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Investigation of Drying Phenomenon of Terry Woven Fabrics

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Abstract
The paper presents an investigation of the drying ability of terry fabrics with respect to pile height and finishing. The terry fabrics used in the experimental work were made from linen/cotton yarns, and the pile height of the samples was 6 and 12 mm. The fabrics analysed were grey (without finishing) as well as affected by washing with detergent, softening, centrifuging and tumbling procedures. The uniformity of dispersions was proved, and the high informativity of the experiment was found by analysing all data of the remaining water ratio of the terry fabrics. The evaporating process lasted till 130-150 min for grey terry fabrics and till 130-190 min or longer for finished variants. The regressions investigated showed a very good or good match with experimental data: determination coefficient R2=0.7882-0.9492. Mainly the results are best described by logarithmic, polynomial and linear regressions.

Key words: *drying ability, finishing, pile height, terry fabric.*

Introduction

The scientific understanding of the processes involved in moisture transmission through textiles and the factors affecting this phenomenon are important for designing textiles and clothing with efficient moisture transfer in different environmental and workload conditions. Diffusion, absorption, transmission, desorption, adsorption and migration are mechanisms by which moisture may transfer through textiles [1]. It was found that the pile height of terry fabrics had an effect on their static water absorption [2]. Some changes in static water absorption were determined even after a passive procedure like macerating . The increases in static water absorption for washed and softened fabrics were 310.3 - 394.1% compared with grey and macerated samples as well as those washed with detergent. Besides this, the relationships with high determination coefficients were determined for static water absorption with respect to the tumbling time of terry fabrics with low and medium loops.

Moisture related sensations, including the permeability sensation and skin dryness sensation, were interrelated and strongly related to the moisture vapour resistance and percentage of moisture accumulation within clothing [3]. The interaction of water with textiles, which incorporates the water vapour permeability, wicking abilities and drying behaviour of the fabrics, was tested to obtain some comfort-related properties of knitted fabrics made from cotton, acrylic and cotton-acrylic blends [4]. The experimental study showed that irrespective of the tightness, the knitted fabrics made from fine yarn dried faster than the samples made from coarse yarn, although they retained a higher initial amount of liquid, which may be partially attributed to the higher porosity of the fabrics made from fine yarns. Besides, it may also be related to the sizes of pores available within these fabrics. Furthermore, the wicking ability and drying rates of the fabrics increase with an increase in the acrylic fibre ratio within the composition. It was also established that moisture regain values had significant correlations with the liquid transport properties such that the drying rate, longitudinal wicking and transfer wicking ratios decreased as the regain values of the fabrics increased.

The interaction of the moisture transport properties of the different layers in multilayer protective clothing fabrics proved to be very important for the distribution of moisture [5]. The authors found that the overall moisture distribution in multilayer protective clothing can be influenced by using defined combinations of hydrophilic and hydrophobic textile layers. The impact of fabric moisture transport properties on physiological responses when wearing protective clothing was investigated in [6]. Experimental investigations in [7] showed that fabrics with a new biomimic plant structure had clearly faster liquid water transport and better moisture management properties. Surface evaporation rates were also measured when the fabrics were completely saturated with water. Garments made of plant structured fabrics facilitate the transport of sweat faster away from the skin to the outer layer of fabric, making the wearer feel drier.

During active action and at defined environmental conditions, the ranges in which knitted material will be defined as comfortable depend on the rate at which the material allows water vapour to pass through it. The authors concluded that viscose and Tencel® assemblies pose a minor barrier to water vapour transfer. Besides this, they would result in a drier feeling than in the case of cotton or a cotton/modal assembly [8]. The quick dry properties of woven fabrics were investigated in [9]. A new type of honeycomb-patterned micro-porous polyester fibre was used to develop good moisture absorption. The remaining water ratio at the 40th minute was calculated, and for all fabrics investigated this value was

Table 1. *Structure of terry woven fabrics.*

Fabric variant	Pile height, mm	Linear density of yarns, tex			Yarn density, dm^{-1}	
		Pile warp	Ground warp	Ground weft	Pile and ground warp	Weft
A6 A12	6 12	68 tex, unbleached linen yarn	25 tex x 2, plied cotton yarn	50 tex, cotton yarn	250	200
B6 B12	6 12	50 tex, bleached linen yarn				

less than 35%. It was found that treatment with a silicon softening agent significantly reduced the quick dry property of the textile.

