Transfer Properties of Single Jersey Knitted Fabrics Made from Structurally Modified Micro-Pore Ring Spun Viscose Yarns

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Abstract: **- This paper deals with the study of transfer properties of knitted fabrics produced with structurally modified micro-pore ring spun viscose yarn. The micro-pores within the yarn and fabric have been created by dissolving the PVA fibres in hot water at a temperature of 90^0 C. The micro-porous yarns with varying packing densities and level of pore volumes are produced by changing the PVA fibre blend proportion, yarn twist multiplier(TM) and spindle speed at ring spinning machine.A three variable factorial design technique proposed by Box and Behnken has been used to study the interaction effects of these variables on the transfer properties of fabrics.The results shows that the air permeability and thermal conductivity of fabric decreases with the increase in PVA proportion and increases with the increase in spindle speed and yarn TM.The water vapour permeability and wickability of knitted fabric increases with the increase in PVA proportion and decreases with the increase in spindle speed and yarn TM.The OMMC of knitted fabric increases with the increase in PVA blend proportion and decreases with the increase in spindle speed and yarn TM.**

Key words: **micro pore, PVA, wickability, thermal conductivity, air permeability, OMMC**

I. INTRODUCTION

Structural modification of yarn is opening up a new field of applications (Chandrasekaran et al. 2018, Pwaan Kumar et al. 2014,). The comfort characteristics of the fabrics depend mainly on the structure and type of yarn used (Senthilkumar, 2009; Singh et al 2010). Fibre being the structural unit of a yarn, its nature, composition and arrangement of constituent fibres can influence the structure, properties and the performance of yarn (Sujit Kumar Sinha et al. 2016, Pawan Kumar et al. 2016). The basic aim of generating micro-pores in a textile structure is to provide better thermophysilogical comfort by enhancing the breathability and hence improving moisture management behavior of fabrics (Navendu Sharma 2015). Air rich yarn and fabrics with micro-pores throughout the yarn cross-section have an increased capacity to absorb water and release moisture faster while drying (Pradip Debnath, &Swadesh Verma 2012).The use of hollow/micro porous yarns plays an important role in enhancing the thermo-physiological comfort properties of fabrics (Mukhopadhyay et al. 2011). The pore size of yarn and its distribution influence the structural, physical, moisture and thermal behavior of the fabrics (Singh et al.2010; Das & Ishtiaque, 2004: Chandrasekaran et al 2014). Fabric liquid moisture transport properties in multi-dimensions, called moisture management properties significantly influence human perceptions of moisture sensation (Wang et al 2005). Moisture transmission through textiles has a great influence on the thermo-physiological comfort of the human body which is maintained by perspiring both in vapour and liquid form (Brojeswari et al, 2007). Clothing should assist the human body in maintaining body temperature in a narrow range and keep the skin dry under different environmental conditions (Das et al. 2007; Das et al. 2009). The efficiency of sweat transport in sportswear is an important factor affecting the physiological comfort and physical performance of wearer. The moisture transport properties of textile fabrics are essentital to clothing comfort. Ideally, fabrics should prevent the accumulation of sweat on the skin surface by facilitating the transport of sweat away from the skin and evaporation of sweat to the outside environment. The fabric worn next to the skin should have two important properties, to evaporate perspiration from the skin and to transfer the moisture to the atmosphere and make the wearer to feel comfort (Das, Ishtiaque & Yadav, 2003; Zhou et al 2007). Air permeability and water vapour transimission rate of all kind of single jersey fabrics produced from hollow yarns increased as well as weight of the fabrics decreased which will cause more comfort during any exercise (Pelin Gurkan Unal & Mustafa Erdem Ureyen 2017).Woven fabrics by using porous yarns as weft showed higher value of moisture transfer when compared with 100% cotton yarn fabrics (Asal Lolaki et al.2017).However, few studies have been dedicated to the comfort properteies of single jersey knitted fabrics made from micro-pore ring spun viscose yarn. Also limited works have been reported about the structurally modified ring spun yarn used for sportswear applications and high activewear to attain wearer comfort.The present work concerned with the detailed study of comfort properties like air permeability, water vapour permeability, overall moisture management capacity (OMMC), fabric wicking, and thermal conductivity of a single jersey knitted fabric made from micro-pore ring spun viscose yarn and to optimize the design variables for each property of the fabric and to assess suitability of designed fabrics in providing wearer comfort .

II. MATERIALS AND METHODS

2.1 Materials

The staple viscose fiber (Denier - 1.07, 2.5% span length - 44.3 mm, fiber tenacity- 2.76 g/d, elongation - 18.72%, specific volume-1.51cm^3/gm) and water soluble polyvinyl alcohol (PVA) staple fiber (Denier - 1.38, 2.5% span length - 40.3mm, tenacity- 7.04 g/d, elongation- 10.9%) were used for the production of micro-pore ring spun viscose yarns.

2.2 Methods

2.2.1 Experimental design and yarn production

The viscose-PVA blended yarn samples were prepared on a lab model spinning line (Trytex, India). The slivers were prepared on a miniature model carding and draw frame machine. The viscose and PVA fibers were mixed manually prior to the carding with three different blend proportions. The carded web was collected in the front of card by a drum. The web was again processed in the card and collected as a sliver in a can by means of trumpet. The carded slivers were given two draw frame passage with six doublings each in a miniature draw frame machine.The sliver weight was maintained as 3.69 ktex.

In this present research, a three level and three variable factorial designs, proposed by Box and Behnken was used to investigate the influence of variables and their interaction on yarn properties. Box-Behnken design requires an experiment number according to $N = k^2 + k + c_p$, where (k) is the factor number and (c_p) is the replicate number of the central point. The most important parameters which affect the packing of fibers in the yarn is blend proportion of PVA, TM and spindle speed have been selected for the yarn production. In order to study the combined effect of these factors, experiments were performed at different combinations of the physical parameters using statistically designed experiments.

