On Thermal Conductivity of Some Fabrics

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Synopsis

The apparent density and the thermal conductivity of some samples of different wool/terylene blends were measured. It was shown that by increasing the terylene percentage, both the apparent density and the overall thermal conductivity increase to a maximum, and then decrease again. The blend consisting of 50% wool and 50% terylene has the maximum values of both thermal conductivity and apparent density.

INTRODUCTION

The use of synthetic fibers in blends with wool produces fabrics with modified properties. Moreover, the productivity of spinning and weaving machines increases, due to the improvement of spinning and weaving conditions, as a result of the relatively high tenacity of chemical fibers. Blending makes it possible to use old and lower grades of wool. Although the relationship between different properties of blends of fabrics and the composition of these blends has been studied, the relation between apparent density, the thermal conductivity, and the percentage composition of wool/terylene blends have not been fully studied. The objective of this work was to determine the relationship between chemical composition of fabric blends and the thermal conductivity.

Textile materials are not homogeneous. When a temperature potential is developed across such a material, normal to its surface, heat is transferred by conduction through the solid fibers as well as by combination of conduction, convection, and radiation through the interstitial gas. The thermal conductivity, determined by measuring temperature potentials, thickness, and heat flux, is therefore only an effective thermal conductivity, describing the effect of combined process of energy transfer.

It has been shown that the thermal conductivity of high density fibrils of oriented polymer is affected by the air gaps content.[1] Also the thermal conductivity of low density textile fabrics, corresponding to an air space volume of about 90%, is practically independent of the component fiber.[2] The conductivity increases with the bulk density, depending on the type of fibre used, a result that has been explored to determine the thermal conductivity of natural fibre.

The thermal conductivity of a textile material as a fiber–air mixture is given by the following equation[3]:

$$K = x(v_f K_f + v_a K_a) + y\left(\frac{K_f K_a}{v_a K_f + v_f K_a}\right) \qquad (1)$$

Journal of Applied Polymer Science, Vol. 30, 2343–2350 (1985)
 CCC 0021-8995/85/062343-08$04.00

where K is the thermal conductivity of a textile material, v_f and v_a are the volume fractions of fiber and air, respectively, and k_f and K_a are the thermal conductivities of the solid fiber and air, respectively. The first term of eq. (1) describes an ideal model of a fabric construction whose fibers are totally parallel to the flow of heat, while the second term describes an ideal model of a fabric construction whose fibers are totally in series to the flow of heat.

The simple apparatus used for the determination of the thermal conductivity of fibers and textiles at varying densities was similar to those reported previously.[4,5] The thermal conductivity was determined by comparison with the conductivity of a sample of an incompressible standard material, e.g., a solid plastic disc.

The thermal conductivity of a selected variety of Egyptian cotton textiles was measured for samples of different fiber lengths and different fabric structures. The measurements showed obvious variation of the thermal conductivity of fabric with the length of fiber. A correlation between the thermal conductivity of the fabric and the fiber, the yarn and the fabric has been reported previously.[6]

EXPERIMENTAL RESULTS AND DISCUSSION

The thermal conductivity measurements were done at steady state conditions. The samples were fabricated by Misr Spinning and Weaving Co. at Mehalla El-Kobra, Egypt. The samples were manufactured from wool and terylene with different percentage compositions.

The fabric specifications were:

Picks/in.	42
Ends/in.	40
Warp count	36/2 metric
Weft count	36/2 metric
Weave design	Plane weave 1/1

The experimental data are shown in Table I and Figures 1–6.

A single phase fabric is considered as a two-phase system: the air of lower thermal conductivity and the solid fiber of much higher thermal conductivity. It is well known that both the volumetric proportions and the fibre configuration inside the system affect the thermal conductivity of the fabric. However, the fabric in the present work may be considered as a three-phase system: two solid phases (two different kinds of fiber) and the gas phase (air). The contribution of the volumetric proportion of each phase to the thermal conductivity was expected to be quite different from those in the two-phase system. The experimental results supported this proposal.

