Moisture management properties of eri silk knitted fabrics

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Moisture management and wicking properties of eri silk knitted fabrics have been studied. Three different knit structures, namely single jersey, single pique and honeycomb, have been developed with the combination of two different yarn count and tightness level. The fabrics developed are analyzed in terms of wetting time, spreading speed, absorption rate, and maximum wetting radius, accumulative one way transport index (AOTI) and overall moisture management capacity (OMMC). It is discerned that the variables, such as yarn count, fabric tightness and knitting structure, have a significant influence on the wicking and moisture management properties. The OMMC indexes of eri silk knitted fabric are found to range from 'very good' to "excellent" category, which indicates the suitability of eri silk yarn to skin fit as well as active wear applications.

Keywords: Eri silk, Honeycomb, Knitted fabric, Moisture management, Pique, Single jersey, Wicking

1 Introduction

Moisture management properties are very important for any textile material for transportation of liquid moisture from skin through fabric to environment, which provides necessary comfort for the wearer[1]. Many researchers have explored the influence of fibre type, physical properties of fibres, yarn variables, fabric structure on moisture management properties[2,3]. Onofrei *et al.*[4] studied the influence of fabrics and structure on the thermo physiological properties of knitted fabrics made of Coolmax® and Outlast®. They demonstrated that the type of knit structure has greater influence on wicking ability than knitted structure parameters. Moisture management properties of bamboo-cotton knitted fabric were also investigated and it was reported that when the bamboo content is increased, the wetting time, maximum wet radius, spreading speed and OMMC decrease, whereas the rate of absorption increases[5].

Zhou *et al.*[6] posited the overall moisture management capacity of pure wool, wool/polyester and wool/cotton blended knitted fabrics with different structures. They reported that wool/cotton blended fabrics are better than other combination of fabric types. Süpüren *et al.*[7]investigated the moisture management properties of double-face knitted fabrics by using cotton and polypropylene materials and reported that the fabric with cotton (outer layer) and polypropylene (inner layer), provides high level of comfort and can be preferred for summer, active and sportswear.

Moisture management characteristics of knitted casein fabric were compared with cotton and it was reported that the casein fabric has better absorption rate and spreading rate, whereas cotton fabric possess better properties like maximum wetting radius and one way transport index values[8]. Yamini *et al.*[9] studied the effect of yarn count used in inner and outer layer as well as the difference in yarn count of both layers on moisture management properties of polyester-cotton knit structures. The yarn counts of inner and outer layer affect the sweat transfer rate and sweat spreading on the surface of outer layers. Wetting time and spreading speed are enhanced with the increase in inner and outer layer yarn counts. Bivainyte *et al.*[10] analyzed the influence of yarn count on wicking properties of cotton- acrylic yarns and fabrics and indicated that the linear density of yarn has a positive correlation with wicking properties. Suganthi *et al.*[11] assessed the moisture management characteristics of bi-layer knitted fabrics with different yarn combinations of viscose,

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polypropylene, modal and polyester for outer and inner layers. They revealed that the micro-fibre polyester in the inner and modal in the outer layer provide better comfort properties and are the most suitable for active sportswear.

Eri silk is one of the wild silk varieties, produced in India by the tribals in the north-eastern states of the country on commercial scale. It possesses excellent strength and elongation, soft feel, excellent thermal comfort and moderate lustre properties[12]. Gupta *et al.*[13] examined the physical characteristics and structures of four commercial varieties of Indian silk fibres and reported that eri silk fibres usually have a flat, elongated near rectangular-like cross-sectional shape, with the presence of fewer striations on the fibre surface. The mill spun eri silk yarn was produced in worsted spinning system and the yarn count ranges from 10^s Nm to 210^s Nm[14-16]. Senthilkumar *et al.*[17] reported that eri silk is suitable

Table 1 — Eri silk yarn properties

Parameter	Coarse yarn	Finer yarn
Yarn linear density, Nm	2/80^s	2/140^s
Actual yarn count, tex	24.92	14.32
Count CV%	3.50	4.20
Twist value, TPM	531.50	492.12
Breaking force, gf	397	297
Elongation, %	11.90	12.20
Tenacity, cN/tex	16.19	17.20
Unevenness U%	10.8	11.2
Thin /1000m (-50%)	12	21

for functional knitted apparels and discussed the suitable process parameters of eri silk knitted fabric production. Though the moisture properties have been studied by different researchers, there is hardly any research work on the moisture management characteristics of eri silk knitted fabrics. Hence, it was thought apt to develop different eri silk knitted structures and to analyze the moisture management properties of the fabric, thereby establishing the use of eri silk products for diversified end uses.

