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Investigation into the Wetting Phenomenon of Terry Fabrics

Abstract
This paper presents investigations into the wetting phenomenon of terry fabrics. Terry fabrics were manufactured using linen warp pile yarns. The high absorption ability of terry textile is acquired by increasing the capability of the moisture absorbing surface to retain liquid in its pores and internal pores of the textile material .The full process of liquid absorption was analysed, from the moment the drop falls onto the fabric's surface until the it is absolutely absorbed by the material, and the spot being changeless. The character of the wetting process depends on the fabric's characteristics, kind of impact and its lasting period e.g. a macerating impact shortens the absorption process. The wetting process is faster, lasting up to 130 s, in fabrics affected by washing operations. The means of changes in the area of the spot compared with the area at the starting moment are always larger in the case of terry fabrics with bleached warps compared with unbleached ones irrespective of kind of impact and duration. Experimental results are best described by polynomial equations. The determination coefficients of the equations obtained vary from 0.9711 to 0.9969.

Key words: *absorption, drop, impacts, terry fabric, wetting.*

Introduction

Terry fabric is the most popular fabric for home textiles such as towels, and bathroom and sauna textiles. This type of fabric is made with loop pile on one or both sides generally covering the entire surface. Such fabrics are produced by three systems of yarns: ground warp, weft, and pile warps. The pile can be formed on one side or on both sides by the pile warps. As one sided pile terry fabric has a low water absorbing capacity, it is not so popular. Pile characteristics have an important effect on the structure of terry fabric and others usage properties. The raw material used for weft, ground warp and pile warp as well as pile height provides the main parameters for design properties [1 - 3].

The qualities required for yarns used in terry fabrics are high absorbency, high wet strength, good wash-ability, and soft handle. When high quality is required, two or more ply yarns are used. The use of two-ply yarns also improves visual appearance. The pile loops generally consist of more highly twisted yarns which, while very absorbent, are quite abrasive and thus actively stimulate the skin during drying [1, 4 - 6].

The wetting phenomenon of textiles involves several primary processes: immersion, capillary sorption, adhesion and spreading. During immersion or capillary sorption, the solid-vapour interface disappears and a solid-liquid interface appears. When a liquid drop is placed on fabric, it will spread under capillary forces [7, 8].

Moisture absorption includes the ability of material to retain a liquid in its interstices, pores. Materials used for terry fabrics can be evaluated in terms of how quickly they absorb liquid moisture and the quantities absorbed [9]. Very important properties for terry fabrics are softness, dimensional stability, but hydrophility is the most significant one [10]. It was determined that there is no difference in the water absorption rate of terry towels made from open-end and ring-spun yarns; but maximum absorption was found at a lower fabric density. Karahan M. & Eren R. [2] found that the type of yarns used in the production of terry fabric had the most significant effect on their static water absorption properties. The warp and weft density and pile length also are significant characteristics. The effect of pile height, pile density, thickness, etc. on the surface water absorption characteristics and wicking phenomenon of different cotton terry fabric was investigated in [11]. The water absorption and wicking height increase with the thickness of the fabric.

Cotton and flax fibres are hydrophilic and can, therefore, absorb significant amounts of moisture [5, 6]. As more softeners during rinse cycle are absorbed into the cotton fibres, the wicking capacity of the fabric decreases due to the reduced capillary spaces in the fabric, which leads to a decrease in the water vapour transmission of the fabric [5]. The parameters affecting humidity absorption were theoretically investigated in [12]. The experiments [13] showed that water absorption increases with an increase in area density