Figure 1 shows the relation between the apparent thermal conductivity vs. the percentage composition of the blended wool/terylene fabrics. The apparent thermal conductivity is minimum for the sample composed of 100% wool; then it increases with increasing the percentage of terylene to a maximum value at blend composition 50:50. On increasing the terylene percentage, the apparent thermal conductivity decreases to another minimum value corresponding to 100% terylene. However, this minimum value is still higher than that corresponding to 100% wool. This behavior may be attributed to the change of the spacing between fibers resulting from

TABLE I

Effect of the Composition of Wool/Terylene Blends on the Apparent Thermal Conductivity (K) and on the Apparent Density (ρ)

Blend (wool %)	Percentage (Terylene %)	Weight ($kg \cdot m^{-2}$)	Thickness $t \times 10^3$ (m)	No. of protruding fibers ($in.^{-1}$)	ρ ($kg \cdot m^{-3}$)	K ($J \cdot m^{-1} \cdot h^{-1} \cdot deg^{-1}$)	K/ρ ($J \cdot h^{-1} \cdot deg^{-1} \cdot kg^{-1} \cdot m^2$)	$\rho/t \times 10^{-5}$ ($kg \cdot m^{-4}$)
100	0	0.206	0.584	79	353	869.89	2.46	6.04
75	25	0.194	0.508	50	382	948.15	2.48	7.52
50	50	0.220	0.508	41	433	1014.37	2.34	8.52
25	75	0.201	0.483	44	416	922.57	2.22	8.61
0	100	0.205	0.470	59	436	912.03	2.09	9.28

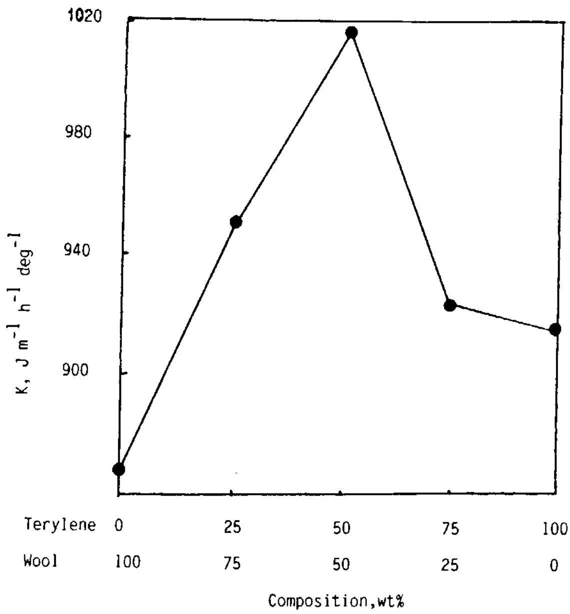

Fig. 1. Relation between wool/terylene blend composition and apparent thermal conductivity.

blending the different fibers together. This in turn changes the quantity of air kept interstitially between the fibers. When the percentage of terylene increases, the apparent thermal conductivity of the fabric blend increases, due to the decrease in the quantity of air present between the fibers, showing that the terylene fibers fill the gaps between the wool fibers. These gaps are present as a result of the presence of crimp in the wool fibers. There is a critical composition of the blend of fibers, above which a reverse be-

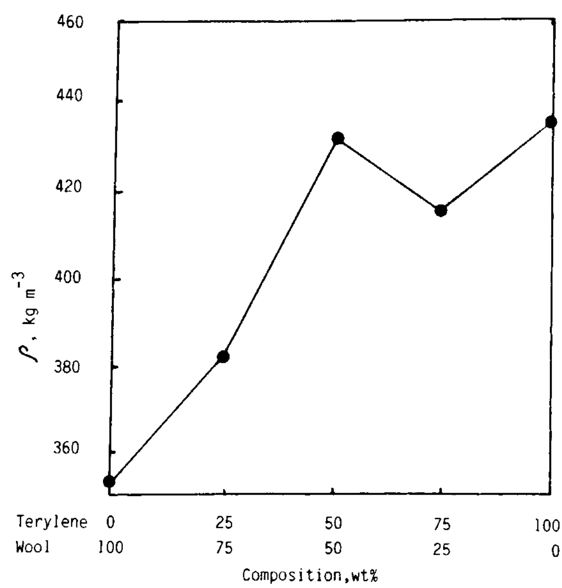

Fig. 2. Effect of wool/terylene blend composition on the apparent density.

