

## Selected barrier properties of some disposable protective coveralls in wet state

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### ABSTRACT – REZUMAT

#### Selected barrier properties of some disposable protective coveralls in wet state

*Certain types of disposable protective clothing should protect its user against liquids including water; therefore, the knowledge of their thermophysiological and barrier properties in wet state is important, as moisture mostly deteriorates comfort-related barrier properties of clothing, namely its water vapour permeability and thermal insulation. However, papers on comfort-related barrier properties are almost missing, as testing of these properties in wet state is very uneasy, due to long times of testing of these properties in standard commercial instruments. If the testing time exceeds 15 to 30 minutes, the sample gets dry and the testing is practically impossible. In the study, a special testing instrument is presented, which enables to measure water vapour permeability and thermal resistance of wetted fabrics within a few minutes, thus making possible the determination of these parameters with satisfactory precision. By means of this unique instrument and other instruments, water vapour permeability, air permeability and hydrostatic resistance of 6 wetted protective coveralls were determined. The main finding of the study is that due to the absorbed moisture, the effective relative water vapour permeability of the studied clothing gets substantively reduced, as well as their air permeability.*

**Keywords:** protective clothing, water vapour, air permeability, hydrostatic resistance, wet state

#### Selecția proprietăților de barieră ale unor salopete de protecție de unică folosință în stare umedă

*Anumite tipuri de echipamente de protecție de unică folosință ar trebui să-și protejeze utilizatorul împotriva lichidelor, inclusiv a apei; prin urmare, cunoașterea proprietăților lor termofiziologice și de barieră în stare umedă este importantă, deoarece umiditatea deteriorează în mare parte proprietățile de barieră legate de confort ale îmbrăcămintei, și anume permeabilitatea la vapori de apă și izolarea termică. Cu toate acestea, lucrările despre proprietățile de barieră legate de confort aproape lipsesc, deoarece testarea acestor proprietăți în stare umedă este foarte dificilă, din cauza timpilor lungi de testare a acestor proprietăți utilizând instrumentele standard comercializate. Dacă timpul de testare depășește 15 până la 30 de minute, proba se usucă și testarea este practic imposibilă. În studiu este prezentat un instrument special de testare, care permite măsurarea permeabilității la vapori de apă și a rezistenței termice a țesăturilor umede în câteva minute, făcând astfel posibilă determinarea acestor parametri cu o precizie satisfăcătoare. Cu ajutorul acestui instrument unic și a altor instrumente, au fost determinate permeabilitatea la vapori de apă, permeabilitatea la aer și rezistența hidrostatică a 6 salopete de protecție în stare umedă. Principala concluzie a studiului este că, datorită umidității absorbite, permeabilitatea relativă efectivă la vapori de apă a îmbrăcămintei studiate se reduce substanțial, precum și permeabilitatea lor la aer.*

**Cuvinte-cheie:** îmbrăcăminte de protecție, vapori de apă, permeabilitate la aer, rezistență hidrostatică, stare umedă

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### INTRODUCTION

Disposable protective clothing is frequently used for protecting the wearer from sprayed pesticides, liquid dyestuffs, blood, detergents etc. and their specific barrier properties are naturally systematically tested and evaluated. Along with the mentioned barrier properties, there are also barrier properties influencing the thermophysiological comfort of protective clothing, such as its thermal resistance (insulation) and water vapour (WV) permeability [1]. Thermal insulation of clothing should protect its wearer from cold and clothing with high WV permeability should provide cooling of the wearer in a hot environment by intensive evaporation of his sweat. Thus, in recent decades, more attention is paid to the development

of protective clothing with optimum thermal resistance, with the highest possible WV permeability and also with certain hydrostatic resistance (resistance against penetration of pressured water) [2–6]. However, the published papers on the evaluation of thermo-physiological properties of protective clothing are focused on testing these properties in laboratory conditions, it means without additional wetting. However, protective clothing is worn not only in dry state, but very often in wet state, and the knowledge of transfer properties of the used fabrics in wet state is important, as higher moisture content mostly reduces water vapour permeability and thermal resistance of any fabrics [7, 8]. However, papers on thermal comfort properties of disposable protective clothing in wet state are very rare [7–9], as standard

instruments for the determination of water vapour permeability (gravimetric testers and common Skin models) do not allow to measure this parameter of fabrics in wet state, as the testing time mostly exceeds 30 minutes. Within this time, the wetted tested fabric gets almost dry and the WVP results are not reliable.

