The liquid moisture management properties of low-temperature cured water-repellent cotton fabrics

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Received March 15, 2018

UDC 677.016.6
Original scientific paper

Water- and oil-repellency of cellulose fabrics can be achieved by fluorocarbon (FC) resin crosslinking at high temperatures in the condensation phase. However, FC resin, even after curing, is not resistant to care conditions, it is economically unfavorable, and leads to cotton fabric damage and very often to hue change. Previous studies revealed that it is possible to achieve durable water-repellency by low-temperature curing that lasts for 5 washing cycles if ironed in between cycles, applying FC resin Sevophob FTU with an addition of polymer waxes Sevophob W and aliphatic polyisocyanate Sevophob-Aktivator BLT. Since the moisture management is one of the key performance criteria regarding the comfort of functional fabric, in this paper the liquid moisture management properties were determined according AATCC TM 195-2017. The Moisture management tester (MMT) by SDL Atlas was used for the determination of liquid moisture management properties of white cotton fabrics before and after finishing as well as after 1, 3, and 5 washing cycles with and without ironing in between. The results indicate that the white cotton fabric is characterized as moisture management fabric, while all FC resin treated fabrics are characterized as Water penetration fabrics capable of excellent one-way transport.

Key words: *cotton, water repellency, low-temperature curing, moisture management*

1. Introduction

It is well known that fluorocarbon (fluorochemical) finishing agents (FC resin) are unique with critical surface tension values bellow 15 mN/m. As a result of forming a water-repellent and oil-repellent polymer film on its surface strongly decrease wettability of textile. This provides a level of protection to textile fiber surfaces against both aqueous and oily liquids, which confers upon FC-treated textiles both stain- and soil repellent properties. In finishing processes, it can be applied by itself or in combination with other chemicals in multifunctional finishing. It is necessary to achieve a uniform repellent treatment, so the wetting agent is preferred. After impregnation, the fabric is dried at temperatures of about 110 °C followed by heat-curing at a temperature normally in the range 150–170 °C in circulating hot air ovens or by single-pass treatment on a stenter. High curing temperature is economically unfavorable and can lead to damage and yellowing of the textile material [1-5].

Fluorochemicals exhibit outstanding chemical and thermal stability, which contributes to the durability of the surface finish to fabric maintenance such as laundering, dry cleaning and tumble-drying [1]. For the polyester fluorine-treated clothes it was subjected that the waterproof effect stays up to 30 laundry cycles [6]. Some researchers noticed that water repellency decreases with washing and partially recovers with ironing [4-6]. The performance depends upon the nature and length of the fluorocarbon chains, as well as curing procedure. It can be characterized through the dynamic repellency (spray rating, Bundesmann performance); static repellency (oil- and water-repellency); durability to domestic laundering; and the durability to dry-cleaning. All these parameters can be modified to optimize the performance [1, 5].

Within this group of authors, the oil- and water-repellency by low-temperature FC resin curing (120 °C) was researched on white and dyed cotton fabrics, and compared to high-temperature curing (160 °C) [7,8]. For that purpose FC resin by TextilColor (Swiss) were applied to cotton fabrics. Aqueous preparation of polymer waxes was added as extender to FC resin, and aliphatic polyisocyanate as low-temperature activator. The fabric properties were determined after treatments, domestic washing with standard ECE detergent without fluorescent whitening agents and ironing. The achieved results of fabric oil-repellency, water-repellency, whiteness, yellowing, and strength proved possibility of durable low-temperature curing. Treatment with cationic FC resin Sevophob FTU, with addition of polymer waxes Sevophob W, and aliphatic polyisocyanate Sevophob-Aktivator BLT resulted as semi-durable finish. It lasts for 5 washing cycles if ironed in between. If not ironed, finish effectiveness gradually diminish in repeated laundering cycles. It is to point out that the best results were achieved at low-temperature curing. Research of mechanical properties expressed as mechanical wear, U_m showed that low-temperature curing procedures almost reduced to half mechanical damage at low-temperature curing, if compared to high-temperature ones. If the fabrics were ironed between washing cycles the damage is even higher, because of action of heat and chemistry during textile care processes. Application of FC resins lower the whiteness, but no significant yellowing occurred, except when FC resin Sevophob FTU was applied with high temperature curing. After 1st washing cycle, the whiteness is better (probably some of resin has been removed), but after 5 washing cycles, some re-deposition happens and the results are lower. This is more enhanced for the ironed fabrics [7]. Best results were achieved on white cotton fabrics because reductive dyestuff reserves some crosslinking places. FC resin on dyed fabrics, even after curing, is not persistent to maintenance conditions - washing and ironing. Additionally, the shade of oil- and water repellent dyed fabrics changed as well [8].

