(REFEREED RESEARCH)

EFFECTS OF SOFTENER APPLICATIONS ON AIR AND WATER VAPOR PERMEABILITY OF COTTON KNITTED FABRICS PRODUCED WITH DIFFERENT YARNS

YUMUŞATICI UYGULANMASININ FARKLI İPLİK YAPILARINNINDAN ÜRETİLMİŞ PAMUKLU ÖRME KUMAŞLARIN HAVA VE SU BUHARI GEÇİRGENLİKLERİNE ETKİSİ

Umut Kıvanç ŞAHIN, Sena CIMILLI DURU

Istanbul Technical University, Textile Technology and Design Faculty

Received: 23.01.2017 Accepted: 12.04. 2017

ABSTRACT

Softeners are commonly applied during manufacture and care of garments, mostly for improved feel and odor they offer. However, they alter some of the properties of the textile materials on which they are applied. To achieve the thermal regulation of the human body, air and water vapor permeability properties of the fabrics are very important parameters. From point of this view, it was the aim of the study to investigate the effects of softener on air and water vapor permeabilities of the fabrics. For a deeply investigation; cationic, non-ionic and silicone were selected as softener types, and they were applied at various concentration levels (0, 1, 2, 3 %) on bleached or bleached&dyed fabrics which were knitted by using ring or open-end yarns. To evaluate the results ANOVA and t-test analyzes were used. According to the results, fabrics made from open-end yarn showed better air and water vapor permeability. In addition to that, additional wet process was shown to change the permeability properties of knitted fabrics. Also, treatment with softener affected permeability properties negatively, but the effects of concentrations of the softeners studied were more significant on air permeability than those on water vapor permeability. Furthermore, among the softeners studied, non-ionic softener performed superior to cationic and silicone softeners in terms of air and water vapor permeability.

Keywords: Ring, open-end, softener, cotton, knitted fabric, bleaching, dyeing, air permeability, water vapor permeability

ÖZET

Yumuşatıcılar, giysilerin üretimi ve bakımında sağladıkları his ve koku özellikleri nedeniyle sıklıkla uygulanırlar. İnsan vücudunun termal dengesini sağlamak için, kumaşların hava ve su buharı geçirgenlikleri önem taşımaktadır. Bu noktadan yola çıkarak, uygulanan yumuşatıcıların hava ve su buharı geçirgenliklerine olan etkileri çalışmada ayrıntılı olarak irdelenmiştir. Çalışma esnasında ayrıca boyamanın bu özelliklere olan etkisini de incelemek adına, ağartılmış ve ağarttma sonrasında boyanmış kumaşlara ayrı ayrı yumuşatıcı uygulanmıştır. Yumuşatıcı tipinin etkisini de araştırmak için katyonik, non-iyonik ve silikon yumuşatıcı çeşitleri ve bu yumuşatıcıların üç farklı konsantrasyonu open-end ve ring ipliklerden üretilmiş % 100 pamuk ipliğinden üretilmiş süprem kumaşlara uygulanmıştır. Elde edilen değerler ANOVA ve t-testi ile istatistiksel olarak değerlendirilmiştir. Elde edilen sonuçlara göre; open-end ipliğinden yapılan kumaşların hem hava hem de su buharı özellikleri daha iyidir ve boyama işlemi kumaşların bu özelliklerini önemli bir şekilde etkilemektedir. Yumuşatıcı ile mamul edilen kumaşların geçirgenlik özellikleri düşerken, non-iyonik yumuşatıcıya tabi olmuş kumaşlar daha iyi performans göstermiştir.

Anahtar Kelimeler: Ring, open-end, yumuşatıcı, ağartma, boyama, hava geçirgenliği, su buharı geçirgenliği

Corresponding Author: Umut Kıvanç Şahin, sahinumut3@itu.edu.tr.

1. INTRODUCTION

Clothing plays a very important role in maintaining the equilibrium of heat and moisture transfer and they are affected by the environment as well as human factors and clothing factors such as fabric and garment openings [1, 2]. During heavy activities, the body produces lots of heat energy and the body temperature rises. To decrease the temperature, the body perspires in liquid and vapor form [3]. A fabric that is perceived as comfortable should transmit moisture vapor during the period the body sweats actively, and when the body has stopped sweating, the fabric should release the moisture vapor held in the space to the atmosphere to reduce the humidity at the skin and body temperature [4, 5]. Thus, the garments should allow the perspiration to pass through to ensure comfort. Mecheels [6] described four mechanisms by which water (liquid or vapor phase) can phase through a textile layer: penetration through the space between fibers according to the laws of diffusion, absorption by the fiber material as a result of transfer within fibers and desorption, transfer of liquid water through capillary interstices in yarns, and migration of water on fiber surfaces. The first two mechanisms are related to water vapor diffusion and the others to liquid transport phenomena. Therefore, thermal and water vapor transmission properties of fabrics are very important.

Air permeability which determines the ability of a fabric to carry out gaseous substances, also significantly influences the thermal comfort of the human body and secures the support of proper body temperature [7]. When the body is at rest, the air in the microclimate contributes up to approximately 50 % to the effective thermal insulation properties of the clothing. When the body is in motion, approximately 30 % of the heat and moisture can be removed by air convection in the microclimate and air exchange via the clothing [8]. Air and water vapor permeabilities are vital quality in such end-use applications as sport garments, underwear products, t-shirts, socks and others. Thus, the effects of the parameters on air and water vapor permeability of the fabrics were the main interest of some researchers [9-17].

