

THE EFFECT OF FINISHING TREATMENT ON THERMAL INSULATION AND THERMAL CONTACT PROPERTIES OF WET FABRICS

BİTİM İŞLEMLERİNİN ISLAK KUMAŞLARIN ISIL İZOLASYON VE ISIL TEMAS ÖZELLİKLERİNE ETKİSİ

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ABSTRACT

Comfort properties of textiles became important part of marketing of clothing with high added value in last decades. The most important parameters characterizing thermo physiological comfort of sport and protective garments are thermal resistance and water vapour permeability. Contrary to common textiles, protective and functional garments and some technical textiles are also used in wet state, which affects their comfort properties. However, these properties can be improved by application of special finishing agents. The objective of this paper is to investigate the effect of moisture on thermal comfort properties of 3 different cotton fabrics which were subject to 5 different finishing treatments. Thermal conductivity, thermal resistance, thermal absorptivity and water vapour permeability of fabrics in dry and wet state were measured. Wet state of the studied fabrics was achieved by means of the so called "sweating impulse". The achieved results were treated by means of advanced statistics and displayed in diagrams. It was found the presence of moisture affected substantively all thermal-insulation and thermal-contact properties.

Key Words: Wet state, Thermal resistance, Thermal absorptivity, Water vapour permeability, Finishing treatment, Analysis of variance.

ÖZET

Son yıllarda, yüksek katma değerli giysilerin pazarlanmasında tek stillerin konfor özellikleri önemli bir yere sahiptir. Spor ve koruyucu giysilerin ısı konfor özelliklerini karakterize eden en önemli parametreler ısı direnç ve su buharı geçirgenliğidir. Klasik tekstillerin aksine, koruyucu ve fonksiyonel giysiler ve bazı teknik tekstiller ıslak durumda da kullanılmakta ve bu durum konfor özelliklerini etkilemektedir. Ancak bu özellikler özel bitim işlemi uygulamaları ile geliştirilebilir. Bu çalışmanın amacı nemin, 5 farklı bitim işlemi uygulanan 3 farklı pamuklu kumaşın ısı konfor özelliklerine etkilerinin incelenmesidir. Bu kumaşların ısı iletkenlik, ısı direnç, ısı soğurganlık ve subuharı geçirgenliği özellikleri kuru ve ıslak durumda test edilmiştir. Kumaşları ıslatma işlemi "terleme impulsu" adı verilen yöntemle gerçekleştirilmiştir. Elde edilen sonuçlar istatistiksel olarak değerlendirilmiş ve grafiklerle gösterilmiştir. Kumaş tanem bulunmasının, tüm ısı izolasyon ve ısı temas özelliklerini önemli derecede etkilediği bulunmuştur.

Anahtar Kelimeler: Islak durum, ısı direnç, ısı soğurganlık, Su buharı geçirgenliği, Bitim işlemleri, Varyans analizi.

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1. INTRODUCTION

Comfort of clothing plays important role during many human activities. Clothing should keep humans in the state of psychological, sensorial and thermo physiological comfort, i.e. state of wellbeing when the person is able to work for long time (1).

Contrary to common textiles, protective and functional garments and

some technical textiles like textile dressings are, due to sweat sorption, rainy climate or some technological reasons, also used in wet state, which affects their comfort properties.

The effect of fibre type, blend level or fabric structure on water vapour transmission werestudied by several authors (2-4).Özdil at al. (5) found that yarn count and yarn twist exhibit also

certain effect on the liquid transport properties of fabrics. Irandoukht S. and Irandoukht A. presented in (5) some nonlinear models for prediction of water vapour resistance of fabrics based on fibre volume, air permeability, weight and thickness of the fabric models, which give very good results. However, all models were proposed for fabrics in dry state only.

Moisture can change many parameters of clothing comfort, but the most important for the wearer of wet clothing are three principal components of thermo physiological and thermal contact comfort of garments: thermal resistance in wet state, thermal absorptivity in wet state and cooling flow resulting from the following mechanisms:

- moisture evaporation from the skin and passing through the clothing,
- direct evaporation of sweat from the fabric surface.

Both mentioned parameters could be improved by application of special finishing agents on the individual fabrics creating the clothing. The influence of sweating on thermal comfort properties is discussed in study (7). It is shown that mercerization has significant influence on thermal properties of knits produced from carded or combed yarns. Increasing content of moisture also has the influence on friction coefficient which increases to limit 40% of moisture regain (8).

