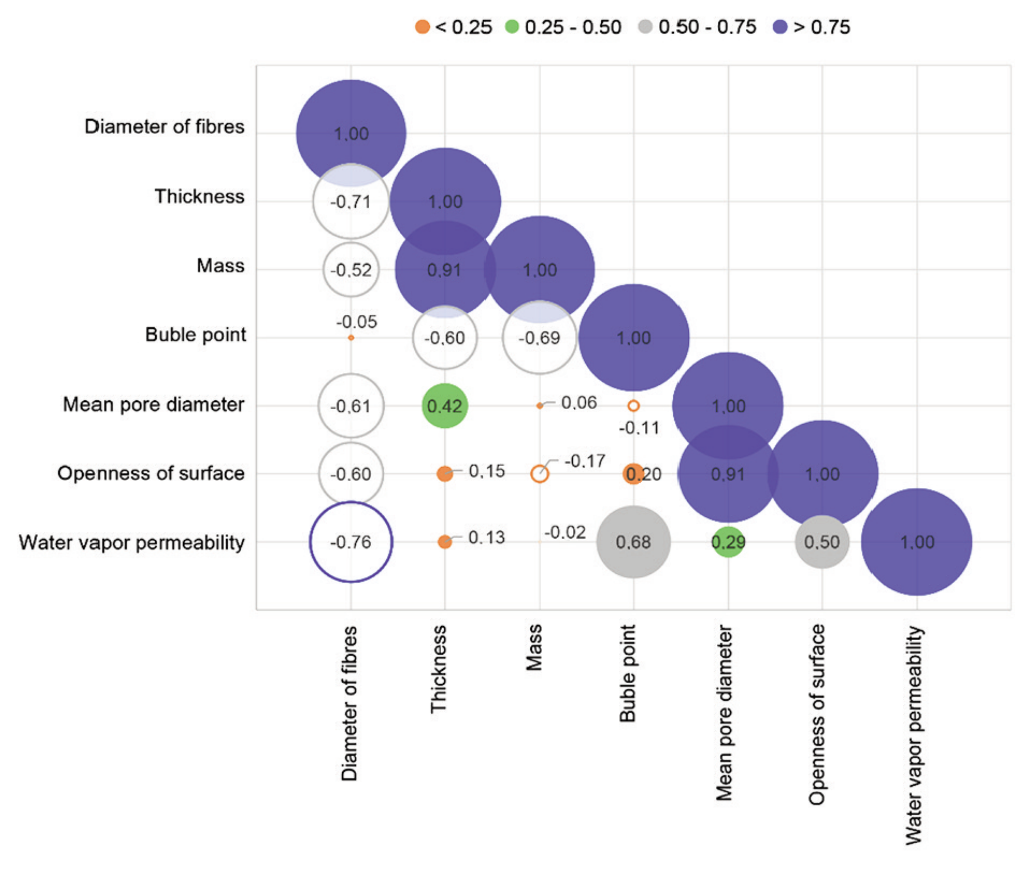

Fig. 7. Correlation analysis between the diameter of fibres, thickness, mass of the sample, bubble point, mean pore diameter, the openness of surface and water vapour permeability