Therefore, the main and only objective of this study is to demonstrate the possibility of experimental determination of thermal comfort-related barrier properties of selected protective clothing in a wet state.

Protective coveralls analysed in the study are one-piece garments, commonly worn by mechanics, oil industry workers, painters, insulation installers, agricultural technicians and laboratory and cleanroom workers. Keeping in view the working environment, such personnel generally need disposable, one-time-use coveralls, which, along with the required barrier properties bringing specific protection, ensure certain thermophysiological comfort of their user in wet state also.

In this study, air permeability, water vapour permeability hydrostatic resistance and water repellence of six protective clothing were experimentally investigated, particularly in wet state. Dry measurements were executed for comparison only; therefore the results of measurements on dry fabrics are not discussed. All

the protective garments were made of very thin thermal bonded nonwovens, resulting in their very low thermal resistance. Therefore, the thermal properties of the overalls were not analysed in this study, even if the related special testing procedure is available [8]. It is important to note, that the objective of this study is not a systematic analysis of barrier properties of commercial protective overalls, it is just probably the first published analysis of the effect of the fabric moisture on the selected properties of this group of protective clothing. Therefore, the description of the structure and composition of the tested overalls is limited.

## MATERIALS AND METHODS

In order to study the barrier properties of disposable protective clothing, six types of protective clothing were obtained from the local market for the study [10]. The basic specifications of these clothing are given in table 1, whereas their shapes are shown in figure 1. In order to avoid any commercial aspects of this study, the overalls are characterized by code names only.

The data of square mass in brackets present the limits of the 95% confidence interval. Mean pore diameter was determined optically. However, the determination

Table 1

SOME CHARACTERISTICS OF PROTECTIVE OVERALLS USED IN THE STUDY [10]					
Sample code: PP or PE + square mass (g/m <sup>2</sup> )	Related standard	Composition	Structure	Mean pore diameter (µm)	Laminated foil
PP 65 (64.2 – 65.9)	EN 943-1	PP + PE	Nw* therm.bond	0.00	Yes
PE 44 (43.2 – 44.5)	EN 14605	Tyvek micro	Fs* therm.bond	7.49	Yes, porous
PE 43 (42.0 – 43.4)	EN 14605	Tyvek micro	Fs* therm.bond	322.00	Yes, porous
PP 41 (40.5 – 41.9)	EN 943-1	PP	Nw* therm.bond	71.94	No
PP 37 (36.6 – 37.7)	EN 14605	PP	Nw* therm.bond	100.80	No
PP 32 (31.3 – 32.3)	EN 13982-1	PP	Nw* therm.bond	163.50	No

Note: Nw means nonwovens, Fs is the nonwoven layer consisting of flash spun fibres, PP means polypropylene, PE is polyethylene



Fig. 1. Various types of protective overalls [9]

of the geometrical porosity was not meaningless, due to the lamination and thermal bonding by a calender with a structured surface. It was found, that the sample PP 65 which is also laminated with the nonporous PE foil on the face side, exhibits the highest hydrostatic and wear resistance.

### Measuring methods and instruments

#### Wetting of the samples

The samples were first kept at standard laboratory conditions for 24 hours and then weighted, in order to determine their reference square mass. Then, the samples were immersed for 6 hours in a large volume of distilled water with 1% of special detergent to get their full saturation by the liquid. Then, the samples were dried with towels in a stepwise manner on both sides and each sample was carefully weighed before each measurement. Due to the small size of the samples (12 cm × 12 cm), this method offers quite uniform moisture distribution, as verified at least 10 times [7]. Simulated sweat was not used in this case, as the salt causes corrosion of the hotplate in the used Skin model.