Fabric softeners have been used for more than 50 years; silicone ones being most popular in garment production due to ‘super soft’ effect, cationic ones mostly applied after washing step during laundering, and their non-ionic alternatives increasing their popularity mostly due to their compatibilities with a variety of different chemicals in various applications [18]. Several studies have been conducted on the effects of softeners on fabric properties, such as the appearance properties (wrinkle recovery, pilling and whiteness) and maintenance properties (dimensional stability and stain release). However, the studies on the effect of fabric softeners on comfort properties such as hand, static electricity and thermal comfort are scanty [19]. Cubric et al [1] focused on the influence of the type of textile fibers, yarn and knitted fabric parameters and finishing (bleaching, dyeing, and softening) parameters on the transfer of water vapor and air permeability of fabrics. It was found that after the finishing process, both air and water permabilities of all investigated fabrics decreased. Ibrahim et al [20] attempted to investigate how fabric constructions as well as post-treatment finishes affect the mechanical, tactile and comfort properties of the finished cellulosic knits. According to their results, heat transmittance, air permeability, hydrophilicity as well as whiteness index of treated fabric samples were decreased after softness finishing process. Parthiban and Kumar [19] investigated the effect of cationic softener on the thermal comfort of fabrics and they found that the fabric softener treatment with different levels concentration significantly decreased the air permeability of cotton fabrics. In order to compare the changes of heat resistance of cotton plain jersey fabrics, Cubric and Skenderi [21] produced cotton knitted fabrics and finished them according to three different recipes (including dyeing and softening). They indicated that finishing treatments decreased the heat resistance of the fabrics. The effects of silicone softeners on some mechanical and functional properties of knitted regenerated cellulose (viscose, modal, Viloft®, micromodal, lyocell and bamboo) fabrics were assessed by Sarioglu and Çelik [22]. For this purpose, they used commercially silicone softeners with three different particle sizes (macro, semi-macro, micro) applied them on these fabrics and found that the application of softeners has a significant effect on air permeability with respect to untreated fabrics.

Garments contacting to human body are usually made of cotton knitted fabrics, and softeners are applied on fabrics or garments in order to have an improved feel and better scent. From point of this view, the main focus of this study was to investigate the effects of three different softeners (namely non-ionic which is more environmentally friendly, cationic which is cheaper and acceptably useful for cotton goods, and silicone which is expensive while offering superior softener performance on cotton goods) on the air and water vapor permeabilities of the cotton fabrics, both of which are important criteria in assessing daily use performance of garments. In addition to that, as the amount of softener applied during care is mostly user-dependent, its effect on the expected performance was also examined in this study.

2. MATERIALS AND METHOD

The samples for the study were 100% cotton plain jersey fabrics made of ring and open-end yarns. The details regarding the properties of the yarns are given in Table 1.

Table 1. Yarn properties

	Ring	Open-End
Yarn count (Ne)	19.88	19.72
Yarn twist (tour/m)	582	618
Yarn strength (rkm)	3.45	2.53
Yarn elongation (%)	6.67	6.25
Yarn hairiness (S3)	3404	657

Prior to dyeing fabrics from open-end or ring yarns were bleached using hydrogen peroxide (37%) as the bleaching agent, following the recipe given in Figure 1. The liquor ratio was 1:10. After rinsing, the bleached samples were neutralized using 0.2 g/L Terbinox Ultra AL antiperoxide agent. Some portion of the fabrics were colored using 30g/L salt, 10g/L soda ash and %1(owf) Reactive Yellow 145 (C.I.Y.145) dye according to the recipe given in Figure 2. The liquor ratio was 1:10. After cooling to 40^{0}C, samples were hot soaped at 98^{0}C for 30 minutes using 2g/L Texapol RSN, which is an anionic soap based on a mixture of polycarboxilate and polyphosphonate, and hot rinsed at 98^{0}C for 30 minutes in distilled water, followed by rinsing in distilled water for 5 minutes. Both bleaching and dyeing processes were performed in an ATC-DYE HT01F lab type exhaust dyeing machine.