In the paper the effect of two type hydrophobic finishes, one softening finish, sanforisation and temporary inflammable finish on thermal comfort properties of three cotton fabrics with square mass 0.145, 0.2 and 0.24 (kg.m⁻²) were investigated. For each of these finishes three concentrations were applied.

The mentioned thermal comfort properties involved thermal conductivity, thermal resistance, thermal absorptivity, relative water vapour permeability, evaporative resistance and air permeability. Wet wearing conditions were simulated by means of the so called "sweating impulse, depending in the application of 0.3 ml of water in the middle of the tested sample.

In the first part of the paper, special measuring instrument for the measurement of thermal conductivity of fabrics in wet state and to experimental determination of thermal conductivity of selected woven fabrics in wet state are described. These instruments exhibit one special advantage when measuring the fabrics in wet state: time of measurement is so short, that during the measurement the sample is kept fully wet, which improves the measurement precision. That is why current measuring instruments for the evaluation of thermo physiological comfort of fabrics cannot be used in such research, as they require more than 30 minutes for full reading, which causes humidity decrease during the measurement. That is also the reason why papers characterising thermal comfort properties of fabrics in wet state are almost missing in the literature. The only few papers were published Schneider et al. (9), and by Ren and Ruckman (10). None of these authors investigated the effect of finishing on thermal comfort of wet fabrics.

2. MATERIAL AND METHOD

2.1. Materials

As already stated, protective and functional garments and some technical textiles are also used in wet state, which affects their comfort properties (10, 11). These properties depend not only on the fabrics structure and composition, but also on their finishing treatment, as mentioned in the previous chapter.

In this study, we focused on the effect of 5 different finishing treatments on 100 % cotton fabrics differing in their square mass – see the next Table 1.

In present time properties as waterproof, size stability and pleasant r yor required for many types of

functional garments. On the other hand very good thermophysiological comfort has to be maintained. Therefore 2 types of hydrophobic, softening and sanforisation (to prevent shrinking) finishes were tested. The cotton fabrics are often used for production of protective garments exposed to higher temperatures. In addition temporary inflammable finish was applied and changes in thermophysiological comfort were observed, too.

Three concentration levels of all types of finishes were used in the experiments. The water dispersion of r yor (marked as HP1) and silicone (HP2) based hydrophobic finishes were applied. The sanforisation (SA) was achieved by means of product based on dimethyloldihydroxyethyleneurea – DMDHEU, softening using the products based on non-ionic ammonium compound with addition of stabilizing substances (SO) and inflammable finish (IF) was realized using the product based on the etherification of (NH₄)₂HPO₄ on cellulose. The applied concentrations of the single finishes are presented in Table 2 and processes of the used finishing treatments are in Table 3. Three measurements were realized for all types of finishes and stages of concentrations.

It should be noted, that the fabrics treated with hydrophobic finishes do not absorb liquid water, but in our case the distilled water simulating the sweat impulse contained 0,1% of r yor wetting agent, and the water drops were during the measurement subject to vertical pressure originated by the falling measuring head. Thus, water entered into the fabric structure and caused some changes of thermal parameters of the fabrics, despite their hydrophobic treatment.

Table 1. Fabric details

Sample	Areal weight (g/m ²)	Sett – warp (threads/1 cm)	Sett – weft (threads/1 cm)	weave
W140	145	26	23	Plain
W200	200	41	20	Atlas
W240	240	32	18	Twill

Table 2. Applied finishes and concentrations

sample	level of concentration	finish (g.g ⁻¹ - grams of product per gram of fabric)				
		HP1	HP2	SA	SO	IF
No.1	Level 1	0,054	0,01	0,026	0,015	0,07
	Level 2	0,066	0,021	0,037	0,024	0,09
	Level 3	0,081	0,03	0,05	0,03	0,111
No.2	Level 1	0,057	0,01	0,029	0,013	0,07
	Level 2	0,076	0,02	0,042	0,025	0,096
	Level 3	0,09	0,03	0,055	0,033	0,126
No.3	Level 1	0,053	0,01	0,028	0,016	0,07
	Level 2	0,069	0,019	0,04	0,023	0,09
	Level 3	0,086	0,03	0,05	0,031	0,12

