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Development of Cotton fabric with Unidirectional Moisture Transport Property

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ABSTRACT

A cotton garment is preferred in normal use due to cotton's moisture absorbing properties and comfort. But this absorbed moisture is not transported away from skin for spreading and evaporation to outer layer of fabric making garment wet and causing fabric cling. The garment-skin microclimate has a large moisture gradient when wearer moves between environments with difference in relative humidity which causes a chilling feeling and negatively affecting thermophysiological comfort of wearer. The objective of this work is to improve sensible perspiration transport property of cotton fabric by developing a knitted structure having different wetting properties on inner (skin side) and outer face of fabric This was achieved by applying a water repellent finish at the yarn stage to ultimately modify the wetting behavior of single jersey and plated single jersey cotton knits to enhance their liquid moisture transport properties.

Keywords: cotton, knitted, microclimate, wetting, moisture transport

1. Introduction and background

Cotton has been used in apparel for a long time due to its unique combination of properties i.e. softness, moisture absorbency and comfort (Dai, Imamura, Liu, & Zhou, 2007; İLETİM & ÇALIŞMA, 2009; Liu, Xin, & Choi, 2012; Patnaik, Rengasamy, Kothari, & Ghosh, 2006; Rearick & Andersen, 2006). It is uniquely suitable for a tropical climate. However, this absorbency is also the reason behind its unsuitability in highly humid climatic conditions when its poor wicking and evaporation properties leads to damp and clammy feeling to the wearer (Nazir, Hussain, Abbas, & Ahmed, 2015). Sweating is the primary cooling mechanism of human body when excessive heat is generated by the body. Under normal circumstances 15 % of heat loss is in form of insensible perspiration (Haghi, 2004; Hu, Li, Yeung, Wong, & Xu, 2005). Moisture transmission is directly related to thermal wet comfort which forms 50% share of human perception of thermophysiological comfort (Das, Das, Kothari, Fangueiro, & Araujo, 2009; Yao, Li, Hu, Kwok, & Yeung, 2006). Moisture generated in microclimate should be transported away from the skin for quick evaporation to prevent instant heat loss in cold climate (Onofrei, Rocha, & Catarino, 2011; Supuren, Oglakcioglu, Ozdil, & Marmarali, 2011; Zhou, Feng, Du, & Li, 2007). In tropical climate, quick moisture transport will give a dry sensation to the skin. Wicking is the primary process for liquid moisture transport normal to fabric plane and is a consequence of wetting. Wetting is the replacement of solid-air interface with solidliquid interface due to interplay of cohesive and adhesive forces between water and fabric. Wetting gives rise to capillary forces which are responsible for wicking of liquid moisture (Hollies, Kaessinger, & Bogaty, 1956; Kissa, 1996; Pan & Zhong, 2006). It has been established that water transfer followed by evaporation is more important than water absorbance to remove sweat from skin and maintain a comfortable microclimate(Dai et al., 2007; Long, 1999). A lot of double layer fabrics with different inner (skin side) and outer layer properties have been developed to accomplish sweat wicking and quick drying where skin layer is hydrophobic to wick away sweat with minimal spreading and outer layer is hydrophilic for large spreading and evaporation (Babu, Senthilkumar, & Senthilkumar, 2015). Skin contact layer has been produced using high denier hydrophobic yarns, hydrophobic mohair fiber, micro denier polyester along with blending of soybean protein fiber and bamboo with cotton (Amran et al., 2015).

The moisture transfer model (refer to Figure 1) describes the advantage of having hydrophobic and hydrophilic yarns on skin and outer side of the fabric respectively, on liquid sweat transport. It shows that if we have a hydrophobic layer next to skin then capillary forces and surface tension gradient induce wicking that keeps the inner layer dry maintaining comfort (refer Figure 1d). There is a strong liking for cotton by many consumers living in tropical climates but the tacky feel of cotton garments in sweaty climatic condition make it unsuitable. Therefore, there is a need to develop a cotton fabric which shows preferential one way transport of liquid moisture from inner to outer side of the fabric. In this work, we demonstrate the development of a moisture transporting cotton knit fabric by modifying the wetting behavior of cotton yarns. Knitted fabrics were chosen because of their comfort, elasticity, conformance to body and porosity (Achour, Hamdaoui, Nasrallah, & Perwuelz, 2015; Yanilmaz & Kalaoglu, 2012).

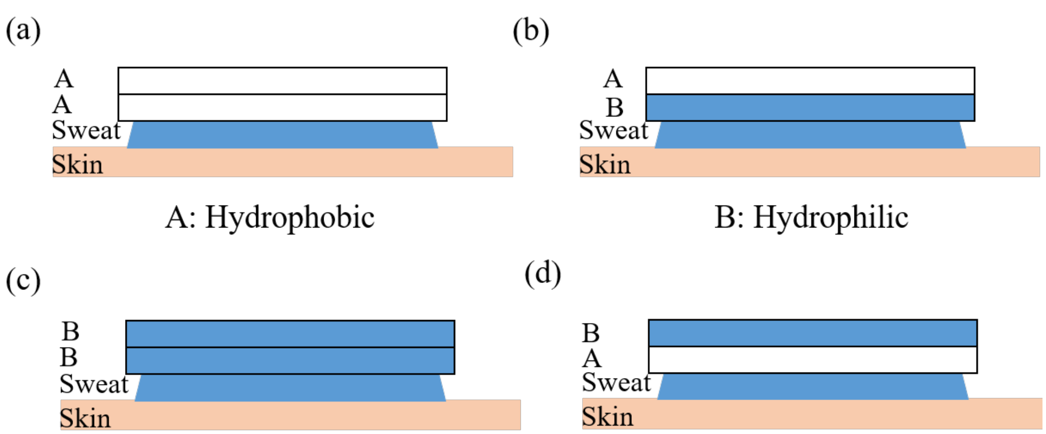


Figure 1: Liquid sweat transfer in two layer knitted fabrics (Long, 1999)

2. Materials and Methods

2.1 Fabrication of water repellent yarns

100% combed hosiery cotton yarn of fineness Ne 40s and tenacity 13.6 g/tex was used to produce the fabrics. The yarns were scoured to remove any impurities and then treated with fluorocarbon based water repellent finish NUVA N2114 liquid (*Archroma)* in package form in Vortex dyeing machine. The yarns were dried at 130°C for 30min followed by curing at 150°C for 5 min. Three levels of water repellent finish were applied: 20g/l, 35g/l and 50g/l. To distinguish water repellent finish treated yarns from untreated ones in the fabric, the untreated yarns were dyed in blue by reactive dye and used as tracer yarns. For the purpose of fabric formation single yarns were converted to ply yarns. Plied yarns were made on a two for one twister by combining untreated and treated yarns. The purpose of plying was to make the yarn coarser in order to produce a fabric with a higher areal density.

