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Investigation of the Liquid Retention Capacity of Terry Fabrics

Abstract
The paper presents an investigation of the liquid retention capacity of terry fabrics with respect to pile height and impacts/finishing. The terry fabrics used in the experimental work were made from linen or linen/cotton yarns. The pile height of the samples was 6, 9 and 12 mm. The fabrics were effected by various impacts/finishing like macerating, washing with detergent or without it, washing with detergent and softener as well as tumbling procedures. The highest liquid retention capacity (9.598 g/g) was determined for grey linen/cotton fabric with a 6 mm pile height. A significant difference exists in the liquid retention capacity of differently treated fabrics; the intensity of the procedure also plays a role here. The liquid retention capacity of terry fabrics with respect to the tumbling period could be described by polynomial equations.

Key words: *impact/finishing, retention capacity, terry fabric.*

Introduction

The liquid wetting properties of fibrous materials are fundamentally important to their chemical processing and functional performance. The wettability of fibre surfaces can be modified by changing the chemistry of the constituent polymers or by applying topical finishes. To move in a fibrous medium, a liquid must wet the fibre surface before being transported through the interfibre pores by means of capillary action. The manner in which a liquid wicks through the pores depends on capillary forces [1, 2]. The wettability of fibre assemblies (yarns and fabrics) with liquids depends on the chemical nature of the fibre surface, the geometry of fibre assemblies, especially surface roughness as well as pore size distribution and fibre diameter [3].

The comfort of textile materials is mostly related to the transfer of heat and water vapour through textile structures [4]. When a person perspires, the sweat can be transported through the micro-porous structure of functional fabrics to the surface and then evaporates, which makes human skin feel dry and comfortable [5]. Linen and cotton yarns are very desirable materials for terry fabrics because of their good water absorption properties. At this time, the assortment of terry fabrics is wide, but there is still a tendency that not only the look of the garment is important to the consumer, but also the raw material, where the priority is given to organic and natural plant fibres [6 - 8].

Generally terry materials absorb water perfectly. Karahan and Eren found that terry fabrics produced with two-ply ring-carded yarn have the highest percentage of static water absorption, whereas terry fabrics produced with two-ply open-end yarn have the lowest [9]. Yarn type has been found to have the most important effect on the dynamic water absorption properties of terry fabrics. 29.5 tex ring-carded yarn has a faster water absorption than 29.5 tex × 2 ring-carded yarn and 29.5 tex × 2 open-end yarn. Besides this, 29.5 tex × 2 open-end yarn has the lowest water absorption speed. Regression analysis was applied to experimental data of water absorption, the logarithmic curves of which showed a very good match with the experimental results [10].

A high absorption ability can be imparted to a terry textile by increasing the capability of the moisture absorbing surface to retain liquid in its structure and internal pores of the textile material. Terry fabrics are produced using weft, ground warp and pile warp yarns. Pile structure has a very important effect on the structure and usage properties of terry fabrics. The qualities required for yarns used in terry fabrics are high absorbency, high wet strength, good wash-ability, and soft handle. It was found that the pile height of terry woven fabrics has a significant effect on their static water absorption. The increases in static water absorption for washed and softened terry fabrics were 310.3 - 394.1% compared with grey and macerated ones as well as those washed with detergent only. 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. Fibre swelling and the decrease in pore sizes could be the main reasons for the increase in static water absorption in more intensively treated terry fabrics [8, 11].

It is known that the absorption of terry fabrics depends not only on their raw material and structure but also on the finishes applied. Various characteristics could be used for the determination of the behaviour of a textile in contact with liquid. Many researchers have investigated the absorption phenomenon in various fabrics and other textile materials using various methods of analysis, but no research work has been found in literature investigating the liquid retention capacity (LRC) of terry fabrics. From a theoretical and practical point of view, it is important to investigate the liquid retention capacity of pure linen or linen/cotton terry fabrics as well as to establish the influence of their structure and water, heat, mechanical and chemical impacts. Hence, this paper presents an experimental investigation of this area.

Experimental

Object and method of investigation

Experiments were carried out with four kinds of terry fabric structures, as presented in ***Table 1***.

__Table 1.__ Terry woven structures.

Fabric variant	Pile height, mm	Linear density of yarns, tex		
		Pile warp	Ground warp	Ground weft
A6	6	68 tex, unbleached linen	25 × 2 tex, cotton	50 tex, cotton
A9	9			
A12	12			
C12	12	68 tex, unbleached linen	56 tex, unbleached linen	56 tex, unbleached linen

__Table 2.__ Porosity of terry fabrics; Impact/finishing: 1- grey (without finishing); 2 – macerated; 3, 4, 5 - washed with water for 10, 30 and 120 min; 6 - washed with detergent; 7 - washed with detergent and softened; 8, 9, 10, 11, 12 - washed with detergent, softened and tumbled for 30, 60, 90, 120, 150 min.