2 Materials and Methods

2.1 Materials

Eri silk yarn was procured from Uniworth Textiles, Raipur, India. The physical parameters of eri silk fibre used for development of spun yarn are: density 1.31g/cm^3; fineness 3.33 - 4.44 dtex; tenacity 27.43 cN/tex; elongation-at-break 22% and moisture regain 10 % (ref.18). The count of yarn samples was measured according to ASTM D 1907-01 standard, and single yarn strength was evaluated by using Instron strength tester as per ASTM D2256 standard. The evenness parameters were measured as per ASTM D 1425 M: 14 method by using USTER evenness tester UT 5. Table 1 shows the various yarn characteristics.

2.2 Fabric Development

The fabric samples were produced as per the sample plan furnished in Table 2. Single jersey, single

Table 2 — Fabric sample plan

Sample code	Fabric structure	Yarn count, Nm	Machine set loop length, cm
CSJ-T	Single Jersey	2/80^s	0.27
CSJ-S		2/80^s	0.33
FSJ-T		2/140^s	0.25
FSJ-S		2/140^s	0.31
CSP-T	Single Pique	2/80^s	0.27
CSP-S		2/80^s	0.33
FSP-T		2/140^s	0.25
FSP-S		2/140^s	0.31
CSH-T	Honeycomb	2/80^s	0.27
CSH-S		2/80^s	0.33
FSH-T		2/140^s	0.25
FSH-S		2/140^s	0.31

C–coarse yarn, F–fine yarn, T–tight fabric structure, S–slack fabric structure, SJ–single jersey, SP–single pique and HC–honeycomb.

pique and honeycomb fabric samples were knitted in two different tightness levels (slack and tight), with the same machine settings. The single cylinder circular knitting machine with the following specifications was used for the development of samples: gauge 24 GG; diameter 24 inch; speed 10 rpm; feeders 74; number of needles 1720 and yarn input tension of 3.5 cN/tex. Knitting room humidity of 60% and a temperature of 32±2°C were maintained.

2.3 Testing

The dimensional properties of the fabric were evaluated according to international testing standards, such as weight per unit area (ASTM D 3776), wales and courses per unit length (WPcm & CPcm) and loop length (ASTM D 3887), and thickness (ASTM D 1777) by using Shirley thickness gauge. All measurements were performed under the standard atmospheric conditions of 20°±2°C and 65% RH. Five readings were taken for each of the knitted fabrics and then the averages were calculated. Vertical wicking tests were performed according to DIN 53924 standard. The specimens were cut along the wale-wise and course-wise directions (250mm × 30 mm)**,** which is suspended vertically with its bottom edge of 5 mm immersed in a reservoir of distilled water. The wicking heights were measured and recorded at regular intervals for 10 min to evaluate the wicking ability.

2.4 Moisture Management Properties

According to AATCC test method 195-2009, the multi-directional moisture transport capabilities of fabrics were measured by using moisture management

test (MMT) device. The fabric specimen is placed between two horizontal electrical sensors each with concentric pins. A predetermined amount of test solution is dropped onto the top center of the fabric specimen surface. The test solution is allowed to freely move in multi-directions, spreads on the fabric top surface, moves through the specimen from top to bottom surface, and radially spreads on the bottom surface of the specimen. The electrical resistance values have been used to calculate fabric liquid moisture movement that quantifies dynamic liquid moisture transport behavior of fabric.