Table 3. The course of the sample preparation

finish				
HP1	HP2	SA	SO	IF
sample size for all types of finishes: 0.3 x 0.21 cm				
preparation of padding bath with required concentration				
padding				
hot air drying at 130°C, 5 min	hot air drying 155°C, 5 min	hot air drying 100°C	hot air drying 80°C	hot air drying 100°C
		baking 160°C, 4 min		baking 155°C, 15 min
ironing				

The measurements were carried out on the instruments ALAMBETA (12), PERMETEST (13) and TEXTEST FX 3300. All of them provide reliable non-destructive measurements connected with thermo physiological comfort.

2.2. Measured properties

a) Thermal properties of textiles

Thermal properties of textiles such as thermal resistance, thermal conductivity and thermal absorptivity are influenced by fabric properties such as structure, composition, density, humidity, and properties of fibres, surface treatment, temperature and other factors (10, 11). Thermal properties were measured on the Alambeta device (12).

Thermal conductivity λ of polymers is quite low, ranging from 0.2 to 0.4 W/(m.K), and that of textile structures generally reaches levels from 0.033 to 0.1 W/(m.K). Thermal conductivity of steady air by 20°C is 0,026 W/(m.K), while thermal conductivity of water is 0.6 W/(m.K), which is 25 times more. That is why the water presence in textile fabrics is undesirable.

Thermal resistance R (thermal insulation value) depends on fabric thickness h and thermal conductivity λ :

$$R = \frac{h}{\lambda} \quad (\text{m}^2\text{K/W}) \quad (1)$$

Thermal absorptivity b of fabrics was in 1987 introduced by Hes (7) to characterise thermal contact feeling during short contact of human skin with the fabric surface. For time of thermal contact τ between the human skin and the fabric shorter than several seconds, the measured fabric can be simplified into semi-infinite homogenous mass with thermal capacity ρc (J/m³) and initial temperature t_2 . Unsteady temperature field between the human skin (with temperature t_1) and fabric

with respect to of boundary conditions offers a relationship, which enables to determine the heat flow q (W/m²) course passing through the fabric:

$$q = \frac{b(t_1 - t_2)}{\sqrt{\pi \tau}} \quad \text{where}$$

$$b = \sqrt{\rho c} \quad (\text{Ws}^{1/2}/(\text{m}^2\text{K}))$$

Where ρc (J/m³) is thermal capacity of the fabric and the term b presents thermal absorptivity of fabrics. The higher is thermal absorptivity of the fabric the cooler is its feeling. In the textile praxis this parameter ranges from 20 Ws^{1/2}/(m²K) for fine nonwoven webs to 600 Ws^{1/2}/(m²K) for heavy wet fabrics.

b) Water vapour permeability

The used PERMETEST instrument enables the determination of relative water vapour permeability P_{WV} (%) and evaporation resistance R_{et} (m²Pa/W) of dry and wet fabrics within 3-5 minutes. Cooling flow caused by water evaporation from the thin porous layer is immediately recorded by a special sensing system and evaluated by the computer (10).

Results of measurement can be expressed in terms of the water vapour resistance R_{et} defined in the ISO 11092 Standard, according to the following relationship:

$$R_{et} = (p_{wsat} - p_{wo}) \left(\frac{1}{q_a} - \frac{1}{q_s} \right) = C(100 - \varphi) \left(\frac{1}{q_a} - \frac{1}{q_s} \right) \quad (3)$$

Here, q_s and q_o mean heat losses of moist measuring head in the free state and covered by a sample. The values of water vapour partial pressures p_{wsat} and p_{wo} (Pa) in this equation represent the water vapour saturate partial pressure valid for 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 can be determined by the calibration procedure.

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 the relation

$$P_{WV} = 100 \frac{q_s}{q_a} \quad [\%] \quad (4)$$

c) Air permeability

This parameter was measured by means of the non-destructive instrument TEXTEST FX 3300 instrument at the pressure drop 200Pa. The measurement procedure is fully described at the ISO 811 Standard. The relative water vapour permeability, evaporative resistance and air permeability has been measured in dry state only.