Impact/ finishing	Porosity of fabric and absolute error				Relative error of porosity, %			
	A6	A9	A12	C12	A6	A9	A12	C12
1	0.937 ± 0.001	0.935 ± 0.001	0.916 ± 0.001	0.930 ± 0.002	0.1	0.1	0.1	0.2
2	0.923 ± 0.001	0.925 ± 0.001	0.906 ± 0.001	0.912 ± 0.002	0.1	0.1	0.1	0.2
3	0.920 ± 0.001	0.911 ± 0.001	0.904 ± 0.001	0.931 ± 0.002	0.1	0.1	0.1	0.2
4	0.917 ± 0.001	0.906 ± 0.002	0.889 ± 0.001	0.908 ± 0.003	0.1	0.2	0.1	0.4
5	0.908 ± 0.003	0.881 ± 0.001	0.898 ± 0.001	0.911 ± 0.003	0.3	0.2	0.1	0.4
6	0.906 ± 0.001	0.890 ± 0.002	0.876 ± 0.001	0.901 ± 0.005	0.1	0.3	0.1	0.5
7	0.897 ± 0.001	0.869 ± 0.003	0.878 ± 0.001	0.902 ± 0.006	0.1	0.3	0.1	0.7
8	0.888 ± 0.001	0.872 ± 0.002	0.881 ± 0.004	0.883 ± 0.005	0.1	0.2	0.4	0.6
9	0.904 ± 0.001	0.876 ± 0.001	0.880 ± 0.002	0.882 ± 0.002	0.1	0.1	0.2	0.2
10	0.901 ± 0.003	0.877 ± 0.002	0.884 ± 0.002	0.866 ± 0.002	0.4	0.2	0.2	0.3
11	0.907 ± 0.001	0.876 ± 0.001	0.898 ± 0.001	0.880 ± 0.002	0.1	0.2	0.2	0.3
12	0.882 ± 0.001	0.876 ± 0.001	0.893 ± 0.003	0.880 ± 0.003	0.1	0.2	0.3	0.4