Pore size and its distribution in needle punched nonwoven fabrics play an important role in water permeability characteristics [10]. As was concluded in [11], the capacity of a fibrous material to retain liquid is not only determined by its pore sizes but also its overall porosity. Moreover, hydrophilic additive treatment can improve the water vapour transmission property of textile [9]. Investigations on the general tendencies of liquid sorption and transport in grey and finished terry woven structures were performed in [12, 13].

In spite of the interest in the drying phenomenon of textiles, no research has been performed into the drying ability of terry textiles. The aim of our study was to conduct experimental research into the drying process of terry woven fabrics with respect to pile height and finishing procedures.

Table 2. *Statistical results of RWR for grey terry fabrics of variants A6, A12, B6 & B12; V – coefficient of variation of RWR, δ_a – relative error of RWR, 0 - evaporation process was finished, - relative error was higher than selected.*

Evaporating time, min	Variant of grey terry fabric							
	A6		A12		B6		B12	
	V, %	δ_a, %	V, %	δ_a, %	V, %	δ_a, %	V, %	δ_a, %
10	4.65	5.77	2.91	3.61	1.90	2.36	0.86	1.07
20	3.33	4.14	2.47	3.07	3.74	4.65	3.38	4.19
30	5.52	6.86	2.50	3.09	4.78	5.92	3.95	4.90
40	7.37	9.15	4.43	5.50	5.31	6.60	3.43	4.26
50	10.20	12.66	6.67	8.28	7.47	9.27	4.32	5.36
60	9.39	11.66	9.29	11.53	7.05	8.76	4.64	5.76
70	-	-	10.27	12.75	8.19	10.16	7.26	9.00
80	-	-	8.69	10.81	10.37	12.87	8.48	10.55
90	-	-	-	-	11.71	14.53	12.08	15.00
100	-	-	-	-	-	-	-	-
110	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-
130	0	0	-	-	-	-	0	0
140	0	0	0	0	-	-	0	0
150	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0

Table 3. *Statistical results of RWR of finished terry fabrics of variants A6, A12, B6 & B12; V – coefficient of variation of RWR, δa – relative error of RWR, 0 - evaporation process was finished, - relative error was higher than selected.*

Evaporating time, min	Variant of finished terry fabric							
	A6		A12		B6		B12	
	V, %	δ_a, %	V, %	δ_a, %	V, %	δ_a, %	V, %	δ_a, %
10	1.70	2.12	2.88	3.57	2.41	3.00	4.24	5.26
20	5.73	7.11	4.79	5.95	5.38	6.69	4.07	5.06
30	3.49	4.33	4.41	5.48	7.13	8.86	3.17	3.94
40	4.88	6.06	6.94	8.61	6.44	8.01	3.15	3.92
50	4.47	5.55	-	-	6.50	8.07	4.49	5.57
60	5.00	6.20	-	-	6.39	7.94	5.83	7.24
70	2.91	3.61	-	-	11.07	13.74	7.75	9.61
80	4.65	5.77	-	-	12.62	15.69	-	-
90	6.83	8.49	-	-	-	-	-	-
100	9.09	11.28	-	-	-	-	-	-
110	12.77	15.86	-	-	-	-	-	-
120	11.21	13.92	-	-	-	-	-	-
130	-	-	-	-	0	0	-	-
140	-	-	-	-	0	0	-	-
150	-	-	-	-	0	0	0	0
160	-	-	0	0	0	0	0	0
170	-	-	0	0	0	0	0	0
180	-	-	0	0	0	0	0	0