3. RESULTS AND DISCUSSION

For data analysis the one-way analysis of variance was used. Generally, hypothesis H_0 means that effects of factor X are the same and the factor X has no influence on the observed property. All F -tests were realized for level of significance $\alpha=0.05$. The hypothesis H_0 is accepted for $\alpha \geq 0.05$. For $\alpha < 0,05$ the hypothesis H_0 is omitted and alternative hypothesis H_1 is accepted, where H_1 means, that at least one of effects is differed from the other for the factor X . Calculations were carried out by means of the statistical software STATISTICA 9.

It was found that the concentration increase does not play statistically significant role in changes of all measured properties. Therefore, only comparisons between samples without

any finishes and with finishes are discussed in the following two chapters.

As regards thermal resistance, the concentration level of all kinds of finishes exhibits no statistically significant effect on this parameter.

a) *Thermal properties*

The reached results show that only sanforisation led to the statistically significant changes in all measured thermal properties in wet state and except thermal absorptivity also in dry state (see Table 3). The explanation depends in reduced porosity and increased thickness of the treated fabrics, due to thermally induced shrinking. Softening did not cause any significant changes in thermal properties, as it did not result in bigger structural changes. Other three finishes affected properties only in the single cases.

Application of both hydrophobic finishes led to the approx. 15 – 25% increase of thermal conductivity for textiles in dry state. Here, the mentioned increment has probably an origin in the increased mass of thermally more conductive polymer on fabric/fiber surface. Only for finish HP2 the increase was not statistically significant (Table 4 and Figure 1). For textiles in wet state the increase was not statistically significant or no changes were found, as the amount of water entering the studied samples during the sweating impulse simulation is quite low and moisture in the treated fabrics is mostly well conducted along

the fabric surface. Therefore, local concentration of moisture under the measuring sensor can be quite low, thus avoiding bigger changes in thermal properties of the studied fabrics. Similar results were also achieved for sanforised textiles in dry state, where the increase of λ was about 10% only. Increasing level of concentration has no statistical significance for other changes of thermal conductivity for all type of finishes.

Higher thermal resistance was found for both hydrophobic finish for textiles in dry state (probably due to reduced amount of moisture in fabrics), but for HP2 the change was not significant. The statistically significant changes were observed also for sanforisation and inflammable finish (growth) for textiles in dry state. For textiles in wet state following results were found: for hydrophobic finishes and softening no changes were recorded and for inflammable finish no significant growth was determined, probably due to good conduction of moisture along the fabric surface out of the measuring zone of the instrument. Only one difference of influence of finishes was found for sanforisation where application of this finish led to high increase of thermal resistance.

No changes or statistically not significant differences in thermal absorptivity were found for the most finishes for textiles both in dry and in wet state. The reasons of this behavior will be similar to the above mentioned reasons, only sanforisation led to the

significant decrease of thermal absorptivity for textiles in wet state, due to lower porosity, which caused lower local concentration of moisture.

b) *Relative water vapour permeability P_{WV} , evaporative resistance R_{et} and air permeability AP*

No trends or only statistically not significant differences were found for all these properties. Due to optimized, relatively low amount of the used finishing, small reduction of porosity only can be expected, which results in small changes of the above mentioned parameters.

All the effects of finishing treatment on relative water vapor permeability, evaporative resistance and air permeability are summarized in Table 5.

When evaluating the results in the Table 4, it is necessary to emphasize, that these results present just the relative changes in relation to the initial level of these results, either in dry or wet state. Thus, wet thermal conductivity of the tested fabrics is higher than thermal conductivity of these fabrics in dry state (see Fig. 1). Similarly, thermal absorptivity of the studied fabrics in wet state is higher (cooler) than this property measured on dry fabrics, and that inversely, thermal resistance of fabrics in wet state is lower than this in dry state. The results are in compliance with findings of Oğlakcioğlu and Marmarali (7).

Table 4. Generalized results of the effect of the finishing agents on thermal properties.

Finishing treatment	thermal conductivity λ		thermal resistance r		thermal absorptivity b	
	dry / wet conditions		Dry / wet conditions		dry / wet conditions	
	Dry	Wet	Dry	Wet	dry	wet
IF	increasing (n)	decreasing (n)	increasing (s)	increasing (n)	increasing (n)	decreasing (n)
SA	increasing (s)	decreasing (s)	increasing (s)	increasing (s)	decreasing (n)	decreasing (s)
HP1	increasing (s)	no trend	increasing (s)	no trend	no trend	decreasing (n)
HP2	increasing (s)	no trend	increasing (n)	no trend	no trend	decreasing (n)
SO	increasing (n)	increasing (n)	no trend	no trend	no trend	no trend

s – statistically significant change, n – statistically not significant change, $\alpha=0.05$.

