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# Air and Water Vapour Permeability in Double-Layered Knitted Fabrics with Different Raw Materials

**Abstract**
*On the basis of a computer image analysis, the surface porosity of knitted fabrics was evaluated by establishing the size of clearances created as an effect of flight channels in the plain double-layered and lining knitted fabrics. It was found that air permeability, in contrary to water vapour permeability, is a function of the thickness and surface porosity of the knitted fabrics.*

**Key words:** *double-layered knitted fabrics, computer image analysis, surface porosity of knitted fabrics, structure parameters, air permeability, water vapour permeability, correlation.*

## Introduction

A typical double layered construction of knitted fabrics (Figure 1) includes the following elements:
- a knitted fabric layer made of conductive and diffusive yarns which directly adjoins the body. Its role is to remove and transport humidity from the body in liquid and vapour forms.
- a knitted fabric layer made of sorptive yarn which is not in direct contact with the skin. The role of this layer is to keep the humidity far from the body and vaporisae it to the environment.

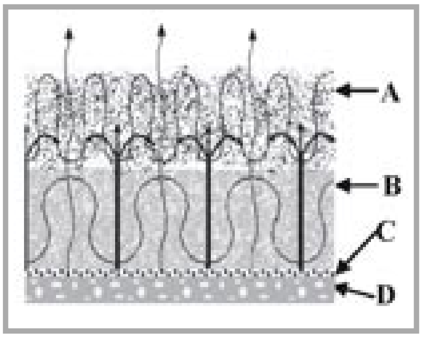


***Figure 1.** The model of knitted fabric with high bio-physical properties; A – sorptive layer, B - conductive and diffusive layer, C – under clothing microclimate, D – skin.*

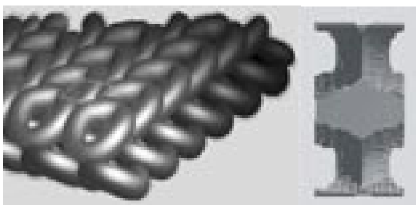

***Figure 2.** The virtual model of double-layered knitted fabric, with flight channel shown.*

Although the layer structure of knitted fabrics with improved bio-physical properties is known [1 - 11], there is a lack of research comparing the influence of raw material and knitted fabric structure on bio-physical properties, particularly on air and water vapour permeability. This research, which this work aims to undertake, is necessary in view of the wide variety of knitted yarns advertised as being most appropriate for the construction of this type of knitted fabric. Moreover, a trial was undertaken to link bio-physical media permeability with a new parameter of knitted fabric structure, surface porosity.

## Programme, material and research methods

### Research programme

Before our research into the bio-physical properties of knitted fabrics, we carried out research into the basic structural parameters and surface mass of knitted fabrics with the following measurements:
- thickness of knitted fabrics according to standard PN-EN 5084:1999,
- course density $P_r$ and wale density $P_k$ according to standard PN 85/P-04787,
- surface mass according to standard PN-P-04613 1997,
- surface porosity according to the authors' method based on computer image conversion.

The research programme regarding the evaluation of the bio-physical parameters of knitted fabrics contained the following measurements:
- air permeability of knitted fabrics according to standard PN- EN ISO 9237:1998,
- water vapour permeability according to standard BS 7209:1990

### Research material – the types and characteristics of the yarns and double-layered knitted fabrics used

The main group of knitted fabrics were double- layered knitted fabrics, where the yarns mentioned in the first order in Table 1 were used as raw materials with conductive and diffusive properties. However, as raw materials with sorption properties we used the cotton yarn with linear mass 20 tex (Table 1). The knitted fabrics were made of two plain stitches, shifted mutually by half a width of wale ('elastic' set over of needles), linked by the tucking technique with the use of textured polyamide thread with a low linear mass of PA 22 dtex f7. The virtual model of this knitted fabric structures shown in Figure 2. The second group of knitted fabrics was made on an open top machine contained lining knitted fabrics (Table 1). For the comparison of the bio-physical properties of knitted fabrics, double-layered cotton/cotton knitted fabric and polyester/polyester knitted fabric were made.

