Mini Review

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Evaporation resistance of garment systems involving semi-permeable textile laminates with hydrophilic membranes

Abstract

Water vapour permeability, often expressed as evaporation resistance Ret, belongs to the most important thermal comfort parameters of protective, sport and other functional clothing (garments) and related textile fabrics. For outdoor applications, these garments should exhibit the so-called semi-permeability: the textile laminates creating the outside garment fabrics contain micro- or nano-porous membranes, which prevent the penetration of outside liquid water into the laminates, but simultaneously allow the passage of water vapour from the body through the whole fabric system. In nano-porous membranes, when entering the laminate, water vapor molecules first condensate into single water molecules, which then travel through the macro-molecular structure of the polymer fibres. The more water molecules are present in the amorphous phase of the polymer, the higher is the flux of moisture. The average moisture level inside the fibre structure is then proportional to the moisture level on both sides (surfaces) of the nano-porous membranes. The moisture level is in this case expressed (proportional) to the level of water vapour partial pressure on both surfaces of the nano-porous membrane.

In the study, a new observation based on the requirements of the highest level of water vapour partial pressure on the membrane surface is presented.

Keywords: evaporation resistance, permeability, garment systems, textile laminates, hydrophilic membranes

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Introduction

Water vapour permeability, often expressed as evaporation resistance Ret, belongs to the most important thermal comfort parameters of protective and other functional clothing (garments) and related textile fabrics. Water vapour permeability of all textile products should be as high as possible, in order to prevent the accumulation of sweat in the garment system and simultaneously to enable efficient cooling of the wearer's body through sweat evaporation. For outdoor applications, such garments should also exhibit the so-called semi-permeability: the textile laminates creating the outside garment fabrics contain micro - or nano-porous (hydrophilic) membranes, which prevent the penetration of outside liquid water into the laminates, but simultaneously allow the passage of water vapour from the body through the whole fabric system.[1,2]

In microporous membranes, this semi-permeability is given by differences between the dimension of minimal water drops – compact clusters of water molecules (hundreds of micrometres) and size of pure water (water vapour) molecules (about 0,4 nm). In nano-porous membranes, when entering the laminate, water vapor molecules first condensate into single water molecules, which then travel through the macromolecular structure of the polymer fibres. The more water molecules are present in the amorphous phase of the polymer, the higher is the flux of moisture. The average moisture level inside the fibre structure is then proportional to the moisture level on both sides (surfaces) of the nano-porous membranes. The moisture level is in this case expressed (proportional) to the level of water vapour partial pressure on both surfaces of the nano-porous membrane. In the study, a new observation based on the requirement of the highest level of water vapour partial pressure on both membrane surfaces is presented.[3,4]

Theory of water vapour transfer in nano-porous membranes

When testing the evaporation resistance Ret of proper commercial laminates with micro and nano-porous membranes, the next to skin membrane surface is (in Skin models or gravimetric testers) exposed to highest level of moisture, presented by the saturated water vapour partial pressure (WVPP). The other surface faces lower WVPP simulating the environmental conditions. Thanks to this high WVPP on one of the membrane surfaces, the experimentally determined evaporation resistance Ret levels of the tested nano-porous laminates are low, thus indicating protective clothing with excellent WV permeability.[5,6]

The manufacturers and vendors of jackets with nano-porous laminates are promising excellent wearing comfort of these goods. As follows from the recent results presented in this study, their optimistic marketing claims may not be justified, due to the negative effect of an undergarment and other fabric layers, which are worn (within the garment structure) under the outside semi-permeable laminate. All evaporative resistances of these textile interlayers are linked in series and reduce significantly the water vapor flow, before this gaseous form of moisture reaches the next to skin surface of the nano-porous laminate.

Thus, the average moisture level inside the nano-porous membrane can be significantly lower, then in case of testing the nano-porous laminate by means of testing instruments. This low moisture inside these membranes will significantly, in non-linear way, reduce WV permeability of the laminates, resulting in very high evaporation resistance linked in series with evaporation resistances of other textile layers. That is why the effective water vapour permeability of outdoor

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jackets with nano-porous membranes, when worn over several fabric layers, can be lower than what is claimed in the marketing literature of these outdoor garments. Wearers of these clothing may therefore suffer from sweat accumulation and overheating caused by the reduced transfer of the evaporated sweat. Gibson in[7] analysed the effect of temperature on the evaporation resistance of nano-porous membranes with the conclusion, that the effect of temperature is much lower than the effect of moisture concentration in the membrane.