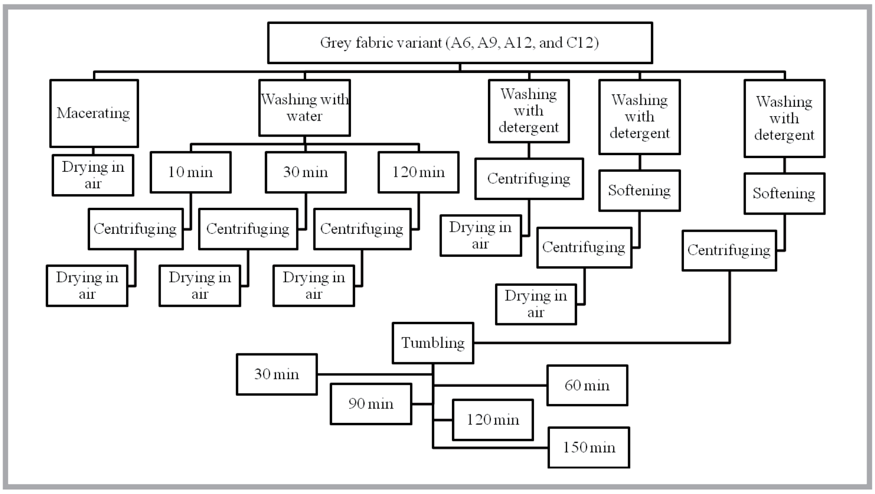

__Figure 1.__ Scheme of impact/finishing procedures applied to the fabrics.

The pile of the terry fabrics used in the research was constructed on both sides of the fabric. The pile and ground warp density was 250 dm^{-1} , and the weft density was 200 dm^{-1} for fabric variants A6, A9 and A12. The pile and ground warp density was 250 dm^{-1} , and the weft density was 180 dm^{-1} for fabric variant C12. The high absorption ability of flax fibre was the main reason for the choice of pile material. The investigations were made with grey fabrics (without any finishing) as well as with samples influenced by water/heat/mechanical/chemical impacts. ***Figure 1*** presents a scheme of the impacting/finishing procedures applied to the fabrics. For the wetting procedure the specimens were placed in water for 2 - 3 s, which is necessary to complete wetting, and then dried in air. Washing with water was performed according to ISO 6330-2000 [12]. Industrial finishing processes were performed by the joint-stock company 'A Grupė' (Jonava, Lithuania). In this research the detergent NOG CHT R. Beitlich GmBH (Germany) was used for industrial washing at 60 °C for 60 min. The industrial washing was performed in a BK rope bath (Russia). The tumbling process gives a fuller volume and nice handle to the fabric. For this purpose the samples were washed with detergent at 60 °C for 60 min, softened at 40 °C for 60 min, then centrifuged and tumble-dried for different periods from 30 to 150 min in an Aipress 15 tumbler (Germany). A Tubingal SMF CHT R. Beitlich (Germany) silicone conditioner was used for softening. After tumbling for 30 and 60 min, the fabrics were dried in air. If necessary, the samples were dried in air after tumbling for 90 min.

The liquid retention capacity was calculated according to the method in [1, 2]. The samples were conditioned in laboratory conditions, cut into pieces (10 × 10 cm) and then weighed; the thickness of the fabric was also measured. The liquid retention capacity was calculated using the following formula:

$$C = \frac{q_l}{q_f} \frac{\theta}{1-\theta} \quad (1)$$

where q_l is the liquid density (0.997 g/cm^3 for distilled water), q_f the fibre density of linen and cotton (1.54 g/cm^3) and θ is the overall porosity of the fabric.

The overall porosity of the fabric (θ) was calculated using the following formula:

$$\theta = 1 - \frac{q_b}{q_f} \quad (2)$$

where q_b – fabric bulk density.

The fabric bulk density (q_b) was calculated using the following formula:

$$q_b = \frac{T_p}{s} \quad (3)$$

where T_p is the fabric surface density; s – fabric thickness.

The thickness (s) and surface density (T_p) of the fabric were measured in accordance with ISO 5084:1996 [13] and LST ISO 3801:1998 [14], respectively.

Results and discussion

Analysis of the liquid retention capacity of terry fabrics was performed with respect to the succession and intensity of the impact/finishing procedures presented in ***Figure 1***.

The liquid retention capacity of grey and macerated terry fabrics is presented in ***Figure 2***. The porosity of terry fabrics is presented in ***Table 2***.

It was determined that the grey terry fabrics had the highest liquid retention capacity of all the variants investigated. The grey fabric with the shortest pile height (6 mm) had the highest porosity (0.937) and liquid retention capacity (9.598 g/g) compared with the other grey fabrics. Besides this, the liquid retention capacity (7.025 g/g) and porosity (0.916) of the grey linen/cotton fabric with a 12 mm pile was the lowest compared with the other variants investigated. Meanwhile, it was determined [15] that the loop length has more influence on the porosity of a jersey structure than the stitch density and thickness.

Macerating is a very passive procedure compared with industrial finishing operations. Macerating has only a water impact on fabric. From the data presented in ***Figure 2***, it can be seen that after the macerating operation, the liquid retention capacity of the fabrics decreased by 11.4 - 22.2% compared with grey fabrics, respectively, which is due to changes in the porosity of macerated fabrics (see ***Table 2***). In spite of the littleness of the impact, after the macerating procedure the structure of the terry fabric changed – the fabric's bulk density increased up to 22.7% for variants A6, A9, A12 and to 25.9% for variant C12, hence the porosity decreased to 1.9% compared with grey fabrics, respectively. The fibre swelling process also plays a role here. The liquid transport phenomena in pores was determined [2] using the pore size distribution and connectivity.

As concluded in [10], an increase in the pile height, warp density and/or weft density causes a rise in the fabric weight per unit area, and as a consequence the water absorption capacity of pre-washed terry fabric increases. A linear relationship was observed between water absorption over 300 seconds and the dry fabric weight. ***Figure 3*** shows the liquid retention capacity of fabrics washed in water over different periods (10, 30 &120 min). Washing with water changed the structure of the fabric much more than the macerating operation, because during the whole washing cycle the fabric is affected by a complex of factors like water, heat, abrasion etc. Fabric structure changes during washing and drying processes could be explained by the swelling-shrinkage model. The fabric bulk density after 120 min of washing had increased by 6.8 - 33.6% compared with fabrics washed for 10 min, respectively. Of all the variants the highest liquid retention capacity (8.707 g/g ± 0.324) was found for pure linen fabric washed in water for 10 min. The LRC of pure linen fabric washed for 30 min decreased by 26.9% compared with the fabric washed for 10 min; the change in the liquid retention capacity of fabric C12 washed for 120 min was not statistically significant when compared with the sample washed for 30 min. The liquid retention capacity of linen/cotton fabrics after 10 min of the washing procedure had decreased by 12.9 - 28.8% compared with grey fabrics, respectively. The liquid retention capacity of linen/cotton fabrics after 30 min of washing had decreased by 4.4 - 15.4% compared with fabrics washed for 10 min. The highest liquid retention capacity (7.445 g/g) was found for variant A6 washed for 10 min, and the lowest liquid retention capacity (4.810 g/g) was found for fabric A9 washed in water for 120 min. The liquid retention capacity of linen/cotton fabrics washed for 120 min decreased by 10.4% for variant A6 and 23.2% for variant A9 compared with fabrics washed for 30 min and by 18.8 - 48.4% (analysing variants A6, A9 & A12) compared with grey ones, respectively. The highest liquid retention capacity (6.633 g/g ± 0.278) after 120 min of washing was determined for pure linen fabric (C12). The increase in the LRC of variant A12 from 5.177 to 5.706 g/g when washed for 30 min and 120 min, respectively, was determined.