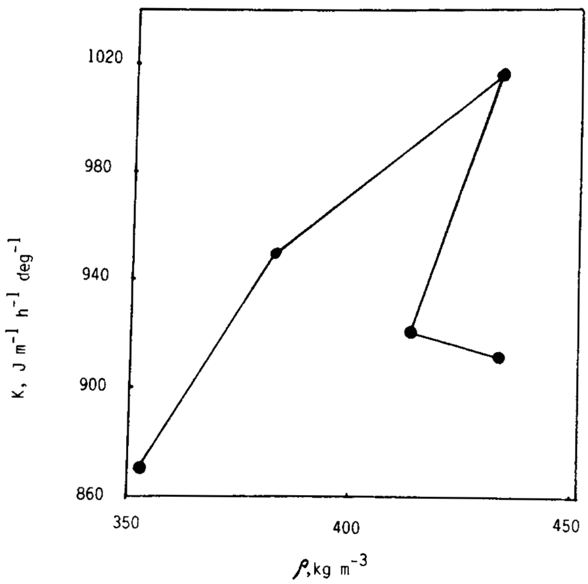

Fig. 3. Correlation between apparent thermal conductivity and apparent density.

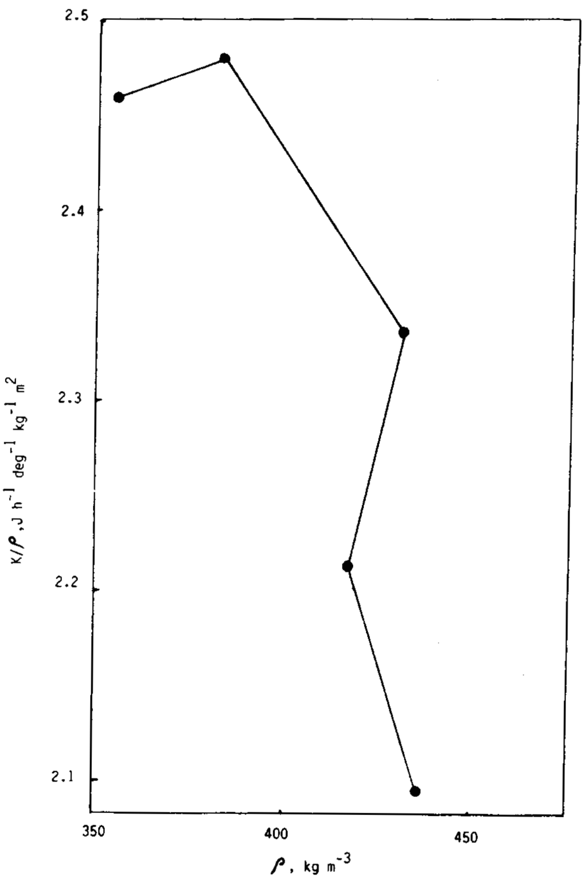

Fig. 4. K/ρ ratio vs. for wool/terylene blends.

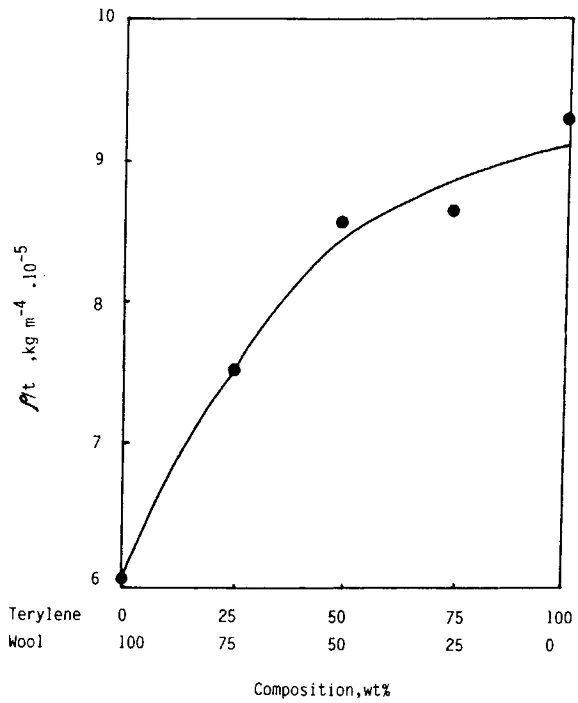

Fig. 5. ρ/t vs. wool/terylene blend composition.

havior occurs and the apparent thermal conductivity decreases. It is quite possible that above this critical composition, the increase of the percentage of terylene increases the spacing between the crimped wool fibers. The apparent density variation of wool/terylene blend vs. the percentage composition is shown in Figure 2. The apparent density of the wool/terylene blend increases to a maximum value at 50:50 blend and then decreases to a minimum at 75% terylene.