A multiple regression analysis is done to obtain the coefficients and the equation can be used to predict the response. The design is preferred because relatively few experimental combinations of the variables are adequate to estimate potentially complex response functions. A total of 15 experiments were necessary to estimate the 10 coefficients of the model using multiple linear regression analysis. Table 1 shows coded levels and actual values for processing viscose/PVA blended yarns in ring frame.

Table 1 Coded levels and actual values for production of mocro-pore yarn in ring frame

Variables	Coded Levels		
	-1	0	+1
PVA proportion (%) (X_1)	5	10	15
Twist Multiplier TM (X_2)	2.7	2.9	3.1
Spindle speed (rpm) (X_3)	10000	13000	16000

2.2.2 Experimental design and fabric production

Fifteen single jersey knitted fabrics were produced with the micro-pore ring spun viscose yarn as per the design of experiments proposed by Box and Behnken and the last sample (sample no.16) is of 100% viscose as a reference sample. The yarn count were kept coarser by 5%, 10% and 15% (as per the blend proportion of PVA) in order to get the nominal count of 30^s Ne after dissolving the PVA fibers. The coded and actual values of variables taken for the study are shown in Table 1. After production of the knitted fabric the PVA was removed by treating the fabric in hot water at a temperature of 90^0 C for 20-30 minutes followed by cold wash. . Even after removal of PVA, the fabric is not affected because compacting forces created by the fabric structure itself hold the system together

2.3 Evaluation of fabric properties

The details of instrument used, testing standards and the number of samples tested for each fabric characteristics are given in Table 2. All the tests were carried out after conditioning the samples in standard atmospheric condition.

Table 2 Details of fabric characteristics tested

Test type	Standard
Moisture Management	AATCC: 195-2009
Air permeability	ASTM: D 737-96
Knitted fabric Course per inch	ASTM: WK 30250
Knitted fabric wales per inch	ASTM: WK 30250
Fabric thickness	ASTM: D 1777-96
Fabric Areal Density (GSM)	ASTM: 3776-96
Water vapour permeability	British Standard, BS 7209
Wicking	ATCC TM 197-2011

2.4 Design of experiment

The experimental data was analyzed using the statistical software, Design Expert software version 8.0.7.1 (STAT-EASE Inc., Minneapolis, US), for regression analysis to fit the equations developed and also for the evaluation of the statistical significance of the equations. Statistical significance of the equation was determined with ANOVA feature of the Design Expert Software. Subsequently, the feasibility and grid searches were performed to locate the composition of optimum formulations.

III. RESULTS AND DISCUSSION

The knitted fabric constructional parameters such as yarn count, wales per inch (WPI), courses per inch (CPI), thickness and fabric GSM after dissolving the PVA are shown in Table 3. From the Table 3, it is noticed that the actual count after dissolution of PVA from the yarns is close to the nominal count of 30s Ne. Further, no significant difference was noticed in WPI, CPI and fabric GSM after the dissolution of PVA and is similar to the control fabric. Hence, all the trends have been explained in terms of yarn variables, i.e. PVA%, yarn TM and Spindle speed. The design matrix of the variables in the actual units along with their fabric properties after dissolving the PVA fibers along with control sample (100% viscose knitted fabric) is given in Table 4.

3.1 Model Building and Statistical Analysis of Fabric Properties

The empirical relationships for response variables such as air permeability (Y1), water vapour permeability (Y2), wicking height (Y3) thermal conductivity (Y4), and OMMC (Y5) were obtained by application of response surface methodology (RSM). The final mathematical model after the elimination of using factors in terms of coded factors as determined by Design-Expert Software is shown in Table 4. The regression co-efficient (R^2) value indicates a good correlation of selected experimental region with the comfort properties of fabric. The model with the $R^2 \geq 0.6$ (60%) can be considered as a valid model. The goodness of the model can be checked by the determination coefficient R^2 and the adjusted R^2 (multiple correlation coefficient R). The value of adjusted R^2 of 0.987, 0.938, 0.964, 0.952 and 0.953 suggests that the total variation of 98.7% for air permeability, 93.8% for water vapour permeability, 96.4% for fabric wicking, 95.2% for thermal conductivity, 95.3% for OMMC, are attributed to the independent variables and only about 1.3%, 6.2%, 3.6%, 4.8% and 4.7% of the total variation cannot be explained by the model respectively. The closer the value of adjusted R^2 to 1, the better is the correlation between the experimental and predicted values The large deviation between adjusted R^2 and predicted R^2 may indiacte a large block effect in the model.The adequacy measures in total were in reasonable agreement and indicated adequate models. The adequate precision compared the range of the predicted value at the design points to the average prediction error. The value of adequate precision was significantly greater than four. An adequate precision ratio above 4 indicates adequate model other values that support the efficacy of the model and the relevant significant terms are given in the same table. The ANOVA results of the selected model on different yarn properties are given in Table 6. The value of "Prob. > F" in Table 6 for the model is less than 0.05 which indicates that the model is significant, which is desirable as it indicates that the terms in the model have significant effect on the response. The lack-of-fit can also said to be insignificant.