The achieved results by ISO 4920:2012 (Spray test) and ISO 9865:1991 (Bundesmann rain shower test) showed that fabrics have significant water-repellent/water-resistant/water-proof character [7, 8]. Waterproof fabrics completely prevent the penetration and absorption of liquid water, water-resistant is the ability to resist the penetration of water to some extent but it is not entirely waterproof; whilst water-repellent only delay the penetration of water, allow the perspiration, making fabric more comfortable to wear [1]. However, for high levels of comfort, a fabric must allow air, and especially the moisture (water vapor) generated by the exudation of perspiration from the skin during physical activity, to pass through the fabric. This maintains the wearer of the garment in warm, dry conditions with high levels of thermophysical and thermophysiological comfort [9-14]. The moisture management is one of the key performance criteria regarding the fabric comfort. Moisture may transfer through fabric in liquid and in vapor form. As water vapor it can transfer by diffusion, absorption, transmission and desorption through fabric layers; as adsorption and migration along the fiber surface, and as transmission by forced convection; whilst the liquid moisture transfer through a fabric consists of two processes – wetting and wicking [9-17]. Wetting is a process when the fiber-air interface is replaced with a fiber-liquid interface. Wicking process follows wetting; it starts when the liquid enters into the capillary formed between two fibers or yarns by the capillary forces [15-17]. Spreading and absorption of the liquid over the surface of the fabric depends on the interaction between the forces of cohesion (within the liquid) and the forces of adhesion (between the fibers and the liquid). There is heterogenity of the test methods and of the time scales for wetting, wicking and absorption determination, which led to difficulties with the interpretation of the results. Drop test is quick test indicating if the material is hydrophilic or hydrophobic. The spray test is applicable to all fabrics which may or may not have been given a water-resistant or water-repellent finish. It is not intended to predict the rain penetration resistance of fabrics, since it does not measure penetration of water through the fabric. For that purpose Bundesmann test is appropriate. On the other hand, the liquid moisture management tester (MMT) was developed to measure the dynamic moisture transport in the fabric. For all these reasons, in this paper the liquid moisture management properties were determined according AATCC TM 195 – 2017 on Moisture management tester (MMT) by SDL Atlas on durable low-temperature cured water-repellent white cotton fabrics after treatment and after 1, 3, and 5 washing cycles with and without ironing in between.

2. Material and Methods

2.1. Material and treatments

White optically brightened damask fabric of mass per unit area 175 g/m^2,

Tab.1 The labels and the bath composition

Label	The treatment and/or bath composition
B	No treatment (Untreated – white optically brightened damask fabric)
FTU-A	Treatment with 40 g/l Sevophob FTU, 40 g/l Sevophob W; 4 g/l Sevophob-Aktivator BLT; 1 g/l Kemonetzer NI. Conditions: pH 5; T_D=80 °C for 4 min; T_C=120 °C for 4 min
FTU	Treatment with 40 g/l Sevophob FTU, 40 g/l Sevophob W; 1 g/l Kemonetzer NI. Conditions: pH 5; T_D=80 °C for 4 min; T_C=160 °C for 3 min

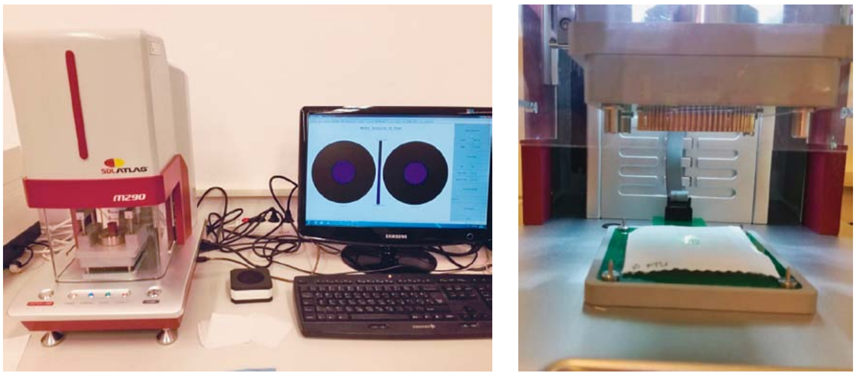
with possible application as table cloth, bedding or protective lab coat, was used for this research. It was treated by pad-dry-cure procedure in Benz Pad-dry system with Sevophob FTU, a cationic fluorocarbon resin (FC) by TextilColor (Swiss) for the permanent water, soil and oil repellent finish. Aqueous preparation of polymer waxes Sevophob W was added as extender to FC resin, and aliphatic polyisocyanate Sevophob-Aktivator BLT as low-temperature activator. The cotton fabric was padded (impregnated) in bath containing FC resin, 1 g/l Kemonetzer NI - nonionic wetting agent, having wet pick of 90 %. In continuous process impregnated fabric was dried (T_D) at 80 °C for 4 min and afterwards cured (T_C) at low-temperature of 120 °C for 4 min or at high-temperature of 160 °C for 3 min. The labels and the bath composition are listed in Tab.1.

For the purpose of determination durability of applied treatments, fabrics were laundered according to ISO 6330:2012 *Textiles - Domestic washing and drying procedures for textile testing* at 60 °C for 45 min with 2.5 g/l of standard ECE detergent without fluorescent whitening agents (ISO 105-C06:2010 *Textiles - Tests for colour fastness - Part C06: Colour fastness to domestic and commercial laundering)*. Fabrics were rinsed and air-dried. One set of fabrics was ironed between washing cycles at 200 °C on laboratory roller press iron, whilst the other one was not.

Before testing, all fabrics were conditioned for 24 h.

2.2. Methods

The evaluation and classification of liquid moisture management properties of fabrics were determined after treatment and textile care processes, according to *AATCC 195-2017 Liquid Moisture Management Properties of Textile Fabrics* on Moisture management tester (MMT) by SDL Atlas (Fig.1).



a) b)

Fig.1 Moisture management tester (MMT) by SDL Atlas at University of Zagreb Faculty of Textile Technology at Department of Textile Chemistry and Ecology: a) instrument during measurement, b) sample after testing

Tab.2 The major types of fabrics to describe fabric performance [19]

Type of Fabric	Fabric performance
Water Proof Fabric	- Very slow absorption - Slow spreading - No one-way transport, no penetration
Water Repellent Fabric	- No wetting - No absorption - No spreading - Poor one-way transport without external forces
Slow Absorbing and Slow Drying Fabric	- Slow absorption - Slow spreading - Poor one-way transport
Fast Absorbing and Slow Drying Fabric	- Medium to fast wetting - Medium to fast absorption - Small spreading area - Slow spreading - Poor one-way transport
Fast Absorbing and Quick Drying Fabric	- Medium to fast wetting - Medium to fast absorption - Large spreading area - Fast spreading - Poor one-way transport
Water Penetration Fabric	- Small spreading area - Excellent one-way transport
Moisture Management Fabric	- Medium to fast wetting - Medium to fast absorption - Large spread area at bottom surface - Fast spreading at bottom surface - Good to Excellent one-way transport