This behavior is in agreement with the results summarized in Figures 3 and 4, which show the relation between apparent density and apparent thermal conductivity and the ratio of apparent thermal conductivity to the apparent density. Figure 3 shows that above the critical composition the apparent thermal conductivity becomes very sensitive to change in the apparent density. Thus the apparent thermal conductivity decreases considerably with a slight decrease of the apparent density. The apparent thermal conductivity, lower than the critical value, increases with the apparent density, i.e., with decreasing the volume of a constant weight which corresponds to a decrease in the quantity of air present interstitially between the fibers. Figure 4 shows a maximum in K/ρ ratio at certain critical apparent density value.

Figure 5 shows the relation between ρ/t and the composition of the fabric blend, where t is the sample thickness. Starting from 100% wool and with increasing the percentage of terylene, ρ/t increases at a higher rate till the critical composition (50:50 wool/terylene), after which ρ/t increases with relatively small rate. The ratio of apparent thermal conductivity to the

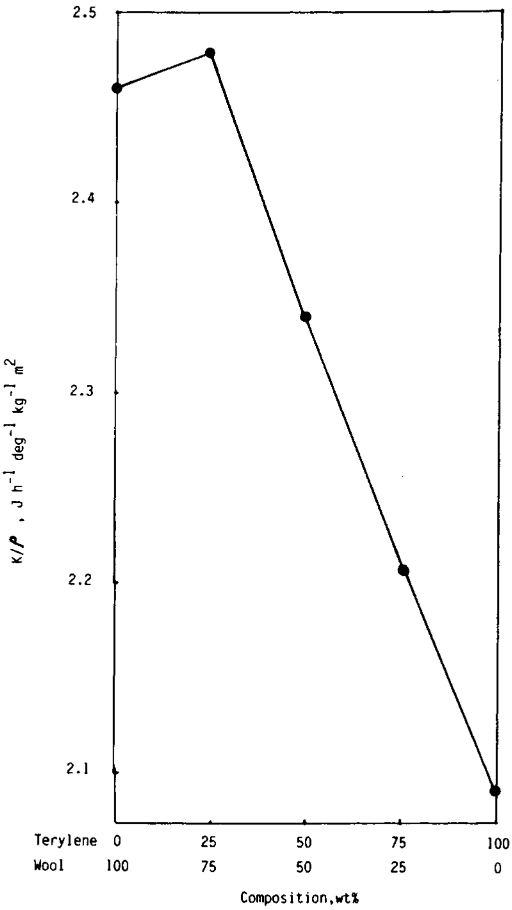

Fig. 6. Influence of wool/terylene blend composition on K/ρ ratio.

apparent density increased slightly, and then displays a fast drop to a minimum at 100% terylene, as shown in Figure 6.

The critical composition of the blend produces fabrics having minimum yarn permanent waving by crossing, where it is clearly shown from Table I that fabric of 100% wool has the maximum number of protruding fibers, since 1 in. contains 79 protruding fibers. This number decreases with increasing percentages of terylene fiber till reaching the critical composition, and then increases again. The minimum permanent waving by crossing at 50/50 blend may indicate that the yarn is more uniform at this ratio. Any change in this ratio causes a change in the yarn uniformity, which in turn causes a change in the number of protruding fibers, which is probably due to the combined action of tenacity, elasticity, and fiber migration of the two blend components (wool and terylene).

The physical properties of fibers may be related to the crystalline/amorphous nature of the fiber materials beside the chemical nature of the molecules. The thermal characteristics and morphology of fiber systems and crystallization kinetics of blends are generally interrelated.[7] However, melting point lowering may occur for morphological reasons as well as chemical potential variation of the polymer fiber.[8] The heat conduction of high density polyethylene fibrils had a maximum around 3% of the air gap contents; such a behavior of the heat conduction is not fully understood, as the authors reported.[1]

In conclusion, fiber blends of wool and terylene are to be considered as three-phase systems (wool, terylene, and air). The measurements of apparent thermal conductivity and density of the blend are useful for evaluation of fiber fabric characteristics.

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Received November 18, 1983
Accepted September 12, 1984