Table 3 Constructional parameters of micro-pore single jersey knitted fabrics

Sample no	PVA% (X_1)	TM (X_2)	Spindle speed (X_3)	Yarn count (Ne)	Yarn Diameter (µm) (BD)*	Yarn Diameter (µm) (AD)*	WPI*	CPI*	Thickness (mm)	Fabric areal density (g/m^2)
1	5	2.7	13000	29.7	239	238	24	21	0.72	137
2	15	2.7	13000	30.5	223	247	24	20	0.75	140
3	5	3.1	13000	29.4	201	212	23	22	0.73	136
4	15	3.1	13000	29.2	199	202	23	21	0.75	140
5	5	2.9	10000	30.7	223	217	23	20	0.74	137
6	15	2.9	10000	30.1	217	206	22	21	0.76	141
7	5	2.9	16000	29.7	223	222	24	22	0.73	136
8	15	2.9	16000	29.3	205	204	24	22	0.75	140
9	10	2.7	10000	30.4	242	229	25	22	0.73	139
10	10	3.1	10000	30.6	190	172	22	23	0.72	137
11	10	2.7	16000	29.2	218	224	24	22	0.72	138
12	10	3.1	16000	30.9	182	170	22	23	0.74	137
13	10	2.9	13000	30.4	202	203	22	23	0.74	137
14	10	2.9	13000	30.1	206	211	23	22	0.74	137
15	10	2.9	13000	29.3	207	203	24	21	0.73	139
16**	00	2.9	13000	30.2	162	-	22	21	0.75	141

* BD – Before dissolving PVA, AD – After dissolving PVA, WPI-Wales/inch, CPI-Course/inch ** 100% viscose as a reference fabric

Table 4 Transfer properties of micro-pore single jersey knitted fabrics

Sample No	PVA% (X_1)	TM (X_2)	Spindle speed (X_3)	Air Permeability ($cm^3/cm^2/s$)	Water Vapour Permeability ($g/m^2/day$)	Fabric Wicking (cm)	Thermal conductivity (W/mK)	OMMC
1	5	2.7	13000	430	618	11.8	0.048	0.5852
2	15	2.7	13000	332	640	10.8	0.045	0.6122
3	5	3.1	13000	435	579	10.7	0.052	0.5214
4	15	3.1	13000	355	633	10.1	0.048	0.5952
5	5	2.9	10000	432	600	12.5	0.051	0.5515
6	15	2.9	10000	328	635	10.3	0.047	0.6259
7	5	2.9	16000	445	562	10.9	0.053	0.5261
8	15	2.9	16000	380	602	10.1	0.052	0.5934
9	10	2.7	10000	415	600	12.8	0.05	0.5615
10	10	3.1	10000	448	580	11.8	0.056	0.5577
11	10	2.7	16000	432	588	11.5	0.054	0.5495
12	10	3.1	16000	463	578	10.2	0.057	0.5287
13	10	2.9	13000	420	598	12.3	0.05	0.5413
14	10	2.9	13000	419	595	12.1	0.051	0.5415
15	10	2.9	13000	418	596	12.3	0.05	0.5492
16**	00	2.9	13000	475	552	10.2	0.069	0.3992

** 100% viscose as a reference fabric

Table 5 Response surface equations for micro-pore single jersey knitted fabrics

Fabric Properties	Regression equation	p-value	Co-efficient of determination R^2
Air Permeability($cm^3/cm^2/s$)	$+419.00-3.38X_1+11.50X_2+12.13X_3+4.50X_1X_2+9.75X_1X_3-0.50X_2X_3-37.12X_1^2+6.13X_2^2+14.37X_3^2$	0.0003	0.987
Water vapour Permeability($g/m^2/day$)	$+596.33+18.87X_1-9.50X_2-10.63X_3+8.00X_1X_2+1.25X_1X_3+2.50X_2X_3+17.21X_1^2+3.96X_2^2-13.79X_3^2$	0.0150	0.938
Wicking height(cm)	$+12.23-0.58X_1-0.51X_2-0.59X_3+0.10X_1X_2+0.35X_1X_3+0.075X_2X_3-1.00X_1^2-0.38X_2^2-0.28X_3^2$	0.0041	0.964
Thermal Conductivity(W/mK)	$+0.050-0.002.250X_1+3.12\text{-}003X_1+1.87003X_3+2.50X_1X_2+7.50X_1X_3-1.50X_2X_3-6.66X_1^2+2.083X_2^2+1.083X_3^2$	0.0005	0.952
OMMC	$+0.54+0.03X_1+0.013X_1+0.012X_3-0.007X_1X_2-0.0004X_1X_3-9.725X_2X_3+0.03X_1^2+0.004X_2^2-0.0005X_3^2$	0.0195	0.953

Table 6 ANOVA results of micro-pore single jersey knitted fabrics

Source	Air Permeability ($cm^3/cm^2/s$)		Water vapour Permeability ($g/m^2/day$)		Wicking height(cm)		Thermal Conductivity (W/mK)		OMMC	
	F-Value	p-value	F-Value	p-value	F-Value	p-value	F-Value	p-value	F-Value	p-value
Model	43.269	0.0003*	8.474	0.0150*	14.9763	0.004*	11.241	0.0080*	11.3419	0.0078*
A-PVA%	242.565	< 0.0001*	32.175	0.0024*	29.1192	0.003*	22.710	0.0050*	54.03496	0.0007*
B-TM	17.051	0.0091*	8.151	0.0356*	23.1330	0.004*	43.808	0.0012*	10.20781	0.0241*
C-Spindle Speed	18.954	0.0073*	10.195	0.0242*	30.3990	0.002*	15.771	0.0106*	8.987605	0.0302*
AB	1.305	0.305	2.890	0.150	0.44036	0.5363	0.140	0.723	4.025067	0.1011
AC	6.128	0.056	0.071	0.801	5.39449	0.0678	1.262	0.312	0.09264	0.7731
BC	0.016	0.904	0.282	0.618	0.24770	0.6398	5.047	0.075	0.531104	0.4988

A^2	82.014	0.0003*	12.343	0.0170*	40.9887	*0.001	0.920	0.382	23.92139	0.0045*
B^2	2.232	0.195	0.653	0.456	5.844037	0.0603	8.986	0.0302*	0.628609	0.4638
C^2	12.296	0.0172*	7.928	0.0373*	3.16796	0.1352	2.430	0.180	0.007841	0.9329
Lack of Fit	102.750	0.010	62.607	0.016	10.6875	0.0868	8.250	0.110	10.50776	0.0881

* indicates significant difference ($p < 0.05$)

3.2 Effect of Ring Frame Process Parameters on Air Permeability of Single Jersey Knitted Fabrics

The air permeability values of fabric samples are shown in Table 4 and the contour plots for low, medium and higher twisted yarn fabrics are shown in Figures 1 (a),(b) and (c) respectively.