Experimental

Object and method of investigation

Experiments were carried out with four kinds of terry fabric structures, as presented in ***Table 1***. Terry fabrics were woven from linen and cotton yarns. Fabrics with a 6 mm (A6, B6 variants) and 12 mm pile height (A12, B12 variants) were investigated. The pile of the terry fabrics used in the research was constructed on both sides of the fabric. The ground warps were plied cotton yarns of 25 tex × 2, whereas the ground wefts were cotton yarns of 50 tex. The loop pile was made from unbleached linen yarns (in A6, A12 variants) or bleached linen yarns (in B6, B12 variants) of wet spinning. The excellent absorption properties of flax fibre and the popularity of such an assortment were the main reasons to choose such a composition of the fabric. The cotton-linen terry fabrics used in the experimental work were woven by joint-stock company "A Grupė" (in Jonava, Lithuania). The investigations of liquid evaporation were made with grey fabrics (without any finishing procedure) as well as with samples influenced by water/heat/mechanical/chemical impacts. The latter were affected by washing with detergent, softening, centrifuging and were then tumbled for 90 min. The detergent Felosan NOG CHT R. Beitlich GmbH (Germany) was used for washing at a temperature of 60 °C, over a period of 60 min. The softening procedure was performed using silicone conditioner Tubingal SMF CHT R. Beitlich GmbH (Germany) over a period of 60 min, at a temperature of 40 °C.

Method [14] was used to test the drying ability of the fabric. All samples were conditioned for 24 hours in standard conditions (temperature: 20 ± 2 °C; relative humidity: 65 ± 2%). This procedure was performed with every sample: the specimen was cut to a 5 cm × 5 cm square, put on the weighing plate of the microbalance, and the dry weight W_f (in grams) was recorded. A micropipette was used to drip water onto the sample and the wet weight W_0 (in grams) recorded. The change in water W_i was continuously recorded at 10-minute intervals throughout the 180-minute observation. The remaining water ratio (RWR) was calculated

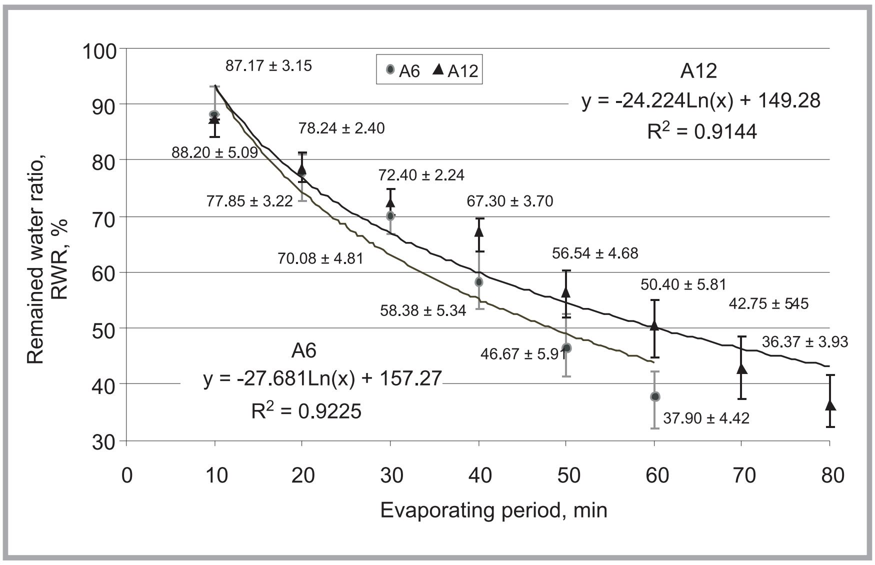

***Figure 1.** Remaing water ratio of grey A6 and A12 fabrics in relation to the evaporation period.*

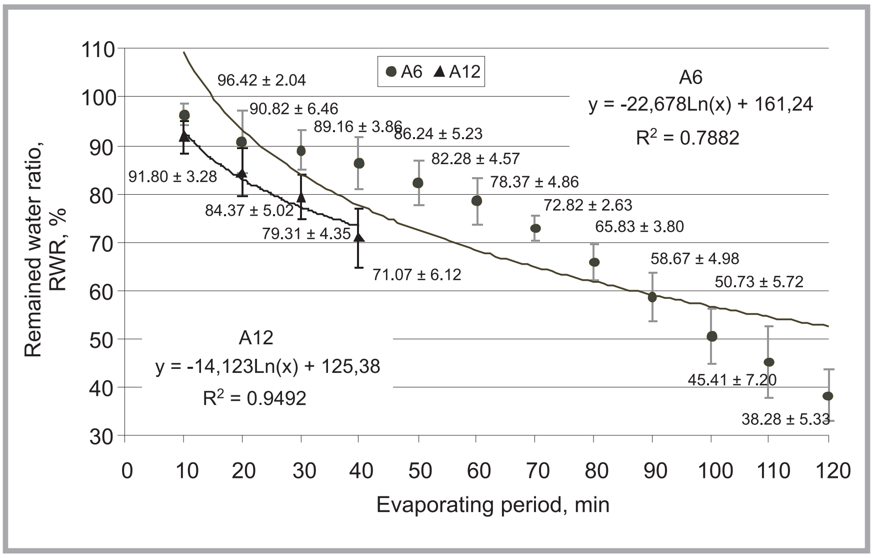

***Figure 2.** Remaining water ratio of finished A6 and A12 fabrics in relation to the evaporation period.*

by formula (1) to express the change in water remaining in the specimen by the specified time. The remaining water ratio (%) at the i-minute:

$$RWR = 100 \times (W_i - W_f)/(W_o - W_f) \quad (1)$$

Results and discussion

Regression analysis was made using a Microsoft Excel Analysis Tool Pack. After the analysis of experiments, factorial designs were made. The informativity of the experiment was proved using the criterion of R. A. Fisher. The experimental results for the remaining water ratio were statistically evaluated at a 95% confidence level, and the standard deviation, coefficient of variation, absolute and relative errors were calculated. With the purpose of interpreting only precise results, only selected evaporation periods where the relative error was less than 10 % were investigated further, except some cases where this value was higher, but not exceeding 15.86%.

Tables 2** & **3 show statistical results of the evaporating (drying) process over time of grey as well as finished (after washing, softening, centrifuging, and tumbling procedures) terry fabrics of A6, A12, B6, B12 variants. For the grey terry fabrics the coefficient of variation of RWR varied from 0.86% to 12.08% and from 1.70% to 12.77% for finished ones. Moreover, the standard deviation of RWR varied within the range of 1.64-5.80 % for variants A6 & A12 and 0.82-5.18 % for variants B6 & B12. The experimental results proved the uniformity of dispersions for all experiments, using the criterion of W. G. Cochran: $0.11 - 0.35 = G < G_{Tabl.} = 0.44 - 0.49$.

It took 130 min from the start moment until absolute water evaporation for grey terry fabric with a loop pile of 6 mm made from unbleached linen yarns (see ***Table 2***). The water evaporation lasted 10 min longer (i.e. till 140 min) for the grey A12 variant. It was found that the remaining water ratio was slightly bigger for the fabric with a high loop pile, except for the first period (after 10 min), but mostly the differences were not statistically significant. It was determined that the relative error of the results did not exceed 12.75%, while the evaporation process lasted until 60 min for fabric A6 and until 80 min for the A12 variant. Hence for grey fabrics A6 and A12 only the evaporation periods till 60 - 80 min were analysed and interpreted.

High informativity was determined by analysing grey terry fabrics with unbleached pile warps: the criterion of Fisher calculated was F = 65.7 ($F_{Tabl.} = 5.9$) for variant A6 and F = 69.9 ($F_{Tabl.} = 5.9$) for variant A12.

In order to describe the results for which the informativity of experiment was proved by mathematical equations, the logarithmic, polynomial, linear, power and exponential types of regression were analysed. In ***Figure 1*** the logarithmic equations are shown. The determination coefficients $R^2 = 0.9225$ (for A6 variant) and $R^2 = 0.9144$ (for A12 variant) indicate the existence of a very good relationship between the parameters investigated. It was also established that the linear and polynomial regressions describe the results very well.

Figure 2 shows the remaining water ratio of finished A6 and A12 fabrics with respect to the evaporation period. The phenomenon of liquid evaporating depends on the structure of the fabric. The structure and appearance of terry fabrics with unbleached and bleached pile warps after such finishing procedures like washing with detergent, softening, centrifuging and tumbling are modified greatly compared with grey fabrics. The spaces between loops and yarns changed, the loops became bulky, sometimes a spiral or snarl loop structure could be found, and the fabrics became soft and fluffy after such finishing.