According to the AATCC TM 195-2017 [18] the obtained results are based on water resistance, water repellency and water absorption characteristics of the fabric structure, including the fabric's geometric and internal structure and the wicking characteristics of its fibers and yarns. In this paper the results are presented by the average values and CV for each fabric measurement unit: Wetting Time – WT T (top surface) and B (bottom surface), Absorption Rate – AR T and B; Maximum Wetted Radius – MWR T and B, Spreading Speed – SS T and B, Accumulative One-way Transport Capability – (R), and Overall (liquid) Moisture Management Capability (OMMC). Grading Summary Table e.g. Finger Print is given to summarize and illustrate the liquid moisture management properties of the tested fabrics [18,19]. Formulae for these units are given in the AATCC TM 195 in detail. According to the grading, the MMT can distinguish seven major types of fabrics to describe fabric performance (tab. 2) [19].

The MMT results are compared to the results shown in [7] achieved by AATCC TM 79-2014 *Absorbency of Bleached Textiles (Drop test)*; ISO 4920:2012 - *Textiles - Determination of resistance to surface wetting (spray test) of fabrics* and ISO 9865:1991 - *Textiles - Determination of water repellency of fabrics by the Bundesmann rain-shower test*, including the measuring results after 3rd cycle which were not presented before.

3. Results and discussion

In this paper, for the purpose of saving mechanical properties and energy, the low-temperature curing of FC resin was researched and compared with commercial high-temperature process. The durability was investigated up to 5 domestic washing cycles. One set of fabrics was ironed in between washing cycles, whilst the other was not. The fabric properties were determined after treatments, domestic washing and ironing. The achieved results of water absorbency by AATCC TM 79-2014 (Drop test); and repellency by ISO 4920:1981 (Spray test) and ISO 9865:1991 (Bundesmann rain shower test) presented in [7] are shown in Tab.2-4. For the purpose of determination of the liquid moisture management properties of such treated fabrics measurements according to AATCC TM 195-2017 were performed on Moisture management tester (MMT) by SDL Atlas. Results are presented in Tab.6-14 and Fig.2-10.

From the results of Drop test shown in Tab.3 it is quite evident that bleached cotton fabric (B) has excellent hydrophility, high water absorbency, and for that reason it does not have any water-repellency. It was expected after removal of all impurities of cotton in scouring and bleaching processes. The Wetting time (WT) measured on MMT is the time period in which the top and bottom surfaces of the fabric just start to get wetted, and can be compared with the absorbency drop test [19]. Therefore, the results of Wetting Time for bottom surface show similar behavior as

Tab.3 Drop test expressed as penetration time *t* [s] into the cotton fabrics

Fabric	Penetration time [s]				Penetration time [s] of ironed samples			
	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]
B	<1	<1	<1	<1	<1	<1	<1	<1
FTU-A	>300	>300	232	72	>300	>300	>300	>300
FTU	>300	>300	189	39	>300	>300	>300	>300

Tab.4 Resistance of surface wetting of cotton fabrics determined according to ISO 4920:2012 (Spray test)

Fabric	After treatment				Ironed			
	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]
B	ISO 0	ISO 0	ISO 0	ISO 0	ISO 0	ISO 0	ISO 0	ISO 0
FTU-A	ISO 5	ISO 4	ISO 2	ISO 2	ISO 5	ISO 4	ISO 5	ISO 5
FTU	ISO 5	ISO 4	ISO 2	ISO 2	ISO 5	ISO 4	ISO 4	ISO 5

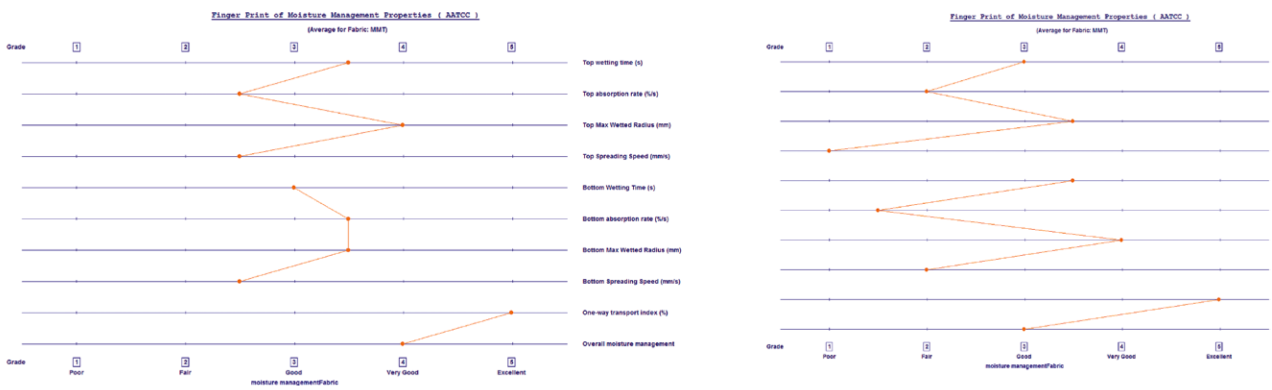
Tab,5 Bundesmann rain shower test on cotton fabrics determined according to ISO 9865:1991

Fabric	After treatment				Ironed			
	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]	Treatment	1st washing cycle [7]	3rd washing cycle	5th washing cycle [7]
B	1	1	1	1	1	1	1	1
FTU-A	5	3	2	2	5	4	4	5
FTU	4	2	2	2	5	3	4	4

Tab.6 The liquid moisture management properties of bleached cotton fabric acc. to AATCC TM 195-2017

B		Non-iron		Iron	
		Mean	CV	Mean	CV
WT (s)	T	5.101	0.091	11.747	0.051
	B	6.037	0.077	6.178	0.621
AR (%/s)	T	22.9974	0.6379	10.7120	0.0030
	B	50.1177	0.1142	9.5686	0.6690
MWR (mm)	T	20.0	0.4	17.5	0.2
	B	17.5	0.3	20.0	0.0
SS (mm/s)	T	1.9681	0.1097	0.9792	0.0030
	B	1.7449	0.2191	1.4656	0.4250
R (%)		638.5117	0.4191	575.6262	0.3110
OMMC		0.6735	0.0709	0.5445	0.0810
Type of fabric		*Moisture Management Fabric*		*Moisture Management Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC).