Semi-permeable laminates analyse and testing results

In this part, experimental analysis of the abovementioned problem is presented, involving experimental determination of relative water vapour permeability (WVP) and evaporation resistance Ret of 10 nano-porous and one microporous laminate, tested in the quick PERMETEST Skin model (Figure 1).

Figure 1 Evaporation resistance Ret of 10 nano-porous and one microporous laminate, tested in the quick PERMETEST Skin model.

In the first step, evaporation resistances of single laminates were determined, and in the second step, an additional interlayer fabric, simulating the evaporation resistance R_{et} (here 9,2 m^2Pa/W) of an undergarment, created an interlayer of the tested laminates, was applied in the testing. The below measurements confirmed, that in case of the included evaporation resistance of the simulated undergarment, evaporation resistance levels of the proper laminates with nano-porous membranes were significantly higher than in case without the simulated interlayers (Figures 2–6).

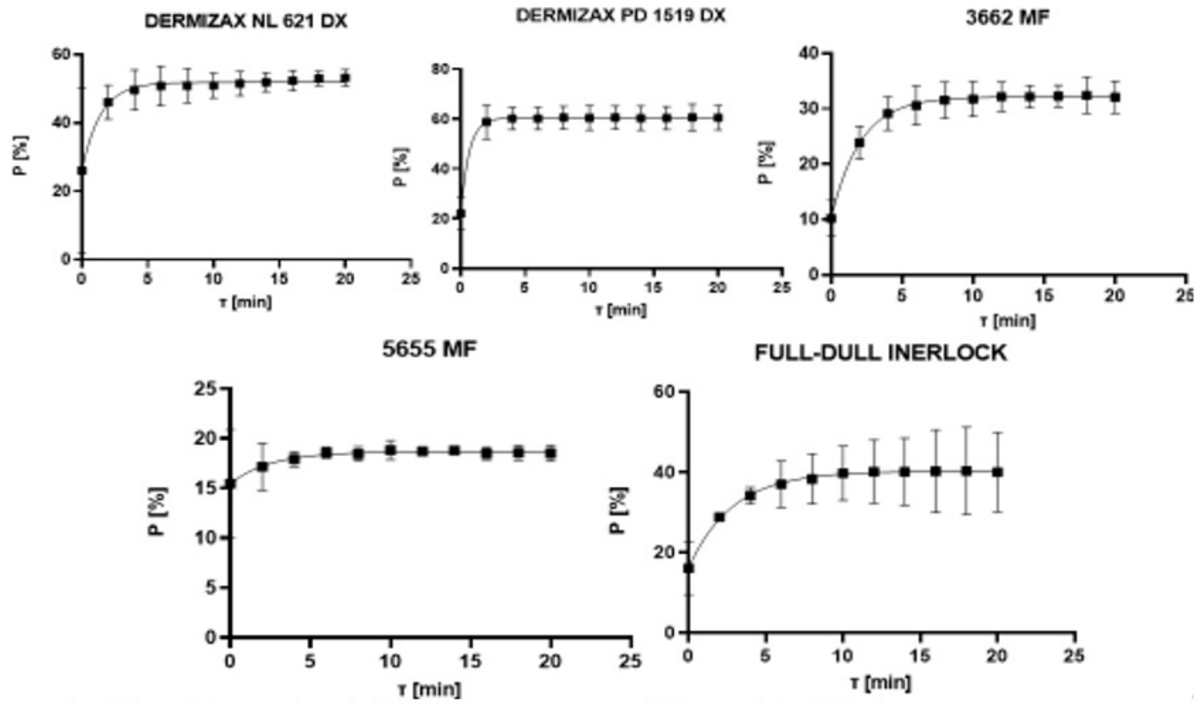

Figure 2 The effect of time on the relative water vapour permeability P of single laminates.

