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Studies on elastane-cotton core-spun stretch yarns and fabrics: Part III — Comfort characteristics

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Air permeability, thermal characteristics and microclimate conditions of the woven fabrics made of stretchable elastane core-spun yarns have been studied. The weft yarns are spun with different spinning parameters, namely elastane stretch, proportion of elastane core and twist multiplier. A three-variable factorial design technique, proposed by Box &Behnken, is used to investigate the combined interaction effect of the above variables. The effect of these variables on air permeability, thermal resistance, thermal absorbtivity and various microclimate conditions (temperature and relative humidity) with or without air flow has been analyzed. The work has been performed in two stages, non–convective mode and convective mode for examining microclimate behavior of the above fabrics. For the analysis, the contour plots are obtained to examine the interactive effect of all the variables on different fabric characteristics. It has been observed from the experimental results that twist multiplier is the most influencing parameters on air permeability and thermal behavior of the fabrics. The selected levels of the variables do not show marked difference on the microclimate under convective and non-convective modes, and all fabric samples achieve same microclimate conditions after certain period of time.

Keywords: Cotton, Comfort characteristics, Core-spun yarn, Elastane, Microclimate, Permeability, Yarn twist

1 Introduction

In PartI[1] of the series, the characteristics of elastane core-spun yarns and interaction effects with different variables have been discussed, while Part II[2] of this series deals with the low-stress mechanical characteristics of fabrics made of elastane core-spun yarns. The elastane core-spun is a very popular textile product which is being largely used in many fields of application, but there is little literature available about comfort behavior of these materials. The three-variable factorial design technique, proposed by Box & Behnken[3], has been used to investigate the combined interaction effect. The spinning parameters do have a significant influence on the product characteristics including comfort behavior[4,5]. The comfort behavior of any clothing largely affects performance of wearer. It is also known that elastane yarn is widely used as many performance wear. The fabric characteristics which influence clothing comfort include its thermal behavior, moisture vapor interaction, surface characteristics, etc[6-11]. There is no single measurement test for comfort and it also includes non-calculable subjectivity which makes it more complex. Human psychology and response of individual to various circumstances during wear of particular clothing is something very difficult to predict. The subjectivity in the perception of comfort is driven by many physio-psychological features.

The surrounding area of a local atmospheric zone where climate differs is called microclimate[12]. The climate between human skin and clothing is referred as microclimate in clothing system. The temperature and relative humidity in this region influence thermo-physiological comfort of clothing to a great extent. These conditions of relative humidity and temperature depend on various factors such as type of fabric, environmental conditions, physical state of wearer, e.g. rate of sweat generation, body temperature, etc. The air movement around clothing system has a great influence on microclimate[12,13]. The clothing system has been stated as a quasi-physiological system which interacts with the human body. The clothing system has some undesirable functions that hinder natural state of human comfort, e.g. it imparts thermal insulation when one does not require it. Thermal behavior of a fabric is a function of many variables that includes fibre, yarn and fabric characteristics. It is found that different fibres do have different thermal characteristics yet thermal behavior of a textile is largely influenced by other factors. Das and Ishtiaque[4] suggested that the transmission behavior of fabrics made from hollow yarns is entirely different from normal yarns. Yarn bulk also influences comfort characteristics of a textile

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material. The yarns produced on different spinning technologies differ in their comfort characteristics. The material and process parameters affect transmission behavior of textile material[4, 10].

There are some studies which report the dimensional and other related mechanical properties of elastane core-spun yarn fabrics[14-16], but study on comfort or microclimate conditions of woven fabrics made of these yarns are not available in the literature.The basic objective of the present investigation is to study the microclimate conditions of plain woven fabrics made from the elastane cotton core-spun stretch yarns. Also, the interactive effects of some yarn production parameters, like elastane stretch, proportion of elastane content and yarn twist multiplier, on conditions of microclimate without airflow have been studied in detail. The microclimate conditions of these fabrics are greatly influenced by the wind condition. The impact air flow over the outer surface of the fabrics on the microclimate conditions has also been reported.

