ENGINEERING DESIGN OF THE THERMAL PROPERTIES IN SMART AND ADAPTIVE KNITTING STRUCTURES

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Abstract:

This work reports on research being carried out in thermal comfort in smart and adaptive knitting structures (functional structures).
The total comfort of a garment comprises not only the sensorial, thermal and physiological component, but also aesthetic, colour and size aspects, which make up the so-called psychological comfort. It should be noted that when buying a piece of clothing for daily wear, the psychological point of view may well play an important role. Nevertheless it is the thermal and physiological components which have historically been the primary functional component of clothes, since they must protect us from cold and heat and, simultaneously, have to allow an appropriate moisture and heat transfer through the different layers.
Thermal comfort is characterised by three important properties:

- *Thermal resistance;*
- *Thermal conductivity;*
- *Thermal absorptivity.*

In this research we present the engineering design of these principal thermal properties in functional structures and we propose three new equations that simulate the reality of the behaviour of this knitting structures.

Keywords:

Textile materials, thermal comfort, functional structures, mathematical model, heat transfer

1. Introduction

This work is intended to contribute to the improvement of thermal comfort in functional knitted fabrics and consequently an increase in the utility value of clothes made with these kinds of knitted fabrics.

In the last decade much attention has been paid to this area of exploration, justifying the need for the current research work. The desire to feel well inside the garments that we wear is becoming a more and more important aesthetic and social matter (Yi Li, 1994).

In an effort to attain and maximize comfort, especially in sports and protective clothing, knitted textile structures have been developed, designed by “functional knitted structures”.

And what is a “functional knitted structure”?

The main characteristics of a functional knitted structure are concerned with the existence of two different fabric layers based on different textile components (the separation layer with a hydrophobic textile material, and the absorption layer with an hydrophilic textile material). The separation layer will be the inside layer of the fabric (in contact with the skin) and the absorption layer will be the outside layer, as illustrated in Figure 1 below (Geraldes, 2000).

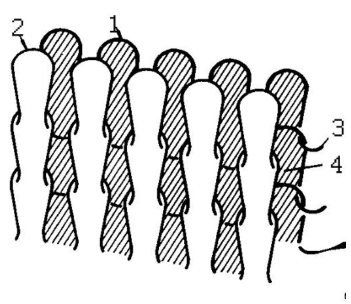
Indeed comfort is one of the major aspects to be considered when buying and wearing a specific piece of clothing.

Based on the results achieved by various researchers (Li and Holcombe, 1992; Hollies, 1997; Umbach and Mecheels, 1997), the following equation for the total comfort was derived:

$$K_{total} = \frac{1}{3} K_{sensorial} + \frac{2}{3} K_{thermophysio\log ical}$$

where,

K_{total} = Total comfort;
$K_{sensorial}$ = Sensorial comfort;
$K_{thermophysiological}$ = Thermophysiological Comfort.



Legend:
1 – hydrophobic layer;
2 – hydrophilic layer;
3 – polypropylene yarn
4 – cotton yarn.

Figure 1. Schematic representation of a functional knitted fabric

It is possible to define thermophysiological comfort in both the static and dynamic state. Thus the thermophysiological comfort for a non-active permanent state is defined when the average temperature of the skin is between 31,5°C and 32,5°C and the relative humidity of the air close the skin surface is not higher there 60% (Hes, 1987).

Dynamic thermophysiological comfort" is defined as a situation in permanent work conditions when the relative humanity of the air near the skin does not surpass 70% and average temperature is between 35,5°C and 34,5°C (Hes, 1987).

Thermophysiological comfort is characterised by two important concepts:

- Mass transfer;
- Heat transfer.

We focus on heat transfer with the aim of evaluating, controlling and optimizing, using appropriate values, the three principal thermal properties: thermal resistance, thermal conductivity and thermal absorptivity. In order to do this we have studied the relations between those thermal properties and the composition structure, the number of suction channels presents in the structures, and the drying time (Geraldes 2000).

After that, a mathematical model of these thermal properties has been developed, considering the functional structures in the wet state, since simulates the knitting structure during wear. To validate this model, a study between the experimental and theoretical results of thermal properties has been done and some conclusions have been achieved (Geraldes, 2000).