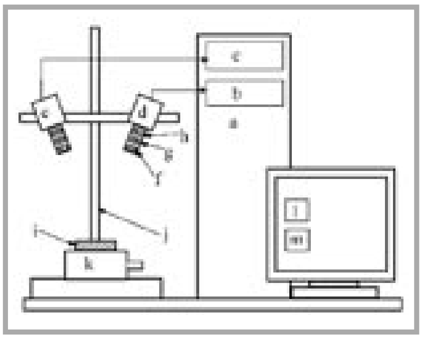


***Figure 3.** The measurement system: a) PC computer, b) video card No.1, c) video card No.2, d) video camera No.1, e) video camera No.2, f) focus setting, g) zoom setting, h) diaphragm setting, i) sample of tested material, j) stand, k) micrometrical table with light, l) Textil2D application, m) Loo2D application.*

*Table 1. The variants of 'plain' double-layered (**A-O**) and lining double-layered (**1-9**) knitted fabrics and their structural parameters.*

| | Indication of knitted fabric variant | Mass G, g/m$^2$ | Thickness g, mm | Course density $P_r$, 1/dm | Wale density $P_k$, 1/dm |
|---|---|---|---|---|---|
| A | PPcut 20tex//Cotton20tex | 255 | 1,18 | 160,0 | 109,5 |
| B | PA66Skinlife78dtexf68x2FT//Cotton20tex | 251 | 1,14 | 149,5 | 126,6 |
| C | PP84dtexf25x2//Cotton20tex | 240 | 1,02 | 161,4 | 112,5 |
| D | PAMerylSpun185dtexf136//Cotton20tex | 257 | 1,10 | 150,5 | 125,5 |
| E | PA6660dtexf30//Cotton20tex | 220 | 1,13 | 148,0 | 127,5 |
| F | PA78dtexf23x2//Cotton20tex | 260 | 1,24 | 154,0 | 122,0 |
| G | Coolmax20tex//Cotton20tex | 258 | 1,07 | 151,5 | 126,5 |
| H | PES167dtexf96//Cotton20tex | 248 | 0,97 | 152,0 | 124,5 |
| I | Thermastat20tex//Cotton20tex | 258 | 1,10 | 149,5 | 123,5 |
| J | Cotton15tex//Cotton20tex | 226 | 1,08 | 158,4 | 118,0 |
| K | PEScut-Elana13tex//Cotton20tex | 216 | 0,98 | 148,5 | 127,5 |
| L | PEScut-Elana20tex//Cotton20tex | 240 | 1,02 | 148,5 | 124,5 |
| M | PA66Tasland140texf102//Cotton20tex | 218 | 1,03 | 145,5 | 124,0 |
| N | PES167dtexf96//PES110dtexf144 | 197 | 0,86 | 140,0 | 130,0 |
| O | Trevira167dtexf96//Trevira150dtexf256 | 195 | 0,79 | 128,0 | 122,5 |
| 1 | PP84dtexf25x2//Cotton20tex-2 | 186 | 1,28 | 152,0 | 116,0 |
| 2 | PEScut-Elana15tex//Cotton20tex-2 | 186 | 1,18 | 158,5 | 102,5 |
| 3 | Thermastat20tex//Cotton20tex-1 | 162 | 0,80 | 158,5 | 116,0 |
| 4 | Cotton15tex//Cotton20tex-1 | 146 | 1,27 | 161,5 | 111,5 |
| 5 | PES167dtexf96//Cotton20tex-2 | 160 | 1,23 | 158,5 | 105,5 |
| 6 | PES110dtexf24 x2/Cotton20tex-2 | 159 | 1,17 | 162,0 | 108,5 |
| 7 | PES167dtexf96//Cotton20tex-1 | 153 | 0,87 | 154,5 | 112,0 |
| 8 | Coolmax20tex//Cotton20tex-1 | 163 | 0,78 | 157,5 | 114,5 |
| 9 | PA78dtexf23x2//Cotton20tex-1 | 153 | 0,78 | 142,5 | 122,5 |