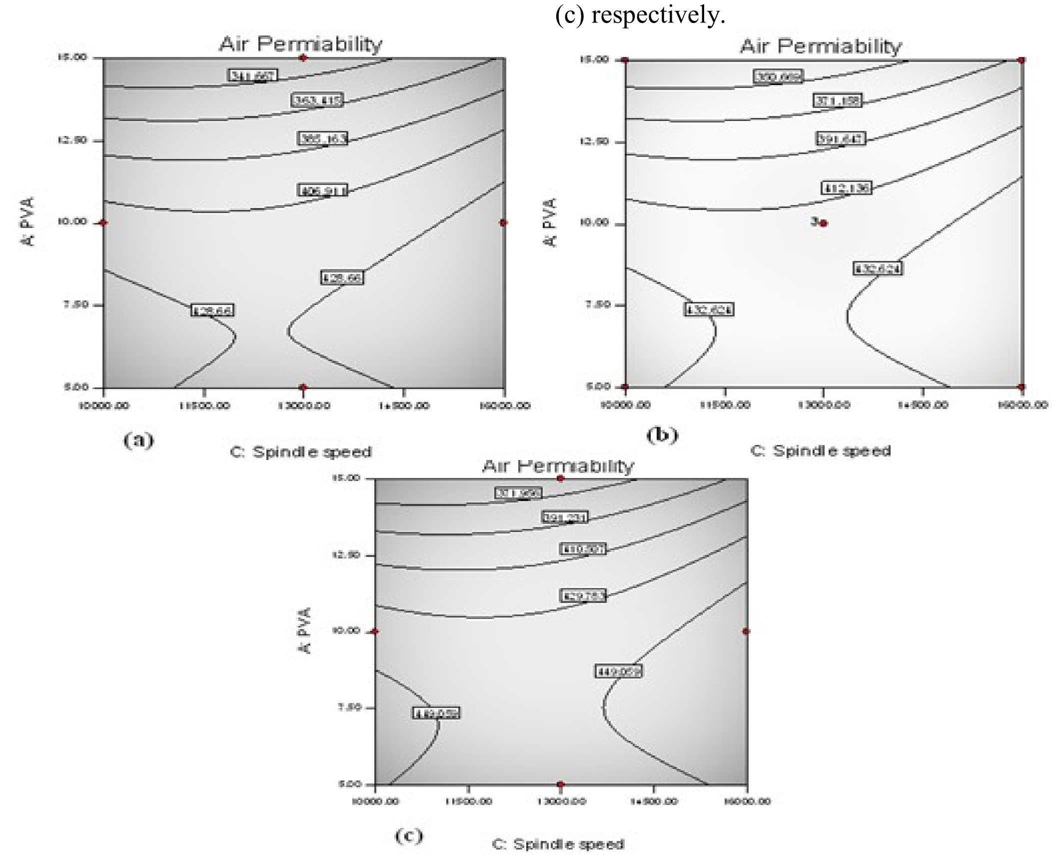

Figure 1 Contour plots of Air permeability of fabrics (a) TM=2.7 (b) TM=2.9(c) TM=3.1

By analyzing the response surface equation and contour plots, it can be shown that maximum air permeability is achieved at PVA proportion of 12.7%, with yarn TM of 3.1 and a spindle speed of 16,000 rpm. From the contour plots, it is evident that as the PVA content in the yarn increases, there is a decrease in the air permeability of the fabrics. As the PVA propotion increases in the yarn, the yarn diameter also increases after disolving the PVA as shown in Table 3 and the yarn becomes bulkier. The increase in yarn diameter with increase in PVA content leads to reduction in inter-loop spaces in the knitted fabric which could have resulted in reduciton of air-permeability of fabrics with the increase in PVA content.

Further, with the increase in PVA content, the micro-pores will be high after disolving it and hence, more compressiblity and flattening of yarns could also result in reduction of inter-loop spacing and lower airpermeability of fabrics (Das et al. 2009, Das & Ishtiaque 2004).From the contour plots (Figures 1 a, b and c), it is observed that as yarn TM increaes,air permeability also increases. This could be due to the compact packing of fibres in the yarn which resulted in decrease in yarn diameter. The lower yarn diameter resulted in more inter-loop spaces in the fabric which resulted in increase in air permeability of fabrics.The air permiability indices were considerably high for fabrics containing high twisted yarns than for the fabrics made with low-twisted yarns as expected and the twist factor and spindle speed influences the fabric comfort by modifying the yarn hairiness,packing coefficienrt and diameter(Tyagi et al. 2010).

3.3 Effect of Ring Frame Process Parameters on Water Vapour Permeability of Single Jersey Knitted Fabrics

The water vapour permiability of fabric samples are shown in the Table 4. It is observed from the Table that the fabric samples with micro- pores within the yarn structure show higher water vapour permiability than the reference fabric (100% viscose yarn fabric, Sample No:16). The contour plots of water vapour permeability of the fabrics are shown in Figure 2 (a),(b) and (c).