Water was still evaporating from finished sample A6 even after the 190th minute of observation. Of course, this process was not investigated further because of its slightness. In finished sample A12 the drying process also continued considerably longer: till the 160th min (see ***Table 3***). However, the relative errors showed that precise enough results can be obtained till 120 min (for variant A6) and till 40 min (for variant A12). As the informativity of the experiment was proved ($F = 39.9$; $F_{Tabl.} = 5.8$) for variant A6, ($F = 17.2$; $F_{Tabl.} = 5.9$) for A12 variant), mathematical relationships between the remaining water ratio and evaporation period were established. Logarithmic curves with determination coefficients of $R^2 = 0.7882$ (for A6 variant) and $R^2 = 0.9492$ (for A12 variant) were analysed (see ***Figure 2***). As is evident from ***Figure 2***, the remaining water ratio of finished variant A6 is bigger compared with this index for finished variant A12, analysing all evaporating periods. The results not applied in further analysis because of insufficient precision also showed the same tendency. Furthermore it was established that during 10 - 40 min, the RWR decreased from 96.42% to 86.24% for variant A6 and from 91.80 to 71.07% for variant A12. It was found that RWR decreased to 38.28% during the evaporation period 10 - 120 min for finished terry fabric with a low loop pile made of unbleached linen yarns.

Important changes in the fabric's structure lead to a very intensive transformation of its absorption-evaporation capacity. The loops made of linen yarns are rigid and range perpendicularly to the base of the grey fabric. Contacting with liquid, such fabric acts in a very special manner. The rigid loop pile in grey terry fabric with a linen pile when in contact with liquid firstly demonstrates resistance [13] to water uptake, and later on the fabric absorbs the drop. The evaporation process is closely related to the absorption phenomenon. In the finished samples the absorption process was shortened considerably [12, 13]. Moreover the liquid was absorbed very quickly at the beginning of process, and the absence of the drop's specular reflectance from the moment when it touched the fabric's surface was determined. In our experiment, during the period 10 - 40 min, the remaining water ratio decreased by 11.8% and 29.2% for finished variants A6 and A12 , respectively. Besides this, it was found that at the 60th minute of the evaporation period, the remaining water ratio reached a value of 37.90% for grey fabrics (see ***Figure 1***) and 78.37% for finished variant A6, i.e. the change was twice as much. Such behaviour between the liquid and terry fabric is conditioned by structural peculiarities. The structure of the loop pile in grey fabric is of very regular geometry, especially if the pile height is 6 mm. The character of curves determined for the finished fabrics are different compared with the results for grey fabrics (see ***Figures 1** & **2***). It is evident that there is a tendency for liquid to evaporate more slowly in the finished terry fabrics than in the grey ones; however, the height of the loop pile plays a role here. It was determined that there are significant differences in RWR for an evaporation period of 10-40 minutes for grey and finished fabrics with a low loop pile (6 mm): from 8.5 to 32.3%. The comparable results of this index for fabrics with a high loop pile (12 mm) were within the range of 5.0 - 8.7%. Such results indicated that the drying of grey terry fabric with a low loop pile compared with a finished one proceeded more quickly. Besides this, it was found that the decreases in the RWR of the grey and finished A6 variants for all evaporation periods are more considerable compared with the grey and finished A12 variants. Hence the important influence of pile height on the evaporating process of grey and finished fabrics with an unbleached linen loop pile was established.