2.2 Knitted fabric production

Two types of fabric structures, single jersey and plated single jersey were selected for investigation which consisted of treated water repellent yarns and untreated yarns. Single jersey knits were produced on circular knitting machine; RIUS Protex-1 on 18 gauge with cylinder diameter of 3.5" with yarns having different levels of water repellent finish to select the optimum level of finish. Since the plated single jersey knit fabrics have two distinct faces so they were made with two different types of yarns, treated water repellent yarns and untreated yarns on each side. One face, which will be the inner face (skin side), consisted of treated water repellent cotton yarns and the outer face of untreated cotton yarns. The treated yarns in the inner face encourage wicking of liquid moisture and quickly transfer it to the outer surface for evaporation leaving the inner face dry. Note that in this paper, the fabric face consisting of untreated cotton yarns is referred to as hydrophilic face and that consisting of treated water repellent yarns is called hydrophobic back. Yarns with optimum level of finish were used to produce plated single jersey fabrics on a 12 gauge V-bed flat knitting machine. The face and back sides of fabric had untreated and treated yarns respectively. Further, plated single jersey knits with three different levels of loop length and two levels of yarn fineness obtained by plying were produced. The details of the fabrics produced are summarized in Table 1. The knitted fabrics produced were mildly washed before testing for moisture transport according to ISO Test No.2. The samples were allowed to run for 45 minutes at 50ºC in the Launder-O meter.

Table 1: Knitted fabrics produced for this study

Fabric type	Constituent yarns
Single jersey	ply yarn consisting of untreated yarns
	ply yarn consisting of treated 20g/l & untreated yarns
	ply yarn consisting of treated 35g/l & untreated yarns
	ply yarn consisting of treated 50g/l & untreated yarns
Plated single jersey	2 ply untreated yarn on face and 2 ply treated (20g/l) yarn on back (Loop length : short , medium and high)
	3 ply untreated yarn on face and 3 ply treated (20g/l) yarn on back (Loop length: short)

2.3 Physical characterization of fabrics

The wales per inch (WPI) and course per inch (CPI) of the knitted fabrics were measured as per standard ASTM D3887. The areal density (mass per unit area) was determined according to ASTM D3776/D3776M. The fabric thickness was measured at 20gf per square cm using Essdiel thickness gauge as per ASTM D1777-96. Table 2 summarizes physical properties of single jersey knitted fabrics. It can be seen that all fabrics had similar physical characteristics so only the effect of treatment levels was expected to be seen in the subsequent moisture transport tests. Table 3 highlights physical properties of plated single jersey knits. Fabrics with shortest and longest loop lengths had tight and relatively loose fabric construction respectively. It was observed that the fabric made of coarser yarns and lower loop length had the highest areal density whereas the fabric consisting of finer yarns and higher loop length had the least.

Table 2: Physical properties of single jersey knit fabrics

Sample made from	Loop length (mm)	WPI	CPI	Stitch density (loops/inch²)	Thickness (mm)	Fabric weight (g/m²)
Untreated yarn	5.25	21	17	364	0.94	210.03
50% yarns treated with 20g/l NUVA N2114	5.36	21	18	366	0.85	217.23
50% yarns treated with 35g/l NUVA N2114	5.41	21	17	353	0.90	213.17
50% yarns treated with 50g/l NUVA N2114	5.52	21	17	349	0.96	214.58

NUVA N2114: water repellent agent

Table 3: Physical properties of plated knit fabrics

Yarn count (Ne)		Fabric characteristics						
Fabric back	Fabric face	WPI	CPI	Stitch density (loops/inch²)	Loop length (mm)	Fabric construction	Fabric weight (g/m²)	Thickness (mm)
3/40s	3/40 s	18	25	450	Short (5.71)	Tight	374	1.24
2/40 s	2/40 s	18	24	432	Short (5.65)	Tight	236	1.14
2/40 s	2/40 s	18	23	414	Medium (6.34)	Medium	224	1.13
2/40 s	2/40 s	16	22	352	High (6.5)	Slack	203	0.92

2.4 Optical microscopy

The images of knitted fabrics were recorded using Nikon Stereoscopic Zoom Microscope SMZ 1500 (Nikon Digital Sight DS, Japan) as shown in Figure 2. It can be clearly seen that single jersey face and back have 50% treated (white) yarns whereas plated fabric contains treated yarns in back and untreated (blue) yarns in the face.

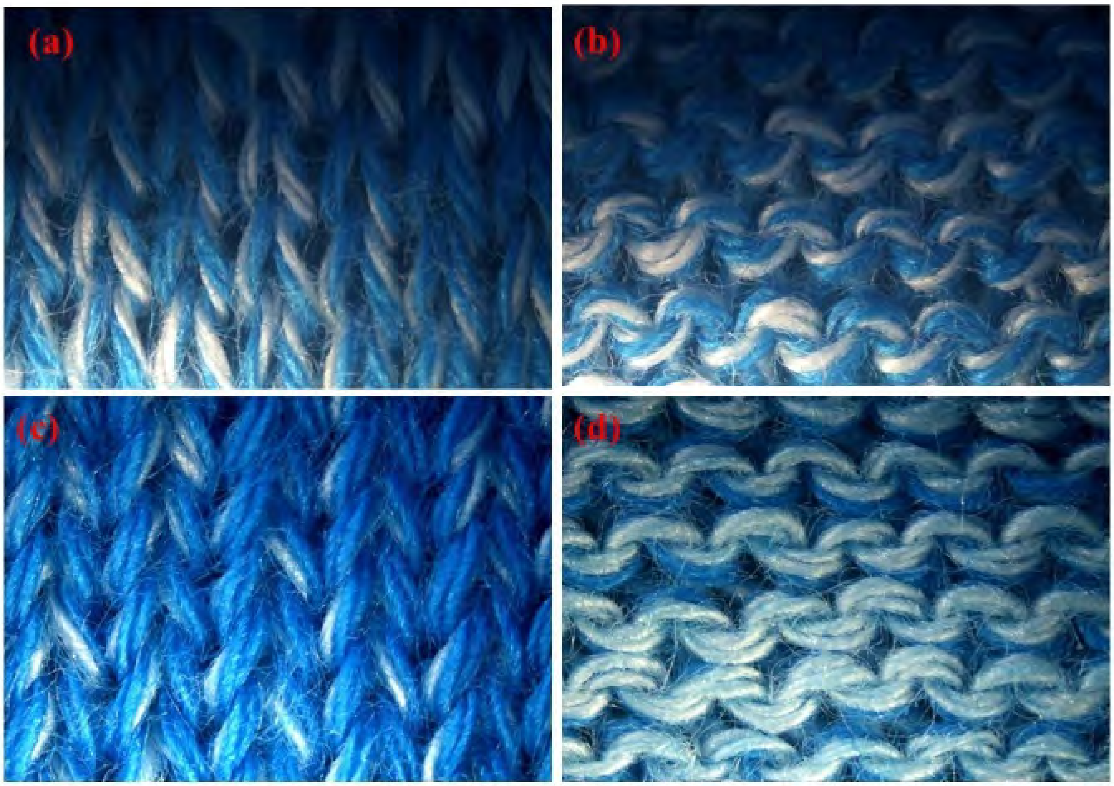


Figure 2: Knitted fabrics: (a) Single jersey face, (b) Single jersey back, (c) Plated knit face, and (d) Plated knit back