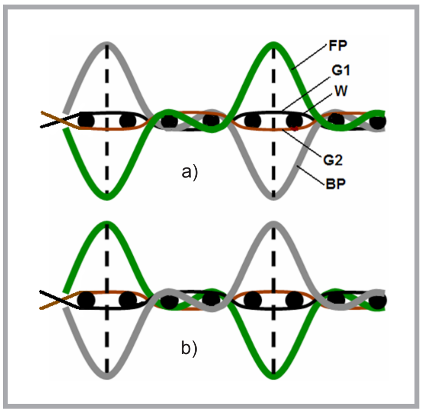

Figure 1. *Structure of the terry fabric: a - order of weave of the first FP and second BP warp , b - order of weave of the third FP and fourth BP warp, FP - front side pile warp, BP - rear pile warp, G1 – the first ground warp, G2 -the second ground warp, W – weft.*

and pile height. The percentage of water absorbed by fabrics with a high loop density is more than that of those having a lower loop density [14].

Wicking occurs when the fabric is completely or partially immersed in a liquid or in contact with a limited amount , such as a drop placed on the fabric. The authors in [15, 16] reported that in the case of fibrous structures and woven fabrics, the distribution of pores with different sizes along any planar direction is expected. The wicking rate and liquid transported in a fabric depend on these pore sizes and their distribution. When the smaller pores are completely filled, the liquid then moves to larger pores. The researchers in [17] studied the wetting properties of woven fabrics and their constituent single fibres. The authors in [18] compared non-softened cotton terry fabrics with fabrics treated using two different fabric conditioners. Wicking data for water and the perfectly wetting liquid n-octane show that fabric conditioners do not influence the absorption capacity of fabric, indicating that the physical parameters of fabric, such as porosity and pore size, are not changed by the use of fabric conditioner. The advantages and disadvantages of softeners were analysed in [19], examining their effect on the hydrophility and softness of towels.

Too much fabric softener would make the textile waterproof. The spatial/geometric distribution of fibres in a fabric might also play a significant role in water absorption. As the fabrics thickness and fibre volume percentage increase, resistance to water transmission also increases [5]. [17, 20 - 22] presented research on the effect of bleaching and scouring pre-treatment on the wettability of cotton fabrics. However, the experiments in these studies do not provide information about the speed of the wicking process. The vertical positioning of a fabric during the wicking process also induces gravitational effects, which influence the water absorption capacity [17, 21]. The wicking process is single dimensional, which causes differences in the wicking behaviour in the warp and weft direction [17].

The aim of this research is to investigate general tendencies of the wetting process of terry fabrics regarding the various impacts – water/heat/mechanical, also the finishing process – of industrial washing. The object of this study was selected because of a lack of research dealing with investigations into the behaviour of terry structure when in contact with liquid in general. We also sought to provide better understanding of the wetting phenomenon - from a finite 'reservoir' (drop wetting) until full absorption, of which the absorption capacity has the greatest significance.

Materials and method

Materials and fabrics

Our experiments were carried out with terry fabrics woven using unbleached linen and bleached linen in the pile warp (respectively LU and LB fabrics). The reason for the selection was the popularity of terry fabrics in home, sauna, and leisure textiles, such as towels, dressing-gowns, slippers, headgear, etc. The structure and weave repeat can be seen in ***Figure 1***. The investigations were conducted with fabrics that have pile loops on both sides. As is seen in ***Figure 1***, ground warp G1, which is up at the beginning, goes down, and G2, which is first down and then goes upwards through the two yarns. Back side pile (BP) warp is always opposite to the pile (FP) warp of the front side. When the BP warp makes the first loop on one side of the fabric, a second loop will be formed on the other side. The FP warp operates in a similar fashion. The nominal pile height is 9 mm. The composition of the fabrics and the linen density of the yarns are presented in ***Table 1***. Three types of yarns were used in the

Table 1. *Characteristics of the terry fabrics.*

Characteristic		Fabric variant	
		LU	LB
The linear density of yarns, tex	Pile warp	68 unbleached flax	50 bleached flax
	Ground warp	25x2 cotton	
	Ground weft	50 cotton	
Yarn density, dm^{-1}	Pile and ground warp	250	
	Weft	200	