2 Materials and Methods

2.1 Materials

The same elastane cotton core-spun yarns and fabrics, as reported earlier[1,2], were used in the study. Since proportion of elastane core, elastane stretch and twist level are three important factors which determine the stretch-ability characteristics of elastane-cotton core-spun yarns and comfort characteristics of fabrics made out of these yarns, a three level factorial design proposed by Box & Behnken[3]was used for the study. Elastane cotton core-spun yarns, as explained earlier[1], were used as weft and normal cotton yarns were used in warp to make different fabric samples. The three variables chosen for experimental study were elastane stretch (ES), yarn twist multiplier (TM) and proportion of elastic core (C). The coded levels for all these variables are listed in Table 1. The lists of chosen levels of these variables for the yarn preparation as per the experimental design are presented in Table 2. A set of 15 different fabric samples was prepared using the above set of elastic core-spun yarns in weft. The thread densities i.e. warp/cm and weft/cm were kept constant at 20 and 16 respectively for all the fabric samples.

2.2 Methods

2.2.1 Preconditioning of Fabric Samples

All the fabric samples were washed and dried as per the method reported in Part II[2]. The fabrics were allowed to relax after manufacturing for 24 h under standard laboratory condition (27±2°C and 65±2% RH). Thereafter the samples were washed by mild detergent and finally dried by line drying.

2.2.2 Testing

The comfort characteristics of fabrics are associated with air permeability, thermal transmission characteristics and also the microclimate conditions. The air permeability of fabric samples was tested on the instrument FX3300Texttest Switzerland following BS standards 5639. Thermal characteristics of the samples are being tested on Alambata. Microclimate experiments were performed on an indigenously developed instrument[12,13]. The microclimatic behavior of the fabric was observed in two conditions: under non convective mode and convective mode. This instrument works on the principle of simulating human body and sensing change in relative humidity and temperature. The experiments were customized so as to get the reliable results with repeatability. For the material to be studied, it takes generally above 85 min to reach saturation state hence time is set for 90 min for each experiment in non convective state and for convective mode time has been kept as 40 min. The convective mode is executed by a fan installed on

Table 1—Actual values of process variables corresponding to coded levels

Factor	Level		
	-1	0	1
Elastane stretch (ES), A	1.5	2	2.5
Yarn twist multiplier (TM), B	3.5	4	4.5
Proportion of elastane core %, C	10	15	20

Table 2—Coded value table

Sample number	Elastane stretch (ES)	Twist multiplier (TM)	Core % (C)
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	-1	1
11	0	1	1
12	0	1	-1
13	0	0	0
14	0	0	0
15	0	0	0

machine and its fan air speed is regulated at different pre measured air speed, thereby controlling rate of convection is attained, as reported earlier[12]. The experiments have been carried out in the standard atmospheric condition, so any significant influence due to atmospheric reasons has been ruled out.

After every experiment run, the temperature and humidity were recorded. These results were plotted using *Design Expert software*. The change in the humidity and temperature for every fan speed was also recorded and plotted. The contours plots were also obtained to see the interactive effects of these variables on different comfort properties.

3 Results and Discussion

3.1 Effect on Air Permeability

The air permeability is one of the significant characteristics of fabric. Figure 1 shows the effect of all these variables on the air permeability of the fabrics. It is observed from Figs 1(a) and (c) that air permeability increases with increasing twist multiplier. This may be attributed to the reduction in yarn diameter with the increase in twist and hence the fabric samples are more permeable. Increasing twist in the yarn results in compact yarn with lesser bulkiness, which increases the amount of air flow through the fabrics. At the lower level of elastane stretch, with the increase in core %, air permeability increases initially and later it stabilizes followed by no change in air permeability with the further increase in core % [Fig. 1(b)]. With the increase in elastane core % in the yarn, there is decrease in number of sheath fibres in the yarn cross-section. This finally results in lesser bulkiness of the yarns in the fabric, which makes the fabric more porous for the air passage. On the other hand, at higher elastane stretch, the effect of core % does not show significant effect on the air permeability. This is due to increase in the bulkiness of the yarn with increasing elastane stretch which contradicts the effect of core % and hence nullifies the overall effect.