2. Thermal Properties and Composition Structure Correlations

The following results have been attained in analysis of the principal thermal properties and the structure composition (Geraldes, 2000):

A. Thermal absorptivity

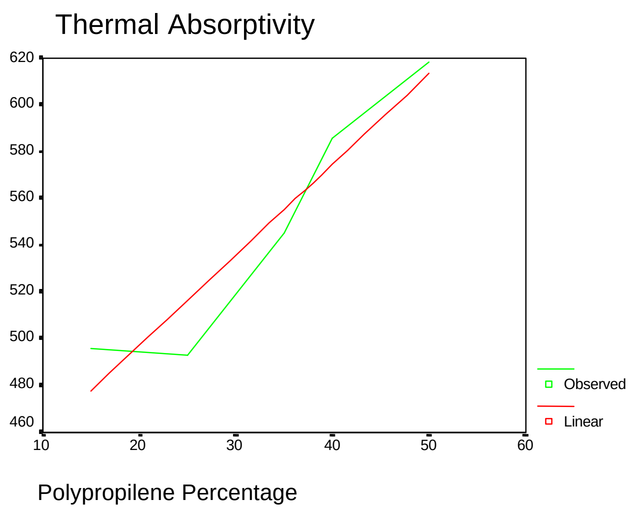


Figure 2. Variation of thermal absorptivity with different percentages of PP

The plot of results in Figure 2 below shows a linear relation between thermal absorptivity and the percentage of the hydrophobic component (polypropylene) present in the structure.

B. Thermal resistance

The analysis of thermal resistance has revealed a strong linear relationship with the percentage of the hydrophobic component in the functional knit structure, as can be seen in Figure 3 below.

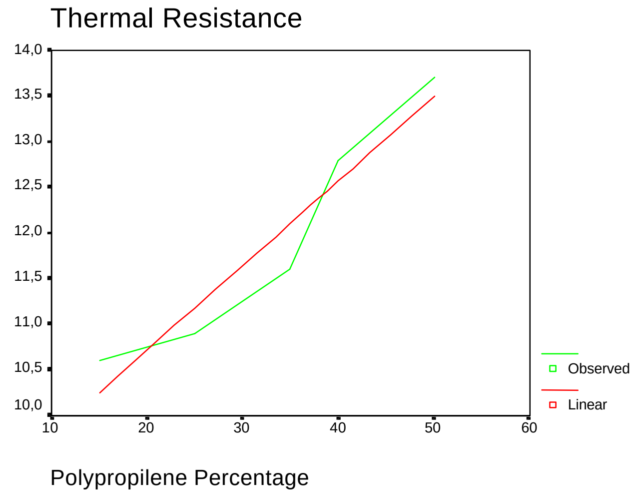


Figure 3. Variation of thermal resistance with different percentages of PP in the fabric

3. Correlation between Thermal Properties and Optimized Functional Structure (nº. of suction channels)

The following results have been obtained from analysis of the principal thermal properties and the number of suction channels present in structures (Geraldes, 2000):

A. Thermal absorptivity

The relation between thermal absorptivity and the number of suction channels has proved to be quadratic, as shown in Figure 4 below.

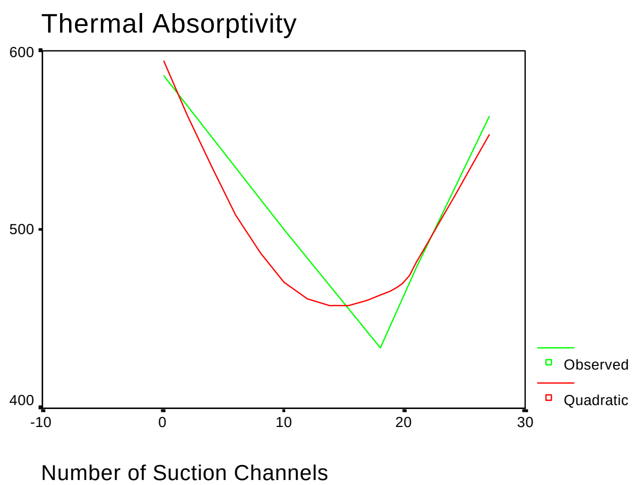


Figure 4. Variation of thermal absorptivity in relation to the number of suction channels

B. Thermal resistance

The number of suction channels has a quadratic relationship with thermal resistance, as shown in Figure 5 below.