2.5 Drop absorbency test

The sink in time of a 50µl drop of red reactive dye (2g/l M8B) solution dropped from a height of 40mm on face and back of a fabric was recorded to evaluate the effect of water repellent finish on wetting and absorbency properties.

2.6 Gravimetric absorbency test

M/K GATS (Gravimetric Absorption Testing System) was used to assess wicking in thickness direction referred to as demand wetting. A dry sample comes in contact with liquid supplied from a reservoir and is absorbed due to capillary action. The water absorption rate Q (gram water per second) and the water absorption capacity C (gram water per gram) of the fabrics were recorded.

2.7 Moisture Management Testing (MMT)

The moisture management tester developed by SDL Atlas was used to determine the liquid moisture spreading properties in multiple directions objectively. In this test, sample is placed between top and bottom sensor rings and 0.15g of saline solution is applied at center of fabric from top, simulating skin side of garment coming in contact with sensible sweat. Initially the dry fabric has a very high electrical resistance but when it comes in contact with liquid water, there is a drop in electrical resistance as recorded by concentric copper ring sensors (refer Figure 3), which is directly related to the water content in fabric (Yao et al., 2006). A water content curve (refer Figure 4) is generated and following information is obtained, namely,

- *Wetting time (s);* time required for initial slope of water content curve to become greater than tan (15°);
- *Absorption rate (%/s);* initial slope from wetted point to peak value; *Maximum wetted radius (mm),*

- *Spreading speed (mm/s)*; average spreading speed from center of fabric to maximum wetted radius and
- *One way transport capacity/capability*; difference between water content between inner skin and outer face of fabric.

It is very difficult to make definite conclusions from the above results so Yao et al., 2006 have suggested a grading methodology (refer Table 4) to classify fabrics based on these moisture management test parameters (Baltušnikaite et al., 2014). The grades obtained are then used to classify the fabrics into seven different types as per the algorithm shown in Figure 5 (Yao et al., 2006). The seven types of fabric, 1– 7 (refer Table 5), classified based on the grades and values of indices give a direct overall evaluation and result for the liquid moisture management properties of the tested fabrics.

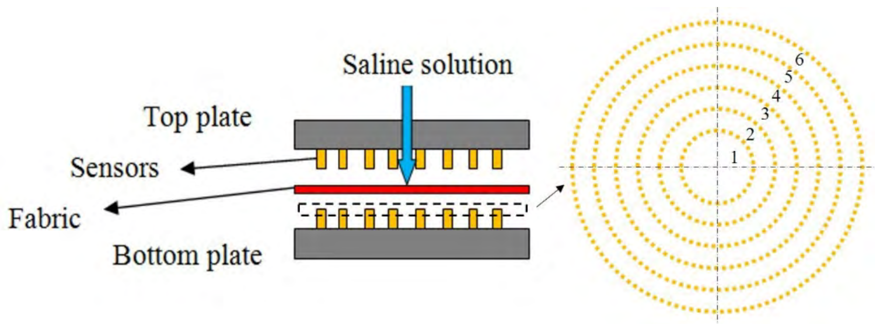
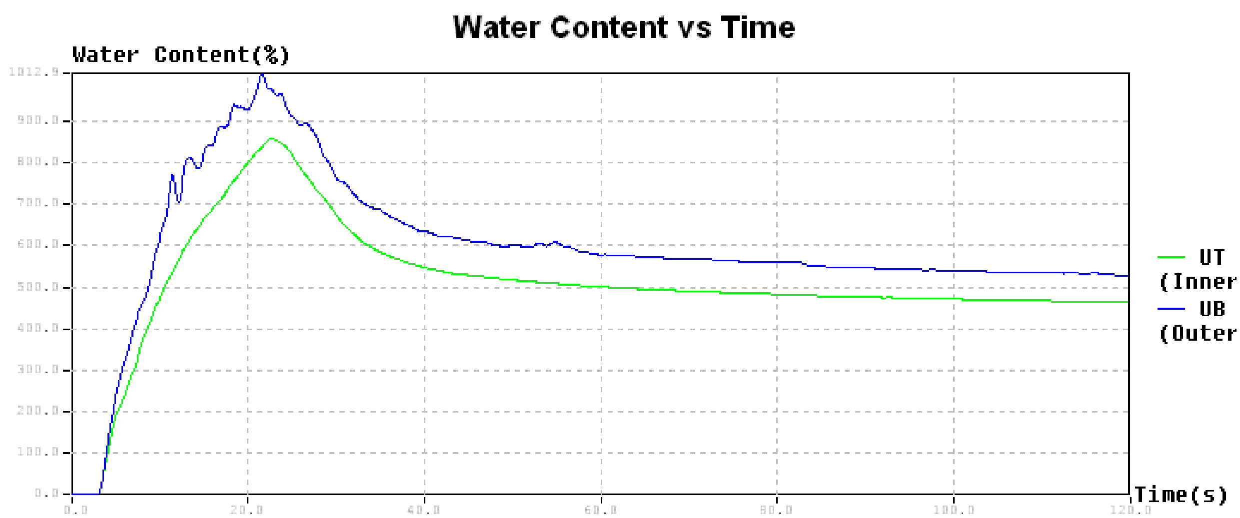


Figure 3: Moisture Management Tester sensor configuration for determining water content (Yao et al., 2006)



	Top Surface	Bottom Surface
Wetting time(sec)	2.343	2.343
Absorption rate(%/sec)	41.4123	50.6938
Max wetted radius(mm)	25.0	25.0
Spreading Speed(mm/sec)	6.4224	6.4556
One way transport capability	85.9274	
Description	MMT-	

Figure 4: Sample water content curve generated by the moisture management tester where UT refers to water content in top face of fabric (side coming in contact with liquid) and UB refers to water content in bottom face of fabric which is not in contact with liquid