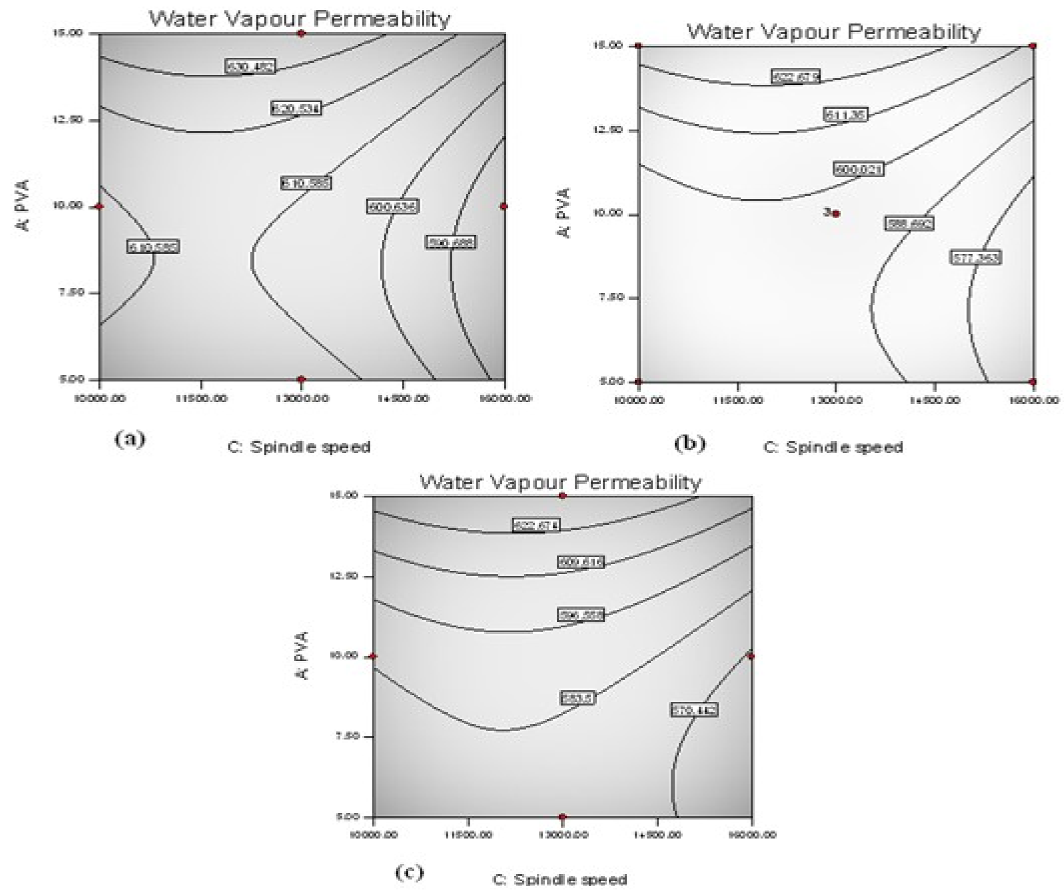

Figure 2 Contour plots of water vapour permeability of fabrics (a) TM=2.7,(b) TM=2.9,(c) TM=3.1

By analyzing the response surface equation and contour plots, it can be shown that maximum water vapour permeability is achieved at PVA proportion of 15%, with yarn TM of 2.7 and a spindle speed of 11,644 rpm. From the contour plots, it is clear that the water vapour permeability of fabrics increases with the increase in the PVA proportion and reduces with increase in spindle speed. In moisture vapour permeability tesitng, one face of the fabric is humid which is closer to the water kept in the dish and the opposite side of the fabric is relatively dry. The moisture vapour transmits through the fabric by means of diffusion. The rate of diffusion depends upon the size and number of micro-pores / voids in the yarn structure created by dissolution of PVA fibres (Das & Istiaque2004, Das et al. 2009).The micro-pores in the yarn structure created by the dissolution of PVA fibres from the yarn resulted in better transfer of water particle in vapour form from one face of the fabric to the other side of the fabric by diffusion process, through the micro-pores within the yarn structure. The diffusion within the yarn structure plays an important role in water vapour transfer of fabrics. With the incresae in PVA content, the size and number of micro-pores within the yarn structure could be higher after disolving it from the yarn, which could lead to diffusion of more water particles in the form of vapour though the micro-pores in the yarn strucutre, leading to higher water vapour permeability of fabrics.

The increase in the spindle speed results in more tightly packed fibres in the yarn structure, thus, the difussion rate is slow; hence, the water vapour permeability value is less with higher spindle speed. Water vapour permiability values reduced with the increase in the yarn twist due to the fact that the increase in the yarn twist results in more tightly packed yarn, hence lesser difussion results in reduction in water vapour permiability values. The trends are similar with medium and higher level of yarn TM as shown in Figure 2(b) and (c).With the increase in yarn TM, overall decrease in moisture vapour permeability of the fabrics were noticed irrespective of PVA content and spindle speed. Compact packing of fibres with increase in yarn TM leads to decrease in yarn diameter and diffusion of water vapour throught the yarn structure which resulted in decrease in water vapour permeability of fabrics.

3.4 Effect of Ring Frame Process Parameters on Wicking of Single Jersey Knitted Fabrics

The vertical wicking values of fabric samples are shown in Table 4. It is observed from the table, that the fabric samples with micro-pores within the yarn structure shows higher vertical wicking value than the reference fabric (100% viscose yarn fabric, Sample No:16). The contour plots of liquid moisture transportation in vertical direction of the fabrics are shown in Figure 3 (a),(b) and (c). By analyzing the response surface equation and contour plots, it can be shown that maximum wickability is achieved at PVA proportion of 11.72%, with yarn TM of 2.79 and a spindle speed of 10,714 rpm.

The contour plots of fabric on vertical wicking value at lower level of yarn twist is shown in Figure 3. From the contour plot, it is observed that the wickability of fabrics increases with the increase in PVA content up to a certain level and then decreases at higher PVA%. The initial increase in wickability of knitted fabrics could be due to the creation of micro-pores which resulted in better capillary effect. At higher PVA proportion, the removal of more number of PVA fibres from the yarn structure could have resulted in larger capillary size, which affects the capillary effect of water leading to decrease in wickability of fabrics. Similar trends are noticed in the case of medium and higher level of yarn twist, as showun in Figure 3(b) and 3(c) respectively. With the increase in spindle speed and yarn TM, the wickability of fabric decreases .The compact yarn strucure at higher twist and spindle speed leads to formation of smaller capillary size resulting in lower wickability of fabrics. The lower wickability corresponds to higher spindle speeds and the higher values correspond to the fabrics made from the yarns produced with lower spindle speeds, alteration in the twist factor also significantly modify wickability of the fabrics and a lower twist factor is preferable (Tyagi et al. 2010).