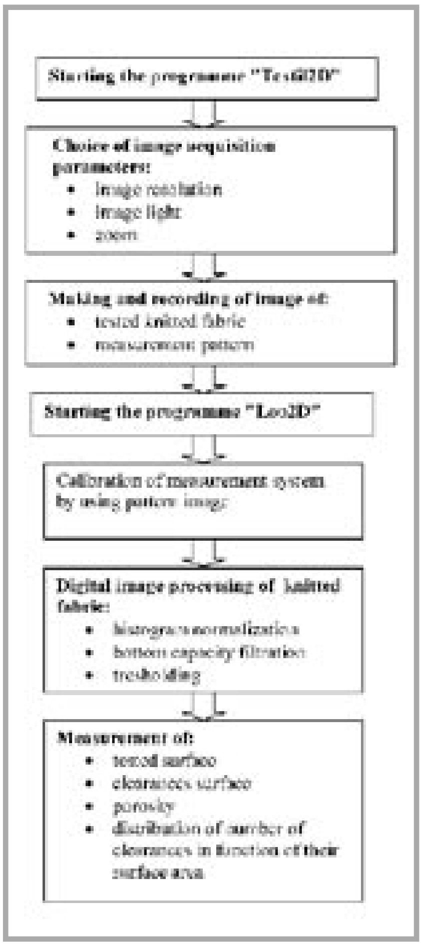


***Figure 4**. The block draft of clearance measurement.*

The basic structural parameters of both types of knitted fabrics are enumerated in Table 1. They show that the surface mass of plain double-layered knitted fabrics was in the range from 195 g/m$^2$ to 186 g/m$^2$. The lining knitted fabrics are characterised by a surface mass smaller by an average of 30% than plain double-layered knitted fabrics.

**Research methods – authors' method of measurement surface porosity based on computer pictures converting**

The measurement system was constructed on the basis of a PC computer, video card and cameras, and is presented in Figure 3. The software of the system is combined by two individual applications: Textil2D, which is responsible for recording the image from video cameras, and Loo2D, used for analysing the 2D pictures.

The measurement method is based on basic picture filters. Its block layout is shown in Figure 4. The main part of the system is the digital image processing of the knitted fabric. After the operation of the normalisation and bottom capacity filtration histograms, the thresholding operation transforms the picture recorded in the grey scale into a black and white monochromatic picture. The appropriate choice of thresholding significantly influences the precision of computer algorithms of clearance evaluation. The last stage of the picture transformation is the operation of negation. The effect of thresholding filter action and negation on the original image from Figure 5a is presented in Figures 5b and 5c.

The image prepared in this way is the basis of identification of the linked together pixels, which form a single clearance resulting from the flight channels. After identification, each clearance size is measured. Next, the surface porosity parameter is evaluated according to the following model:

$$P = \frac{P_P}{P_C} \times 100\%$$

where: $P_P$ – clearance surface area, $P_C$ – tested surface area. The model of histogram distribution of the clearance surface area is shown in Figure 6 (page 79).