Table 5. Generalized results of the effect of the finishing agents on water vapor and air permeability.

finishing treatment	relative water vapour permeability P_{WV}	evap. resistance R_{et}	air permeability AP
IF	decreasing (n)	increasing (n)	decreasing (n)
SA	no trend	no trend	no trend
HP1	no trend	no trend	decreasing (n)
HP2	no trend	no trend	no trend
SO	no trend	no trend	decreasing (n)

s – statistically significant change, n – statistically not significant change, $\alpha=0.05$.

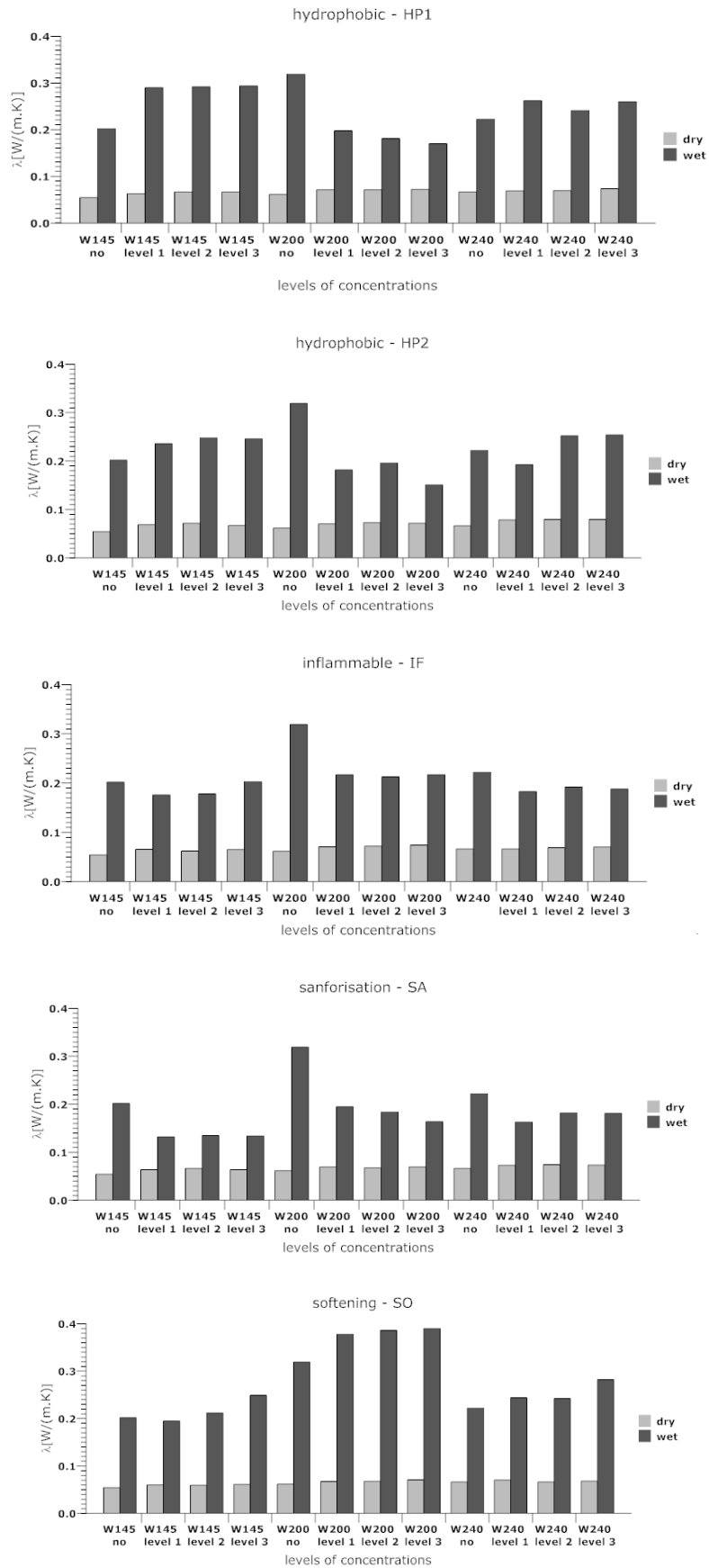


Figure 1. Comparison of thermal conductivity λ of textiles in dry and wet state under different concentrations of finishing agents.