Table 2. *Investigated moments in images record.*

Impacts, fabric variant		Stopped moment in image record after a fixed time, s						
Grey fabric, LU	Starting moment, SM	10	40	70	130	250	370	490 (LM)
Grey fabric, LB		10	40	70	130	190	250 (LM)	
Macerating, LU		10	40	70	100	130	190	250 (LM)
Macerating, LB		10	40	70	100	130	190 (LM)	
Washing with water 10, 30 and 120 min,, industrial washing LU, LB		10	25	40	55	70	100	130 (LM)

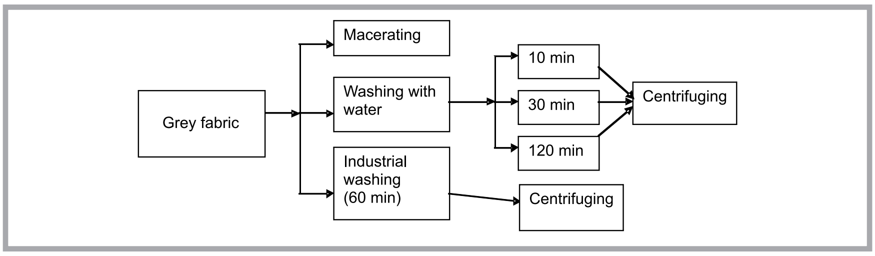

Figure 2. *Scheme of impacts on the terry fabrics.*

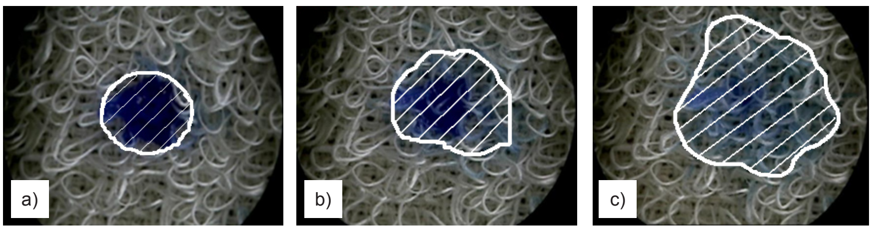

Figure 3*. Behaviour of the water drop on the surface of the grey LB fabric: a - full specular reflectance of the drop at the starting moment; b - spot after an absorption period of 40 s; c - full absorption of the drop after 250 s (marked area indicates wetted fabric).*

production of the terry fabrics. The high absorption ability of flax fibre was the main reason for the choice of pile material. The investigations were made with grey fabrics as well as with samples influenced in a water/heat/mechanical way. The finishing operation used was industrial washing, i.e. 12 variants were considered (see ***Figure 2***, page 63). The detergent "Felosan NOG" was used for the industrial washing process at a temperature of 60 °C for 60 minutes. All the samples were dried in air.

Method

The experiments were made using a Nikon SMZ 800 stereoscopic zoom microscope and a Coolpix 4500 digital camera. In the procedure used, a 110 mg drop of distilled water fell onto the terry fabric. The height of falling was as minimal as possible, i.e. it was chosen so that the drop could fall without being disturbed and to make sure the drop did not touch the dropper and fabric surface at the same moment. The time for the drop to lose its specular reflectance was measured.Any other behaviour that occurred during the contact with the textile was filmed. Complete loss of specular reflectance occurs from the moment when the drop has been absorbed into the material that is until it appears as a dull wet spot. The film was stopped when the area of the liquid spot became stationary. Metric 7.0 PE-Live software was used for analysis of the image record. ***Figure 3*** shows the progression from the drop to a complete dull wet spot in grey LB fabric (three pictures).

Results and discussion

As is seen in ***Table 2*** (see page 63), the image record of wetting phenomena investigations is divided into pictures from the starting moment (SM) – the first moment that can be fixed after the drop has fallen onto the fabric surface till the last moment (LM) when the drop is absolutely absorbed by the terry fabric, and the spot remains changeless. 5 - 6 intermediate moments were recorded in the period from SM to LM.