Table 4: Grading of MMT indices

Index\Grades		1	2	3	4	5
Wetting time	Top	≥120 No wetting	20-119 Slow	5-19 Medium	2-5 Fast	<3 Very fast
	Bottom	≥120 No wetting	20-119 Slow	5-19 Medium	2-5 Fast	<3 Very fast
Absorption rate	Top	0-10 Very slow	10-30 Slow	30-50 Medium	50-100 Fast	>100 Very fast
	Bottom	0-10 Very slow	10-30 Slow	30-50 Medium	50-100 Fast	>100 Very fast
Maximum wetted radius	Top	0-7 No wetting	7-12 Small	12-17 Medium	17-22 Large	>22 Very large
	Bottom	0-7 No wetting	7-12 Small	12-17 Medium	17-22 Large	>22 Very large
Spreading speed	Top	0-1 Very slow	1-2 Slow	2-3 Medium	3-4 Fast	>4 Very fast
	Bottom	0-1 Very slow	1-2 Slow	2-3 Medium	3-4 Fast	>4 Very fast
OWTC		<-50 Poor	-50-100 Fair	100-200 Good	200-400 Very good	>400 Excellent

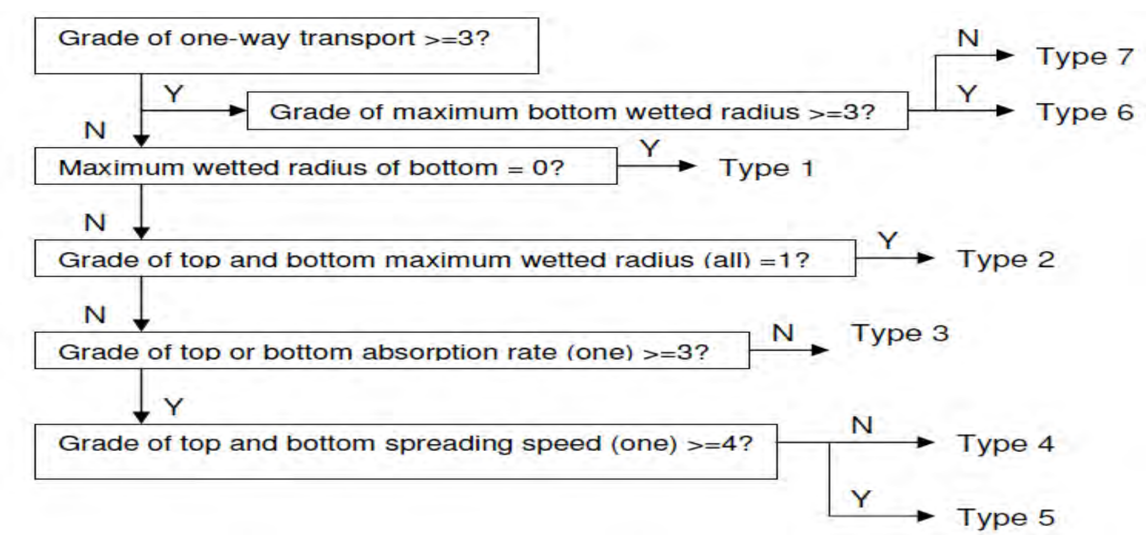


Figure 5: Flowchart of MMT fabric classification method (Yao et al., 2006)

Table 5: Fabric classification by MMT

Type no.	Type name	Properties
1	Water proof fabric	Very slow absorption, slow spreading, no one way transport, no penetration
2	Water repellent fabric	No wetting, no absorption, no spreading, poor one way transport without external forces
3	Slow absorbing & slow drying fabric	Slow absorption, slow spreading, poor one way transport
4	Fast absorbing & slow drying fabric	Medium to fast wetting, medium to fast absorption, small spreading area, slow spreading, poor one way transport
5	Fast absorbing & quick drying fabric	Medium to fast wetting, medium to fast absorption, large spreading area, fast spreading, poor one way transport
6	Water penetration fabric	Small spreading area, excellent one way transport
7	Moisture management fabric	Medium to fast wetting, medium to fast absorption, large spread area at bottom surface, fast spreading at bottom surface, good to excellent one way transport

3. Results and Discussion

3.1 Drop Absorption Test

3.1.1 Single jersey fabric

When a drop of dye solution was placed on single jersey knitted fabric made of untreated yarns it was found to spread quickly indicating faster wicking and absorbency of the cotton fabric (see Figure 6a). But when the same drop of liquid was released on the single jersey fabric containing 50% treated yarns then the time to get absorbed and completely sink into the fabric was delayed (see Figure 6 b, c, and d). There was a marked difference in the sink in time between fabrics made from untreated yarns and those containing treated yarns. The sink in time increased from 0s to 12s and from 12s to 24s with increase in amount of finish from 20 to 35 g/l but thereafter there was not much change (see Figure 7).