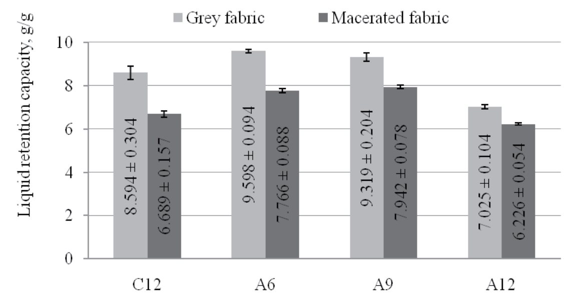

Figure 2.

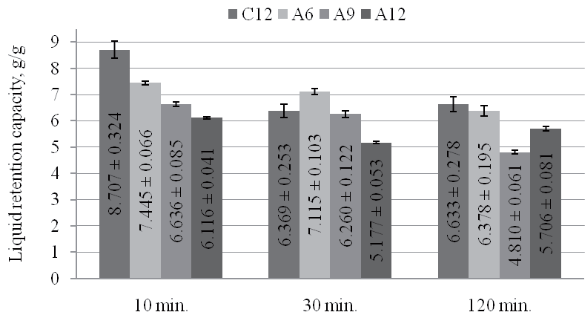

Figure 3.

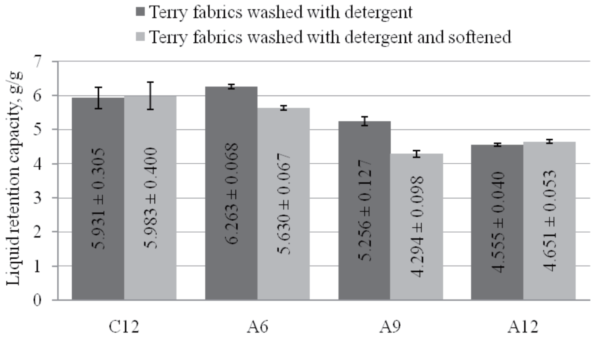

Figure 4.

Figure 2. *Liquid retention capacity of grey and macerated terry fabrics.*

Figure 3. *Liquid retention capacity of fabrics washed with water for 10, 30 and 120 min.*

Figure 4. *Liquid retention capacity of fabrics washed with detergent as well as after washing with detergent and softening procedures.*

Table 3. Liquid retention capacity of fabrics (C12 and A9) washed with detergent, softened and tumbled for different periods.

Fabric variant	Tumbling time, min	Liquid retention capacity (LRC), g/g	Coefficient of variation of LRC, %	Relative error of LRC, %
C12	30	4.907	4.1	5.1
	60	4.819	1.2	1.4
	90	4.177	1.7	2.2
	120	4.761	1.9	2.3
	150	4.770	2.4	2.9
A9	30	4.426	1.3	1.6
	60	4.569	0.7	0.9
	90	4.637	1.6	2.0
	120	4.577	1.1	1.3
	150	4.596	1.1	1.4