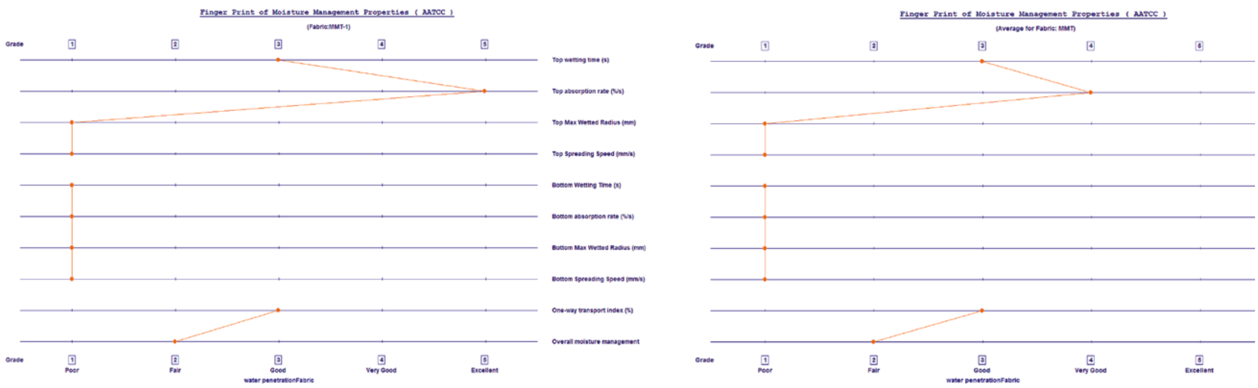
a) b)

Fig.2 Fingerprint of bleached cotton fabric acc. to AATCC TM 195-2017;
a) untreated, b) ironed

Tab.7 The liquid moisture management properties of cotton fabric at low-temperature curing (FTU-A) according to AATCC TM 195-2017 on MMT

FTU-A		After treatment		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	10.858	0.045	12.917	0.202
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	277.9407	0.1230	91.6903	0.2288
	B	0.0000	0.0000	0.0003	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.4527	0.0621	0.3816	0.1996
	B	0.0000	0.0000	0.0000	0.0000
R (%)		130.0939	0.0467	130.8122	0.7556
OMMC		0.2000	0.0220	0.2009	0.6289
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC).



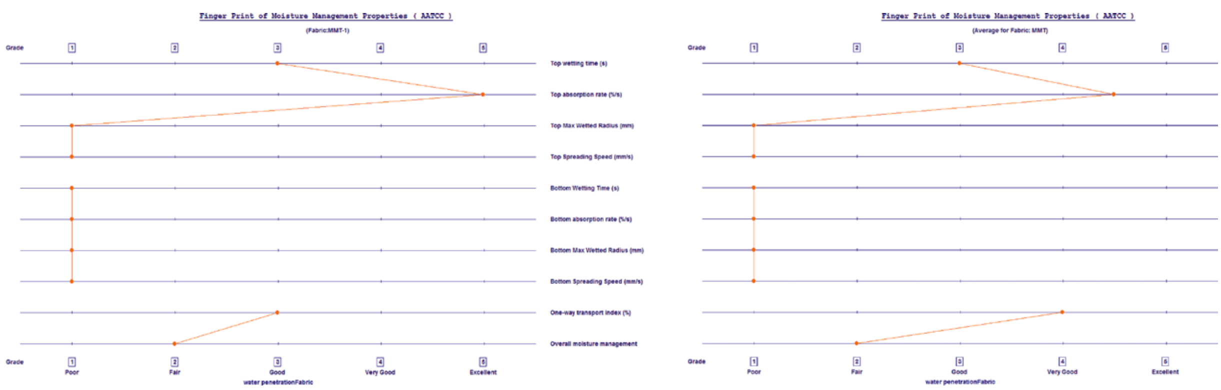
a) b)

Fig.3 Fingerprint of cotton fabric at low-temperature curing (FTU-A) according to AATCC TM 195-2017; a) after treatment, b) ironed

Tab.8 The liquid moisture management properties of cotton fabric at low-temperature curing (FTU-A) after 1st washing cycle according to AATCC TM 195-2017 on MMT

FTU-A – 1st washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	11.419	0.023	12.402	0.112
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	252.6480	0.4520	77.1283	0.0510
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.4308	0.0333	0.3996	0.1104
	B	0.0000	0.0000	0.0000	0.0000
R (%)		166.4751	0.2870	201.0065	0.3949
OMMC		0.2405	0.1454	0.2756	0.3153
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