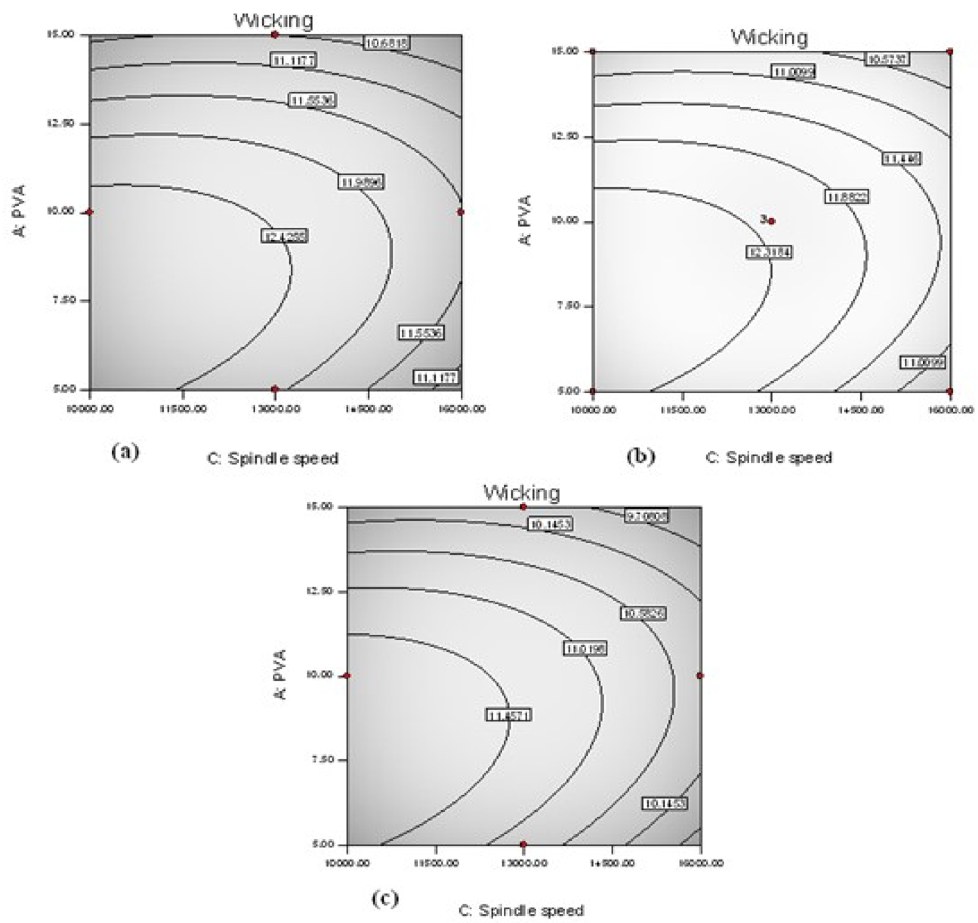

Figure3 Contour plots of vertical wicking of fabrics (a) TM=2.7,(b) TM=2.9, (c) TM=3.1

3.5 Effect of Ring Frame Process Parameters on Thermal Conductivity of Single Jersey Knitted Fabrics

The thermal conductivity of the fabric samples are shown in Table 4. It is observed from the table that the fabric samples with micro pores within the yarn structure shows lower thermal conductivity values than the control fabric (100% viscose yarn fabric, Sample No:16). Normally, the thermal conductivity of the fabrics will be less when the fabric has the capability to entrap the air within the fabric/yarn structure; because the still air has the lowest thermal conductivity (0.025 W/mK) value compared to fibres.