3.2 Effect on Thermal Charecteristics

Table 3 shows different thermal behavior of the fabrics samples. Figures 2(a) and (b) show the effect of these variables on the thermal behaviour of the fabric samples. Figure 2(a) indicates the reduction in thermal resitance with the increase in twist multiplier. This can be expalined by the facts that the bulkiness of the yarns decreases with increasing twist and the yarns become compact which reduces the entrapement of heat within loose fibres. Hence, there is more amount of heat flow from the fabric sample.

Table 3—Thermal characteristics of the samples

Sample number	Air permeability $m^3/m^2/s$	Thermal resistance m^2K/W	Thermal absorbitivity $WS^{1/2}/m^2K$	Fabric thickness mm
	(A)	*(r)*	*(b)*	*(h)*
1	19.09	68.78	68.44	2.71
2	56.94	46.70	67.22	1.76
3	84	33.36	63.58	1.34
4	54.8	33.00	65.84	1.33
5	22.3	37.45	39.28	1.4
6	42.65	37.93	69.22	1.5
7	47.4	42.06	66.98	1.59
8	30.98	41.57	69.47	1.54
9	19.81	52.22	73.68	2.15
10	27.25	42.36	72.11	1.68
11	18.23	36.30	74.00	1.35
12	61.61	36.81	56.50	1.39
13	55.44	42.36	62.67	1.57
14	55.45	42.30	62.50	1.55
15	55.3	42.07	62.80	1.58

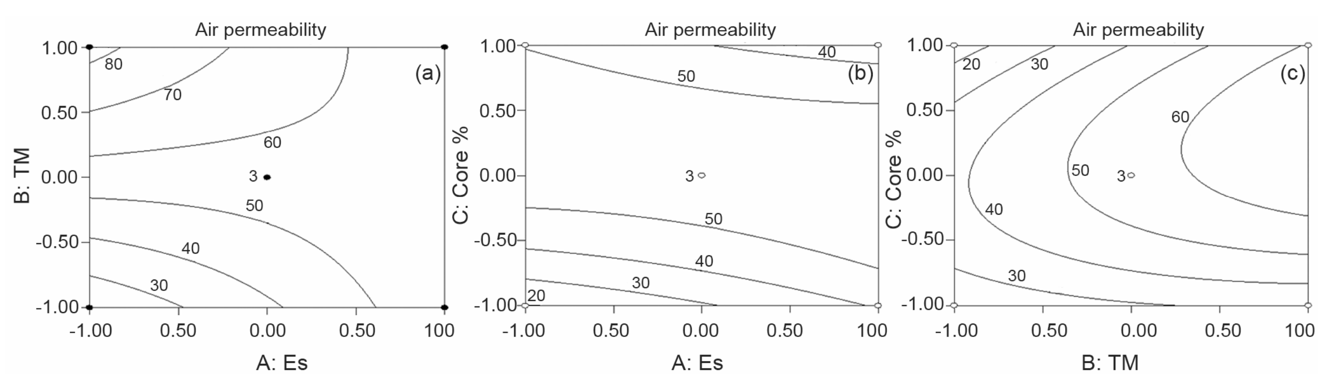

Fig. 1—(a) Effect of twist multiplier and elastane stretch on air permeability, (b) Effect of elastane stretchand core % on air permeability, and (c) Effect of twist multiplier and core % on air permeability