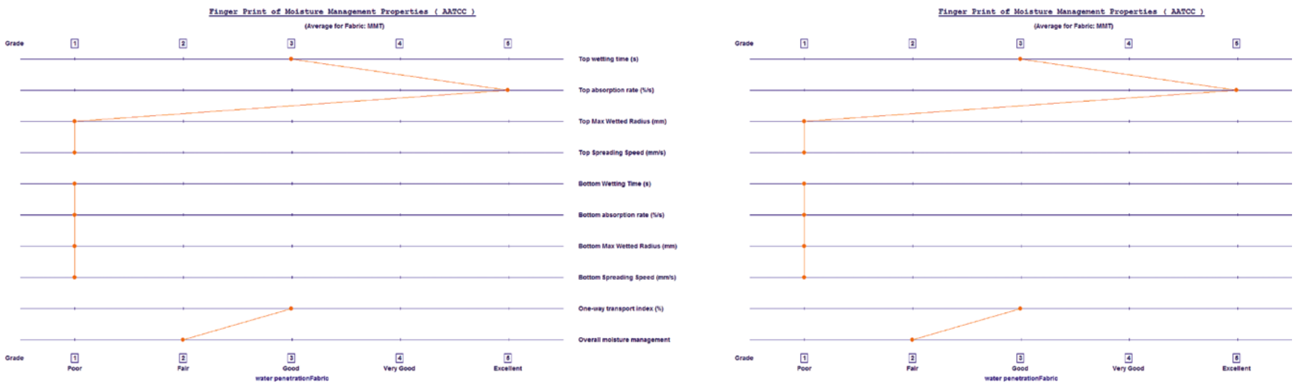
a) b)

Fig.4 Fingerprint of cotton fabric at low-temperature curing (FTU-A) after 1st washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed

Tab.9 The liquid moisture management properties of cotton fabric at low-temperature curing (FTU-A) after 3rd washing cycle according to AATCC TM 195-2017 on MMT

FTU-A – 3rd washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	12.683	0.110	13.666	0,114
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	186.4516	0.6109	105.9153	0.6570
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.3908	0.1080	0.3609	0.0981
	B	0.0000	0.0000	0.0000	0.0000
R (%)		165.9765	0.1239	180.5186	0.1410
OMMC		0.2400	0.0952	0.2561	0.0942
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



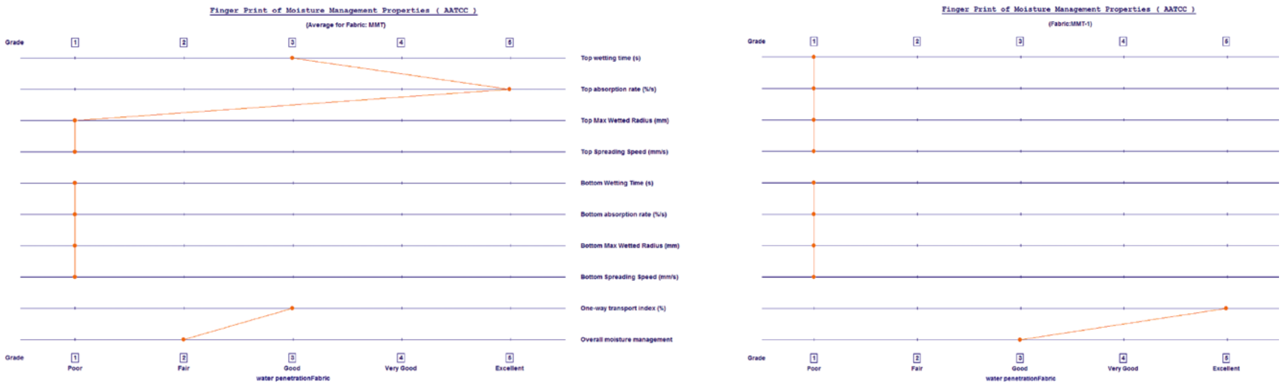
a) b)

Fig.5 Fingerprint of cotton fabric at low-temperature curing (FTU-A) after 3rd washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed

Tab.10 The liquid moisture management properties of cotton fabric at low-temperature curing (FTU-A) after 5th washing cycle according to AATCC TM 195-2017 on MMT

FTU-A – 5th washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	11.934	0.006	120.000	0.000
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	183,2365	0,7834	0.0000	0.0000
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	0.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0,4125	0,0055	0.0000	0.0000
	B	0.0000	0.0000	0.0000	0.0000
R (%)		173.3069	0.4605	951.2359	0.0000
OMMC		0.2481	0.3574	0.5000	0.0000
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



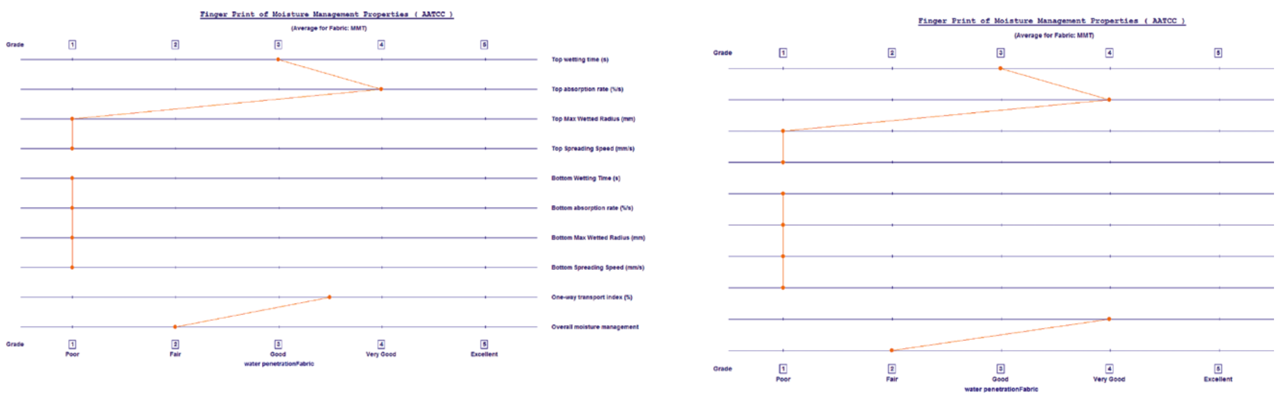
a) b)

Fig.6 Fingerprint of cotton fabric at low-temperature curing (FTU-A) after 5th washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed

Tab.11 The liquid moisture management properties of cotton fabric at high-temperature curing (FTU) according to AATCC TM 195-2017 on MMT