In this experiment, the specimens of size 8.0×8.0 cm^2 were washed and conditioned for a day in the standard atmospheric conditions before testing. The indices were graded according to the AATCC 195-2009 method on five grade scale. Table 3 gives the details of grading of moisture management indices.

3 Results and Discussion

3.1 Physical Properties of Knitted Fabrics

The properties of fabric samples are given in Table 4. The fabric weight per unit area and thickness of the fabrics vary with the change in yarn count, stitch length and knit structures. Geometrical properties of eri silk knitted fabrics are found in accordance with established understanding of knitted fabric behavior.

3.2 Vertical Wicking Test

Table 5 gives the data on wicking height (cm) at 10 min for both course and wale directions. Eri silk knitted fabric has rapid and better wicking, which may be due to the presence of higher ratio of

Table 3 — Grading of moisture management indices					
Measuring parameters	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Wetting time, s					
Top (WT_t)	≥120	20-119	5-19	3-5	<3
Bottom (WT_b)	≥120	20-119	5-19	3-5	<3
Absorption rate, %/s					
Top (AR_t)	0-10	10-30	30-50	50-100	>100
Bottom (AR_b)	0-10	10-30	30-50	50-100	>100
Max wetted radius, mm					
Top (MWR_t)	0-7	7-12	12-17	17-22	>22
Bottom (MWR_b)	0-7	7-12	12-17	17-22	>22
Spreading speed, mm/s					
Top(SS_t)	0-1	1-2	2-3	3-4	>4
Bottom(SS_b)	0-1	1-2	2-3	3-4	>4
Accumulative one-way transport capacity index (AOTI), %	< -50	-50 to 100	100-200	200-400	>400
Overall moisture management capability (OMMC)	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	>0.8

Table 4 — Physical properties of fabric samples

Short code	Mean loop length cm	Tightness factor tex$^{1/2}$, cm	Weight per unit area g/m^2	Stitch density, loops/cm^2 (wales density × course density)	Thickness mm
CSJ-T	0.27	18.53	250	16 × 21=336	0.92±2
CSJ-S	0.33	15.16	205	15 × 18=270	0.81±2
FSJ-T	0.25	15.12	140	18 × 22=396	0.74±2
FSJ-S	0.31	12.20	110	17 × 19=323	0.69±2
CSP-T	0.28	17.86	262	13 × 26=338	1.04±2
CSP-S	0.34	14.71	215	12 × 23=276	0.92±2
FSP-T	0.26	14.54	152	14 × 29=406	0.79±2
FSP-S	0.32	11.82	116	13 × 26=338	0.68±2
CSH-T	0.28	17.86	283	13 × 27=351	1.24±2
CSH-S	0.34	14.71	245	12 × 26=312	1.06±2
FSH-T	0.26	14.54	186	15 × 30=450	1.07±2
FSH-S	0.32	11.82	134	14 × 27=378	0.82±2

Table 5 — Wicking height (cm) at 10 min

Short code	Course-wise wicking height, cm				Wales-wise wicking height, cm			
	1 min	3 min	5 min	10 min	1 min	3 min	5 min	10 min
CSJ-T	3.5	5.4	7.4	9.5	3.9	6.0	8.0	10.4
CSJ-S	3.0	5.0	6.6	9.0	3.3	5.2	7.2	9.8
FSJ-T	2.6	4.1	5.2	7.9	2.8	4.9	6.6	8.7
FSJ-S	2.2	3.8	4.9	7.4	2.3	4.3	5.9	8.3
CSP-T	2.8	4.6	6.0	8.7	2.9	5.1	7.7	9.3
CSP-S	2.3	3.9	5.3	8.1	2.7	5.1	7.1	8.9
FSP-T	2.2	4.0	5.5	8.0	2.2	4.0	5.6	8.6
FSP-S	2.0	3.5	4.6	7.0	2.0	3.6	4.9	7.4
CSH-T	2.6	4.3	5.5	8.4	2.9	5.1	6.8	9.1
CSH-S	2.3	3.7	4.8	7.3	2.4	4.4	5.6	7.6
FSH-T	2.3	3.6	5.0	6.9	2.4	4.0	4.8	7.1
FSH-S	2.1	3.5	4.4	5.9	2.1	3.1	4.4	6.3

hydrophilic to hydrophobic of amino acids residues in its chemical structure[19, 20].