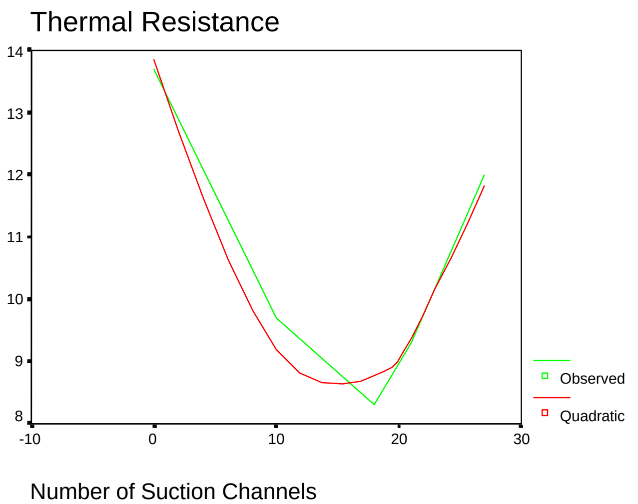


Figure 5. Variation of thermal resistance in relation to the number of suction channels

4. Thermal Properties and Drying Time Correlations

Figures 6 and 7 show the relationship between the principal thermal properties and the drying time (Geraldes, 2000):

A. Thermal absorptivity

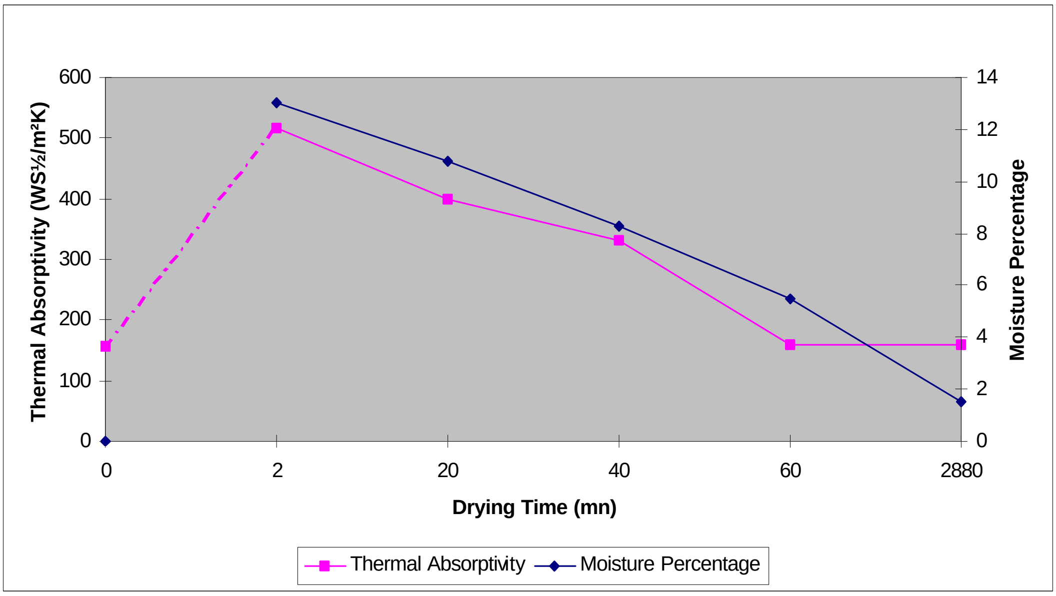


Figure 6. Thermo absorptivity versus drying time and moisture percentage in the sample

B. Thermal resistance

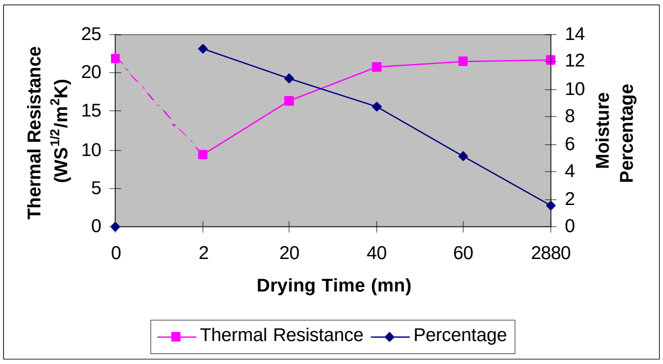


Figure 7. Thermo resistance versus drying time and moisture percentage in the sample

5. Mathematical Modelization of Thermal Properties in the Wet State (2)

The development of this model was done based on some theoretical suppositions, such as:

- The knit structure is in the wet state and is completely saturated (which is not completely true);
- Only the static state is taken into consideration, because in the dynamic state we encounter the influence a number of parameters, such as contact pression;
- In the static state, all the conditions are well defined and we intend to determine a relation between the principal thermal properties.

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- In the static state, all the conditions are well defined and we intend to determine a relation between the principal thermal properties.

The following relations have been found (Geraldes, 2000):

1) Thermal Conductivity

$$l_T = \frac{h_T}{R_{abs} + R_{sep}}$$

where:

l_T : Total thermal conductivity;
h_T : Total thickness;

R_{abs} : Thermal resistance of the absorption layer;
R_{sep} : Thermal resistance of the separation layer.