#### Air permeability

Air permeability can be characterized by the rate of volumetric airflow  $Q$  in  $m^3/s$  or derived units, passing perpendicularly through a known area  $A$  in  $m^2$  under a prescribed air pressure drop  $\Delta p$  in Pa between two surfaces of material with thickness  $H$  in m. The airflow should respect the following Darcy law either at a fixed pressure drop or at a fixed airflow rate  $Q$  ( $K$  is the permeability and  $\mu$  means the viscosity):

$$Q/A = K \cdot \Delta p \cdot \mu^{-1} \cdot H^{-1} \quad (1)$$

Permeability of the studied samples was determined according to the ISO 9237 by means of the FX 3300 instrument (TEXTTEST) at the pressure drop 200 Pa. Each sample was measured 10 times.

#### WV permeability

As regards the testing of WV permeability of wet clothing, these data are rare [6–9] as this unique parameter cannot be determined by any widely used gravimetric WV permeability testing method [11]. Standard Skin model-based WV permeability or resistance testers are too slow, to keep the sample wet during the testing. Therefore, there are no standards on WV permeability of clothing in wet state. Thus, the PERMETEST fast Skin model is probably the only tester, which enables reliable determination of WV permeability and thermal resistance [11, 12] of fabrics in wet state.

The PERMETEST commercial instrument used in this study enables the determination of relative WVP [%] and evaporation resistance  $R_{et}$  in  $m^2Pa/W$  of dry and wet fabrics within 3–5 minutes. The measuring head of this small Skin Model is covered by a semi-permeable foil, which avoids the liquid water transport from the measuring system into the sample. Cooling flow caused by water evaporation from the thin porous layer is recorded by a special sensing system and evaluated by a computer. The results are

treated statistically [11]. The PERMETEST testing does not require the preparation of samples of any special dimensions; the testing is non-destructive [4]. Following the ISO 11092 Standard, the measurement results can be expressed in terms of water vapour resistance  $R_{et}$  in  $m^2Pa/W$ , from the relationship:

$$R_{et} = C \cdot (p_{wsat} - p_{wo}) \cdot (q_o^{-1} - q_s^{-1}) \quad (2)$$

where  $q_s$  and  $q_o$  mean non-calibrated heat losses of the wetted measuring head in a free state and covered by a sample. The values of water vapour partial pressures  $p_{wsat}$  and  $p_{wo}$  in Pa in this equation represent the water vapour saturate partial pressure valid for the temperature of the air in the measuring laboratory  $t_o$  (22–25°C), and the partial water vapour pressure in the laboratory air. The constant  $C$  will be determined by the already mentioned calibration procedure. Special hydrophobic polypropylene reference fabric for this purpose is delivered with the instrument.

Besides the water vapour resistance, also the relative water vapour permeability of the textile sample  $P_{wv}$  can be determined by the instrument, where  $P_{wv} = 100\%$  presents the permeability of free surface. This practical parameter is given by equation 3.

$$P_{wv} (\%) = 100 \cdot q_s / q_o \quad (3)$$

However, the determination of WV permeability of wet fabrics by Skin models is quite complicated. As it can be seen in figure 2, total cooling flow from the wet fabric consist of cooling flow  $q_{fab,surf}$  which is given by the moisture evaporation from the surface of the wet fabric (dashed line) and cooling flow  $q_{skin}$  caused by the sweat evaporation from the skin. When the investigated wet fabric is placed directly on the porous measuring surface of the PERMETEST tester, then the Skin model sensing head records the sum of both cooling flows,  $q_{tot}$ . The new measurement principle involves another measuring step, depending on covering the wet porous surface of the tester with a thin non-permeable foil. In the following step, the wet sample is placed again in the instrument, but this time over this non-permeable foil, which stops moisture transfer from the skin. Thus, the instrument measures the cooling flow  $q_{fab,surf}$  only, which is given by the moisture evaporation from the surface of the wet fabric. The difference between the  $q_{tot}$  and the  $q_{fab,surf}$  then presents the effective