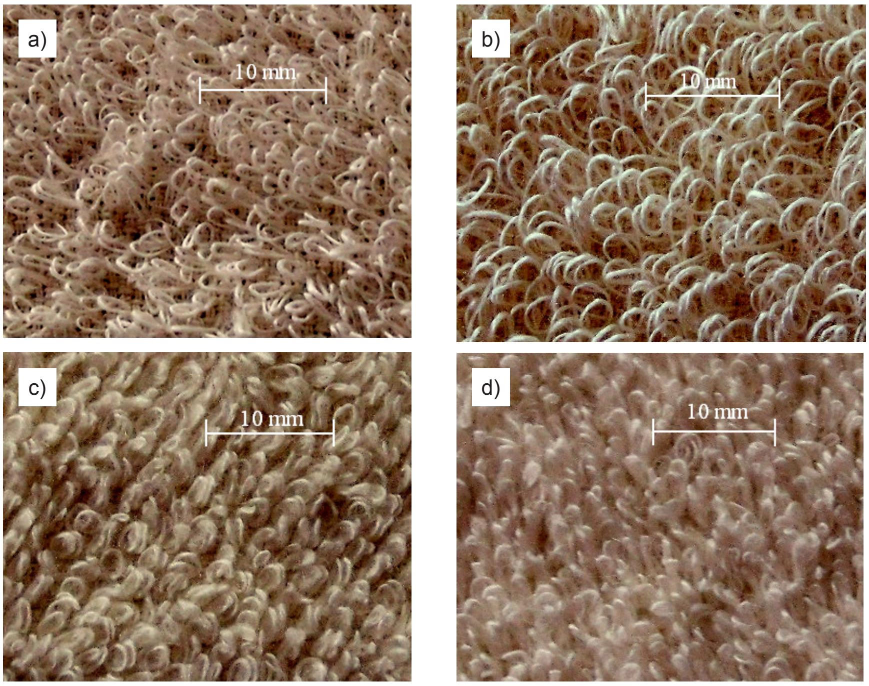

Figure 3. *Terry fabrics: a – grey B6, b – grey B12, c – finished B6, d – finished B12.*

It took 150 min and 130 min from the start moment till absolute water evaporation for grey and finished terry fabrics made with bleached linen pile warp yarns with a loop pile of 6 mm. The water evaporation lasted shorter (i.e. till 130 min) for grey variant B12 and 20 min longer (i.e. till 150 min) for finished variant B12. The appearance of grey and finished terry fabrics of B6 and B12 variants is presented in ***Figure 3***.

It was found that the relative error of the remaining water ratio did not exceed that appointed, while the evaporation process lasted till 90 - 80 min for fabric B6 and till 90 - 70 min for the B12 fabrics. Hence only the evaporation periods till these values were analysed and interpreted.

The informativity of all the experiments was proved because the criterion of Fisher calculated was as follows: for grey samples - $F = 62.6$ ($F_{Tabl.} = 5.9$) analysing variant B6 and $F = 105.1$ ($F_{Tabl.} = 5.9$) analysing variant B12; for finished samples - $F = 67.0$ ($F_{Tabl.} = 5.9$) analysing variant B6 and $F = 69.4$ ($F_{Tabl.} = 5.9$) analysing variant B12. As the results show, the degree of informativity is very high.

The results for which the informativity of the experiment was proved in a manner of logarithmic regressions were analysed. ***Figures 4** & **5*** show the evaporation process of grey as well as finished

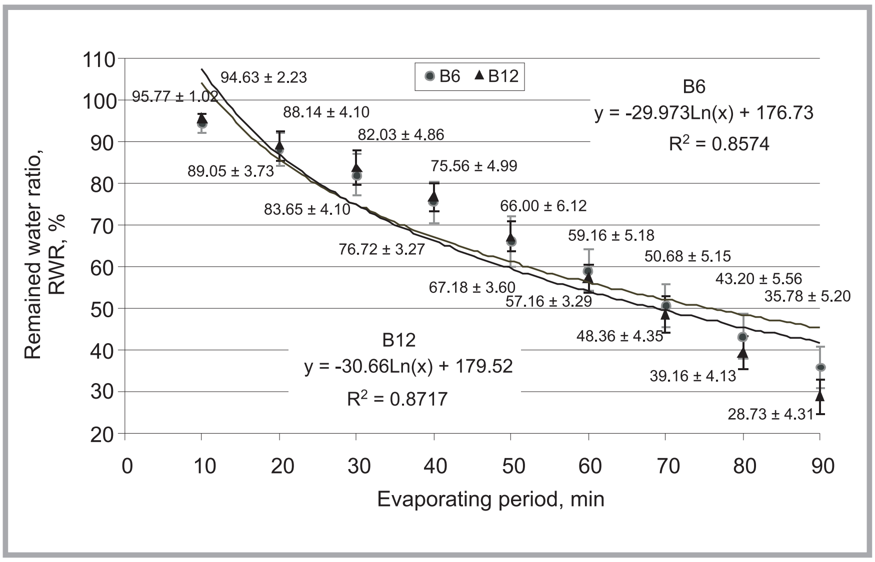

Figure 4. *Remaining water ratio of grey B6 and B12 fabrics in relation to the evaporation period.*