To describe the results, linear, logarithmic, polynomial, power, and exponential types of regressions were analysed. Only equations with the highest determination coefficient were analysed and interpreted further. The change in the area of the spot compared with the area of the SM in terry fabrics regarding the inspection time are presented in ***Figures 4 - 9***.

It was found that the behaviour of liquid in contact with terry fabric of LU and LB variants is quite different. The characteristics of the fabric, kind of impact and duration also determine the wetting phenomenon. It was determined that LU and LB variants of grey terry fabrics absorb water in almost stable periods, from SM to LM. It was found that the area of the liquid spot increased by 1.06-1.48 times after 10 s for the LU and LB terry fabrics compared with the area in the SM. Throughout all period investigated, the absorption areas of the liquid increased by 2.10 (LU fabrics) – 4.27 (LB fabrics) times. As is seen from ***Figure 4*** the change

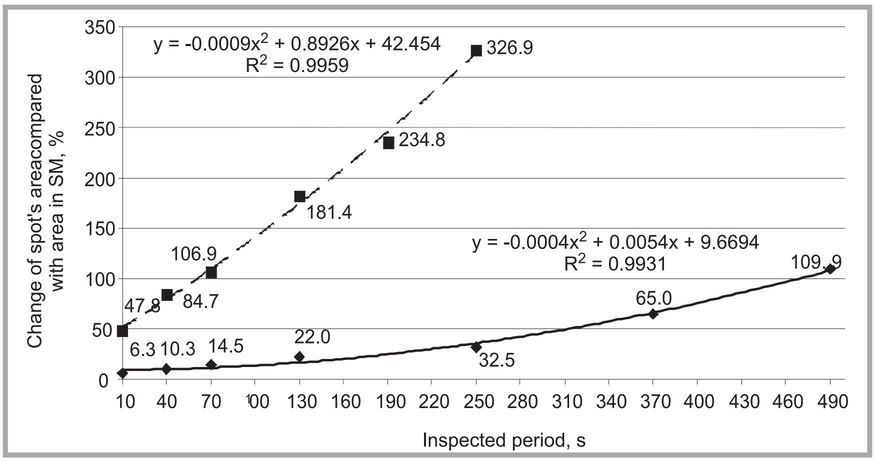

Figure 4. The change in spot area of grey LU_____ and LB _ _ _ terry fabrics.

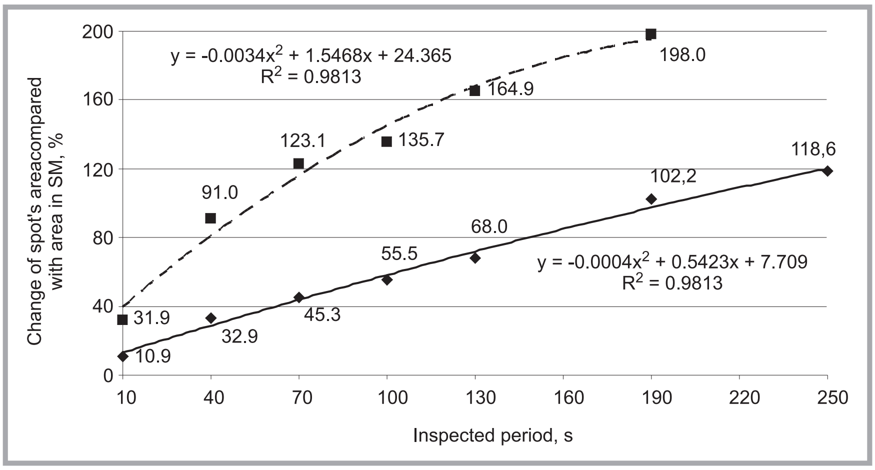

Figure 5. The change in spot area of the macerated LU____ and LB _ _ _ terry fabrics.