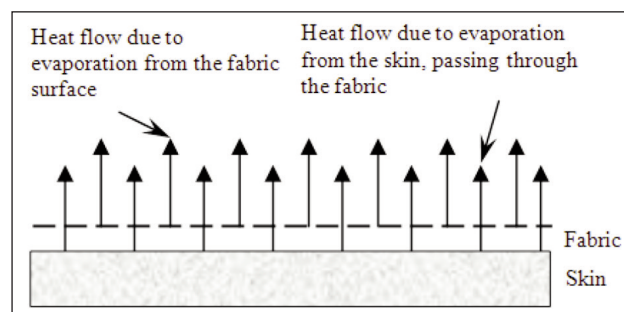


Fig. 2. Cooling effect from the wet fabric surface and passing from the skin through the wet fabric [6]



relative WV permeability of the proper samples – see the theory in [4]. The clothing wearer will feel the negative effect of the reduced WV permeability in cases when there is a gap between the wet outer fabric and the skin, as indicated in figure 2 [4, 12].

#### Hydrostatic resistance

Hydrostatic resistance, also called “water column”, was determined by the SDL ATLAS tester “M018”, according to the ISO 811 standard. The resistance to passage of water through the circular fabric specimen of area 100 cm<sup>2</sup> mounted on a hydrostatic head was measured. Water was forced to penetrate through the fabric due to steadily increasing pressure and reading was taken when water penetrated the fabric. The mean pressure of water was measured by the height of water column in centimetres.

### EXPERIMENTAL RESULTS

#### Air permeability of the studied protective clothing

Examples of the structure of the studied samples are presented in figure 3. The dry state tests in figure 4 follow that clothing without the laminated foil and with lower areal density exhibits higher air permeability as compared to denser clothing, due to more open spaces per unit fabric area. In porous laminated fabrics PE44FP and PE43FP made of Tyvek the air permeability also increases with a decrease

in fabric density. However, laminated fabrics without open pores are practically impermeable for air. Figure 5 indicates a weak inverse relationship between air permeability and moisture content of the fabrics. The variation coefficient of air permeability of dry samples extended from 8% to 10%. The PE65 and PE44 fabrics are practically impermeable for air. Preparing fabrics of the same moisture level is very time consuming, thus avoiding repeated measurements on wetted samples and creating the error bars.

#### Water vapour permeability of the studied protective clothing

Water permeability (WV) test results of fabrics in dry state as shown in figure 6 indicate that WV permeability increased with the decrease of the areal density of the fabrics. Similarly, the evaporation resistance steadily decreased with a decrease in the areal density of the tested fabrics. The samples without lamination foil expressed very little evaporation resistance as compared to samples with lamination.

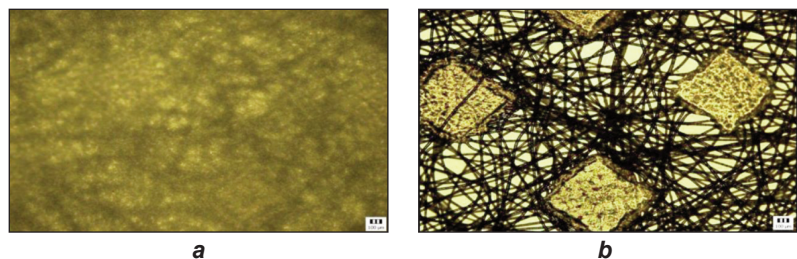


Fig. 3. Amplified picture of thermally bonded (calendered) samples: a – PP 65 (front); b – PP 37 (backside)