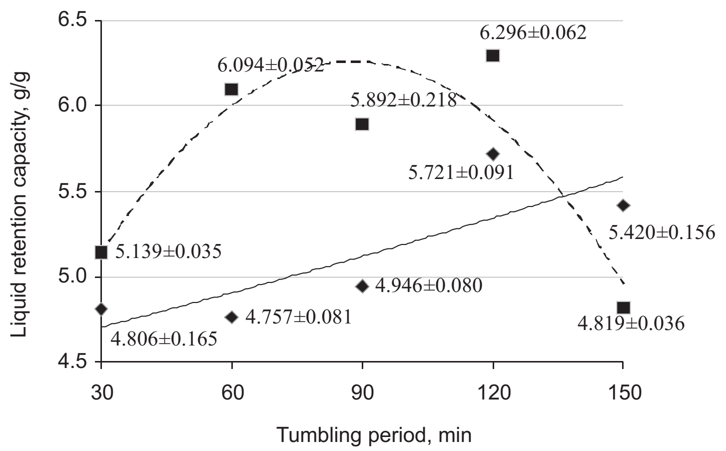

Figure 5. Liquid retention capacity of fabrics washed with detergent, softened and tumbled in relation to the tumbling period; ■ - A6, $y = -0.000338x^2 + 0.059369x + 3.65040$, $R^2 = 0.8089$; ♦ - A12, $y = 7E\text{-}06x^2 + 0.0061x + 4.5134$, $R^2 = 0.6761$.

Washing with detergent or washing with detergent and softener changes the fabric's structure much more when washing only with water because during the industrial washing cycle the fabric is also affected by the washing or softening solution. Important changes in the fabric's structure lead to an intensive transformation of its physical properties: permeability, absorption capacity, and usage peculiarities such as the fabric handle [6 - 8, 11]. ***Figure 4*** shows the liquid retention capacity of terry fabrics washed with detergent, and also that of terry fabrics washed with detergent and then softened. The change in LRC of washed and softened fabrics with the highest pile height (C12 and A12) was not statistically significant. The liquid retention capacity of A6 and A9 fabrics after washing and a later softening operation had decreased by 10.1% and 18.3% compared with those washed with detergent, respectively. The liquid retention capacity of fabrics washed with detergent decreased by 31.0 - 43.6%, while for those washed with detergent and then softened it was 30.4 - 53.9% compared with grey ones, respectively.

The liquid retention capacity of tumbled terry fabrics is presented in ***Table 3*** and ***Figure 5***.

The liquid retention capacity of tumbled fabrics was 4.177 - 4.907 g/g, 4.819 - 6.296 g/g, 4.426 - 4.637 g/g, and 4.757 - 5.721 g/g for variants C12, A6, A9, A12, respectively. The coefficient of variation of the LRC of tumbled pure linen fabrics and linen/cotton fabrics did not exceed 4.1%. The relative errors of LRC varied within the range of 0.7% to 5.1%. The decreases determined for the liquid retention capacity of tumbled fabrics after 150 min and grey terry fabrics were 1.8 times for variant C12, 2.0 times for variants A6 and A9 and 1.3 times for variant A12. In order to describe the results for which the informativity of experiment proved, polynomial, linear, logarithmic, power, and exponential types of regression were analysed. The experimental results of LRC regarding the tumbling period are described by polynomial equations (see ***Figure 5***) the best. The determination coefficient indicates the existence of a good relationship between the parameters investigated.

Conclusion

- The pile height of terry woven fabrics had a significant effect on their liquid retention capacity. The highest liquid retention capacity (9.598 g/g) was determined for linen/cotton grey fabric with a 6 mm pile height. The liquid retention capacity of pure linen grey terry fabric (pile height 12 mm) was 22.3% higher than that of linen/cotton grey terry fabric with a pile height of 12 mm.
- The liquid retention capacity of pure linen and linen/cotton fabrics depends on the kind and intensity of the impact/finishing applied to the fabric. A significant difference exists in the liquid retention capacity of differently treated fabrics, i.e. water/heat/mechanical/chemical impacts were made.
- Some changes in liquid retention capacity were determined even after a passive procedure like macerating . The highest liquid retention capacity (8.707 g/g ± 0.324) was found for pure linen fabric washed in water for 10 min compared with all the other variants washed in water. The highest liquid retention capacity (6.633 g/g ± 0.278) after 120 min of washing was determined for pure linen fabric, while the lowest (4.810 g/g ± 0.061) was found for linen/cotton fabric with a 9 mm pile height.
- The liquid retention capacity of the terry fabrics investigated, which were washed with detergent, decreased by 31.0 - 43.6%, while for those washed with detergent and then softened, it was 53.9% compared with grey ones, respectively.
- The liquid retention capacity of terry fabrics with respect to the tumbling period could be described by polynomial equations. The determination coefficients of the equations obtained are up to 0.8089.

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- Tetrachlorophenol, Pentachlorophenol (PCP)
- Hexachlorocyclohexane (lindane)
- Aromatic and polyaromatic hydrocarbons
- Benzene, Hexachlorobenzene
- Phthalates
- Carbohydrates
- Glycols
- Polychloro-Biphenyls (PCB)
- Glyoxal
- Tin organic compounds

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