It is observed that the single jersey fabric shows better wicking property than single pique and honeycomb structures. The result confirms the earlier findings of Wong et al.[21]. They reported that according to the capillary principle, small pores are packed first and the liquid then moves to the larger pores. The higher pore size of honeycomb and single pique structures are attributed to poor wicking. Furthermore, coarser eri silk yarn possesses better wicking property than finer eri silk yarn. Presence of more number of fibres in the yarn cross-section and the resultant higher thickness might support the higher capillarity of fabrics with the coarser yarns. It is observed that the tight forms of the structures possess better wicking ability than that for slack forms in both directions. The fabric also shows shorter wicking heights in course-wise direction than that in wale-wise direction for all knit structures. It may be due to varied loop shapes and densities of the structures for wale-wise and course-wise directions.

The rate of vertical wickability is found fast, ranging from 0.65 mm/s to 0.38 mm/s for the first three minutes and subsequently it slow down in the range of 0.18 - 0.08 mm/s beyond that time. As reported by Zhuang et al.[22], the initial rapid wicking rate could be due to gravitational forces that is interfered with the capillary rise of the liquid through the fabric and also due to the fibre surface energy. Eri knit single jersey has instant water absorbing capacity of 0.65 -0.55 mm/s, followed by single pique 0.52 - 0.47 mm/s and honeycomb structure 0.48 - 0.35 mm/s.

3.3 Moisture Transmission Properties

The results of multi directional moisture management properties of eri knitted fabrics are summarized in Table 6.

Table 6 — MMT results for eri knitted fabrics using grades 1-5 scale

Sample	WT,s		AR, %/s		MWR, mm		SS, mm/s		AOTI, %	OMMC
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom		
CSJ-T	3	2	3	4	3	3	3	2	2	2
CSJ-S	3	2	3	4	4	3	3	3	2	3
FSJ-T	3	2	4	4	4	4	5	5	3	3
FSJ-S	3	3	4	5	5	4	5	5	3	4
CSP-T	3	2	3	4	4	3	3	3	4	3
CSP-S	3	3	4	4	4	4	3	3	4	4
FSP-T	3	3	4	4	5	4	5	5	4	4
FSP-S	4	3	4	5	5	4	5	5	4	4
CSH-T	3	3	4	4	3	3	3	3	4	3
CSH-S	3	3	4	4	4	3	4	3	5	4
FSH-T	4	3	4	4	4	3	5	4	5	4
FSH-S	4	3	4	5	5	4	5	5	5	5

WT –wetting time, AR –absorption rate, MWR –max wetted radius, SS –surface spreading speed.
Grade: 1- poor, 2-average, 3-good, 4-very good, and 5-excellent.

In general, the indices of the moisture management properties of all eri knitted fabrics are in the range of 'Good-3' to 'Excellent-5', except the single jersey fabrics made out of coarser yarn. According to these results, moisture management properties of single jersey fabrics are low (Average-2 to Good-3) and the fabric would fall to 'slightly feel wet' category to the wearer on active applications. Following the single jersey fabrics, single pique with single tuck in alternate course line and honeycomb with continuous tuck stitches on course line possess better properties. Tuck stitch knitted fabrics spreads moisture on a large area and facilitates faster evaporation.

3.3.1 Effect of Loop Length, Yarn Count and Fabric Structures on Wetting Rate

Top (WT_t) and bottom (WT_b) wetting time denote the time taken by the inner and outer layers of the fabric to absorb the liquid. From Fig. 1, it is observed that the wetting time of top surface is marginally higher than the bottom surface in all eri silk structures. The general wetting trend of eri silk knitted fabric is better due to the presence of high proportion of amino acids with polyalanine compounds in bulky side groups and lower fibre surface tension of eri silk[20]. However, the plied yarn used in knitting leads to slower wicking on outer layer because of low capillary channels.