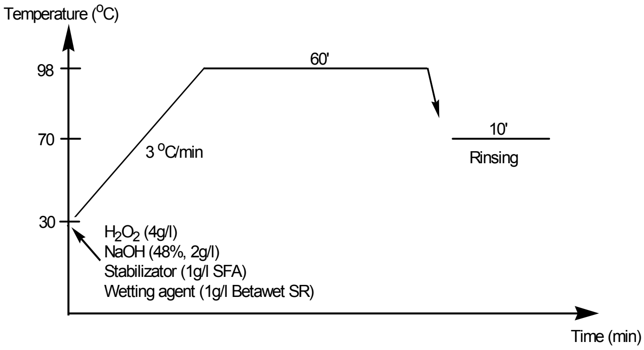

Figure 1. Bleaching recipe

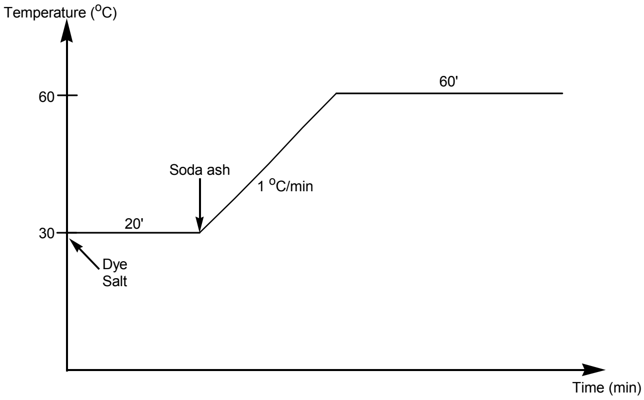

Figure 2. Dyeing recipe

The cationic softener used in this study (SETAFEN SC) was an ethoxylated amine compound with a pH value of 3.5 to 4.5 in a 10% solution and solubility in water. The non-ionic softener used (SETAFEN PE-N) was a blend of polyethylene emulsions with a pH value of 7.0 to 8.0 in a 1.5g/L solution and complete solubility in water. The silicone softener used (SETASOFT 1640) was a macro-emulsion of amino-functional silicone with a pH of 5.0 to 5.5 in a 10% solution and complete solubility in water. All softener solutions were prepared at desired pH with an acetic acid/sodium acetate buffer system, 1 to 3% solutions padded to bleached or bleached&dyed cotton fabrics at 100% wet-pick-up, followed by drying at 50^{0}C. All solution percentages are expressed as weight on weight. Please note that fabrics that were not treated with softener formed 0% softener application level. The factors and their levels chosen for the full-factorial experimental study are given in Table 2.

Air permeability, water vapor permeability, fabric weight, thickness, yarn count, yarn twist, yarn strength, and yarn hairiness were tested in accordance with standard test methods ASTM D 737, BS 7209:1990, EN 12127, EN ISO 5084, EN ISO 2060, ASTM D1422-99, EN ISO 2062, and TS 7123 in turn. The overall porosity is defined as the ratio of open space to the total volume of the porous material and accordingly it was calculated from the measured thickness and weight per unit area values using the following equations [23]:

Table 2. The factors and their levels chosen for the experimental study

Factor	Levels
Yarn Type	Open-end, Ring
Process History	Bleached, Bleached&Dyed
Softener Applied	Cationic, Non-ionic, Silicone
Softener Percentage (%)	0, 1, 2, 3

Bleached and bleached&dyed fabrics without softener application were tested as control groups in order to show the effect of softener type and concentration on the tested performance of the samples. Properties of fabrics are given in Table 3. The samples were coded such that the first letter shows the yarn type (R-Ring and O-Open-end), the second letter refers to the process history (G-Greige, B-Bleached and D-Bleached&Dyed), third letter shows the softener type (C-Cationic, N-Non-ionic and S-Silicone) and finally the last one stands for the softener concentration (1, 2, 3 for, 1%, 2%, and 3%, respectively).

Minitab 17 package program was used to perform the statistical evaluation of the data obtained from full-factorial experiments. One-way ANOVA and t-test methods were employed by using SPSS 18 software package and the factors were considered to be significant at a p-value less than 0.05.

3. RESULTS AND DISCUSSION

In Table 4, the test results of air and water vapor permeability of the samples were shown. In the following sections of the paper, the relevant parts of these results were discussed in detail.

3.1. Air permeability

From the results presented in Table 4, it can be stated that the highest air permeability value was obtained for OBC3 fabric while RBC2 sample had the lowest one when greige fabrics were excluded.

When the air permeability results of the samples made of ring and open-end yarns were compared, as can be seen from Figure 3, those made of the ring ones showed lower air permeability results. The main reason of this obtained result may be the higher yarn hairiness values of the ring yarn as seen from the Table 1. As it is known, incidence of wrapper fibers at the open-end yarn structure results in a compact yarn with reduced hairiness [24] and protruding fibers from a yarn to a pore hinders passage of air through the fabric [3, 25]. Also, paired t-test supported this very result that air permeability values of fabrics made from ring and open-end were different (t=4.679 sig.0.000).