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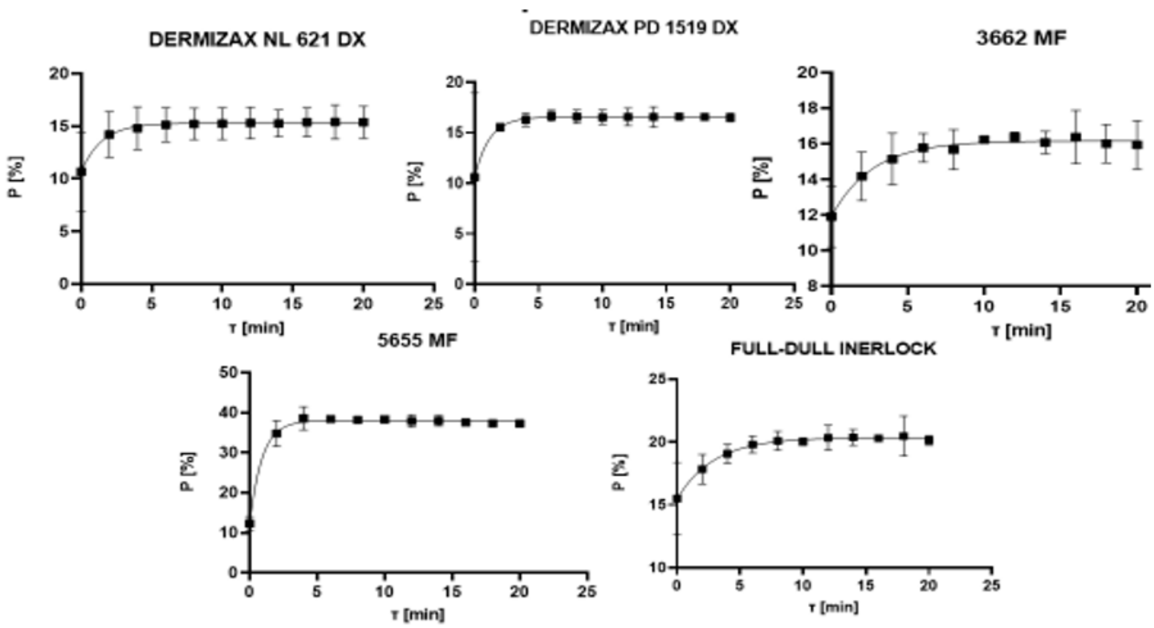
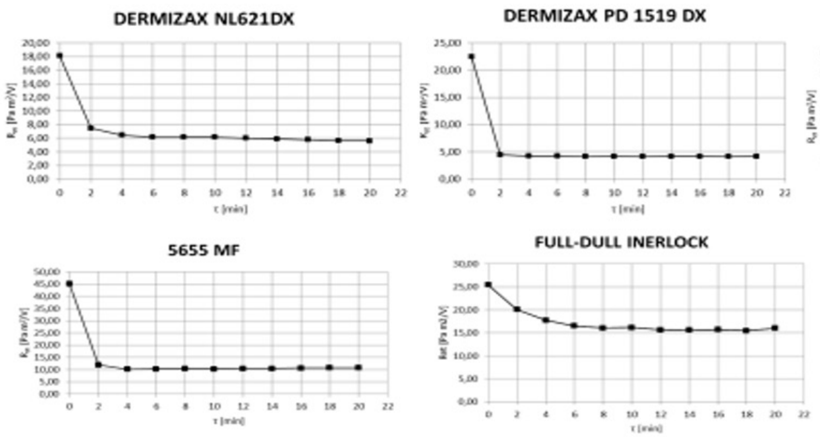
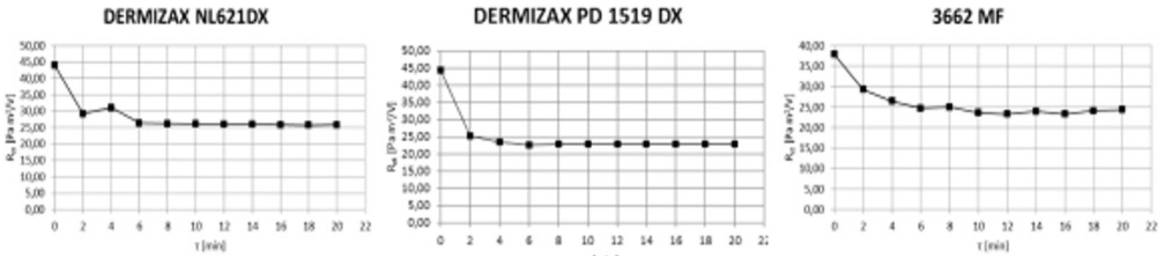