4. CONCLUSION

The effect of two type hydrophobic finishes, softening finish, sanforisation and temporary inflammable finish on thermal comfort properties, such as thermal conductivity, thermal resistance, thermal absorptivity were studied. Measurements on dry fabrics were carried out under standard laboratory conditions. Wet state of the studied textiles was achieved by means of the so called "sweating impulse", based on the injection of 0.3 ml water in the middle of the tested sample. It was found that this simulation of sweating affected thermal properties of the studied fabrics quite substantively.

The highest influence was found for sanforisation, which caused substantial (up to one third) decrease of thermal conductivity of the studied fabrics in wet state. The wet thermal conductivity of the tested fabrics was higher than thermal conductivity of these fabrics in dry state. Similarly, thermal absorptivity of the studied fabrics in wet state was higher (cooler) than this property measured on dry fabrics, and that inversely, thermal resistance of fabrics in wet state was lower than this in dry state.

As regards the effect of various finishing treatments on relative water vapor permeability, evaporative resistance and air permeability, only

textile fabrics in dry state were studied. However, practically no changes of the mentioned fabric properties were found.

The effect of concentration of the used finishing agents on all the studied properties of fabrics both in dry and wet state was not observed.

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REFERENCES

1. Fanger P.O., 1974, "Thermal Comfort", McGraw-Hill. New York, USA.
2. Long H., 1999, "Water Transfer properties of Tow Layer Weft Knitted fabrics", *International Journal of Clothing Science and Technology*, 11(4), pp:198-205.
3. Yoo S.H., Barker R.L., 2004, "Moisture Management Properties of Heat Resistant Work Wear Fabrics Effects of Hydrophilic Finishes and Hygroscopic Fiber Blends", *Textile Research Journal*, 74(11), pp:995-1000.
4. Borhari S., Seirafianpour S., Ravandi S.A.H., Sheikhzadeh M., Mokhtari, R., 2010, "Computational and Experimental Investigation of Moisture Transport of Spacer Fabrics", *Journal of Engineered Fibers and Fabrics*, 5(3), pp:42-48.
5. Özdil N., Özcelik G., Süpüren G., Průchová J., 2009, "A Study on the Moisture Transportation properties of the Cotton Knitted Fabrics in Single Jersey Structure", *TekstilveKonfeksiyon*, 19 (3), pp: 218-223.
6. Irandoukht S, Irandoukht A., 2011, "Development of the predictive Models for the Fabric Water Vapour Resistance", *Journal of Engineered Fibers and Fabrics*, 6(2), pp: 40- 48.
7. Oğlakcioğlu N., Marmarali A., 2010, "Thermal Comfort Properties of Cotton Knitted Fabrics in Dry and Wet State", *TekstilveKonfeksiyon*, 20(3), pp: 213-217.
8. Hes L., Marmarali A., Oğlakcioğlu N., Özdil N., Lima N., 2008, "The Effect of Moisture on Friction Coefficient of Elastic Knitted Fabrics", *TekstilveKonfeksiyon*, 18(3), pp: 206-210.
9. Schneider A.M. et al., 1987, "Heat Transfer Through Moist Fabrics", PhD Thesis, University of New South Wales, Australia.
10. Ren Y., Ruckman J.E., 2003, "Water vapour transfer in wet waterproof breathable fabrics", *Journal of Industrial Textiles*, 32(3), pp: 165-175.
11. Hes L., 2007, "Thermal comfort properties of textile fabrics in wet state", In: *Proc. Izmir International Textile and Apparel Symposium*, Çeşme, Turkey.
12. Hes L., Dolezal I., 1989, "New Method and Equipment for Measuring Thermal Properties of Textiles", *Journal of Textile Machinery Society of Japan*, 35(8), pp: 124-128.
13. Dolezal I., Hes L., 2003, "P-TEST – Computerized Instrument Testing of the Water Vapour and Thermal Resistance of Fabrics", In: *Proc. of 2003 IEEE Internat. Symp. on Industrial Electronics*, Rio de Janeiro, pp: 5.