It may be pointed out that eri silk knit fabric structures made out of coarser yarn exhibit more wetting time than finer yarn in all the structures investigated. This may be due to the fact that liquid has to go through dense of fibre assembly with the resultant thicker fabrics. The observed phenomenon is
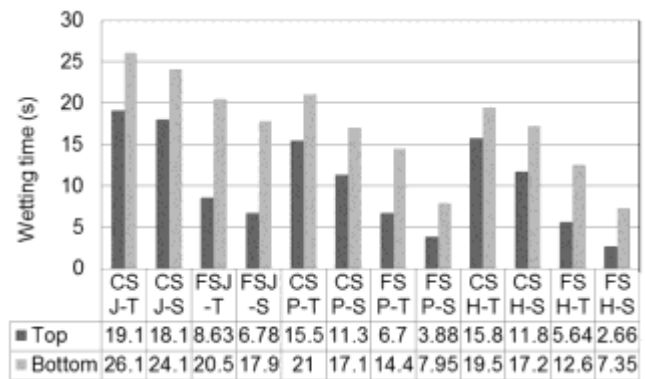

	CS J-T	CS J-S	FSJ -T	FSJ -S	CS P-T	CS P-S	FS P-T	FS P-S	CS H-T	CS H-S	FS H-T	FS H-S
■ Top	19.1	18.1	8.63	6.78	15.5	11.3	6.7	3.88	15.8	11.8	5.64	2.66
▪ Bottom	26.1	24.1	20.5	17.9	21	17.1	14.4	7.95	19.5	17.2	12.6	7.35

Fig. 1 — Wetting time values of fabric (top and bottom)

in agreement with the earlier reports of Ozdil *et al.*[23], as thinner fabric has quick wetting than thicker ones, for the same amount of liquid drops on to a fabric surface. It may be further noted that the fabric with plain stitches would transfer liquid slowly from inner to outer than the fabric with knit and tuck stitch combinations, as pointed out by Öner *et al.*[24]. Eri silk knitted fabrics also behave in a similar way that the bottom surface of single jersey fabric takes more wetting time than the pique and honeycomb structures by the influence of tuck stitches.

3.3.2 Effect of Loop Length, Yarn Count and Fabric Structures on Absorption Rate

Figure 2 shows the top (AR_t) and bottom (AR_b) liquid absorption rates of different eri silk knitted fabric structures. It is observed that the inner layer has low absorption rate than the outer layer, which would provide 'dry feel to skin', thereby indicating that eri silk knit fabrics are suitable to be 'skin fit' as well as active wear applications.

Further, eri silk knitted fabric structures, prepared using finer yarn and slack structural form, give better absorption than coarser yarn and tight form. Also, single pique and honeycomb eri silk knit structures have marginally better absorption rates than single jersey fabric. The presence of fabric pores in these structures attribute to quick absorption rate and it relates to the previous findings by Troynikov et al.[6].

3.3.3 Effect of Loop Length, Yarn Count and Fabric Structures on Surface Spreading Speed

Spreading speed is one of the important phenomena in determining the drying rate of the textile fabric, spreading to a larger area, thereby facilitating faster evaporation of liquid. It may be observed that eri silk knitted fabric structures exhibit 'good to excellent' grades in regard to liquid spreading speed, which contributes to quick spreading and faster drying as delineated in Fig. 3.

It is observed that the tightness of the fabric structure has less influence than eri silk yarn count. Finer eri yarn with all three structures shows faster spreading rate. This may be due to less wetting time with the lighter fabric than heavier fabrics.
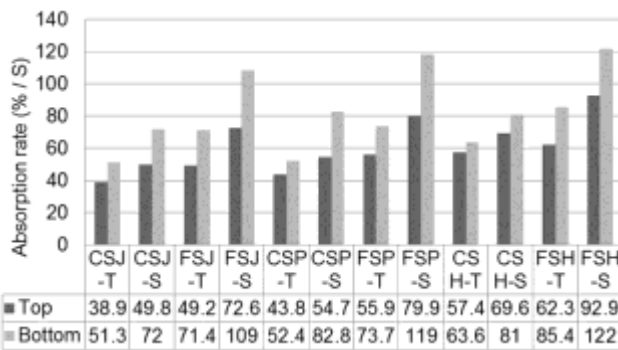

