THE EFFECT OF INDUSTRIAL WASHING ON THERMAL COMFORT PARAMETERS OF DENIM FABRICS

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Abstract
Denim fabric is widely used to make apparels. In most of the cases apparels made by denim fabric are given faded look and special hand feel. For this purpose, denim apparels are processed in industrial apparel washing machines. Different textile auxiliaries are applied to achieve required results. It is quite understandable that this process, commonly denoted as industrial washing, creates certain physical and chemical changes in denim fabric. This study investigates the effect of industrial washing on thermal parameters of the denim fabric. The change in thermal properties leads towards the change in over all comfort of apparels made by denim fabric, which includes thermo-physiological and sensorial changes. Study finds that effect of industrial washing is significant and noticeable. However, its intensity varies and depends upon the process adopted during industrial washing. Results of this piece of work provide guidance to denim apparel manufacturers in selecting the industrial washing process keeping in view the wearer's preferences.
Key words: denim apparel, industrial washing, thermal conductivity, thermal resistance, thermal absorbtivity.

1. Introduction

Unlike other fabrics, denim clothing passes the industrial washing process before handing over to end users. There are two prime objectives of this washing:

* to get a desired hue, brightness and value of color (generally called fading process),
* to achieve desired hand feel and specific properties (surface smoothness, water repellency, antibacterial properties etc).

Industrial washing involves two main steps. In the first step, all sizes applied before weaving are removed and faded look is achieved with the help of bleaching agents, enzymes, pumice stone etc. In second stage, we apply certain textile auxiliaries to impart specific properties (softeners, water proofing agents etc). It is obvious that these changes will affect the thermal properties of the denim fabric. This study aims at determination of the effect of different industrial washings on thermal conductivity, thermal absorptivity and thermal resistance of the treated denim fabrics.

2. Research Description

Clothing made of denim fabric are subject to different finishing chemicals to achieve certain qualities and to offer a faded look, which enhances their appearance. It is an understood fact that such processes can alter thermal comfort parameters, which are crucial in overall comfort for end users[1] . There is a need to find out threshold where one can have better hand feel, attractive look and required comfort during wearing.

2.1. Thermal Comfort Parameters and Their Testing

Thermal properties of textiles such as thermal resistance, thermal conductivity and thermal absorbtivity are influenced by fabric properties such as structure, density, humidity, material and properties of fibres, type of weave, surface treatment, filling and compressibility, surrounding temperature and other factors [2]. The apparatus used in this study for testing thermal comfort properties of denim fabrics was the commercial ALAMBETA instrument manufactured by the Czech company SENSORA and it measures all the above mentioned parameters plus thickness [3]. This instrument basicaly simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22°C) and measuring head (32°C). When the specimen is inserted, the measuring head drops down, touches the fabrics and the heat flow levels are processed in the computer and thermo-physical properties of the measured specimen are evaluated [4]. The measurement lasts several minutes only. The simple descrition of the tested parameters follows.

Thermal conductivity coefficient **λ** presents the amount of heat, which passes from 1 m^2 area of material through the distance 1 m within 1 s and create the temperature difference 1 K. The highest thermal conductivity exhibit metals, whereas polymers have low thermal conductivity, ranging from 0,2 to 0,4 W/m.K. Thermal conductivity of textile structures generally reaches levels from 0,033 to 0,01 W/m.K. Thermal conductivity of steady air by 20°C is 0,026 W/m. Thermal conductivity of water is 0,6 W/m.K, which is 25times more. That is why the water presence in textile materials is undesirable.

Thermal resistance R [m^2K/W] then depends on fabric thickness **h** and thermal conductivity **λ**:

$$\mathbf{R = h/\lambda} \qquad (1)$$

Thermal absorbtivity **b** of fabrics was introduced in 1987 by Hes [3] to characterise thermal feeling (heat flow level) during short contact of human skin with the fabric surface. Providing that the time of heat contact τ between the human skin and the textile is shorter then several seconds, the measured fabric can be simplified into semi-infinite homogenous mass with certain thermal capacity **ρc** [J/m^3] and initial temperature t_2. Unsteady temperature field between the human skin (with constant temperature t_1) and fabric with respect to of boundary conditions offers a relationship, which enables to determine the **heat flow q** [W/m^2] course passing through the fabric:

$$\mathbf{q = b\,(t_1 - t_2) / (\pi\tau)^{1/2}, \qquad b = (\lambda\rho c)^{1/2}} \qquad (2)$$

where **ρc** [J/m^3] is thermal capacity of the fabric and the term **b** presents thermal absorbtivity of fabrics. The higher is thermal absorbtivity of the fabric, the cooler is its feeling. In the textile praxis this parameter ranges from 20 $Ws^{1/2}/m^2K$ for fine nonwoven webs to 600 $Ws^{1/2}/m^2K$ for heavy wet fabrics.