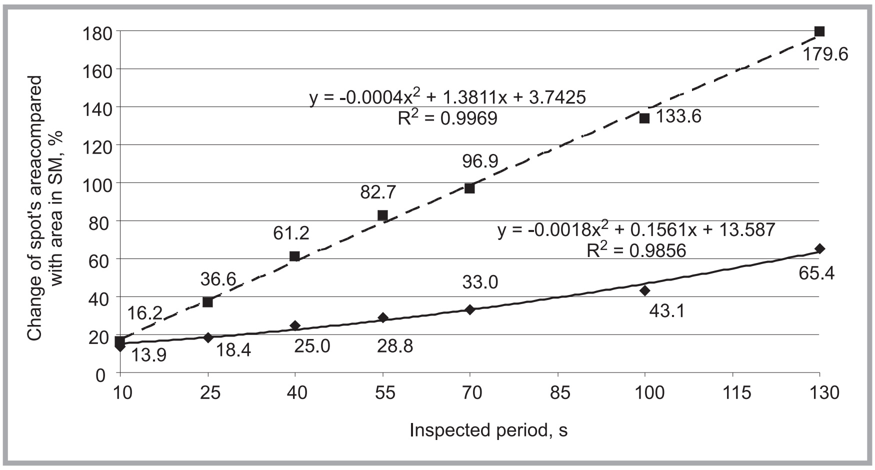

Figure 6. The change in spot area of LU ___ and LB _ _ _terry fabrics washed with water for 10 min.

in the liquid spot of the LU terry fabric increased by 109.9 % in the SM-LM interval. The determination coefficient of the equation obtained is $R^2 = 0.9931$ (a polynomial equation). The change in liquid spot area of the grey LB fabric increased by as much as 326.9% compared to the starting and last moment of absorption, which can be seen inthe polynomial equation ($R^2 = 0.9959$). Therefore the change in spot area of LB fabric is 2.97 times bigger compared with that