	CSJ-T	CSJ-S	FSJ-T	FSJ-S	CSP-T	CSP-S	FSP-T	FSP-S	CS H-T	CS H-S	FSH-T	FSH-S
Top	38.9	49.8	49.2	72.6	43.8	54.7	55.9	79.9	57.4	69.6	62.3	92.9
Bottom	51.3	72	71.4	109	52.4	82.8	73.7	119	63.6	81	85.4	122

Fig. 2 — Absorption rates of fabric (top and bottom)

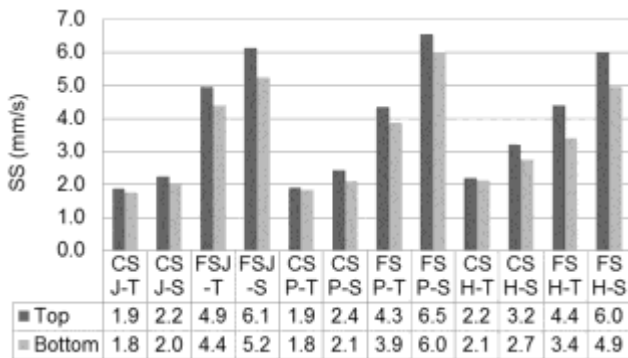|	CS J-T	CS J-S	FSJ-T	FSJ-S	CS P-T	CS P-S	FS P-T	FS P-S	CS H-T	CS H-S	FS H-T	FS H-S
Top	1.9	2.2	4.9	6.1	1.9	2.4	4.3	6.5	2.2	3.2	4.4	6.0
Bottom	1.8	2.0	4.4	5.2	1.8	2.1	3.9	6.0	2.1	2.7	3.4	4.9

Fig. 3 — Surface spreading speed (SS) of fabric (top and bottom)

3.3.4 Effect of Loop Length, Yarn Count and Fabric Structures on Wetting Area

Maximum wetted radius of the knitted fabric with the equal amount of liquid is also examined. It is observed that the top surface (inner layer) of the fabric has more MWR than bottom surface (outer layer), indicating the better moisture properties of eri knitted fabrics (Fig. 4).

It is observed that eri silk knit fabric tightness and yarn count have a more significant impact than the type of fabric structure. The trend of eri knit MWR is observed as single jersey >single pique>honeycomb structures. This result also indicates the positive correlation of vertical wicking with the maximum wet radius, which is also confirmed by the previous research[25].

3.3.5 Effect of Loop Length, Yarn Count and Fabric Structures on AOTI and OMMC

AOTI value is an indicator of liquid transfer capacity of fabric from inner to outer layer. The positive and high values indicate faster rate of transportation, while negative and low values indicate slower transportation associated with larger wetted area in the skin surface.

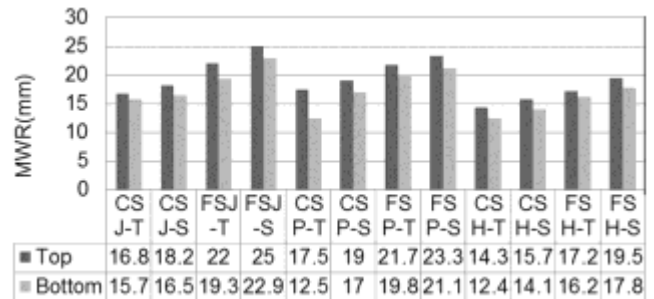It is observed from Fig. 5 that the eri silk Honeycomb knit structure possesses better AOTI

	CS J-T	CS J-S	FSJ-T	FSJ-S	CS P-T	CS P-S	FS P-T	FS P-S	CS H-T	CS H-S	FS H-T	FS H-S
Top	16.8	18.2	22	25	17.5	19	21.7	23.3	14.3	15.7	17.2	19.5
Bottom	15.7	16.5	19.3	22.9	12.5	17	19.8	21.1	12.4	14.1	16.2	17.8