2.2. Types of Finishing Processes

Clothing made of denim fabric is often subject to industrial laundering, also called industrial washing. In this process chemicals are used to remove sizing agent and other impurities and apply chemicals to achieve certain qualities. During this process irreversible changes in the fabric occur. It is likely that such changes will also change the thermal properties of fabrics, which will alter the overall comfort level of denim fabrics. From the survey and discussions with the denim clothing manufactures follows, that the main objective of industrial washing is to give better look and required hand feel. They do not consider its impact on thermal comfort properties. It might be due to fact that user of denim clothing, particularly, wearer of denim jeans, prefer psychological comfort on physiological comfort. Tarhan and Sariisik [5] have investigated thermal effect of different fading and washing methods on strength, color values and weight of the fabric. They found a strong correlation between washing method and other parameters of the fabric. They did not include thermal comfort parameters. The objective of this study is the investigation of the effect of various finishing procedures on thermal comfort parameters of the denim fabrics, which has not been yet systematically studied.

In industrial washing at first stage sizing agents applied during weaving and other impurities added during transportation are removed and a faded look is achieved. At second stage, certain chemicals are applied to have certain hand feel or to impart some specific characteristics, such as water repellency, moth proofing etc. The samples under investigation (the composition and structure of which is described in Table 1) have been treated in 11 different ways, where one sample keeps untreated. Nevertheless, this sample has been mercerized and neutralized but has not passed the industrial washing

Table 1 Fabric Specification

Description	Values
Warp Yarn	100 Cotton (Dyed)
Weft Yarn	100 Cotton (Undyed)
Weave	Twill (3/1 Z, 3/1Broken, 3/1 Hearing Bone

4. Research Procedure

Denim fabric was produced by using cotton in warp and weft. Warp was dyed with sulphur black, while weft was kept un-dyed. This fabric was washed on industrial washing machines in 11 different ways (for washing details see Table 01). Samples of 20*20 cm were prepared and put in testing lab where temperature was 24-26°C and RH was 25-28%. Thermal conductivity, resistance and absorbtivity were determined by means of the ALAMBETA tester.

5. Results and discussion

Table 2 informs about the effect of different industrial washings on thermal comfort properties of the treated fabrics. It is obvious from the value of Table 2 that fabric with sizing agent has the highest thermal conductivity. On the other hand, fabric cleaned from all sorts of finishing chemicals has the lowest thermal conductivity. Addition of softener, cationic or silicone increases the thermal conductivity**.**

Softeners application is primarily to improve the hand feel but on the other hand, one has to scarify the comfort. There is a need to set a threshold point to have both and application of such softeners, which should not disturb the thermal conductivity. Use of more soft yarn could be another solution.

Thermal resistance is another phenomenon, which is also important. It is not just opposite to the thermal conductivity rather it has its own implications. Apparently, conductivity and resistance look opposite to each other but there is a subtle difference between these two.

One important thing is quite clear and obvious from the Figure 1, 2, 3 and also it is evident from the Table 2 that the effect of washing exhibits different effects on thermal conductivity, resistance and absorbtivity. This difference indicates that these three factors predict different behavior. For example, thermal conductivity is a phenomenon, which indicates the capability of material to conduct heat from one point to other point, whereas, thermal absorbtivity is a factor which indicates the ability of the material to adjust as per the thermal condition. In this case, we are taking into account thermal conductivity, specific heat and density. It means that thermal absorbtivity is an indicator, which depends upon thermal conductivity, density and specific heat of the sample. Thermal resistance is directly proportional to thickness and inversely proportional to thermal conductivity. Here, the final sample thickness also plays an important role.

The results in Table 2 prove that there is a significant effect of industrial washing on the three selected parameters related to thermal comfort. The most valuable information is that correlation among all selected parameters is diverse. It ranges from 0.392 to 0.891. Nevertheless, correlation is highly significant (p value is less than .005).