Table 3. Properties of the fabrics

Yarn type	Process history	Sample code	Thickness (mm)	Weight (g/m^2)	Stitch density ($loops/cm^2$)	Porosity (%)
Ring	Greige	RG	0.518	133.65	132.50	83.03
	Bleached	RB	0.63	174.23	155.33	81.81
		RBC1	0.592	160.12	153.00	82.21
		RBC2	0.552	161.88	155.75	80.71
		RBC3	0.584	161.88	151.67	81.76
		RBN1	0.586	153.06	153.33	82.82
		RBN2	0.564	158.79	145.17	81.48
		RBN3	0.564	163.65	151.17	80.91
		RBS1	0.57	162.32	162.00	81.26
		RBS2	0.566	160.56	149.25	81.34
		RBS3	0.542	164.53	153.00	80.03
	Bleached&Dyed	RD	0.6	163.65	157.17	82.06
		RDC1	0.574	163.21	159.08	81.29
		RDC2	0.582	166.73	155.67	81.15
		RDC3	0.558	162.32	157.33	80.86
		RDN1	0.544	158.79	151.42	80.80
		RDN2	0.538	160.12	153.33	80.42
		RDN3	0.522	158.79	149.25	79.99
		RDS1	0.568	159.24	150.75	81.56
		RDS2	0.552	159.68	153.58	80.97
		RDS3	0.55	156.15	155.50	81.32
Open-End	Greige	OG	0.584	146.44	134.58	83.50
	Bleached	OB	0.73	207.76	171.08	81.28
		OBC1	0.66	193.20	185.00	80.74
		OBC2	0.654	197.17	171.17	80.17
		OBC3	0.69	194.52	177.33	81.45
		OBN1	0.638	191.44	171.08	80.26
		OBN2	0.666	199.38	173.58	80.31
		OBN3	0.648	194.96	165.58	80.21
		OBS1	0.626	190.11	175.58	80.02
		OBS2	0.61	190.11	164.83	79.50
		OBS3	0.716	188.35	168.67	82.69
	Bleached&Dyed	OD	0.72	196.29	177.42	82.06
		ODC1	0.66	194.08	172.50	80.65
		ODC2	0.588	189.67	164.83	78.78
		ODC3	0.672	191.88	171.08	81.22
		ODN1	0.65	192.32	169.92	80.53
		ODN2	0.638	200.26	164.75	79.35
		ODN3	0.644	187.91	168.08	80.80
		ODS1	0.644	194.52	166.92	80.13
		ODS2	0.668	193.20	175.50	80.97
		ODS3	0.654	186.14	172.00	81.27

Table 4. Results of air permeability and water vapor permeability

Sample coding	Air permeability ($cm^3/cm^2/s$)	Water vapor permeability, $g/m^2/day$
RG	499.75	902.74
RB	486.67	908.87
RBC1	383.00	896.14
RBC2	333.67	811.54
RBC3	388.33	825.77
RBN1	349.33	835.50
RBN2	368.00	822.02
RBN3	404.33	840.74
RBS1	372.50	813.79
RBS2	407.00	851.22
RBS3	407.67	847.48
RD	398.00	883.62
RDC1	345.33	816.04
RDC2	378.67	786.09
RDC3	346.33	857.21
RDN1	395.00	787.59
RDN2	436.00	957.53
RDN3	380.00	857.21
RDS1	412.00	877.43
RDS2	351.33	834.75
RDS3	390.67	837.00

Sample coding	Air permeability ($cm^3/cm^2/s$)	Water vapor permeability, $g/m^2/day$
OG	475.32	894.82
OB	436.00	929.03
OBC1	447.33	901.38
OBC2	359.67	912.61
OBC3	542.00	839.24
OBN1	391.00	867.69
OBN2	361.50	852.72
OBN3	450.67	848.98
OBS1	438.00	843.74
OBS2	416.33	778.60
OBS3	406.33	858.71
OD	386.00	1053.36
ODC1	420.33	834.00
ODC2	355.67	819.03
ODC3	384.00	822.02
ODN1	481.67	1094.54
ODN2	418.67	866.20
ODN3	449.67	947.05
ODS1	393.33	869.94
ODS2	421.67	792.83
ODS3	490.33	804.06

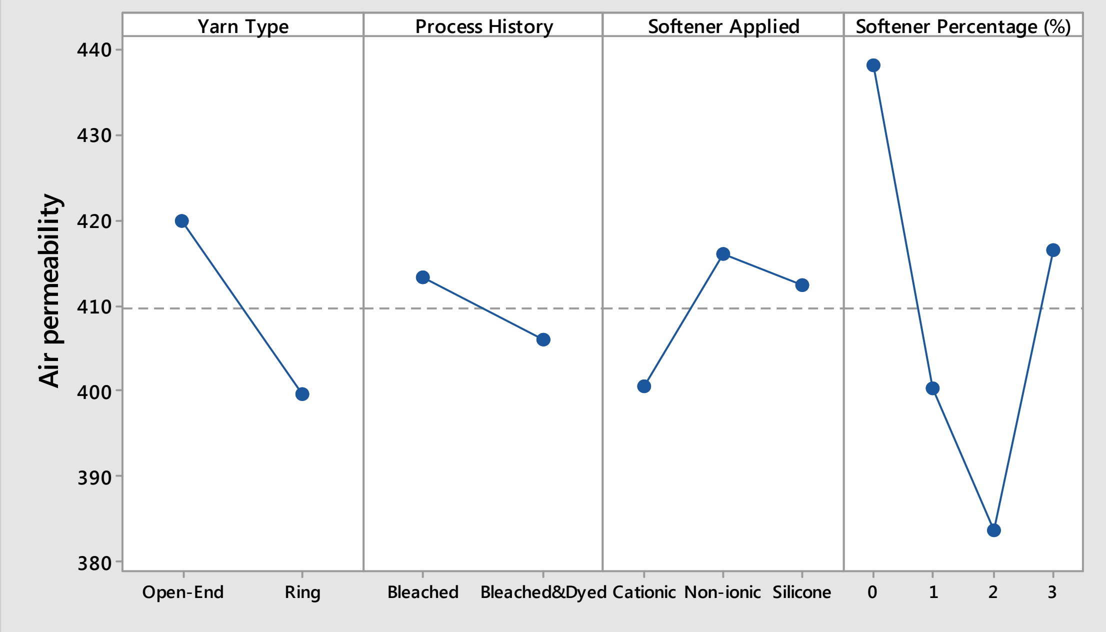

Figure 3. Main effects plot for air permeability ($cm^3/cm^2/s$)