Fig. 4 — Maximum wet radius (MWR) of fabric (top and bottom)

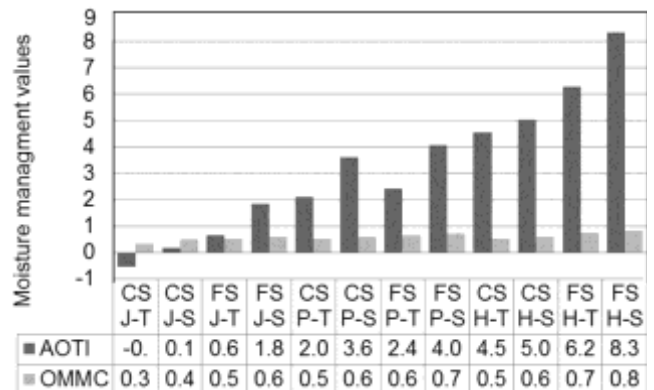|	CS J-T	CS J-S	FS J-T	FS J-S	CS P-T	CS P-S	FS P-T	FS P-S	CS H-T	CS H-S	FS H-T	FS H-S
AOTI	-0.	0.1	0.6	1.8	2.0	3.6	2.4	4.0	4.5	5.0	6.2	8.3
OMMC	0.3	0.4	0.5	0.6	0.5	0.6	0.6	0.7	0.5	0.6	0.7	0.8

Fig. 5 — Accumulative one way transport index (AOTI) and overall moisture management capacity (OMMC) of fabric

values followed by single pique and single jersey structures. A further, slack structural form shows better transmission properties than tighter forms. Tuck stitches and slack structural form are attributed to increased pore size, thereby facilitating faster transportation of liquid from inner to outer layer**.** Eri silk single jersey fabrics made out of coarser yarn and tighter loop length have negative AOTI value. This might be due to dense construction and also slows down the moisture transmission from the skin to outer layer.

OMMC indicates the overall management performance of liquid moisture on fabric. The higher the OMMC value the better is the liquid performance of fabric. Coarser yarn and tighter forms exhibit low OMCC than slack structural forms within the same eri knit structures. The increased stitch density associated with the fabric thickness leads to decrease the instant wetting rate. The order of eri silk knit fabrics for the OMMC values are honeycomb structures followed by single pique and single jersey structure.

4 Conclusion

4.1 Knitted structures, yarn count and tightness have significant effect on vertical wicking ability; single jersey has better wicking property than single pique and honeycomb structure.

4.2 Eri knit single jersey has instant water absorbing capacity of 0.65-0.55 mm/s, followed by single pique 0.52 - 0.47 mm/s and honeycomb structure 0.48 - 0.35 mm/s.

4.3 Eri knit fabric has shorter wicking heights in course-wise direction than in wale-wise direction for all knit structures. Coarser eri yarn and tighter knit structures posses better wicking properties in both directions.

4.4 Fabrics made out of finer yarn show faster wetting rate, absorption rate, spreading speed and max wetted radius as compared to those for coarser yarns.

4.5 Tightness has a significant influence on the moisture management properties of knitted fabrics. Slack structures show increased absorption rate & spreading speed, max wetted radius and reduced time to wetting as compared to tight structures.

4.6 Knitted fabrics with pique and honey comb structures show better absorption rate, faster wetting, and maximum wetted radius. The inner layer of the fabrics shows lower absorption rate than that of outer layer, which indicates that eri knit fabric is suitable for skin fit as well as active wearer applications.

4.7 Accumulative one way transport capacity and OMCC of single pique and honeycomb structures are in the 'very good-4' to "excellent-5' category. It is also observed that the single jersey fabrics made out of finer yarn and slack structure also have sealed upto Grade 4. This also supplements the suitability of eri silk yarn to skin fit as well as active wear applications.

4.8 The studies reveal that the all eri knitted fabric in general have good moisture management properties and confirm their suitability for performance based garments.

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