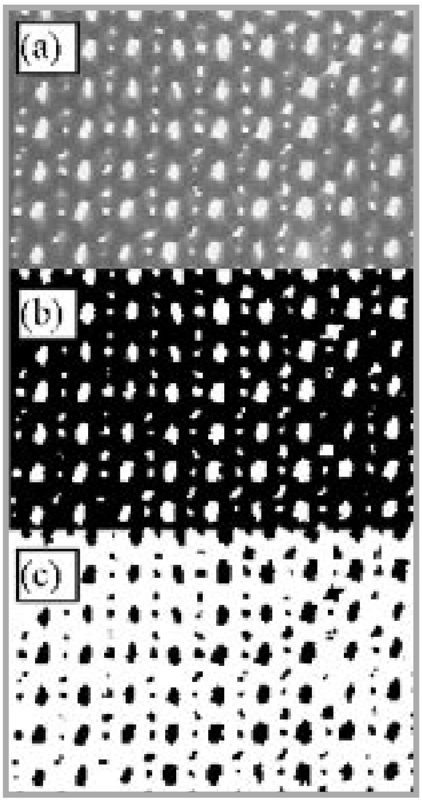


***Figure 5.** Original picture (a), thresholding method operation result(b), and negation (c).*

## Test results and analysis

**Dependence of surface porosity on the type of raw material used and the knitted fabric stitch**

Figure 7 shows that lining knitted fabrics are characterised by slightly higher values of surface porosity. This is caused by

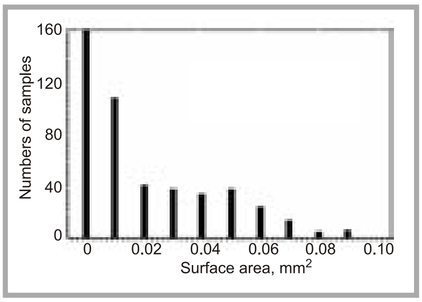


*Figure 6. Histogram distribution of clearance surface area; Total number of samples n = 477.*

the type of stitch, because plain double-layered knitted fabrics are combined of two plain stitches made by the 'elastic' set over of needles which decrease the clearances surface areas. However, lining knitted fabrics are made of single plain stitch.

In the group of plain double-layered knitted fabrics, two variants of knitted fabrics made of textured polyesters without cotton have high surface porosity values: (Trevira 167 dtex f 96//Trevira 150 dtex f 256 i PES 167 dtex f 96//PES 110 dtex f 144).

**The analysis of research into bio-physical parameters**

Figures 8 and 9 present the research results of water vapour estimated according to BS 7209:1990 standard, and air permeability estimated according to PN-EN ISO 9237:1998 standard. It shows that the water vapour permeability of the types of knitted fabrics we have examined is in the range of 650-900 g/m$^2$/24h. It is worth noticing the high values of water vapour permeability for cotton/cotton knitted fabrics. The average maximum water vapour permeability for measurement conditions is 1425 g/m$^2$/24h, and refers to the case of measurements without knitted fabric. Regarding air permeability, the range of values obtained is significant, ranging from 781 to 1670 mm/s, and the highest values are found in PES/PES and PES/cotton-knitted fabrics. The barrierability of knitted fabrics to the air is the knitted fabrics' thickness function, which was presented in Figure 10 for plain double-layered knitted fabrics, where the correlation factor is 0.84.

Regarding water vapour permeability, no correlation of this parameter with the knitted fabrics' thickness was noted (Figure 11). For plain knitted fabrics with thickness in the range g = 1.11 to 1.13 mm, the highest water vapour permeability (903 g/m$^2$/24h) was displayed by connection cotton with a PA of 66 60 dtex f 30 × 2, and the lowest (651 g/m$^2$/24h) by PA Meryl Spun 185 dtex f 136.

**The relation of surface porosity to air and water vapour permeability**

By using the measurement system described on page 79 the surface porosity of the tested knitted fabrics was estimated. Figure 12 presents the relations between air permeability, water vapour permeability and surface porosity for plain double-layered and lining knitted fabrics, and Figure 13 shows the same relations for plain double-layered knitted fabrics alone. The diagrams show that the influence of surface porosity within the range P = 1.6 to 18.4% on water vapour permeability is negligible. This is proved by the values of linear correlation indexes R = 0.33 for the population of plain double-layered and lining knitted fabrics (Figure 12)