When the effect of process history was considered, it is apparent from Table 3 and Figure 3 that regardless of yarn type, air permeability values of fabrics decreased in the order of greige, bleached and bleached&dyed. The reason of this obtained result can be attributed to the effect of additional wet process on changes in fabric dimensions. Previous studies have shown that washing and drying cycles causes reduction in interyarn and interfiber spaces [26]. Moreover, it was reported that to some extent fabric thickness determines air permeability as air has to travel a thicker path and faces higher frictional forces during its passage through the fabric and thus decrease in fabric thickness after dyeing process (see Table 3) resulted in lower air permeability [27, 28]. However, different from the above findings, the paired t-test revealed that the difference between the air permeability values of bleached and bleached&dyed samples were not statistically significant (t=0.111 p=0.714).

From the study, it was found that the softener treatment significantly decreased the air permeability of fabrics (see Figure 3). After additional wetting process by softener, cotton fiber swells after absorption of water and fabric porosity and thickness change. When the degree of porosity and thickness are decreased, the fabric would become less permeable because less air is allowed to flow through the fabric. Moreover, cotton fibers are hydrophilic, and hence absorb great amount of softener [19]. The absorbed softener within fibers could block the air space between fibers or yarns, resulting in decrease in air permeability. According to the independent t-test results, irrespective of softener type, treatment of softener to the fabric was a highly significant factor on the air permeability values of fabrics (t=6.842 sig. 0.03). Moreover, from the obtained results, it was found that softener type affected the air permeabilities of the fabrics (see Figure 3). Cationic and silicone softeners comprising amino functional groups, even when weakly cationic, will exhaust on to cotton fiber surfaces because of hydroxyl groups in the cellulose. On the other hand, distribution of nonionic softeners is possible both on the fiber surface and at the interior of fibers [29]. Thus, the increase in thickness of cotton fabrics treated with nonionic softeners was lower than those treated with cationic and silicone softeners which caused resultant fabric thickness to be lower than those treated with the other ones (see Table 3). Having low thickness, samples treated with nonionic softeners offered higher air permeability. ANOVA evaluation of the results showed that air permeability values of the fabrics treated with cationic softener differed than silicone and non-ionic ones (F=12.981 sig. 0.04). It is apparent from Figure 3 that air permeability decreased with application of softener. This is mostly due to effect of additional wet process on the knitted fabrics structure. During softener application, the knitted fabric shrinks and this caused a decrease in air permeability. However, with increasing the concentration of softener, surfaces of the protruding fibers would be coated with softener leading to a smoother surface and thus air permeability of the fabrics increased comparing to lower concentrations. Also, according to ANOVA evaluation, softener concentration level was important to determine the air permeability values of the fabrics (F=6.031 sig. 0.01).

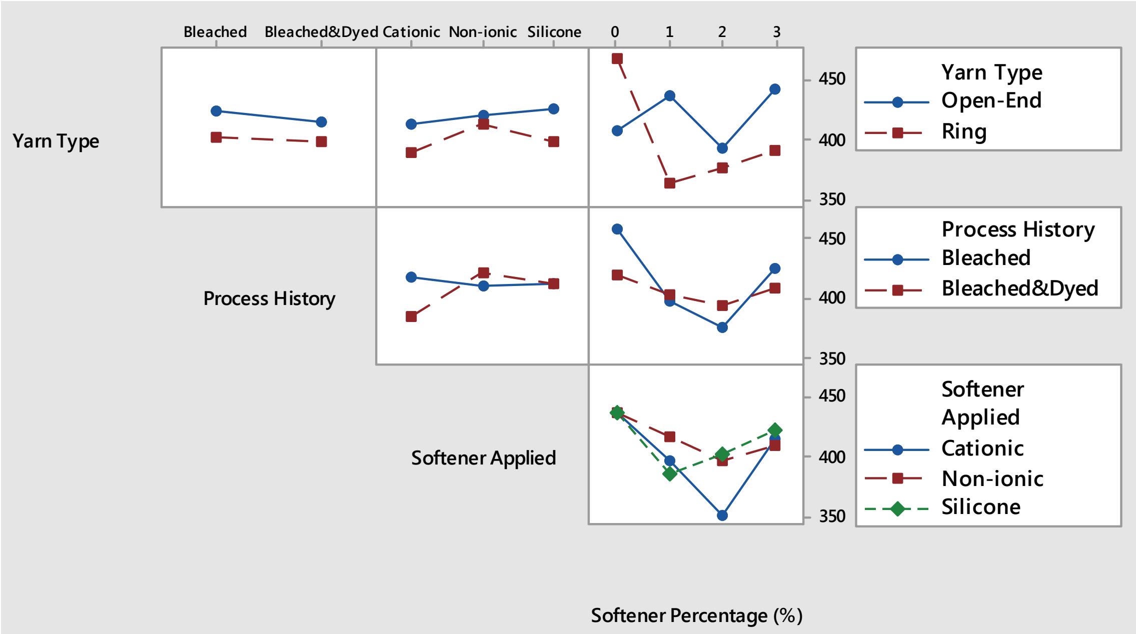

Figure 4. Interaction plot for air permeability (cm^3/cm^2/s)

As can be seen from Figure 4, samples made of open-end yarns were superior to those made of ring yarns in terms of air permeability regardless of the levels of other factors. When the effect of process history was considered, bleached or bleached&dyed samples followed a similar trend in terms of resulting air permeability with the exception of samples treated with cationic softener. Dyed samples showed lower permeability when treated with cationic softener. This phenomenon may be attributed to interaction between reactive dyestuff and cationic softener, resulting in absorption of higher amount of cationic softener, and thus an additional increase and lower air permeability on dyed samples treated with cationic softener when compared to only bleached ones. It was found that softener application had a significant effect on the final air permeability. However, the effects of softener concentration varied depending on yarn type, process history and softener type, all of which resulted differently in air permeability values.