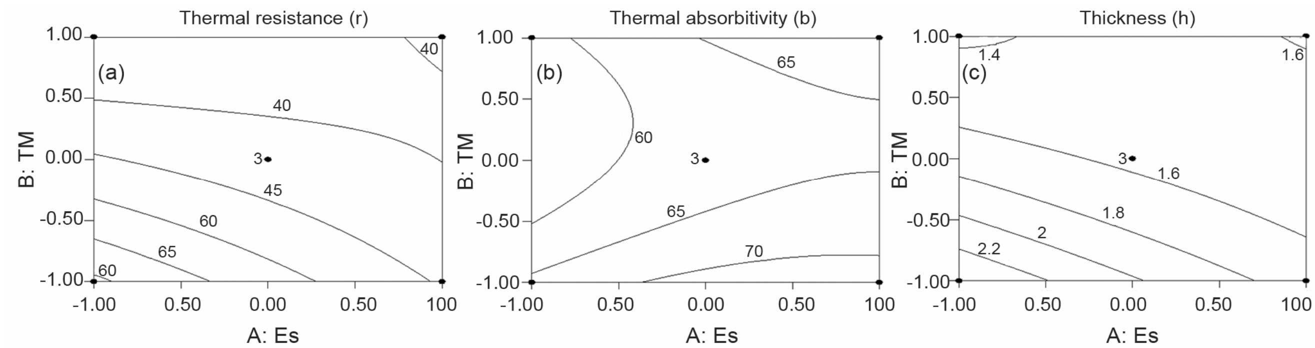

Fig. 2—(a) Effect of twist multiplier and elastane stretch on thermal resistivity, (b) Effect of twist multiplier and elastane stretch on thermal absorbitivity, and (c) Effect of twist multiplier and elastane stretch on fabric thickness

The other reason for the lower theraml resistance of the fabrics at higher twist is due to deacrease in fabric thickness with increasing twist [Fig. 2(c)]. It is a well-known fact that the thermal resistance of a material is directly proportional to its length along which the heat is flowing. So, decreasing thcikness of the fabric with increasing twist results in lower thermal resistance. It is also evident from the Fig.2(a) that the influence of twist multiplier is nullified at higher level of the elastane stretch. This is due to increase in yarn bulkiness in the fabric with increasing elastane stretch which opposes the twist effect on the yarn bulkiness. The effects of these variables do not show noticeable changes on the thermal absorbtivity of the fabric samples [Fig. 2(b)].

3.3 Effect on Microclimate Conditons under Non-covective Mode

The microclimate set-up is heated up to 37° C to mimic the human skin temperature. The heated water vapor from the reservoir passes through the permeable polytetrafluoroethylene (PTFE) coated breathable fabric which is placed between the fabric sample and the water tank[12]. As soon as the test starts, the temperature and relative humidity of microclimate start increasing with time and then finally reach to a saturation level. The initial change in the temperature and humidity of microclimate depend mainly on the transmission characteristics (heat and moisture) of the fabric samples. As the test starts, the rate of heat flow through the breathable fabric (PTFE coated sheet) is very fast as compared to the rate of heat transmitted from the fabric to the duct which results in the initial increase in the temperature of microclimate. The increase in the humidity of the microclimate for the initial phase is also contributed due to change in moisture vapor transmission characteristics of the breathable fabric and test sample. For the above fabric samples, although there is some difference in the initial rate of increase in temperature and humidity of microclimate, the temperature and humidity of microclimate after 90 min are found to be similar (Table 4). The plots of non-convective mode also show that there is not any remarkable influence of process variables on the final microclimate behavior of the samples [Figs 3(a) and (a)]. The above findings suggest that all the fabrics samples are able to achieve nearly same microclimate conditions after certain period of time without air flow in the duct.