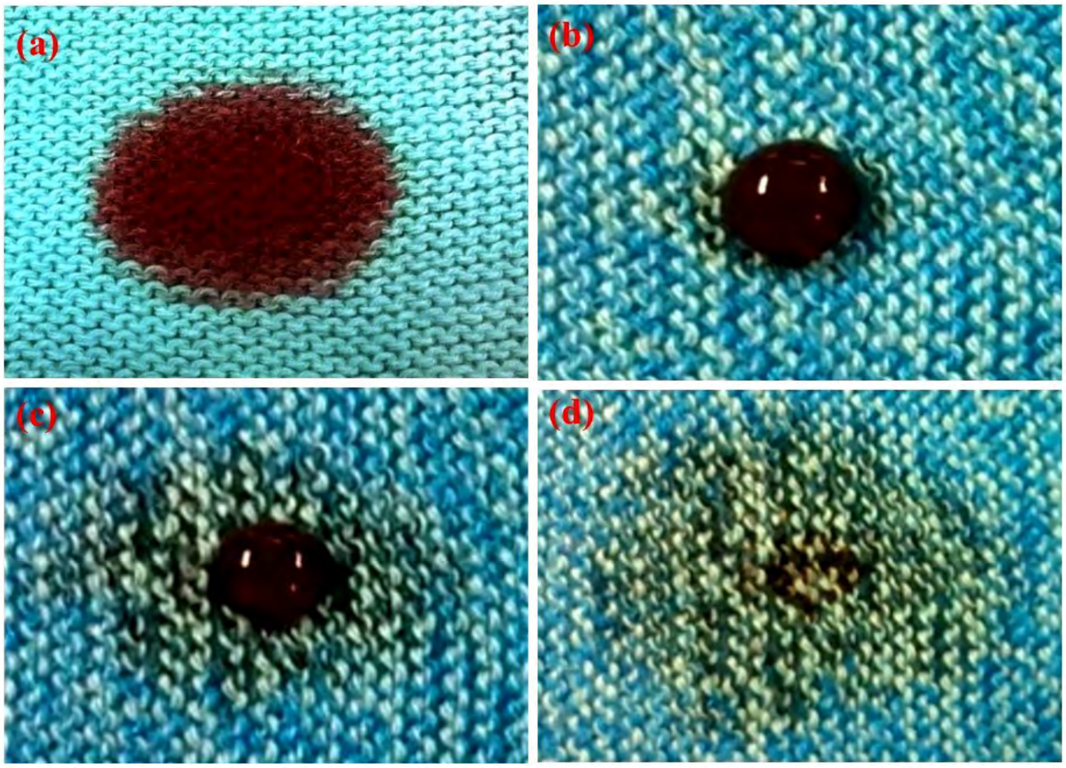


Figure 6: (a) Drop on knitted fabric made from untreated yarn and (b, c, d) represents drop absorption stages by single jersey knitted fabric having 50% treated yarns

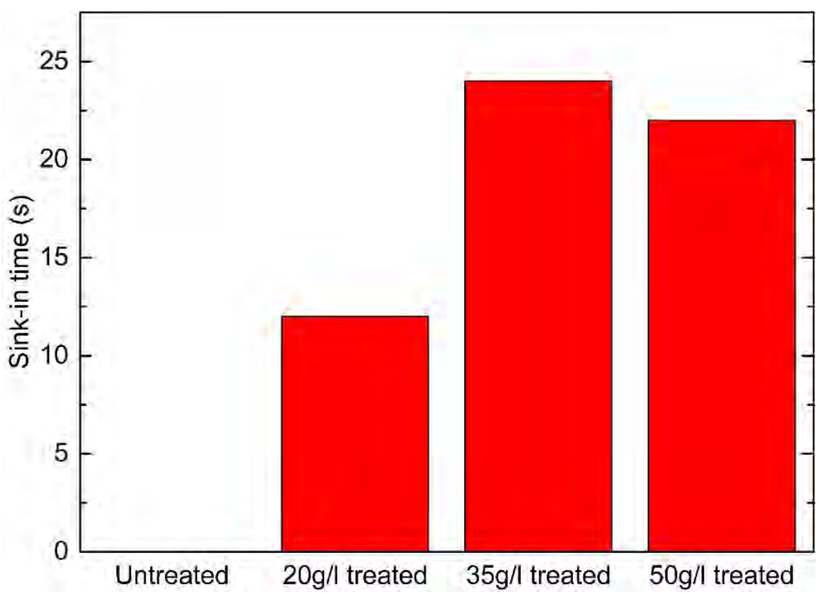


Figure 7: Sink in time of the drop on single jersey knitted fabrics

3.1.2 Plated single jersey fabric

The plated fabrics contained water repellent finish treated yarns on one side (face) and untreated yarns on other side (back). It was observed that the face having untreated yarns absorbed the drop completely and the wet mark was clearly visible (see Figure 8a, b). When a similar drop of dye was placed on the plated fabric back having treated yarns, it quickly percolated through the fabric and was visible as wet spread mark on the other side (face) of the fabric (see Figure c, d, e). This demonstration indicated that plated knits with different kinds of yarns on face and back of fabric in terms of affinity to water can be used as one way moisture transporting fabrics. The liquid transported to the other side due to higher capillary pressure owing to the surface tension gradient of the two layers in the thickness direction. The sink in time of the drop on plated fabrics having different loop lengths and ply yarn count is shown in Fig 9. It can be seen that the hydrophobic back (fabric side with water repellent yarns) has higher sink in time compared to the hydrophilic face (fabric side with untreated yarns) in all cases.

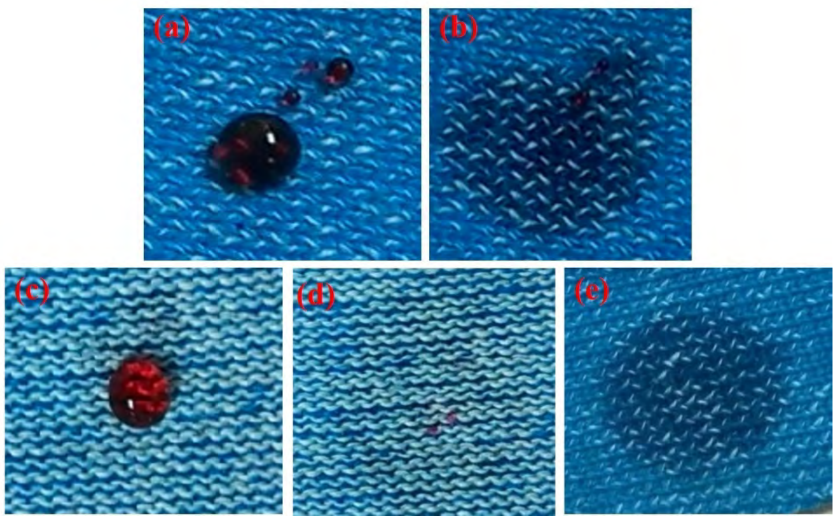


Figure 8: Drop absorption on plated knits. (a, b) Drop on plated knit face having untreated yarns showing spreading and absorption. (c, d) Drop on plated knit back containing treated water repellent yarns showing drop percolation and spreading on opposite side in (e).

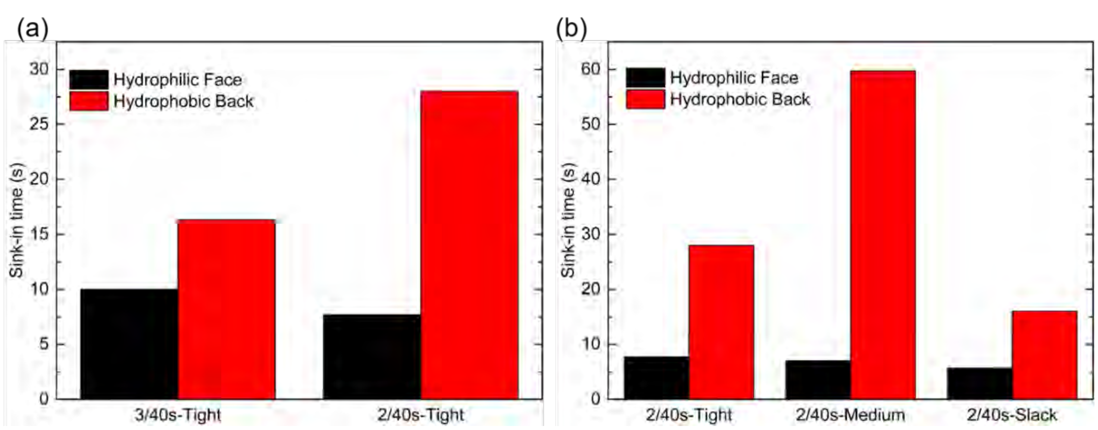


Figure 9: Sink in time of drop on plated knits, (a) with yarns of different fineness and (b) different loop lengths

3.2 Gravimetric absorbency test

The fabric samples were placed in contact with liquid supplied from a reservoir where the water absorption capacity C (gram water per gram) and water absorption rate Q (gram water per second) were recorded.