3.2. Water Vapor Permeability

The results presented in Table 4 showed that all among the samples in the study the water vapor permeability of the ODN1 fabric was the highest whilst OBS2 samples performed the worst when greige fabrics were excluded.

Fabrics made of open-end yarn were shown to have higher water vapor permeability then those made of ring yarns (see Figure 5). Packing and hairiness were two main factors contributing on the obtained results. Wrappings and wrapper fibers at the open-end yarn structure causes a higher packing than ring yarn, which causes higher pore volumes on the fabric and thus lower water vapor resistance throughout the fabric [24, 30]. Also, the higher hairiness of samples made from ring yarns compared to those made from open-end yarns resulted in lower water vapor permeability. Higher hairiness of the yarns cause more hairy surfaces. The presence of more hairs in the yarn has an influence on the interspaces between the yarns, thus resulting in a lower permeability [3, 30]. Paired t-test confirmed these results that there was a significant difference between the water vapor permeability values of ring and open-end samples (t=-2.571 sig. 0.00).

When the effect of process history was concerned, the water vapor permeability values of the bleached&dyed samples were higher than only bleached ones (see Figure 5). Decrease in amounts of impurities after additional wet process (dyeing, hot soaping, hot rinsing and cold rinsing) may have caused further increase in absorbency bringing additional water vapor performance. The paired t-test evaluation also supported this obtained result that dyeing process was an influential parameter on water vapor permeability of the samples (t=-13.542 sig. 0.000).

Fabrics treated with nonionic softener performed better water vapor permeability values due to their superiority on hydrophilicity. Cationic softeners orient themselves with the hydrophobic portion away from the fabric, thus offering lower performance in their relation with water. According to ANOVA evaluation water vapor permeability values of samples treated with cationic and silicone tended to behave in the same manner whereas non-ionic ones differed (F=7.789 sig. 0.01). On the other hand, application of softener decreased the water vapor permeability but its concentration level over 1% did not further influence the discussed parameter significantly. Also, the ANOVA results implied that softener concentration level was not a significant factor on the water vapor permeability values of samples (F=2.571 sig. 0.081).