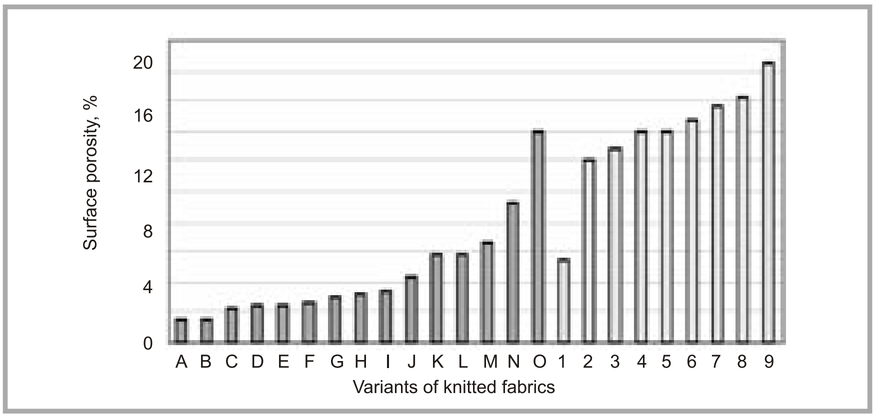


*Figure 7. The values of surface porosity for different variants of knitted fabrics; denotations as in Table 1.*

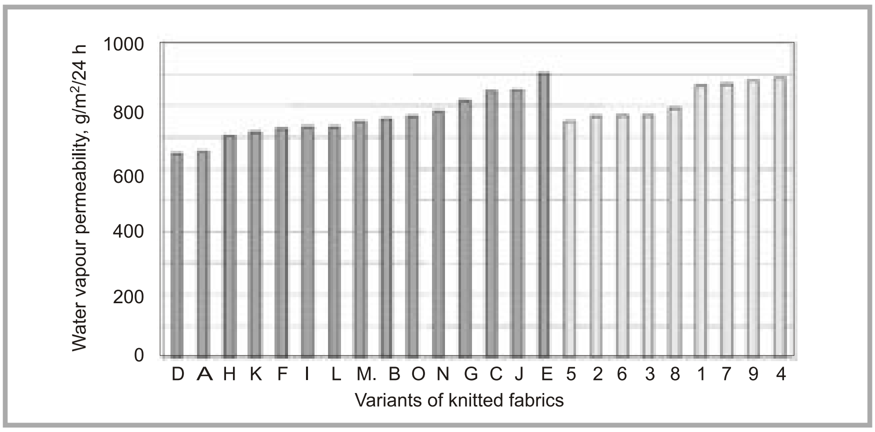


*Figure 8. Water vapour permeability of some variants of knitted fabrics; denotations as in Table 1.*

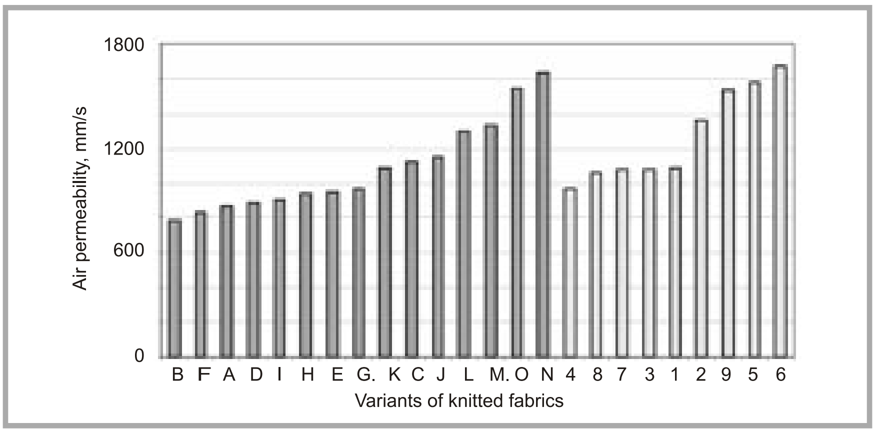


*Figure 9. Air permeability of some knitted fabric variants; denotations as in Table 1.*

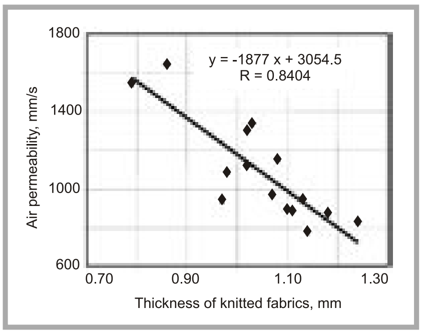


*Figure 10. Air permeability in function of thickness of plain double-layered knitted fabrics.*