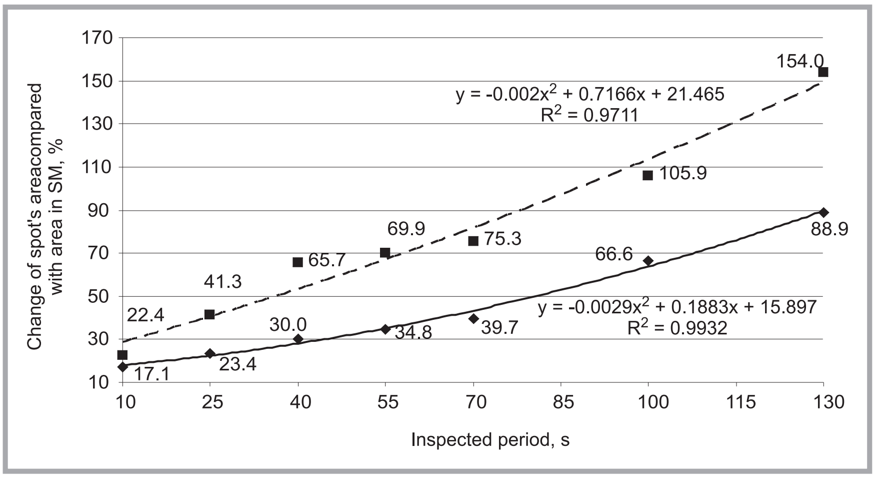

***Figure 7.** The change in spot area of LU____ and LB_ _ _ terry fabrics washed with water for 30 min.*

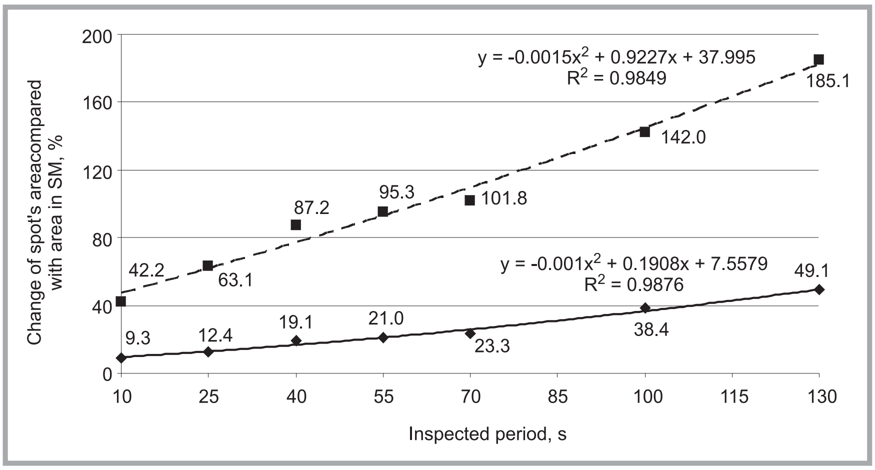

***Figure 8.** The change in spot area of LU ___ and LB_ _ _ terry fabrics washed with water for 120 min.*

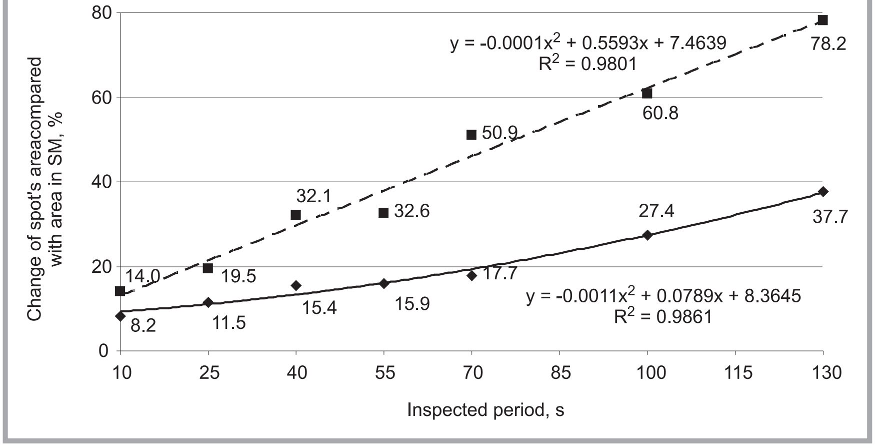

***Figure 9.** The change in spot area of industrially washed LU___ and LB _ _ _ terry fabrics.*

of LU fabric. It was determined that the spot area also had a tendency to spread in different directions.

Macerating influences the internal structure of the fabric as well as the wetting process. The drop of water acts differently in contact with macerated LU and LB fabric. The area of the liquid spot on fabrics affected by a macerating impact increased by 2.19 - 2.98 times from LM to SM, in both variants of the fabrics investigated. As is seen from ***Figure 5*** the determination coefficients are $R^2 = 0.9916$ and $R^2 = 0.9813$, and the results are best described by polynomial equations. After investigation of the video material, it was found that the absorption process of LB fabrics affected by a macerating impact became permanently volatile : at the beginning the drop had a tendency to spread faster, but after 40 s the absorption became slower. It was also found that the area of the liquid spot on the macerated LB fabric increased by 1.13 times during a period of 130 - 190 s, whereas for the SM and LM the area of the liquid spot increased by 2.98 times. The macerating impact influences the absorption time of the liquid: in macerated fabrics the drop was absolutely absorbed, and the spot became stationary after 190 (LB) - 250 (LU) s, while analysing grey samples it was after 250 (LB) - 490 (LU) s.