2) Thermal Absorptivity

$$b_W = \sqrt{\lambda_W \left[\frac{b^2}{\lambda} + m\frac{b^2}{\lambda} + 4200\,\rho m(1+m) \right]}$$

where:

- b_W : Thermal absorptivity in the wet state;
- l_W : Thermal conductivity in the wet state;
- b : Thermal absorptivity in the dry state;
- l : Thermal conductivity in the dry state;
- m : Water weight in the structure (wet state);
- r : Density of the structure in the dry state;
- $r(1+m)$: Density of the structure in the wet state.

3) Thermal Resistance

$$R_T = \frac{R_{co}\, x\, R_{H_2O}}{R_{co} + R_{H_2O}} + \frac{h_{sep}}{\lambda_{pp}\, x \frac{p}{100} + \lambda_{abs}\left(1 - \frac{b}{100}\right)}$$

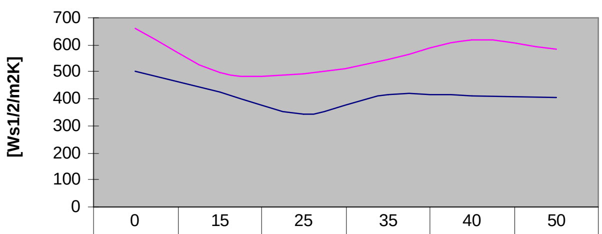
where:

- R_T : Total thermal resistance;
- R_{co} : Cotton thermal resistance;
- R_{H_2O} : Water thermal resistance;
- h_{sep} : Thickness of the separation layer;
- l_{pp} : Polypropylene thermal conductivity;
- l_{abs} : Thermal conductivity of the absorption layer.

6. Comparison between the experimental and theoretical values of the thermal properties

Through a comparative study between the experimental and theoretical results, the following graphs have been compiled (Geraldes, 2000):

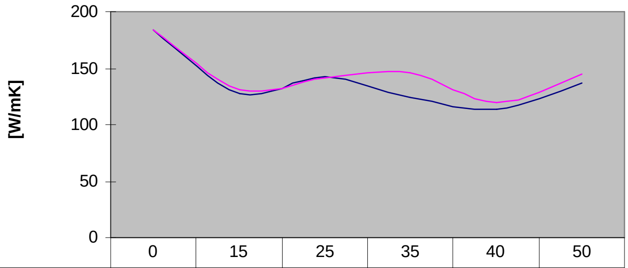
A. Thermal absorptivity



	0	15	25	35	40	50
Theoretical Absorptivity	501,4	424	343,9	415,8	409,4	407
Experimental Absorptivity	662	496	493	545	618	586

Figure 8. Comparison between the theoretical and experimental absorptivity values versus PP percentage

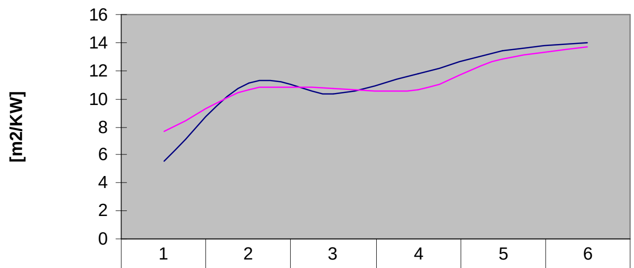
B. Thermal conductivity



	0	15	25	35	40	50
Theoretical Conductivity	184	127,4	142,7	124,6	113,7	136,4
Experimental Conductivity	184	131	141	146	119	145

Figure 9. Comparison between the theoretical and experimental conductivity values versus PP percentage

C. Thermal resistance



	1	2	3	4	5	6
Theoretical Resistance	5,6	11,1	10,3	11,8	13,4	14
Experimental Resistance	7,7	10,6	10,7	10,6	12,8	13,7

Figure 10. Comparison between the theoretical and experimental resistance values versus PP percentage

Indeed Figures 8, 9 and 10 make it possible to conclude that these three new equations for the thermal properties realistically simulate the behaviour of the examined properties.

7. Conclusions

It is possible to achieve maximum comfort by developing products with innovative thermo-physiological properties, particularly leisure garments, sportswear and protective clothing.

The study of the variation of thermo-physical properties in relation to some of the technical characteristics used to design these products leads to the following conclusions:

1. The percentage of the hydrophobic component is crucial to the behaviour of the functional knit.

2. The linear density of the yarn used in knitted fabric doesn't appear to be a critical factor.

3. The number of suction channels significantly affects the thermo-physiological comfort achieved with this type of product.

4. A comparative study carried out to validate the model proved that the theoretical and experimental results are very similar. Thus it is possible to conclude that this model has a very high scientific precision.

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