FTU		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	8.986	0.251	11.232	0.083
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	69.4906	0.2060	65.9511	0.1412
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.5620	0.2454	0.4393	0.0811
	B	0.0000	0.0000	0.0000	0.0000
R (%)		226.5444	0.1868	245.8310	0.0612
OMMC		0.3073	0.1530	0.3287	0.0509
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



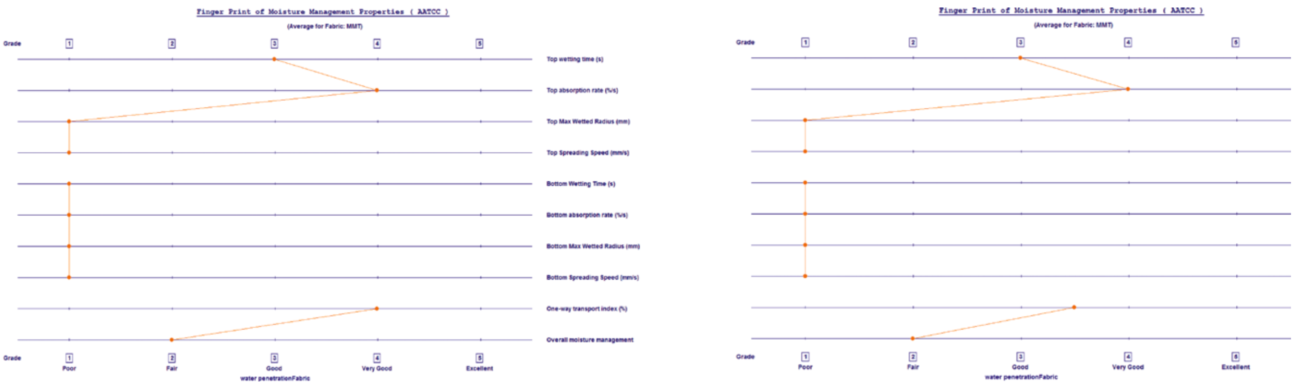
a) b)

Fig.7 Fingerprint of cotton fabric at high-temperature curing (FTU) according to AATCC TM 195-2017; a. not ironed, b) ironed

Tab.12 The liquid moisture management properties of cotton fabric at high-temperature curing (FTU) after 1st washing cycle according to AATCC TM 195-2017 on MMT

FTU – 1st washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	11.232	0.083	10.015	0.040
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	65.9511	0.1412	64.9676	0.0217
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.4393	0.0811	0.4904	0.0389
	B	0.0000	0.0000	0.0000	0.0000
R (%)		245.8310	0.0612	178.8243	0.0541
OMMC		0.3287	0.0509	0.2542	0.0423
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



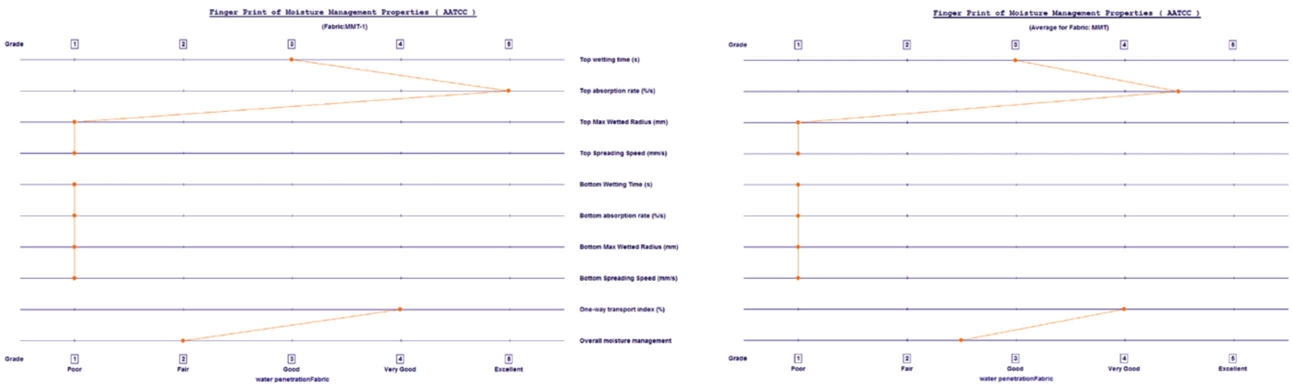
a) b)

Fig.8 Fingerprint of cotton fabric at high-temperature curing (FTU) after 1st washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed

Tab.13 The liquid moisture management properties of cotton fabric at high-temperature curing (FTU) after 3rd washing cycle according to AATCC TM 195-2017 on MMT

FTU – 3rd washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	12.075	0.045	13.759	0.092
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	258.7899	0.5342	70.1532	0.8295
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.4078	0.0435	0.3585	0.0909
	B	0.0000	0.0000	0.0000	0.0000
R (%)		248.8247	0.0000	319.1809	0.1641
OMMC		0.3320	0.0000	0.4102	0.1397
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



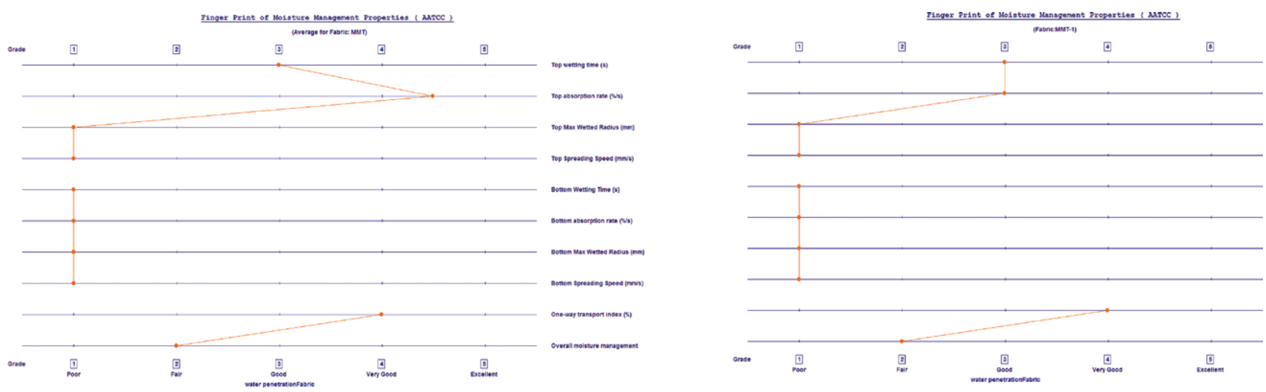
a) b)