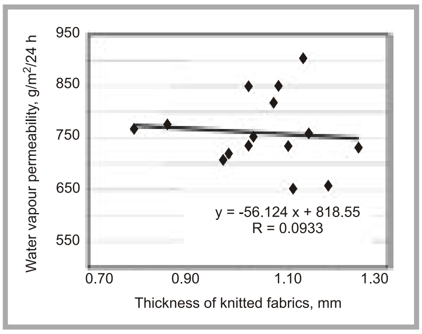


*Figure 11. Water vapour permeability in function of plain double-layered knitted fabrics.*

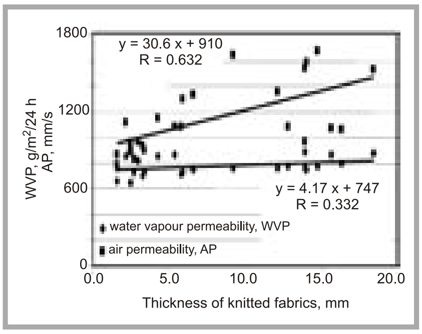


***Figure 12.** The relations between air permeability AP [mm/s], water vapour permeability WVP [g/m2/24h] and surface porosity P [%] for plain double-layered and lining knitted fabrics.*

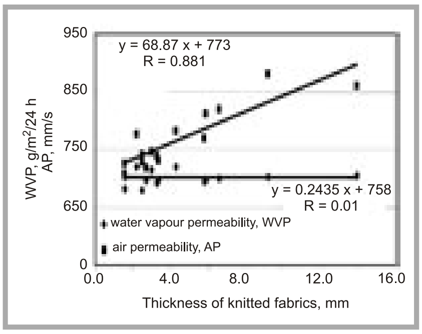


***Figure 13.** The relations between air permeability AP [mm/s], water vapour permeability WVP [g/m2/24h] and surface porosity P [%] for plain double-layered knitted fabrics.*

and R = 0.01 for plain double-layered knitted fabrics (Figure 13). However, the influence of surface porosity on air permeability is significant because the correlation indexes R are properly 0.63 and 0.88. The higher value of the correlation index estimate for plain double-layered knitted fabrics alone shows the influence of stitch type on the air permeability value. It must be emphasised that surface porosity correlates more with air permeability than knitted fabric thickness. This is documented by the test results and statistic analysis presented in Figure 10, where the estimated value of the linear correlation index between air permeability and the knitted fabric thickness is R = 0.84.

The lack of surface porosity's influence on water vapour permeability, in contrast to its influence on air permeability, is caused by the measurement conditions. Water vapour permeability takes place in conditions of free convection, and air permeability in conditions of affected convection, where the larger surface of clearance is good for air transport.

In conditions of free convection, water vapour diffuses in the surfaces between fibres and clearances, and the general high capacity porosity of knitted fabric is conducive to this process. Moreover, the sizes of water vapour molecules are disproportionately smaller than the sizes of pores in the knitted fabric structure, which is characterised by high general porosity. The interpretation presented above explains the distinct absence of any correlation between water vapour permeability and thickness of knitted fabrics in the range g= 0.78 to 1.28 mm.

## Conclusions

- As estimated by the method of computer image analysis, the values of surface porosity based on the sizes of clearances resulted from flight channels in plain double-layered and lining knitted fabrics fall within the range P = 1.6 to 18.4 %, where plain knitted fabrics show smaller values P= 1.6 to 9.3 %.
- Air permeability, in contrast to water vapour permeability, is a function of knitted fabric thickness (R=0.84) and surface porosity (R=0.88). The vital lack of correlation between water vapour permeability and the above-mentioned structure parameters results from the character of media transport by free convection and the general high porosity of knitted fabrics.


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