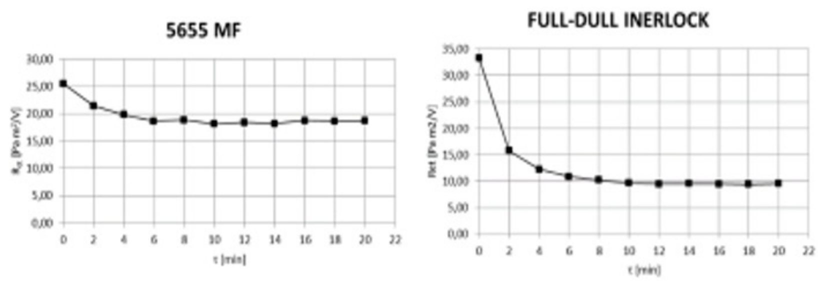
Figure 3 The effect of time on the relative water vapour permeability P of laminates with interlayer.



$$R_{et} = R_{et_0}\,\frac{1-P}{P}$$

Figure 4 The effect of time on the evaporation resistance Ret of single laminates.





$$R_{et} = R_{et_0}\,\frac{1-P}{P} - R_{et_m}$$

Figure 5 The effect of time on the evaporation resistance R_{et} of laminates with interlayer.

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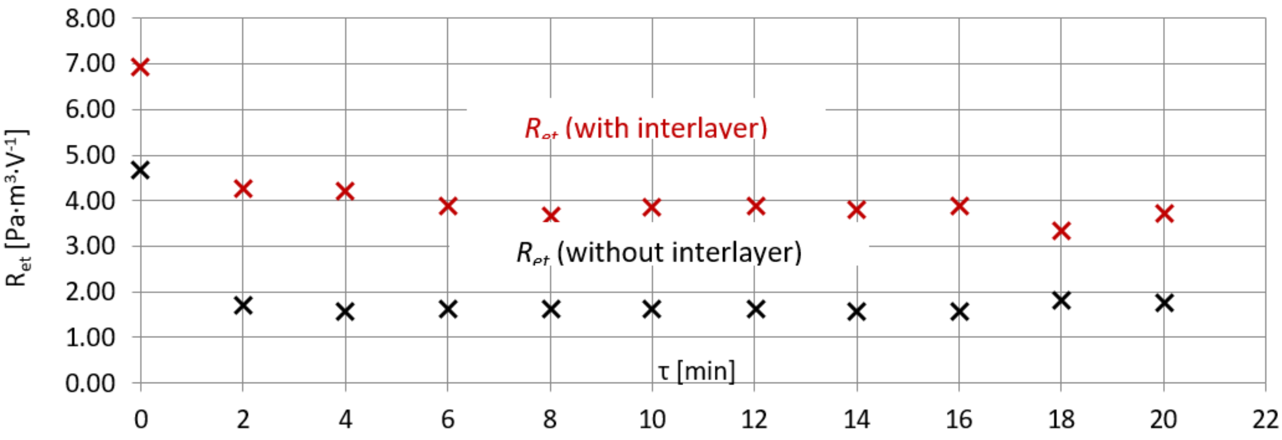

Figure 6 Effect of time and interlayer on the evaporation resistance R_{et} of the Gore-Tex laminate.

The achieved results were expressed in the form of a simple mathematical model of the VW transfer in the analysed garments. In the above Figure 6 it was also confirmed, that contrary to the common nano-porous laminates, evaporation resistances of laminates with microporous membrane (coated with very thin nano-porous polyurethane) was only slightly influenced by the presence of evaporation resistance of other fabric (sublayer) in the garment system (Table 1).

Table 1 Relative WVP and evaporation resistance R_{et} after sample insertion into the tester

Laminate (sample)	R_{et} (m²Pa/W, 6 min)	P (%, 10 min)	R_{et} (m²Pa/W, 10 min) without / with sublayer
GORETEX	2.4	0.794	1.65 / 3.85
DERMIZAX STR 1780DX	5.55	0.598	4.28 / 15.73
DERMIZAX 1461 DX	10.29	0.56	5.00 / 14.54
DERMIZAX PD1519 DX	3.38	0.66	3.28 / 15.58
DERMIZAX NL 621 DX	6.59	0.413	9.04 / 17.02
DERMIZAX P15HDX	5.75	0.526	5.73 / 13.57
FULL-DULL INTERLOCK	11.16	0.345	12.07 / 17.10
KB-205 (SSK 2657)	25.92	0.204	24.82 / 37.85
AGATA PUR, TECHO PL	6.23	0.602	4.20 / 22.71
5655 MF	16.68	0.284	16.03 / 18.97
3662 MF	27.11	0.213	23.50 / 32.22