It was determined that washing with water for 10, 30, and 120 min changes the absorption ability of the fabric. Apart from several moments, the absorption of the LU samples washed with water for 10 min was almost stable during the periods investigated; nevertheless the analysis showed that even such a short washing process without any detergents or conditioners influences the speed of a liquid spreading in LU terry fabrics (see ***Figure 6***). Furthermore, the changes in the area of the spot are more intensive compared with analogous areas of grey fabrics. The wetting intensity was particularly noticeable after a period of 25 - 40 s from the moment the drop fell onto the fabric surface. The last moment of both variants of fabrics washed with water for 10, 30, 120 min was inspected after 130 s; therefore the time of change in the liquid areabecame considerably shorter compared with that of the grey and macerated fabrics. It was determined that the results of the LB fabrics washed with water are effectively described by polynomial equations for all the periods investigated. The determination coefficients varied from 0.9711 (washed for 30 min) to 0.9969 (washed for 10 min) see ***Figures 6*** and ***7***.

The change in spot area of the LB sample, washed for 120 min, was the most intensive: up to 185.1% (see ***Figure 8***, page 65).

The change in the area of the liquid spot increased by 37.7-78.2 % in industrially washed LU and LB terry fabrics, respectively, compared with that of the SM. It was found that the changes in spot area were larger in all the moments of LB fabric investigated when compared with the LU samples (see ***Figure 9***, page 65); therefore the wetting process has a tendency to pass more intensively into the internal layers of fabric made using bleached warp pile.

It is clearly seen that the macerating process, washing with water for different periods or industrial washing have a significant effect on the absorption and how fast the water drop spreads on the surface of terry fabric. The results demonstrated that the means of changes in the spot area compared with the that of the SM always are bigger for terry fabrics with bleached warps compared with unbleached ones irrespective of the kind of impact on the fabric or its duration. Of course, the composition of the fabric plays a role here too. The largest difference – by 3.8 times between the changes in the spot's area analysed, was observed at the LM for LB fabric compared with LU fabrics after washing with water for 120 min, while the smallest difference - 1.7 times was inspected while analysing macerated samples. Besides this while investigating grey and macerated samples, it was observed that the liquid finally wets the fabric by spreading into the largest areas, whereas the smallest areas were indicatedwhile testing industrially washed fabrics irrespective of the fabric composition.

During the analysis of the wetting phenomenon, of terry fabrics general tendencies were stated. However bearing in mind the wide dispersion of the results, and the aim was to increase the accuracy of the experiment, in order to obtain more detailed information on the absorption dynamics of terry fabrics of very different structure as well as to explain liquid transport through terry fabric further research is required. Such experimental work on detailed sorption properties is in progress and will be presented in the subsequent publication.

Summary and conclusions

After a series of experimental studies carried out, the following conclusions can be drawn:

1. Terry fabrics with unbleached and bleached linen pile warps are defined by a high absorption ability. This phenomenon is acquired by increasing the moisture absorption capability of the textile surface to retain the liquid in its pores. The character of the wetting process depends on the fabric's characteristics, as well as on the kind of impact and the period it lasts. The behaviour of liquid in contact with terry textile is quite different in the case of fabrics with unbleached warps (LU) and bleached (LB).

2. It was found that the macerating impact shortened the absorption process: in macerated fabrics the drop was absolutely absorbed, and the spot became stationary after 190 (LB) - 250 (LU) s, compared with grey samples where it was after 250 (LB) - 490 (LU) s.

3. The time of the change in the liquid area became considerably shorter i.e. up to 130 s for fabrics affected by water/heat/mechanical impacts as well as after industrial washing. The change in the area of the liquid spot compared with that during the starting moment of the LB sample washed with water was the most intensive – from 154.0 to185.1 %, while for LU fabrics the areas of the liquid spot increased by 49.1-88.9 %.

4. The change in the area of the liquid spot increased by up to 37.7 % (LU variant) - 78.2 % (LB variant) for fabrics affected by industrial washing; therefore wetting has tendency to pass more intensively into the internal layers of the textile affected by such a finishing operation.

5. It was determined that the means of changes in the area of the spot compared with the area at the starting moment are always larger for terry fabrics with bleached warps compared with unbleached ones; irrespective of the kind of impact or duration; the composition of the fabric also plays the role here. The largest difference – 3.8 times regarding changes in the areas of the spot was observed at the LM, for LB fabric compared with LU fabric after washing with water for 120 min, while the smallest difference was noticed in the macerated samples – 1.7 times.