3.2.1 Absorption capacity

For all the fabric samples, namely single jersey and plated single jersey, the amount of water absorbed increased with time (see Figure 10). The single jersey knits consisting of 50% treated yarns showed much less absorbed water at any time compared to the sample made of untreated yarns due to presence of water repellent finish. The absorbency curve of the sample made of untreated yarns was nonlinear (see Figure 10a) where rate of absorption was fast initially which then decreased as more water was absorbed. On the other hand, samples made of 50% treated (water repellent) yarns showed approximately linear absorbency behavior with significantly low absorption capacity for all concentrations of finish (see Figure 10a). In case of plated knit fabrics (see Figure 10b), the slack fabrics (with longer loop length) absorbed more than tightly constructed ones (short loop length) due to more void space within the fabric. It was also observed that for similar loop length, fabrics made from coarser yarns (3 ply compared to 2 ply), showed a lower absorbent capacity because of decrease in the inter yarn voids.

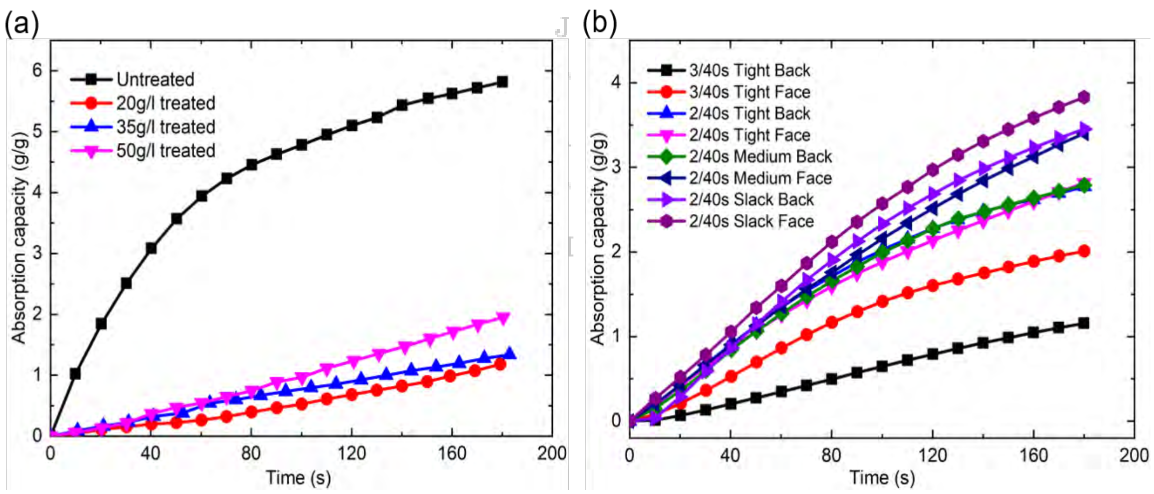


Figure 10: Absorption capacity of (a) single jersey knits and (b) plated single jersey knits

3.2.2 Absorbency rate

The absorbency rate indicates the amount of water absorbed per unit time and the single jersey knits made from untreated cotton yarns showed the highest rate of absorption in comparison to fabrics containing yarns treated with different levels of finish in their structure (see Figure 11a). This is because samples containing water repellent finish treated yarns have reduced affinity to water. In the case of plated knit fabrics, the hydrophilic face (having untreated yarns) had a higher absorbency rate than hydrophobic back (having treated yarns) as seen in Figure 11b, c. There was no significant difference in the absorbency rate between fabrics having different loop length and yarns of different fineness.

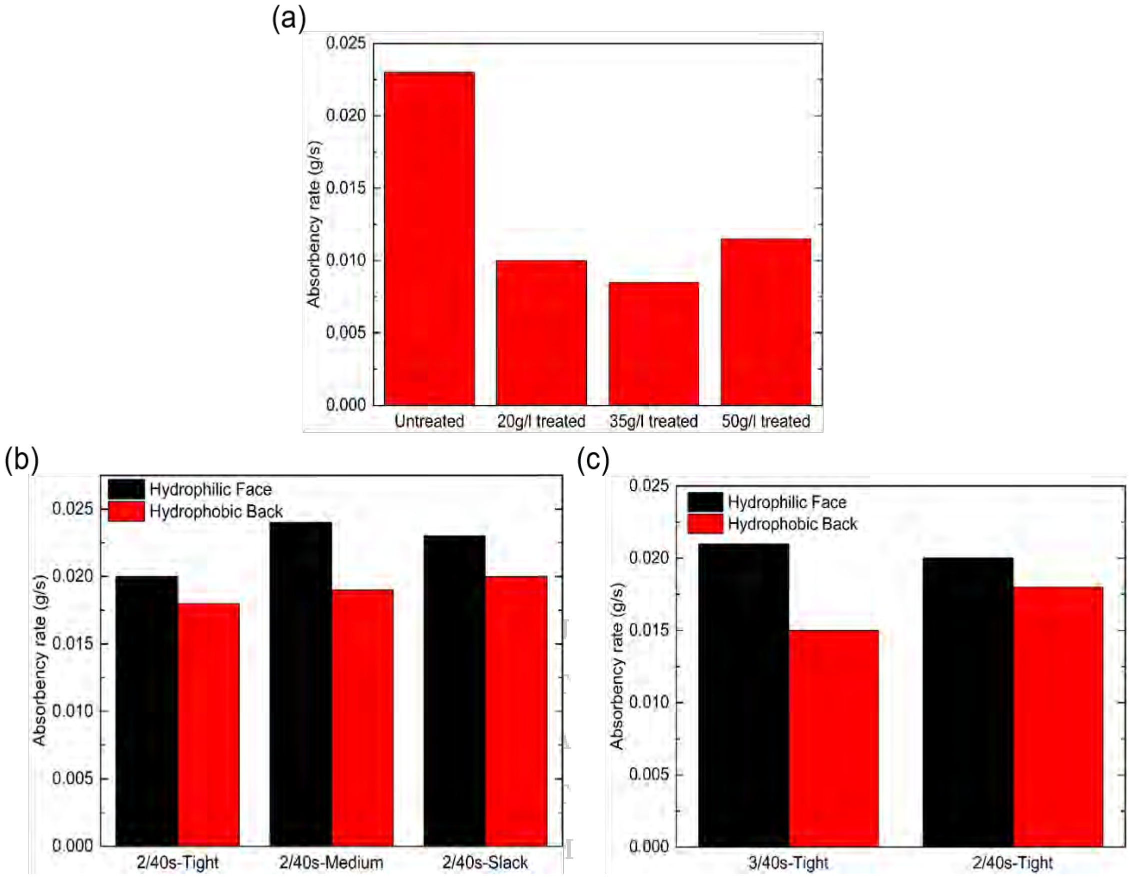


Figure 11: Absorbency rate of (a) single jersey knits, (b) plated single jersey knits with different loop lengths and (c) plated single jersey knits with yarns of different fineness