Table 4—Microclimate at non-convective mode [time 90 min]

Sample number	Temperature °C	Relative humidity %
1	35.02	68.46
2	34.5	76.04
3	35.43	70.65
4	33.92	84.47
5	34.13	75.82
6	32.73	69.45
7	33.27	71.5
8	34.28	65.59
9	34.48	89.31
10	35.29	69.79
11	36.62	73.11
12	33.22	69.38
13	33.06	72.58
14	33.06	74
15	33.05	72.59

3.4 Effect on Microclimate Conditons under Covective Mode

During convective mode, the fan in the duct of the microclimate simulator starts which results in change in microclimate. This is due to forced convection which causes decrease in the temperature and relative humidity of microclimate. Increasing fan speed from 0.48 m/s to 1.13 m/s in the duct results in more drop

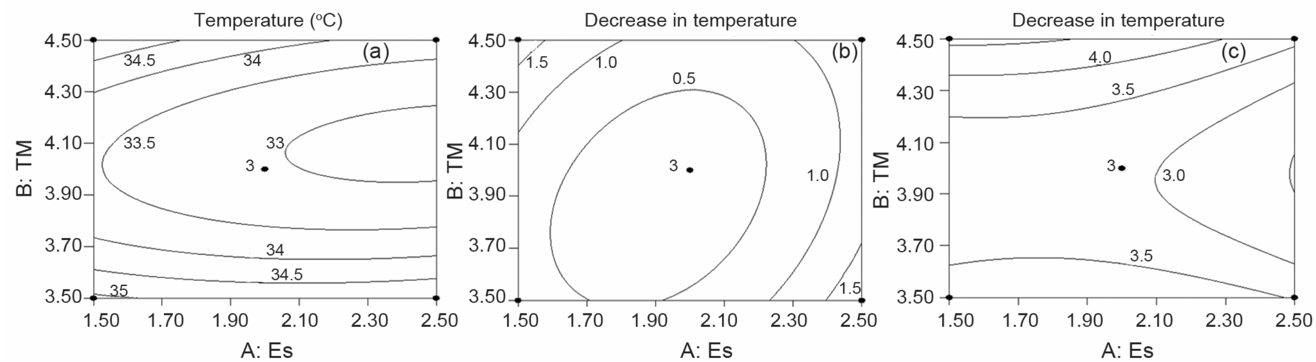

Fig. 3—Effect of twist multiplier and elastane stretch on the temperature of microclimate (a) non-convective mode (time 90 min), (b) convective mode (fan air speed = 0.48m/s), and (c) convective mode (fan air speed = 1.13 m/s)

Table 5—Microclimate at convective mode

Sample number	Microclimate* at 8th min (fan speed 0 m/s)		Microclimate at 40th min (fan speed 0.48m/s)		Decrease in microclimate (fan speed 0.48m/s)		Microclimate* at 8th min (fan speed 0 m/s)		Microclimate at 40th min (fan speed 1.13 m/s)		Decrease in microclimate (fan speed 1.13 m/s)	
	Temp. °C	RH, %	Temp. ° C	RH %	Temp. °C	RH %	Temp. °C	RH %	Temp. °C	RH %	Temp. °C	RH %
1	32.50	76.82	31.945	65.23	0.55	11.59	33.4	78.11	29.94	55.34	3.46	22.77
2	32.81	75.88	31.07	66.56	1.74	9.32	33.77	77.34	30.00	57.20	3.77	20.14
3	32.94	77.34	31.02	65.32	1.92	12.02	32.65	76.03	28.34	57.86	4.31	18.17
4	32.93	76.03	31.29	65.39	1.64	10.64	31.86	76.72	25.82	57.60	6.04	19.12
5	32.82	76.72	31.76	65.19	1.06	11.53	32.09	76.34	30.43	56.61	1.66	19.73
6	32.61	76.34	31.02	65.11	1.59	11.23	31.7	77.19	31.93	56.00	1.77	21.19
7	32.36	77.19	31.52	65.28	0.84	11.91	33.02	76.91	28.23	56.63	4.79	20.28
8	32.41	76.91	31.39	65.41	1.02	11.5	31.95	76.79	29.12	55.67	2.83	21.12
9	32.25	76.79	31.45	64.89	0.80	11.9	32.77	76.77	29.54	57.43	3.23	19.34
10	32.20	76.77	31.33	65.19	0.87	11.58	32.81	77.02	28.69	57.00	4.12	20.02
11	32.04	77.02	31.1	65.23	0.94	11.79	33.18	78.02	29.09	56.76	4.09	21.26
12	31.92	78.42	31.34	65.19	0.58	13.23	32.69	77.19	28.78	56.04	3.91	21.15
13	31.72	77.15	31.08	65.59	0.64	11.56	33.23	75.44	29.11	56.33	4.12	19.11
14	31.68	77.32	31.6	65.98	0.08	11.34	32.19	76.12	30.23	56.65	1.96	19.47
15	31.54	77.52	31.44	64.99	0.10	12.53	32.54	75.34	29.36	56.51	3.18	18.83