Analysis of the achieved results

All evaporative resistances of these textile interlayers are linked in series and significantly reduce the water vapor flow, before this gaseous form of moisture reaches next to the surface of the nano-porous laminate.

$$p_h = p_0 + \frac{(p_k - p_0)\cdot(0.5R_{et} + R_{et,f})}{R_{et,k} + R_{et} + R_{et,f}}$$

Partial pressure of water vapour, mesurement without interlayer

$$p_{h.p} = p_0 + \frac{(p_k - p_0)\cdot(0.5R_{et} + R_{et,f})}{R_{et,m} + R_{et} + R_{et,f}}$$

Partial pressure of water vapour, measurement with interlayer

$$R_{et,m} = R_{et}\left(\frac{p_h}{p_{h.p}}\right)^n$$

Evaporation resistance of the nano-porous membrane when measuring with interlayer

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Thus, the average moisture level inside the nano-porous membrane can be significantly lower, as compared to testing the nano-porous laminate by means of testing instruments. This low moisture inside these membranes will significantly, in non-linear way, reduce WV permeability of the laminates, resulting in very high evaporation resistance linked in series with evaporation resistances of other textile layers. The achieved results were expressed in the form of a simple mathematical model of the VW transfer in the studied sample systems. It was also confirmed, that contrary to the nano-porous laminates, evaporation resistances of laminates with microporous membranes remain constant, their level is not influenced by the presence of evaporation resistances of other fabrics in the garment system (Table 2) (Table 3).

Table 2 Laminated fabric exhibiting quadratic dependence of R_{et} on WV partial pressure inside the semipermeable membrane with interlayer. There is a good agreement

Measured laminate	R_{et} (no interlayer)	$R_{et,m}$ (with interlayer)	$R_{et,m}$ calculated)
Gore-Tex	1,65 m^2 Pa/ W	3,85 m^2 Pa/ W	3,376 m^2 Pa/ W
FD Interlock	12,07	17,1	16,735
5655 MF	16,03	18,97	21,446
3662 MF	23,5	32,22	28,875

Table 3 Laminated fabric exhibiting other then quadratic dependence of R_{et} on WV partial pressure inside the semipermeable membrane with interlayer. There is no agreement

Measured laminate	R_{et} (no sublayer)	$R_{et,m}$ (with sublayer)	$R_{et,m}$ (quadratic?)
DERMIZAX STR 1780DX	4,28 m^2 Pa/ W	15,73 m^2 Pa/ W	6,674 m^2 Pa/ W
DERMIZAX 1461 DX	5	14,54	7,739
DERMIZAX PD1519 DX	3,28	15,58	5,275
DERMIZAX NL 621 DX	9,04	17,02	12,880
KB-205 (SSK 2657)	24,82	37,85	29,929
DERMIZAX P15HDX	5,73	13,57	8,815
AGATA PUR	4,2	22,71	6,274

Conclusion

This study has confirmed the negative effect of undergarments and other fabric layers worn (within the garment structure) under the semi-permeable laminate with nano-porous (hydrophilic) layer, on evaporative resistance of these laminates. It was found that evaporation resistance of laminates with microporous membranes increased just slightly when evaporation resistance of other fabrics (sublayers) takes place within the garment system. Contrary to this finding, evaporation resistance of laminates with hydrophilic (nano-porous) membranes increased very substantially, when another garment piece is worn under this type of laminates. The reason for this effect is explained by the fact that the evaporative resistances of all textile interlayers are linked in series and reduce significantly the water vapor flow before this gaseous form of moisture reaches the next to the 'skin surface' of the nano-porous laminate.

The presented study is just preliminary. Another analysis of this generally unknown phenomena was published later in[8] and confirmed the above findings. Since jackets and other textiles with such laminates are generally worn as the outermost layer with at least one undergarment as inner layer, this observation can have significant technical design implications in terms of thermo-physiological comfort of the wearer. In short, in order to achieve high level of thermo-physiological comfort parameters of the clothing, evaporation resistance of all components of the garment system should be as low as possible.

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Conflicts of interest

The authors declare no conflict of interest.

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