Fig.9 Fingerprint of cotton fabric at high-temperature curing (FTU) after 3rd washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed

Tab.14 The liquid moisture management properties of cotton fabric at high-temperature curing (FTU) after 5th washing cycle according to AATCC TM 195-2017 on MMT

FTU – 5th washing cycle		Not ironed		Ironed	
		Mean	CV	Mean	CV
WT (s)	T	12.355	0.032	10.671	0.023
	B	120.000	0.000	120.000	0.000
AR (%/s)	T	66.9585	0.8166	44.3321	0.0932
	B	0.0000	0.0000	0.0000	0.0000
MWR (mm)	T	5.0	0.0	5.0	0.0
	B	0.0	0.0	0.0	0.0
SS (mm/s)	T	0.4078	0.0316	0.4605	0.0210
	B	0.0000	0.0000	0.0000	0.0000
R (%)		216.1456	0.0242	222.6697	0.0124
OMMC		0.2957	0.0197	0.3030	0.0054
Type of fabric		*Water Penetration Fabric*		*Water Penetration Fabric*	

*CV – coefficient of variation, T - top surface, B - bottom surface, WT - Wetting Time, AR –Absorption Rate; MWT – Maximum Wetted Radius, SS – Spreading Speed, R – Accumulative One-way Transport Capability, OMMC – Overall (liquid) Moisture Management Capability (OMMC)



a) b)

Fig.10 Fingerprint of cotton fabric at high-temperature curing (FTU) after 5th washing cycle according to AATCC TM 195-2017; a) not ironed, b) ironed drop test. It is evident that for the bleached cotton fabric bottom wetting time is 6 s regardless has the fabric been ironed or not. The maximum wetted ring radius of 20 mm for both the top and bottom surfaces. The average is given in table 6. Spreading speed that represents the accumulative spreading speed from the center to the maximum wetted radius is almost 2 mm/s for both - top and bottom surfaces. Cotton fiber has polar bonding sites for water molecules, which is the reason for high apsorption. Therefore, it has high absorption rate. Since there is a large spread area as well as fast spreading, having excellent one-way transport, this fabric is characterized as moisture management fabric. All these results prove that this fabric has excellent hydrophility.

The treatment with cationic FC resin Sevophob FTU, at both, low-temperature and high-temperature curing, according to the Drop test and Spray test indicate highly hydrophobic surface e.g. excellent water repellency. However, Bundesmann rain shower test showed the difference between the processes. Low-temperature curing with addition of activator (FTU-A) showed excellent water-repellency, whilst the high-temperature curing (FTU) resulted in slightly lower results. The results of Wetting Time for bottom surface confirm that. No bottom surface was wetted in test time of 120 s. Wetted radius of 5 mm, and small absorption rate is noticed only for top surface, and spreading speed is slow, whilst the spreading area is small. On the other hand, one-way transport is good for low-temperature cured fabric with addition of activator (FTU-A) and very good for high-temperature cured (FTU) fabric. Therefore, fabrics are characterized as water penetration fabrics, indicating good repellency but having water vapor perspiration.

Considering the results of washing and ironing, it can be seen that both processes resulted as durable finish. All achieved results are better after ironing in between washing cycles. That is consistent to the results of other researchers [4-6] who reported that water repellency decreases with washing and partially recovers with ironing. The most probable reason is the rotation of fluoroalkyl groups into the polymer substrate to avoid the hydrophilic conditions during washing [5]. The differences in results achieved by washing and ironing can be explained by wettability considerations. There are two systems to consider – 1. Cellulose-resin-water system during washing; 2. Cellulose-resin-dry gas system during ironing [4]. As a difference in surface energies in these systems, the rupture of FC resin during washing on the fiber surface occurs and the cellulose is in the contact with water. Drying, as evaporation of water, results in lower adhesion between of cellulose and resin. Therefore the results after washing are significantly lower. However, during ironing the coating melts and the difference between energies at the resin/dry gas interface and cellulose/dry gas one, results in uniform spreading of the resin at the surface, and the formation of resin bridges between the fibers.

The results of Bundesmann rain shower test after 5th washing cycle with ironing in between washing cycles indicate such a behavior. The results of MMT confirmed that. Wetting time and absorption rate are getting slower. This effect is more enhanced for low-temperature curing. For high-temperature cured fabric FTU after 5th washing absorption rate is lower, but for the fabric FTU-A after 5th washing and ironing cycle there is no wetting or absorption on the top surface either, suggesting completely hydrophobic fabric. This corresponds to Drop test results and the excellent evaluation marks for Spray test and Bundesmann rain show test.

Overall Moisture Management Capacity (OMMC) is an index to indicate the overall capability of the fabric to manage the transport of liquid moisture, which includes three aspects of performances: 1) Moisture absorption rate at bottom side, 2) One way liquid transport capability, and 3) Moisture drying speed at bottom side, which is represented by accumulative spreading speed [19]. Considering achieved results, it can be seen that bleached cotton fabric is characterized as moisture management fabric since it has fast absorption, fast spreading and large spread area at bottom surface and good one-way transport. All fabrics treated with FC resin, regardless the temperature, or ironing between washing cycles are characterized as Water penetration fabrics since they have small or none spreading area, but very good to excellent one-way transport.