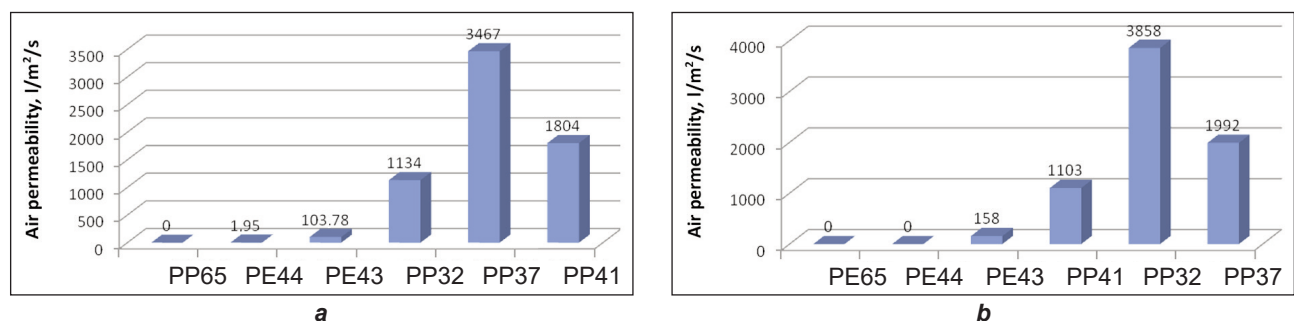


Fig. 4. Air permeability of samples: a – fabric relative moisture 50%; b – in dry samples

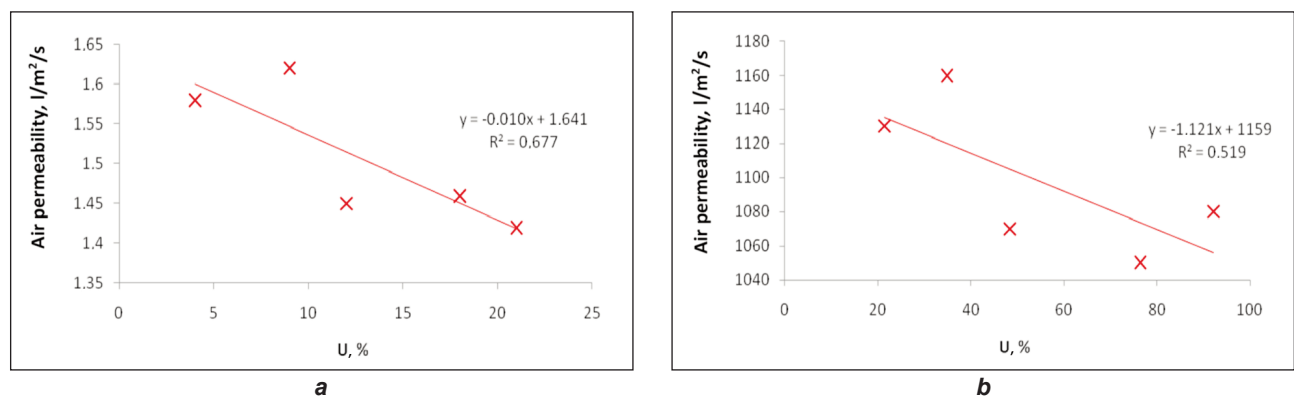


Fig. 5. Air permeability of fabrics at various levels of the relative moisture content U: a – PE43; b – PP32

Higher water vapour permeability enables higher evaporation cooling, thus offering higher thermal comfort to a wearer (figure 7).

The variation coefficient of PP 65, PE 44 and PE 43 samples was about 11%, whereas CV of other samples was 1.1% – 2.8% only.

Effective relative water vapour permeability ERWVP was calculated for all studied samples (bottom red line) as the function of the relative moisture related to the ultra-dry sample. Top blue lines indicate the total cooling flow from the wet fabric  $q_{tot}$  and the green medium line presents the cooling flow  $q_{fab,surf}$  from the wet fabric surface (figure 8). As preparing fabrics with the same moisture level is practically impossible,

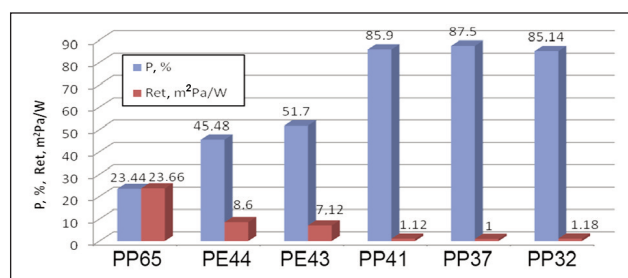


Fig. 6. Relative WV permeability (in blue) and evaporation resistance  $R_{et}$  [ $m^2Pa/W$ ] of dry samples

the measurements were not repeated. Therefore, the error bars are not presented in the diagrams.