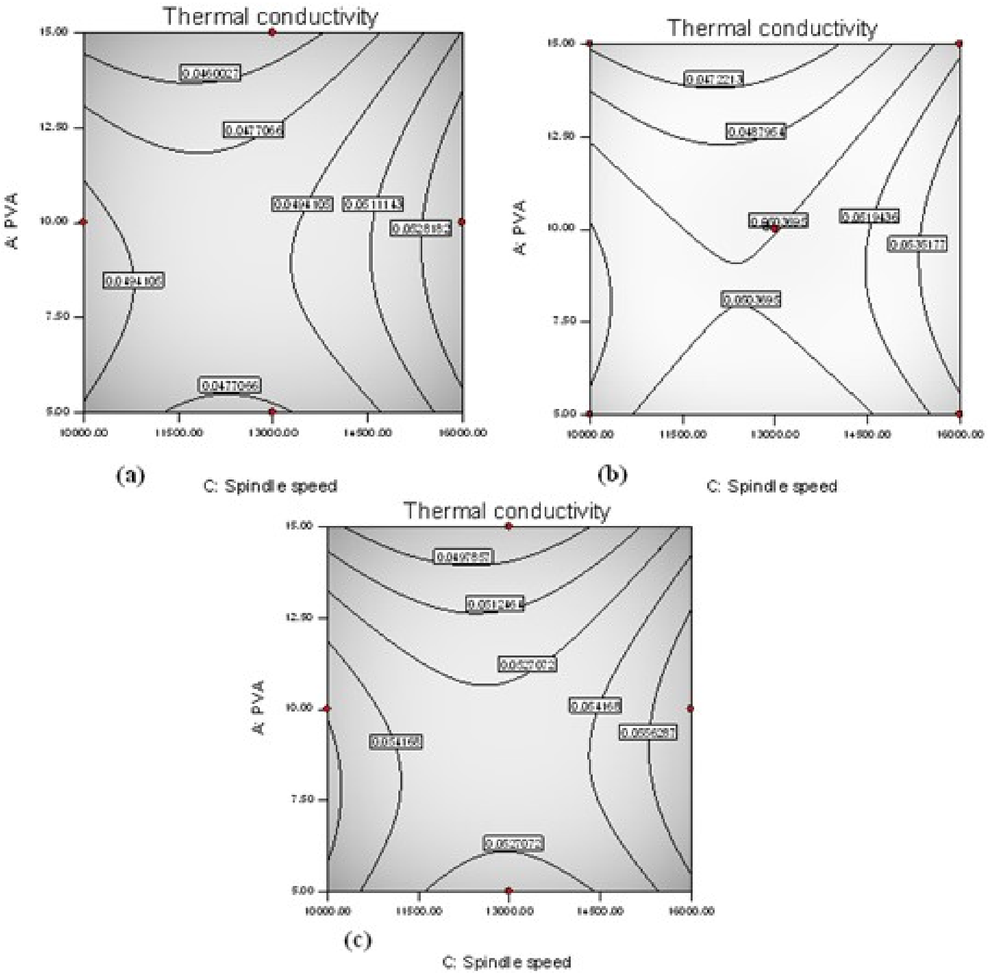

Figure 4 Contour plots of thermal conductivity of fabrics (a) TM=2.7,(b) TM=2.9,(c) TM=3.1

By analyzing the response surface equation and contour plots, it can be shown that maximum thermal conductivity is achieved at PVA proportion of 15%, with yarn TM of 2.75 and a spindle speed of 11,269 rpm. The contour plots of thermal conductivity of the fabrics at lower yarn TM is shown in Figure 4(a). From the contour plot, it is evident that the thermal conductivity decreaess with the increase in PVA proportion and it increases with the increase in the spindle speed irrespective of yarn TM .The micro-pores in the yarn structure created by the removal of PVA fibres result in entrapment of air inside the yarn structure. Since the air is a poor conductor of heat as compared to fibre, it resists transmission of heat through fabrics leading to lower thermal conductivity. Similar findings were observed in the research work carried out on hollow yarn (Das & Istiaque2004). Matsudaiar & Koda (1996) also reported that the thermal conductivity of polyester fibre fabric is reduced by making grooved and non grooved hollowness in a fibre.

Better packing of fibres with the increase in spindle speed leads to decrease in the inter fibre spacing in the yarn and increase in inter-loop spacing in the fabric. This leads to increase in thermal conductivity of fabrics.Similar trends were noticed at medium and higher yarn twist levels (Figure 4b and 4c). It can also be observed that overall thermal conductivity of the fabric is increased with the increase in the yarn TM due to compact packing of fibres which leads to reduction of inter-fibre gap in the yarn. The twist factor is also a dominant factor in determining fabric thermal resistance (Tyagi et al. 2010).

3.6 Effect of Ring Frame Process Parameters on OMMC of Single Jersey Knitted Fabrics

OMMC is an index to indicate the overall ability of the fabric to manage the transport of liquid moisture, which includes three aspects of performance: moisture absorption rate of the bottom side (BAR), one-way liquid transport capacity (OWTC), and spreading/drying rate of the bottom side (SSb) which is represented by the maximum spreading speed. The larger the OMMC,the higher the overall moisture management ability of the fabric. The OMMC values of fabric samples are shown in Table 4. It is observed from the table that the fabric samples with micro pores within the yarn structure shows higher OMMC value than the control fabric (100% viscose yarn fabric, Sample No:16). By analyzing the response surface equation and contour plots, it can be shown that the maximum OMMC value is achieved at PVA proportion of 15%, with yarn TM of 3.1 and a spindle speed of 10,025 rpm.