*The microclimate parameters at 8th min were recorded in different time.

of temperature and relative humidity for each fabric sample (Table 5). This is due to increase in more forced convection because of the air flow in the duct. Figures 3-5 show the contour plot for the effect of different variables on microclimate under convective mode. It is evident from the figures that the microclimate (temperature and humidity) changes are too less for all the fabric samples after 40 min under convective mode for every set rate of convection. The decrease in temperature of microclimate is found to be independent of twist multiplier [Figs 3(b), 3(c) and 5(b)]. Other two variables, i.e. core % and elastane stretch, also show similar results and no significant change in microclimate temperature is obtained for all fabric samples. The results are similar to the non-convective mode and all the above fabric samples provide nearly same microclimate temperature after certain time under convective mode. For the change in relative humidity, it has been found that with changing elastane stretch, slightly lesser drop in relative humidity of microclimate is obtained for constant twist multiplier [Fig. 3(b)]. It is due to the higher bulkiness of the fabric at higher elastane stretch which reduces the moisture vapor transport from the fabrics. However, other two variables do not show significant results on the relative humidity under convective mode. Although, the values of microclimate are found to be different at different

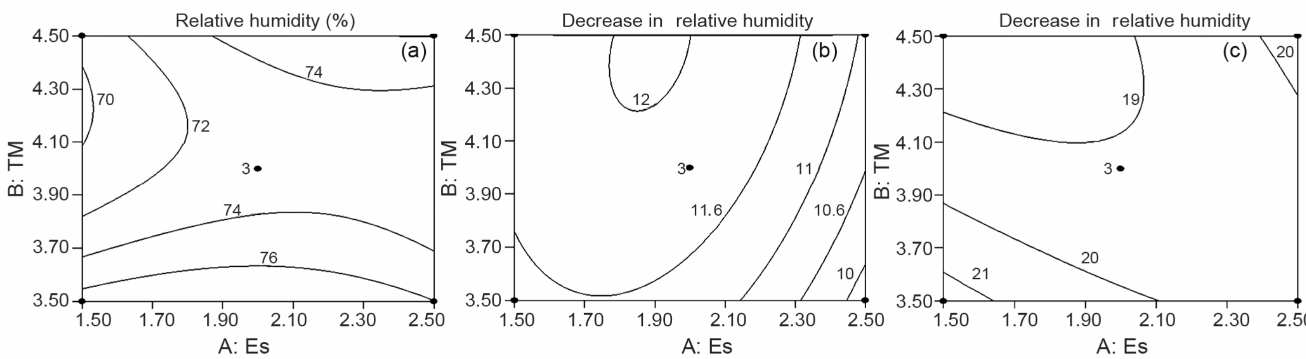

Fig. 4—Effect of twist multiplier and elastane stretch on the relative humidity of microclimate (a) non-convective mode (time 90 min), (b) convective mode (fan air speed = 0.48m/s), and (c) convective mode (fan air speed = 1.13 m/s)