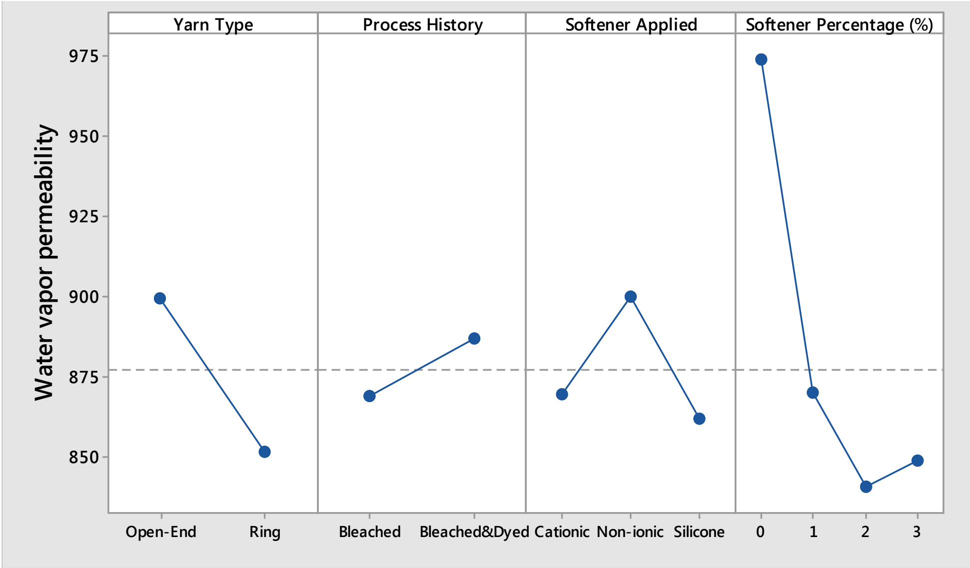

Figure 5. Main effects plot for water vapor permeability, g/m^2/day

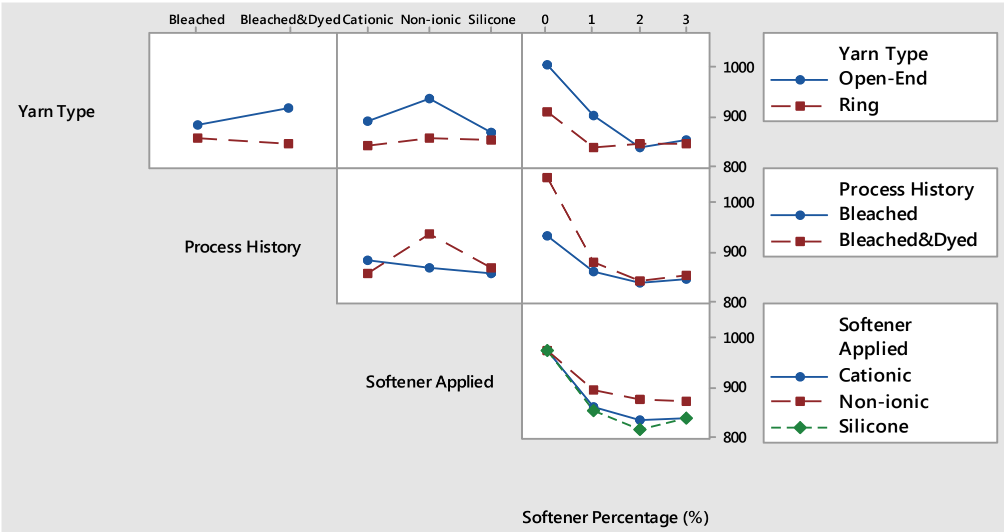

Figure 6. Interaction plot for water vapor permeability, g/m^2/day

Interaction plots given in Figure 6 showed that water vapor permeability of fabrics made of open-end yarns performed better than that of ring yarns. Due to the effect of additional wet process on the fabric construction, bleached&dyed samples mostly offered higher water vapor permeability than only bleached ones. Softener treatment caused a significant decrease in water vapor permeability regardless of softener type. However, the concentration levels among those studied did not have a significant effect on the discussed parameter.

4. CONCLUSION

The aim of the study was the comparison of effects of yarn type (ring and open-end), process history (bleached and bleached&dyed), softener type (cationic, non-ionic and silicone) as well as concentration level (0, 1, 2, 3 %) on the air and water vapor permeability of cotton plain jersey fabrics. ANOVA and t-test analyzes were used to evaluate the test results. The obtained results showed that:

1. Both water and air permeability values of the fabrics made of open-end yarn performed better than those of ring ones.
2. Air permeability values of the samples decreased and water vapor permeability values increased in the order of greige, bleached and bleached&dyed. Change of loop size and loop structure as well as decrease of fabric thickness due to the additional wet process may be the reason of the obtained data. Moreover, increase in absorbency as a result of decrease in amounts of impurities after additional wet process further contributed to obtained water vapor performances.
3. Both water and air permeability decreased with softener application. However, the effects of concentrations of the softeners studied were more significant on air permeability than that on water vapor permeability.
4. Non-ionic softener performed superior to cationic and silicone softeners in terms of air and water vapor permeability.