Error bars are missing again, as preparing fabrics with the same moisture level is practically impossible and repeated measurements are not achievable.

### Hydrostatic resistance test results

The hydrostatic resistance test results (figure 9) in fact also involve wet state of the tested fabrics. From the experiments follows, fabrics with higher areal density showed higher hydrostatic resistance (higher values of water column height). Similarly, the laminated samples also showed higher hydrostatic resistance.

Statistical treatment of the results is missing, as during the measurement of hydrostatic resistance the fabric samples are destroyed.

### Evaluation of results

The study follows, that half of the investigated protective coveralls are practically impermeable for air, as their apparent “pores” caused by thermal calandering with outstanding segments (figure 3) are not open. On the other hand, the air permeability of the resting protective fabrics at the 50% fabric humidity

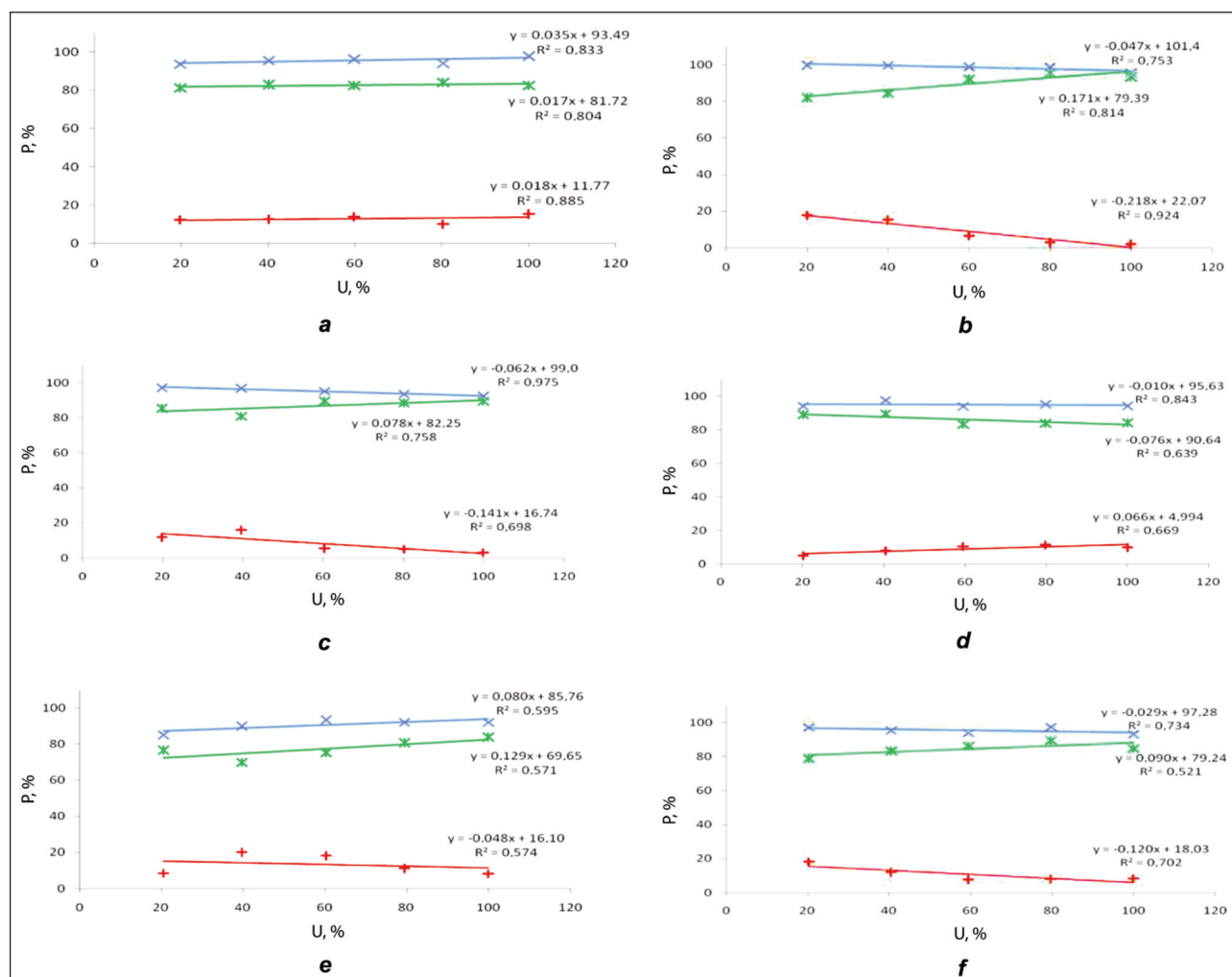


Fig. 7. Relative WV permeability of the sample: a – PP65; b – PE44; c – PE43; d – PP41; e – PP37; f – PP32

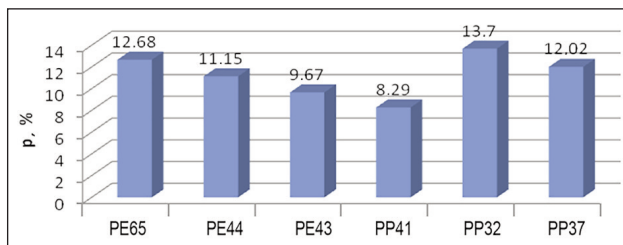


Fig. 8. ERWVP of all samples at their 50% relative moisture

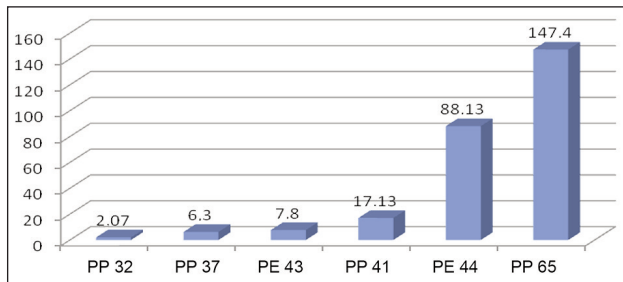


Fig. 9. Hydrostatic resistance of the studied protective coveralls in centimetres of the water column

level was almost the same as their air permeability in dry state.

Regarding the very important parameter of thermophysiological comfort, water vapour permeability, all materials are permeable for water vapour, but in dry state, fabrics made of PP were almost 2 times more permeable than PE (Tyvek) based fabrics. The relative WV permeability of the protective fabrics made of PP fibres was even excellent, but contrary to this (as expected), their hydrostatic resistance was very low. The presence of water in the tested samples reduced their effective WV permeability significantly, which might cause wearing discomfort to their user.