3.3 Moisture Management Testing

The dynamic liquid transport behavior of saline solution (i.e. simulated sweat) was carried out on all cotton fabrics using the moisture management tester. The moisture management test results of all single jersey knitted fabrics are summarized in Table 6. The test results were converted into grades using grading criteria mentioned in Table 4 and the grades obtained were used to classify the fabrics using algorithm outlined in Figure 5. After following the above procedure for analysis of test results of moisture management testing, it was found that all the single jersey cotton fabrics containing treated yarns were classified as water penetration fabrics (small spreading area with excellent one way transport) and the fabric made from untreated yarns was classified as moisture management fabric. This result indicates that incorporating water repellent yarns within single jersey knits improves transport of liquid from one side of fabric to the other side. This characteristic was shown by all single jersey fabrics containing yarns treated with different finish levels so a lower level of finish is sufficient to impart this one way liquid transport functionality. Due to this observation, the lowest finish concentration was used to treat yarns for creating plated knit fabrics.

Table 6: Moisture management test results of single jersey knitted fabrics

Sample made from\ Parameters	WT(s)		AR(%/s)		MWR(mm)		SS(mm/s)		OWTC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	
Untreated yarns	60.3	31.1	16.9	3.96	7.5	10	3.8	10.2	957.9
50% yarns treated with 20g/l finish	1.4	3.1	34.8	10.9	15	15	4.3	3.2	923.1
50% yarns treated with 35g/l finish	3.9	2.2	8.5	6.7	15	15	2.3	4.7	997.2
50% yarns treated with 50g/l finish	4.2	2.8	18.6	3.2	12.5	15	2.3	2.6	954.1

WT: wetting time; AR: absorption rate; MWR: maximum wetted radius; SS: spreading speed; OWTC: one-way transport capacity

The moisture management test results of different kinds of plated knits with two faces categorized as hydrophobic back and hydrophilic face are summarized in Table 7. Following the same procedure as discussed before for fabric classification on basis of moisture management test results, it was found that all kinds of plated knits were classified as water penetration fabrics with excellent one way liquid transport. The comparison of one way transport capacity (OWTC) of plated knits showed that hydrophobic back had a higher moisture transporting capability than hydrophilic face (see Figure 12) irrespective of differences in fabric construction and yarn fineness indicating that presence of water repellent yarns on one side of knit fabric had successfully produced unidirectional moisture transporting cotton fabric (see supplementary video S1). This also means that hydrophobic back side of fabric should be the side contacting the skin for moisture transport.

Table 7: Moisture management test results of plated knits

Parameters \ Fabrics	Sample	3/40s-Tight	2/40s-Tight	2/40s-Medium	2/40s-Slack
WT(t) sec	Hydrophilic Face	2.8	2.9	2.4	3
	Hydrophobic Back	4.5	4	4.8	4.1
WT(b) sec	Hydrophilic Face	2.3	4	4	3.7
	Hydrophobic Back	1.9	2	3.4	2
Absorption Rate (t) %/sec	Hydrophilic Face	40.7	62.4	51.2	60.1
	Hydrophobic Back	16.5	23.8	10.38	12.5

AR(b) %/sec	Hydrophilic Face	4.5	12.6	28.3	14.4
	Hydrophobic Back	17.4	17.3	9.9	19.4
MWRadius(t) mm	Hydrophilic Face	15	22.5	20	25
	Hydrophobic Back	15	17.5	12.5	15
MWR(b) mm	Hydrophilic Face	15	25	20	20
	Hydrophobic Back	17.5	17.5	20	22.5
Spreading Speed(t) mm/sec	Hydrophilic Face	3.5	4.5	5.1	4.6
	Hydrophobic Back	2.5	3.3	2.9	2.6
	Hydrophilic Face	3.9	4.9	3.9	3.9
	Hydrophobic Back	3.9	4.2	4	3.9
OWTC	Hydrophilic Face	1271.9	569.1	590.7	344.83
	Hydrophobic Back	1640.7	1228.5	1224.1	1069.9

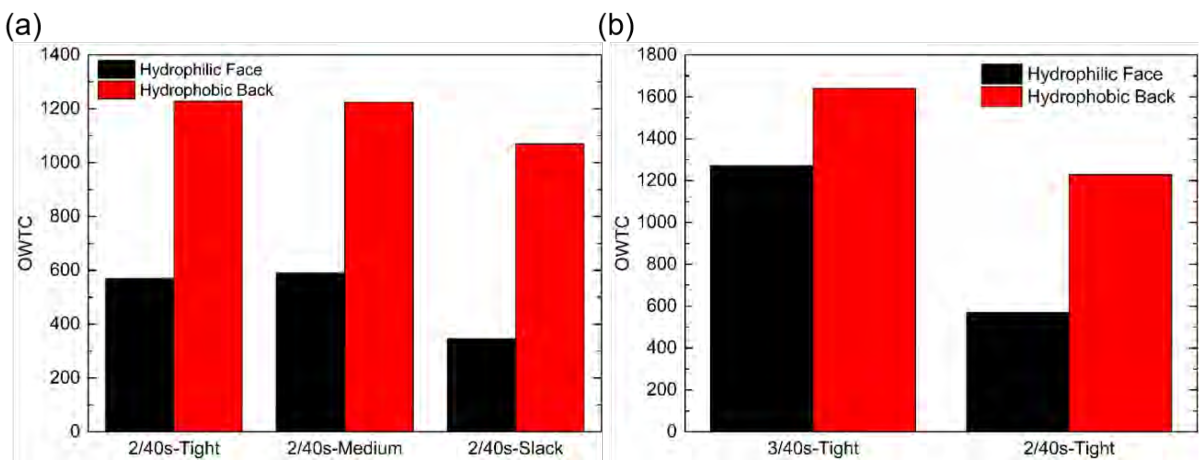


Figure 12: One way transport capacity (OWTC) of plated knit fabrics with (a) different loop lengths and (b) yarns of different fineness