Table 2 The effect of finishing on thermal conductivity, absorbtivity and resistance of denim fabrics

Tested Parameter / **Finishing operation**	Thermal Conductivity $[Wm^{-1}K^{-1}]$	Thermal Absorbtivity $[Ws^{1/2}m^{-2}K^{-1}]$	Thermal Resistance $[mKW^{-1}]$
Desizing and Bleaching	0.03991	19.488	0.354
Desizing and Enzyme Treatment	0.03392	19.331	0.269
Desizing and Rinse Washing	0.0322	14.369	0.367
Desizing, Bleaching and Application of a Cationic Softener	0.0554	26.723	0.587
Desizing, Bleaching and Application of a Quick Dry Auxiliary	0.0445	22.43	0.381
Desizing, Bleaching and Application of a Silicone Softener	0.0618	27.804	0.81
Desizing, Bleaching and Application of a Water Repellent Auxiliaries	0.0566	25.924	0.697
Desizing, Enzyme Treatment + Bleaching	0.0457	21.492	0.465
Desizing, Peaching and Rinse Washing	0.0389	19.811	0.284
Desizing, Stone Washing, Enzyme Treatment and Bleaching	0.0361	18.475	0.207
Desizing, Treating with Enzyme and Fading with Pumice	0.0479	22.353	0.369
UN-Washing	0.1103	31.435	0.664

Table 3 Correlation among thermal conductivity, absorptivity and resistance

Thermal Comfort Parameter		Thermal Conductivity	Thermal Absorbtivity	Thermal Resistance
Thermal Conductivity	Pearson Correlation	1		
	Sig. (2-tailed)			
	N	180		
Thermal Absorbtivity	Pearson Correlation	.891**	1	
	Sig. (2-tailed)	.000		
	N	180	180	
Thermal Resistance	Pearson Correlation	.514**	.392**	1
	Sig. (2-tailed)	.000	.000	
	N	180	180	180
**. Correlation is significant at the 0.01 level (2-tailed).				