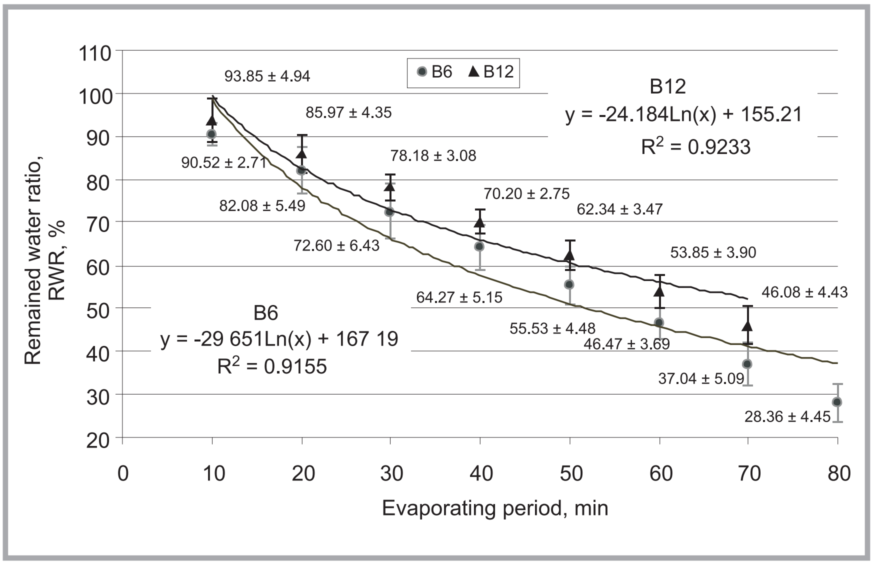

Figure 5. *Remaining water ratio of finished B6 and B12 fabrics in relation to the evaporation period.*

fabrics of the B6 and B12 variants. The logarithmic curves showed a good match with the experimental data: R^2 = 0.8574 - 0.9233. Moreover, the high determination coefficients proved that this is a very good match for both fabrics with respect to the other kinds of regression under investigation: linear, polynomial, and exponential: 0.9469 - 0.9999.

Although the two curves (see ***Figure 4***) correspond to the different fabric structures with respect to the height of the loop pile, both fabrics show very similar character of water evaporation over time. It was found that for a evaporation period of 10-90 min, the remaining water ratio decreased from 94.63 to 35.78% for the grey B6 variant and from 95.77 to 28.73% for the grey B12 variant. Meanwhile, the finished terry fabrics demonstrated a different character of liquid evaporation: the drying rate of fabric B6 is quicker compared with the B12 variant; however, the differences are mostly not statistically significant. Moreover the remaining water ratio of the finished terry fabrics decreased from 90.52% (B6 variant) to 93.85% (B12 variant) in the 10^{th} minute to 28.36% (B6 variant, 80^{th} minute) – 46.08% (B12 variant, 70^{th} minute). It was found that the differences in RWR for an evaporation period of 10 - 80 min for grey and finished fabrics with a low loop pile (6 mm) were 4.5 - 52.3%, which successively increase with an increase in the evaporation period. For an evaporation period of 10 - 70 min for the grey B12 variant and finished samples, the differences in RWR were 2.0 - 9.3%.

Conclusions

- The evaporation process of linen-cotton terry fabrics depends on the fabric characteristics and finishing.
- The evaporation process lasted till 130 - 150 min for grey terry fabrics and till 130 - 190 min or longer for finished fabrics, to which washing with detergent, softening, centrifuging, and tumbling procedures were applied.
- The informativity of the experiment was proved by analysing all data of the remaining water ratio. Regression analysis was applied, and many of the regressions investigated showed a very good or good match with experimental data. Mainly the results are best described by logarithmic (R^2 = 0.7882 - 0.9492), polynomial (R^2 = 0.9932 - 0.9999), linear (R^2 = 0.9722 - 0.9999) regressions, but in some cases other kinds of equations also represent the experiments very well.
- In grey terry fabrics with an unbleached linen loop pile there was a tendency for the water to evaporate at a higher rate compared with finished variants, which is contrary to the tendency of fabrics with bleached linen pile warp yarns – here the drying process passed more slowly in grey samples. In addition the important influence of loop pile height on the drying process was determined by comparing the grey and finished terry fabrics. The drying of grey fabric with a low unbleached loop pile generally followed more intensively compared with a fabric a with high loop pile, while the reverse tendency was evident in finished fabrics.
- It was found that at the 60^{th} minute of the evaporation period, the remaining water ratio reached 37.90% for grey fabrics and 78.37% for finished terry fabrics with an unbleached linen low loop pile.
- During 10 - 60 min, the remaining water ratio decreased by 60.0 - 67.5% for grey fabrics and by 74.3 - 94.8% for finished fabrics with bleached pile warp yarns.

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