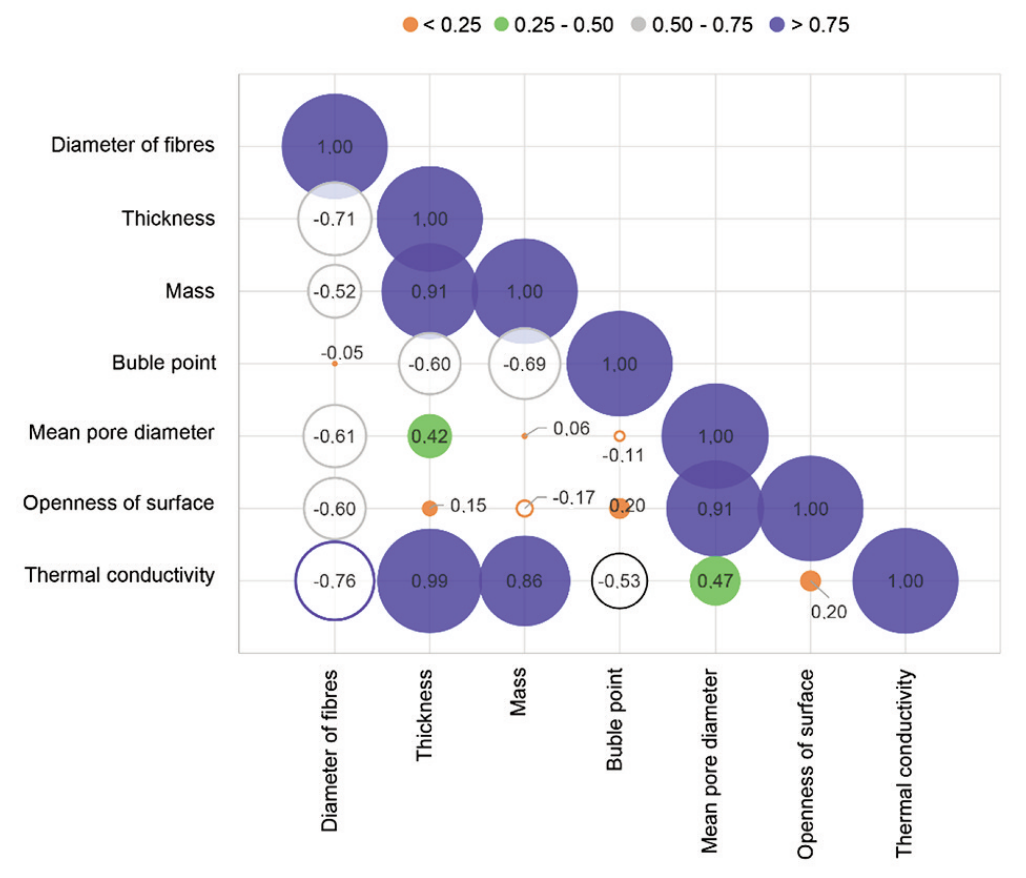

Fig. 8. Correlation analysis between the diameter of fibres, thickness, mass of the sample, bubble point, mean pore diameter, the openness of surface and thermal conductivity

Table 4

SUMMARY OUTPUT OF MULTIPLE REGRESSION ANALYSIS TO PREDICT WATER VAPOUR PERMEABILITY

| **Regression Statistics** | | | **Coefficients** | **Standard Error** | **t Stat** | **P-value** |
|---|---|---|---|---|---|---|
| **Multiple R** | 0.999987 | **Intercept** | 65.58951 | 13.91829 | 4.712470342 | 0.068358543 |
| **R Square** | 0.999974 | **Diameter of fibres, DF** | –3.37638 | 0.540569 | –6.245970607 | 0.012726512 |
| **Adjusted R Square** | 0.999896 | **Thickness, T** | 0.625584 | 0.097055 | 6.445682981 | 0.010269727 |
| **Standard Error** | 3.294982 | **Mass, M** | –0.39745 | 0.486244 | –0.81739309 | 0.005139531 |
| **Observations** | 5 | | | | | |

Equation to predict water vapour permeability: $y = 65.59 - 3.38\,DF + 0.62\,BP - 0.39\,OS$

Table 5

SUMMARY OUTPUT OF MULTIPLE REGRESSION ANALYSIS TO PREDICT THERMAL CONDUCTIVITY

| **Regression Statistics** | | | **Coefficients** | **Standard Error** | **t Stat** | **P-value** |
|---|---|---|---|---|---|---|
| **Multiple R** | 0.998622 | **Intercept** | -0.29131 | 0.253641 | –1.148524823 | 0.456061177 |
| **R Square** | 0.997247 | **Diameter of fibres, DF** | –0.00711 | 0.011343 | –0.627019826 | 0.643460806 |
| **Adjusted R Square** | 0.988986 | **Thickness, T** | 1.45515 | 0.218176 | 6.669630504 | 0.094744783 |
| **Standard Error** | 0.02542 | **Mass, M** | –0.00096 | 0.000746 | –1.289535549 | 0.41991791 |
| **Observations** | 5 | | | | | |

Equation to predict thermal conductivity: $y = -0.29 - 0.0071\,DF + 1.45\,T - 0.00096\,M$

## CONCLUSIONS

The present study focused on permeability (filtration) properties of dry laid (carded) and needle-bonded nonwoven fabrics made of 50% PET + 50% bico PET fibres intended for filters. From the statistical analysis, we can conclude that the air permeability is strongly correlated with the thickness and mass of the nonwovens studied. Besides fibre diameter, which is about 17 μm, thickness and mass are the most important parameters for air permeability and filtration properties, less so fibre diameter and average pore diameter. The water vapour transmission rate (WVT) correlates strongly with the fibre diameter and bubble point of the nonwovens studied. Sample B showed the lowest water vapour permeability and sample E the highest. A much higher water vapour permeability has the samples that have a lower diameter of the fibres (about 13.8 μm) and a higher bubble point (about 105 μm). The thermal conductivity correlates strongly with the diameter of the fibres, the thickness and the mass of the studied nonwovens.

We assume that the maximum value of thermal conductivity is influenced by the diameter of the fibres and the average pore diameter (45.43 μm), which is very high compared to the other analysed samples. The samples have lower thermal conductivity due to the higher diameter of the fibres (about 17 μm) and the smaller mean pore diameter (about 41 μm). The latter probably leads to high air content in the pores and thus to lower thermal conductivity.

The results of the experimental part and statistical analysis confirmed that the sample with a fibre diameter of 15.65 μm, mass of 240 g/m$^2$ and thickness of 1.11 mm has the optimal filtration properties, the lowest surface openness and consequently the lowest water vapour permeability and average air permeability, and the highest thermal conductivity.

Statistical analysis confirmed that water vapour permeability correlates strongly with fibre diameter and bubble point. Air permeability correlates strongly with thickness and mass, and thermal conductivity correlates strongly with fibre diameter, thickness and mass of the nonwovens studied.

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