4. Conclusion

In this paper the low-temperature curing of FC resins was researched and compared with commercial high-temperature process for the purpose of energy saving. The durability was investigated up to 5 washing cycles in between which one set of fabrics was ironed. The treatment with cationic FC resin Sevophob FTU, at both, low-temperature and high-temperature curing resulted as durable finish, which lasts for 5 washing cycles if ironed in between. If not ironed, finish effectiveness gradually diminish in repeated laundering. It is to point out that the best results were achieved at low-temperature curing when cationic FC resin Sevophob FTU was applied with addition of polymer waxes Sevophob W and aliphatic polyisocyanate Sevophob-aktivator BLT.

From the comfort point of view, moisture transmission through textile material both in liquid and vapor forms are equally important. For that reason, the dynamic moisture transport in these fabrics the liquid moisture management properties were determined according AATCC TM 195-2017 on Moisture management tester (MMT) by SDL Atlas after treatments and after 1st, 3rd, and 5th washing cycle with and without ironing in between. Considering the results, it can be seen that bleached cotton fabric is characterized as hydrophilic and moisture management fabric, whilst all FC resin treated fabrics are characterized as Water penetration fabrics with excellent one-way transport. In the case of low-temperature cured fabric FTU-A after 5th washing and ironing cycle there is no wetting or absorption on the top surface either, suggesting completely hydrophobic fabric, but one-way transport is still very good. Therefore, it is to suggest this process for achieving the best results of durable water repellency and one way transport.

Acknowledgements

The work has been supported by Croatian Science Foundation under the project 9967 Advanced textile materials by targeted surface modification. The authors thank the company TextilColor for donation of FC resin and auxiliaries.

References:

[1] Holme, I.: Fluorochemical Repellent Finishes in Textile Finishing, Chapter 5: Water-repellency and waterproofing, Society of Dyers and Colourists, Bradford, England, 2003, ISBN 0 901956 81 3
[2] Černe, L., B. Simončič, M. Željko: The influence of repellent coatings on surface free energy of glass plate and cotton fabric, Applied Surface Science 254 (2008.) 20, 6467–6477
[3] Černe, L., B. Simončič: Influence of repellent finishing on the surface free energy of cellulosic textile substrates, Textile Research Journal 74 (2004.) 5, 426–432
[4] Juhué, D. et al.: Washing Durability of Cotton Coated with a Fluorinated Resin: An AFM, XPS, and Low Frequency Mechanical Spectroscopy Study, Textile Research Journal 72 (2002.) 9, 832-843
[5] Sato, Y. et al.: Effect of Crosslinking Agents on Water Repellency of Cotton Fabrics Treated with Fluorocarbon Resin, Textile Research Journal 64 (1994.) 6, 316-320
[6] Wakida, T. et al.: The Effect of Washing and Heat Treatment on the Surface Characteristics of Fluorocarbon Resin-treated Polyester, Journal of the Society of Dyers and Colourists 109 (1993.) 9, 292–296
[7] Dekanić, T. et al.: The low-temperature curing for durable cotton oil- and water- repellency, Book of Proceedings of the 8th International Textile, Clothing & Design Conference, Zagreb, Croatia, 2-5. October 2016., 159-164, ISSN 1847-7275
[8] Dekanić, T. et al.: Postojanost vodo- i ulje-odbojnih apretura na pamučnim tkaninama na uvjete održavanja, Zbornik radova 10. znanstveno-stručnog savjetovanja Tekstilna znanost i gospodarstvo, Zagreb, Hrvatska, 24. siječnja 2017., 74-78, ISSN 1847-2877
[9] Tang, K.-P. M., C.-W. Kan, J. Fan: Evaluation of water absorption and transport property of fabrics, Textile Progress 46 (2014.) 1, 1-132, DOI:10.1080/00405167.2014.942582
[10] Das B. et al.: Moisture Transmission through Textiles, Part I: Processes involved in moisture transmission, AUTEX Research Journal 7 (2007.) 2, 100-110, DOI. http://www.autexrj.org/No2-2007/0236.pdf
[11] Das B. et al.: Moisture Transmission through Textiles, Part II: Evaluation Methods and Mathematical Modelling, AUTEX Research Journal 7 (2007.) 3, 194-216, DOI. http://www.autexrj.org/No3-2007/0236.pdf
[12] Das B. et al.: Moisture Flow through Blended Fabrics – Effect of Hydrophilicity, Journal of Engineered Fibers and Fabrics 4 (2009.) 4, 20-28
[13] Jhanji Y., D. Gupta, V.K. Kothari: Moisture management properties of plated knit structures with varying fiber types, The Journal of The Textile Institute 106 (2014.) 6, 663-673, DOI:10.1080/00405000.2014.934044
[14] McQueen R.H. et al.: Development of a protocol to assess fabric suitability for testing liquid moisture transport properties, The Journal of The Textile Institute 104 (2013.) 8, 900-905, DOI:10.1080/00405000.2013.764755
[15] Kissa E.: Wetting and Wicking, Textile Research Journal 66 (1996) 10, 660-668
[16] Ramachandran T., N. Kesavaraja: A Study of Influencing Factors for Wetting and Wicking Behaviour, IE (I) Journal-TX 84 (2004.) 37-41
[17] Grancarić A. M., E. Chibowski, A. Tarbuk: Slobodna površinska energija tekstila, Tekstil 57 (2008.) 1-2, 29-39
[18] AATCC 195-2017: Liquid Moisture Management Properties of Textile Fabrics, American Association of Textile Chemists and Colorists, 2018.
[19] M290 Moisture Management Tester, Instruction Manual, Rev. 1.4 (06/18) www.sdlatlas.com