6. The experimental results are best described by polynomial and exponential equations. The determination coefficients of the equations obtained vary from 0.9711 to 0.9969.

References

1. 1. Frontczak-Wasiak I., Snycerski M., Fibres &Textiles in Eastern Europe, vol. 12, No. 1 (45), 2004, pp. 40-44.
2. 2. Karahan M., Eren R., Fibres &Textiles in Eastern Europe, vol.14, No.2 (56), 2006, pp. 59-63.
3. 3. Karahan M., Eren R., Alpay H.R, Fibres &Textiles in Eastern Europe, vol.13, No.2 (50), 2005, pp. 20-25.
4. 4. Zieba J., Fibres &Textiles in Eastern Europe, vol. 11, No.2 (41), 2003, pp. 85-87.
5. 5. Guo Jiangman.,' The effects of Household Fabrics Softeners on the Thermal Comfort and Flammability of Cotton and Polyester Fabrics', M. Sc. Thesis, Blacksburg, Virginia, USA, 2003.
6. 6. Nazire Deniz Yilmaz, Powell N.B., The Technology of Terry Towel Production, Journal of Textile and Apparel., Technology and Management, vol. 4, No.4, 2005, pp. 1-43.
7. 7. E. Kissa, 'Repellent Finishes' in 'Handbook of Fiber Science and Technology', Part II B, Marcel Dekker, New York, USA, 1984.
8. 8. Kissa E., Tex. Res. J., Vol. 66 No. 10, 1996, pp. 660-668.
9. 9. Kadolph S.J., 'Quality Assurance for Textiles and Apparel', New York, Iowa State University, 1998, pp. 200-208.
10. 10. Koc E., Zervent B., Fibres & Textiles in Eastern Europe, vol. 14, No.1 (55), 2006, pp. 39-46.
11. 11. Tarafder N., Chakraborty S., Hossain M., M., Text. India, vol. 45, No.3, 2002, pp. 98-102.
12. 12. Anis P., 'Investigation to the Effect of Woven Structure on the Fabric Properties with a Computer Model in Towel Fabrics' M. Sc. Thesis , Univ. of Uludag, Inst. of Nat. and Appl. Sci., Dep. of Text. Eng., Bursa, 1989 (in Turkish).
13. 13. Bozgeyik K., 'A Quantitative Investigation about Towels', M. Sc. Thesis, Univ. of Ege, Inst. of Nat. and Appl. Sci., Dep. of Text. Eng., Izmir, 1991 (in Turkish).
14. 14. Bhargava G.S., Indian Text. J., vol. 95, No. 1, 1985, pp.95-101.
15. 15. Hsieh Y. L., Thompson J., Miller A., Tex. Res. J., vol. 66, No. 7, 1996 pp. 456-469.
16. 16. Hsieh Y. L., Thompson J., Miller A., Tex. Res. J., vol. 66, No. 1, 1996, pp. 1-10.
17. 17. Hsieh Y. L., Yu B., Tex. Res. J., vol. 62, No. 10, 1992, pp. 677-685.
18. 18. Meeren P., Cocquyt J., Flores S., Textile Res. J., vol. 72, No. 5, 2002, pp. 423-428.
19. 19. Nostadt K., Zyschka R., Softeners in Textile Finishing Industry, Colorage, pp.53-58, 1997.
20. 20. Hartzell M. M., Hsieh Y. L., Tex. Res. J., vol. 68, No. 4, 1998, pp. 233-241.
21. 21. Hsieh Y. L., Tex. Res. J., vol. 65, No. 5, 1995, pp. 299-307.
22. 22. Hsieh Y. L., Cram L. A., Tex. Res. J., vol. 68, No. 5, 1998, pp. 311-319.

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