## CONCLUSIONS

Protective clothing must offer to its wearer optimum thermal resistance, the highest possible WV permeability and also with certain hydrostatic resistance, namely under real conditions of its use. One of these conditions which deteriorate the wearing comfort of protective clothing is the liquid moisture absorbed in fabrics. As stated in the presented paper, standard testing instruments mostly do not allow reliable testing of the effect of moisture on the thermophysiological comfort of clothing.

In this study, a special testing instrument was presented, which enables to measure water vapour permeability and thermal resistance of wetted fabrics within a few minutes. By means of this unique instrument and other instruments, water vapour permeability, air permeability and hydrostatic resistance of 6 wetted protective coveralls were determined. The main finding of the study is that due to the absorbed moisture, the effective relative water vapour permeability of the studied clothing gets substantively reduced, as well as their air permeability. Thus, using the coveralls tested in the study under real conditions of their use characterised by elevated moisture content would certainly cause a seriously reduced level of their wearing comfort and would influence negatively the performance of the user. It is important to emphasise that the mentioned findings, even if practically perceived and understood, was in this paper probably the first time characterized quantitatively. The above-demonstrated possibility of quantitative evaluation of thermophysiological comfort of protective clothing in wet state should enable an advanced design of this clothing with higher water vapour and air permeability even under real wearing conditions. The research in this area will continue.

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