REFERENCES

1. Cubric, I.S., Skenderi, Z. and Havenith,G., 2013, "Impact of Raw Material, Yarn and Fabric Parameters, and Finishing on Water Vapor Resistance", Textile Research Journal, 83(12), pp.1215-1228.
2. Yoo, H.S. Hu, Y.S. and Kim, E.A. 2000, "Effects of Heat and Moisture Transport In Fabrics And Garments Determined with a Vertical Plate Sweating Skin Model", Textile Research Journal, 70(6), pp.542-549.
3. Majumbar, A., Mukhopadhyay, S. and Yadav, R. 2010, "Thermal Properties of Knitted Fabrics Made From Cotton and Regenerated Bamboo Cellulosic Fibers", International Journal of Thermal Sciences, 49, pp.2042-2048
4. Prahsarn, C., Barker, R.L. and Gupta, B.S. 2005, "Moisture Vapor Transport Behavior of Polyester Knit Fabrics", Textile Research Journal, 75(4) pp.346-351.
5. DeMarting, R.N., Yoon, H.N., Buckey, A., Evins, C.V., Averell, R.B., Jackon, W.W. and Schultz, D.C. 1984, "Improved Comfort Polyester, Part3: Wearer Trials", Textile Research Journal, July, pp.447-458.
6. Hatch K. L., Woo, S. S., Barker, R. L., Radhakrishnaiah, P., Markee, N. L. and Maibach, H. I. 1990, "In Vivo Cutaneous and Perceived Comfort Response to Fabric Part .1: Thermophysiollogical Comfort Determinations for Three Experimental Knit Fabrics", Textile Research Journal, 60(7), pp.405-412.
7. Cuikas, R. and Abramaviciute, J. 2010, "Investigation of the Air Permeability of Socks Knitted From Yarns with Peculiar Properties", Fibres&Textiles in Eastern Europe, Vol. 18, No:1(78) pp.84-88.
8. Bivainytė, A. and Mikučionienė, D. 2012, "Influence of Shrinkage on Air and Water Vapour Permeability of Double-Layered Weft Knitted Fabrics". Materials Science (Medžiagotyra), 18(3), pp.271-274.
9. Raja, D. Prakash, C. Gunasekaran G. and Koushik C.V. 2015, "A Study on Thermal Properties of Single-Jersey Knitted Fabrics Produced From Ring and Compact Folded Yarns", The Journal of The Textile Institute, 106(4), pp.359–365.
10. Prakash, C. Ramakrishnan, G. Mani K. and Keerthana S. 2015 "An Investigation of The Relationship Between Blend Ratio, Linear Density and Loop Length on Geometrical and Air Permeability Properties of Bamboo Cotton-Knitted Fabrics". International Journal of Fashion Design, Technology and Education, 8(3), pp.228–234.
11. Gupta, D., Kothari V.K. and Jhanji. Y. 2014, "Heat and Moisture Transport in Single Jersey Plated Fabrics". Indian Journal of Fibre & Textile Research Vol. 39 June, pp.115-121.
12. Gorjanc, D.S. and Bizjak, M. 2015, "Impact of Pre-Finishing Process on Comfort Characteristics of Stretchable Cotton Fabric" Journal of Engineered Fibers and Fabrics, 10(3), pp.57-68.
13. Blaga, M., Ciobanu, A. R., Marmaralı, A., Ertekin, G. and Çelik. P. 2015 "Investigation of the Physicl and Thermal Comfort Characteristics of Knitted Fabrics Used For Shoe Linings" Tekstil ve Konfeksiyon, 25(2) pp.111-118.
14. Jhanji, Y., Gupta, D and Kothari, V. K. 2015 "Liquid Transfer Properties and Drying Behavior of Plated Knitted Fabrics with Varying Fibre Types", Indian Journal of Fibre & Textile Research, Vol. 40, June, pp.162-169.
15. Sharma, N., Kumar, P., Bhatia, D. and Sinha, S.K. 2016 "Moisture Management Behaviour of Knitted Fabric from Structurally Modified Ring and Vortex Spun Yarn" J. Inst. Eng. India Ser. E., 97(2) pp. 123-129.
16. Prakash, C. and Ramakrishnan G. 2014 "Study of Thermal Properties of Bamboo/Cotton Blended Single Jersey Knitted Fabrics", Arab J Sci Eng, 39(3), pp.2289–2294.
17. Ertekin, G., Oğlakcıoğlu, N., Marmaralı, A., Eser, B. and Pamuk M. 2015 "Thermal Transmission Attributes of Knitted Structures Produced by Using Engineered Yarns", Journal of Engineered Fibers and Fabrics,10(4), pp.72-78.
18. Schindler, W. D. and Hauser P. J. 2004 "Chemical Finishing of Textile", Woodhead Publishing Ltd., Cambridge, England. pp 29-38 ISBN 1 85573 905 4.
19. Parthiban, M.and Kumar, M.R. 2007 "Effect of Fabric Softener on Thermal Comfort of Cotton and Polyester Fabrics", Indian Journal of Fibre and Textile Research, 32 December, pp.446-452.
20. Ibrahim, N.A., Khalifa, T.F., El-Hossamy M.B. and Tawfik, T.M. 2010 "Effect of Knit Structure And Finishing Treatments on Functional and Comfort Properties of Cotton Knitted Fabrics", Journal of Industrial Textiles, 40, pp.49-63.
21. Čubrić, I. S. and Skenderi Z. 2014 "Effect of Finishing Treatments on Heat Resistance of One- and Two-Layered Fabrics", Fibers and Polymers, 15(8), pp.1635-1640.
22. Sarioğlu E. and Çelik N. 2015 "Investigation on Regenerated Cellulosic Knitted Fabric Performance by Using Silicone Softeners with Different Particle Sizes". Fibres & Textiles in Eastern Europe 23, 5(113), pp.71-77.
23. Mukhopadhyay, A., Ishtiaque, S.M. and Uttam, D. 2011 "Impact of Structural Variations in Hollow Yarn on Heat and Moisture Transport Properties of Fabrics", The Journal of The Textile Institute, 102(8), pp.700–712.
24. Tyagi, G.K. and Sharma, D. 2005 "Thermal Comfort Characteristics of Polyester-Cotton MVS Yarn Fabrics", Indian Journal of Fibre&Textile Research, Vol. 30 December, pp.363-370.
25. Yoon, H. and Buckley A. 1984 "Improved Comfort Polyester Part 1: Transport Properties and Thermal Comfort of Polyester/Cotton Blend Fabrics", Textile Research Journal, May, pp.289-298,
26. Duru, S.C. and Candan, C. 2013 "Effect of Repeated Laundering on Wicking and Drying Properties of Fabrics of Seamless Garments", Textile Research Journal, 83(6) pp.591–605.
27. Cimilli, S., Nergis, B.U., Candan, C. and Özdemir, M. 2010 "A Comparative Study of Some Comfort-Related Properties of Socks of Different Fiber Types", Textile Research Journal, 80; pp.948-957.
28. Halgas, B.W, Danych, R., Wiecek, B. and Kowalski, K. 2006 "Air and Water Vapour Permeability in Double-Layered Knitted Fabrics with Different Raw Materials", Fibres&Textiles in Eastern Europe, 57, 14(3), pp.77-80.
29. Carr, C.M. 1995 "Chemistry of Textiles Industry", Chapman&Hall, Cambridge, ISBN 0 7514 0054 8
30. Adler, M. M. and Walsh, W. K. 1984. "Mechanisms of Transient Moisture Transport Between Fabrics", Textile Research Journal, May, pp.334-342.
31. Çil, M.G., Nergis, U.B. and Candan C. 2009 "An Experimental Study of Some Comfort-related Properties of Cotton-Acrylic Knitted Fabrics", Textile Research Journal, 79(10), pp.917-923.