4. Conclusion

The incorporation of water repellent finish treated yarns in knitted structures, led to the improvement in one way liquid transport performance of knit fabrics. The lowest finish level, 20g/l of water repellent agent was found to be the optimum concentration for imparting the required hydrophobicity to induce wicking. The single jersey fabrics containing water repellent finish treated yarns exhibited delayed drop absorption while plated knit fabrics transported drop to the opposite side of fabric. The hydrophilic face (having untreated yarns) of plated fabrics had a higher absorbency rate than hydrophobic back (having treated yarns). All the single jersey fabrics consisting of treated water repellent yarns and plated single jersey fabrics (with untreated yarns on one side and water repellent finish treated yarns on other side) were classified as water penetration fabrics according to the moisture management testing because they exhibited small liquid spreading area and excellent one way transport. In particular, hydrophobic back of plated knits showed higher one way transport capacity indicating that hydrophobic back side of fabric should be the side contacting the skin in a garment for achieving moisture transport. This research demonstrated that a cotton fabric with excellent unidirectional moisture transport can be produced by incorporating water repellent yarns in a plated knit construction.

Acknowledgements

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References

Achour, N. S., Hamdaoui, M., Nasrallah, S. B., & Perwuelz, A. (2015). Investigation of Moisture Management Properties of Cotton and Blended Knitted Fabrics. *World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, *9*(7), 879–883.

Amran, N. M., Ahmad, M. R., Yahya, M. F., Fikry, A., Che Muhamed, A. M., & Razali, R. A. (2015). Some Studies on the Moisture Management Properties of Cotton and Bamboo Yarn Knitted Fabrics. *Advanced Materials Research*, *1134*, 225–230. https://doi.org/10.4028/www.scientific.net/AMR.1134.225

Babu, B. S., Senthilkumar, P., & Senthilkumar, M. (2015). Effect of yarn linear density on moisture management characteristics of cotton/polypropylene double layer knitted fabrics/Efectul densitatii liniare asupra caracteristicilor de control al umiditatii tricoturilor din bumbac/polipropilena dublu stratificate. *Industria Textila*, *66*(3), 123.

Baltušnikaite, J., Abraitienė, A., Stygienė, L., Krauledas, S., Rubežienė, V., & Varnaitė-Žuravliova, S. (2014). Investigation of Moisture Transport Properties of Knitted Materials Intended for Warm Underwear. *Fibres & Textiles in Eastern Europe, Nr 4 (106)*. Retrieved from http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-2fbbbdcf-80f6-466a-928b-1c5e2a4e6440

Dai, X.-Q., Imamura, R., Liu, G.-L., & Zhou, F.-P. (2007). Effect of moisture transport on microclimate under T-shirts. *European Journal of Applied Physiology*, *104*(2), 337–340. https://doi.org/10.1007/s00421-007-0628-z

Das, B., Das, A., Kothari, V. K., Fangueiro, R., & Araujo, M. de. (2009). Studies on moisture transmission properties of PV-blended fabrics. *The Journal of the Textile Institute*, *100*(7), 588–597.

Haghi, A. (2004). Moisture permeation of clothing. *Journal of Thermal Analysis and Calorimetry*, *76*(3), 1035–1055.

Hollies, N. R., Kaessinger, M. M., & Bogaty, H. (1956). Water transport mechanisms in textile materials1 Part I: the role of yarn roughness in capillary-type penetration. *Textile Research Journal*, *26*(11), 829–835.

Hu, J., Li, Y., Yeung, K.-W., Wong, A. S. W., & Xu, W. (2005). Moisture Management Tester: A Method to Characterize Fabric Liquid Moisture Management Properties. *Textile Research Journal*, *75*(1), 57–62.

İLETİM, P. S. Ö. K. N., & ÇALIŞMA, Ö. Ü. B. (2009). *A study on the moisture transport properties of the cotton knitted fabrics in single jersey structure*. Retrieved from http://www.tekstilvekonfeksiyon.com/pdf/20090903144446.pdf

Kissa, E. (1996). Wetting and wicking. *Textile Research Journal*, *66*(10), 660–668.

Liu, Y., Xin, J. H., & Choi, C.-H. (2012). Cotton fabrics with single-faced superhydrophobicity. *Langmuir*, *28*(50), 17426–17434.

Long, H.-R. (1999). Water transfer properties of two-layer weft knitted fabric. *International Journal of Clothing Science and Technology*, *11*(4), 198–205.

Nazir, A., Hussain, T., Abbas, G., & Ahmed, A. (2015). Effect of Design and Method of Creating Wicking Channels on Moisture Management and Air Permeability of Cotton Fabrics. *Journal of Natural Fibers*, *12*(3), 232–242. http://dx.doi.org.prox.lib.ncsu.edu/10.1080/15440478.2014.919892

Onofrei, E., Rocha, A. M., & Catarino, A. (2011). The influence of knitted fabrics' structure on the thermal and moisture management properties. *Journal of Engineered Fibers and Fabrics*, *6*(4), 10–22.

Pan, N., & Zhong, W. (2006). Fluid transport phenomena in fibrous materials. *Textile Progress*, *38*(2), 1–93.

Patnaik, A., Rengasamy, R. S., Kothari, V. K., & Ghosh, A. (2006). Wetting and wicking in fibrous materials. *Textile Progress*, *38*(1), 1–105.

Rearick, W. A., & Andersen, B. (2006). *Cellulosic substrates with reduced absorbent capacity having the capability to wick liquids*. Retrieved from https://www.google.com/patents/US7008887

Supuren, G., Oglakcioglu, N., Ozdil, N., & Marmarali, A. (2011). Moisture management and thermal absorptivity properties of double-face knitted fabrics. *Textile Research Journal*, *81*(13), 1320–1330.

Yanilmaz, M., & Kalaoglu, F. (2012). Investigation of wicking, wetting and drying properties of acrylic knitted fabrics. *Textile Research Journal*, *82*(8), 820–831.

Yao, B., Li, Y., Hu, J., Kwok, Y., & Yeung, K. (2006). An improved test method for characterizing the dynamic liquid moisture transfer in porous polymeric materials. *Polymer Testing*, *25*(5), 677–689.

Zhou, L., Feng, X., Du, Y., & Li, Y. (2007). Characterization of Liquid Moisture Transport Performance of Wool Knitted Fabrics. *Textile Research Journal*, *77*(12), 951–956. https://doi.org/10.1177/0040517507083518

S1 Supplementary Video

Link to video:
https://drive.google.com/file/d/1OdS14wHqRFzoHnwMeoCY11QUPuZ3CE5m/view?usp=sharing