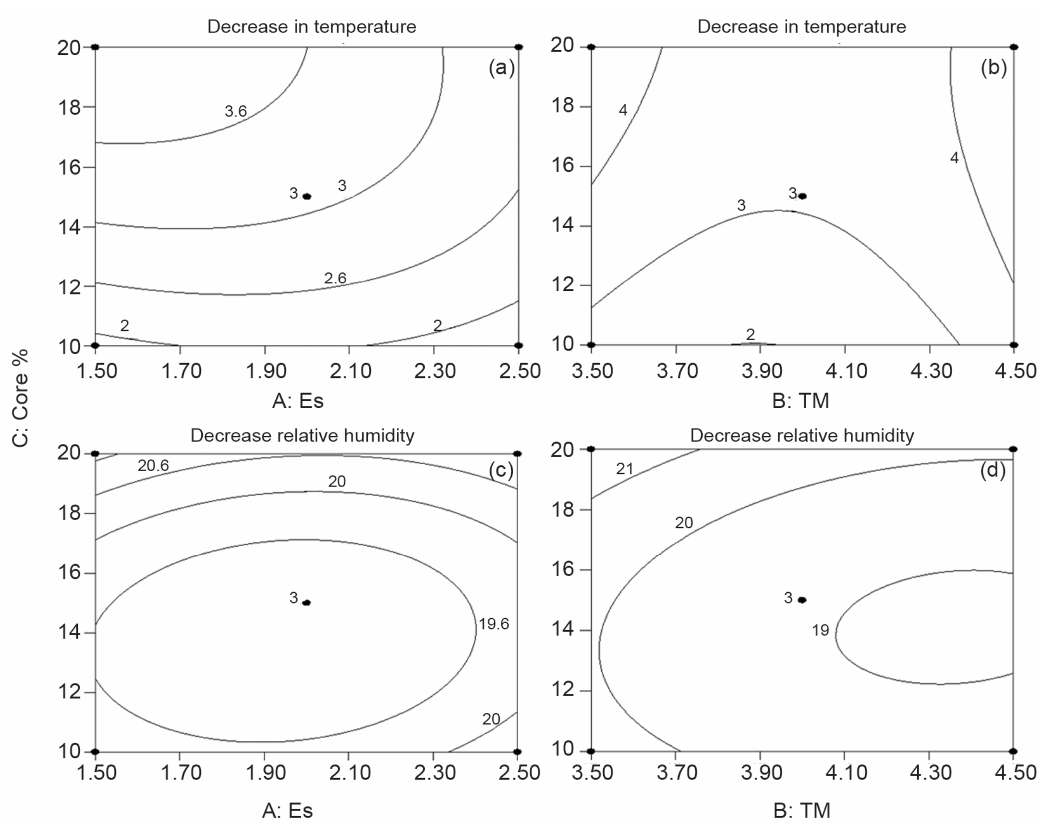

Fig. 5—Microclimate conditions under convective mode fan air speed = 1.13 m/s), (a) Effect of core % and elastane on decrease in temperature, (b) Effect of core % and twist multiplieron decrease in temperature, (c) Effect of core % and elastaneon decrease in relative humidity, and (d) Effect of core % and twist multiplier on decrease in relative humidity

levels, the change in these values is narrow or small, which indicates the lesser influence of these variables on microclimate under convective mode.

4 Conclusion

The experimental results indicate that the twist multiplier is the most influencing parameter affecting air permeability and thermal behavior. The air permeability increases with the increase in the twist multiplier while thermal resistance and fabric thickness are found to reduce with the increase in the twist multiplier. This may be assigned due to the reduction in the yarn diameter with the increase in twist. However, there is not much remarkable influence of other two factors on the thermal properties of the fabrics. Microclimate testing of the fabric samples indicates that these variable does not significantly affect the microclimate under both convective and non-convective modes. The change in microclimate is found to be narrow between the chosen levels of the variables.

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