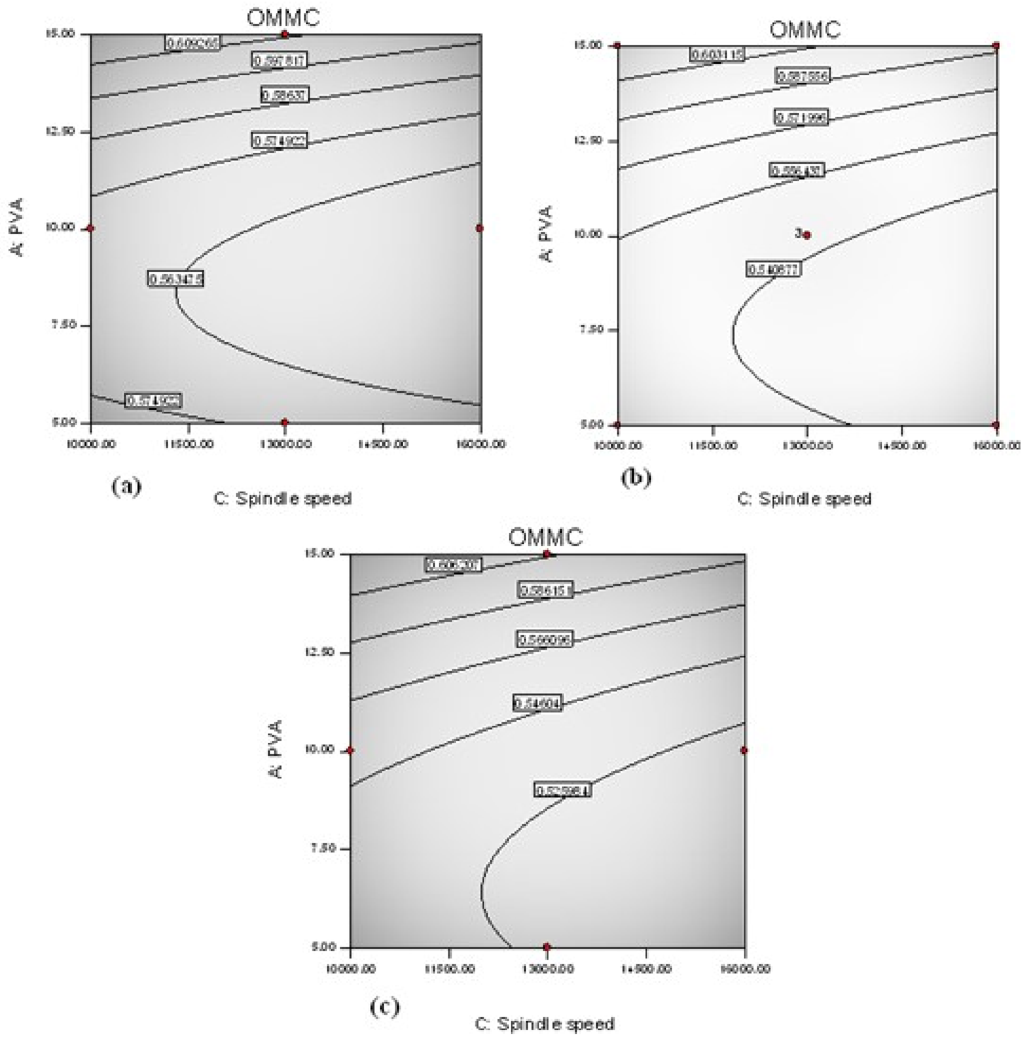

Figure 5 Contour plots of OMMC of fabrics (a) TM=2.7,(b) TM=2.9, (c) TM=3.1

The contour plots of OMMC of the fabrics are shown in Figure 5 (a), (b) and (c). The contour plots of fabric on OMMC value at lower level of yarn twist is shown in Figure 5(a). It is evident from the contour plot that the OMMC value increases with the increase in the PVA proportion due to its higher OWTC and SS_b values. The creation of more micro-pores in the yarn structure after the dissolution of PVA fibres resulted in better transfer/spreading of water particles from one face of the fabric to another side of the fabric through the micro pores in the yarn. Similar findings have been reported by Karthik et al. (2012).Similar trends are noticed in the case of medium and higher level of yarn twist, as showun in Figure 5(b) and 5(c) respectively.The OMMC value decreases with the increase in the spindle speed and yarn TM due to more compact yarn structure.The compact structure of yarn resulted in decrease in one way transport capacity (OWTC) and spreading speed (SS) of the fabric which leads to decrease in OMMC. Air rich yarn and fabric with pores throughout the yarn cross-section have high wettability, quick absorbency and quick dry ability (Pradip Debnath &Swadesh Verma 2012).

IV. OPTIMIZATION AND VALIDATION OF MODEL

The point prediction tool of the design-expert software was used to determine the optimum values of the factors for better fabric comfort properties of micro-pore viscose knitted fabric. Finally, the optimum values of PVA of 6.7%, spindle speed of 12,652 rpm, and TM of 2.7 were determined. The yarn was spun with the above mentioned optimized parameters, and the PVA was dissolved and the knitted fabric was produced to test the comfort properties of the same. The comparison of knitted fabric produced from normal twisted 100% viscose yarn and microporous viscose yarn produced with the optimized process parameters is shown in Table 7.

Table 7 Comparison of predicted and actual fabric comfort properties of microporous viscose yarn obtained with optimized process parameters along with the normal twisted 100% viscose yarn fabric

Fabric caharacteristics	**Normal twisted 100% viscose yarn fabric**	**Micro-pore visocse yarn knitted fabric**	
		Predicted	**Actual**
Air permeabiltiy (cm^3/ cm^2/s)	475	397.6	393.8
Water vapour permeability (g/m^2/day)	552	621.0	618.9
Wicking height (cm)	10.2	11.92	12.29
Thermal conductivty (W/Mk)	0.069	0.047	0.045
OMMC	0.3992	0.597	0.612

From the table, it is observed that there is a better correlation between predicted and actual values of fabric properties. Further, compared to normal twisted 100% viscose yarn fabric, the microporous viscose yarn fabrics have higher water vapour permeability, higher wicking height,lower thermal conductivity, lower air permeability values, lower compressional energy and higher compressional resilience due to the generation of more micro-pores in the yarn structure created by dissolving the PVA from the fabrics.

V. CONCLUSIONS

The present study reveals a significant influence of process variables, namely PVA proportion, yarn TM, and spindle speed on micro-porous viscose yarn knitted fabric properties. In general, the air permeability and thermal conductivity of fabric decreases with the increase in PVA proportion and increases with the increase in spindle speed and yarn TM.Thermal conductivity of fabric decreases with increase in PVA blend proportion due to removal of PVA fibres.This creates more micro-pores in the yarn structure resulting in more entraped air inside the yarn structure.Better packing of fibres with increase in yarn TM and spindle speed results in decrease in inter-fibre spacing in the yarn and increase in inter-loop spacing in the fabric. This leads to increase in thermal conductivity of fabrics

With the increase in PVA content, the size and number of micro-pores within the yarn structure could be higher after disolving it from the yarn. This could lead to diffusion of more water particles in the form of vapour though micro-pores in the yarn strucutre leading to higher water vapour permeability of fabrics.The increase in yarn TM and spindle speed results in more tightly packed fibres in the yarn structure resulting in slower diffusion rate. Hence water vapour permeability of micro-pore ring spun viscose yarn fabric is less with higher spindle speed.

Wickability of fabrics increases with increase in PVA content upto certain level and then decreases at higher PVA%. The initial increase in wickability of knitted fabrics could be due to the creation of micro-pores which resulted in better capillary effect. At higher PVA proportion, the removal of more number of PVA fibres from the yarn structure could have resulted in larger capillary size, which affects the capillary effect of water leading to decrease in wickability of fabrics. The OMMC of knitted fabric increases with the increase in PVA blend proportion and decreases with the increase in spindle speed and yarn TM.

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