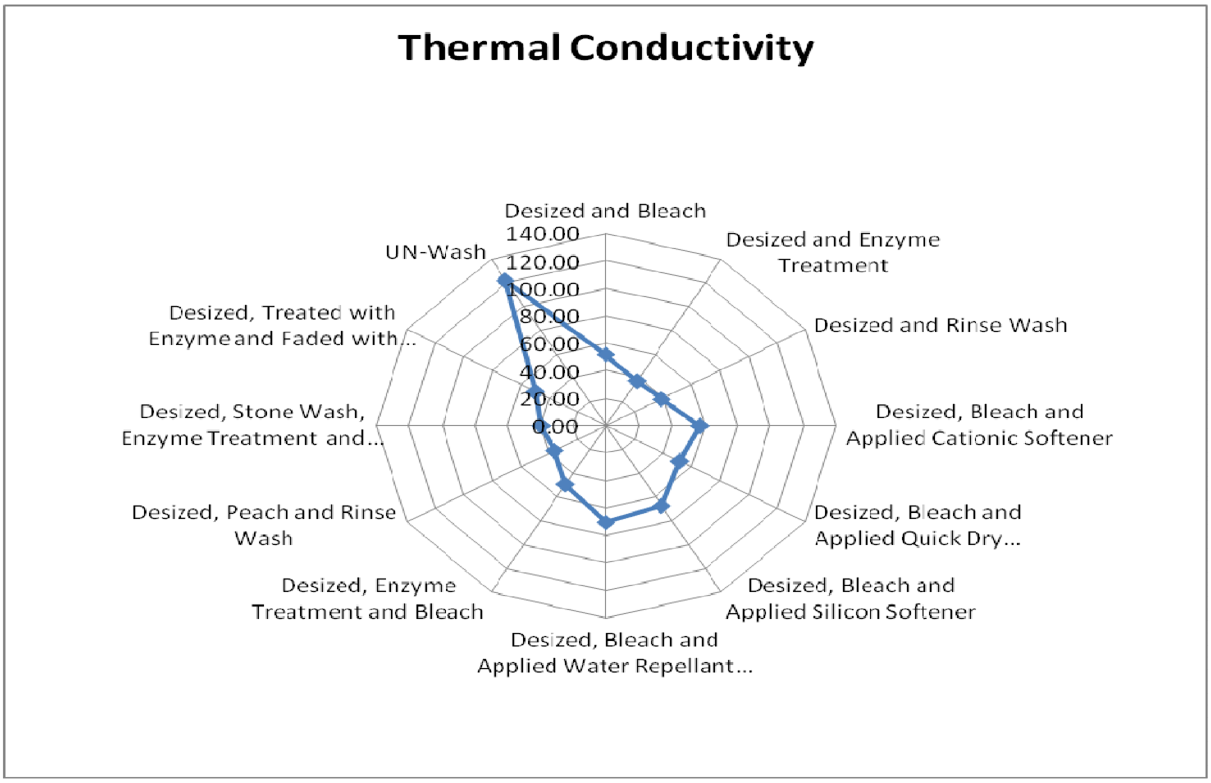

Figure 1 The effect of finishing on thermal conductivity of denim fabrics

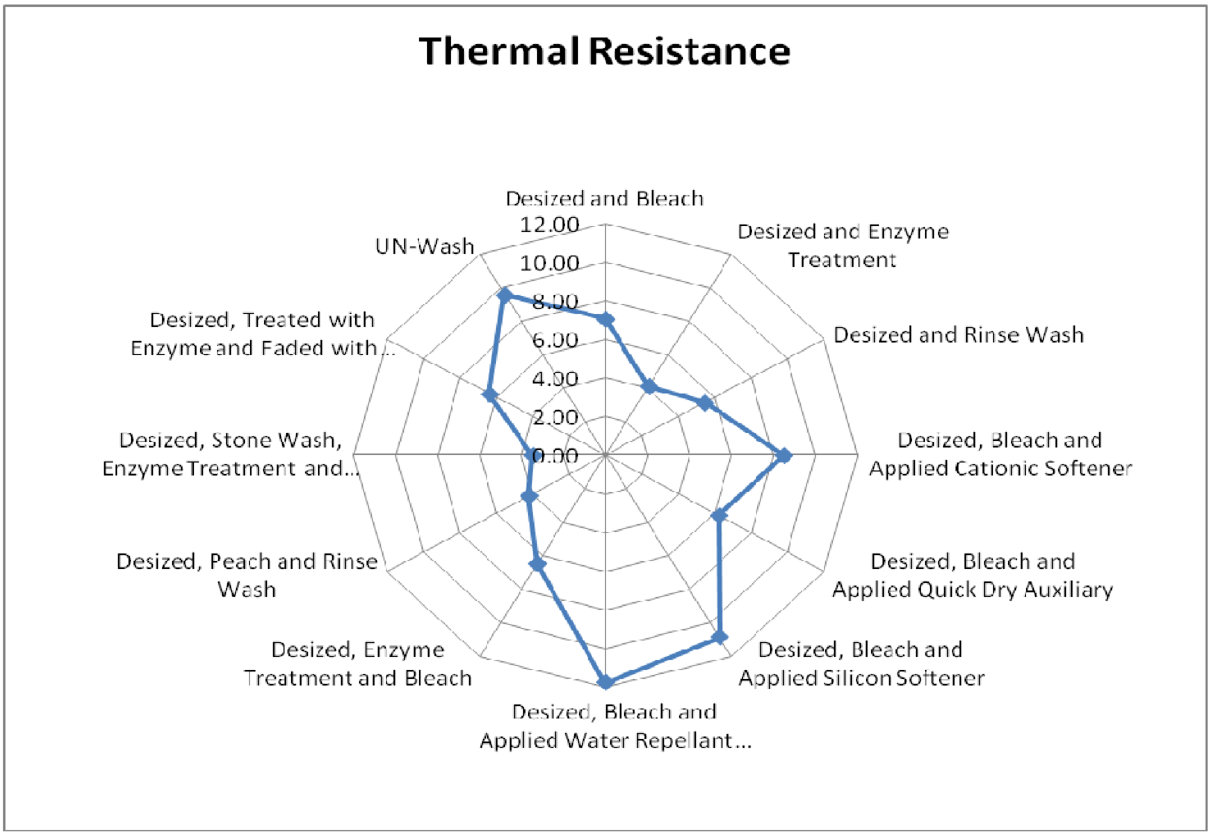

Figure 2 The effect of finishing on thermal resistance of denim fabrics

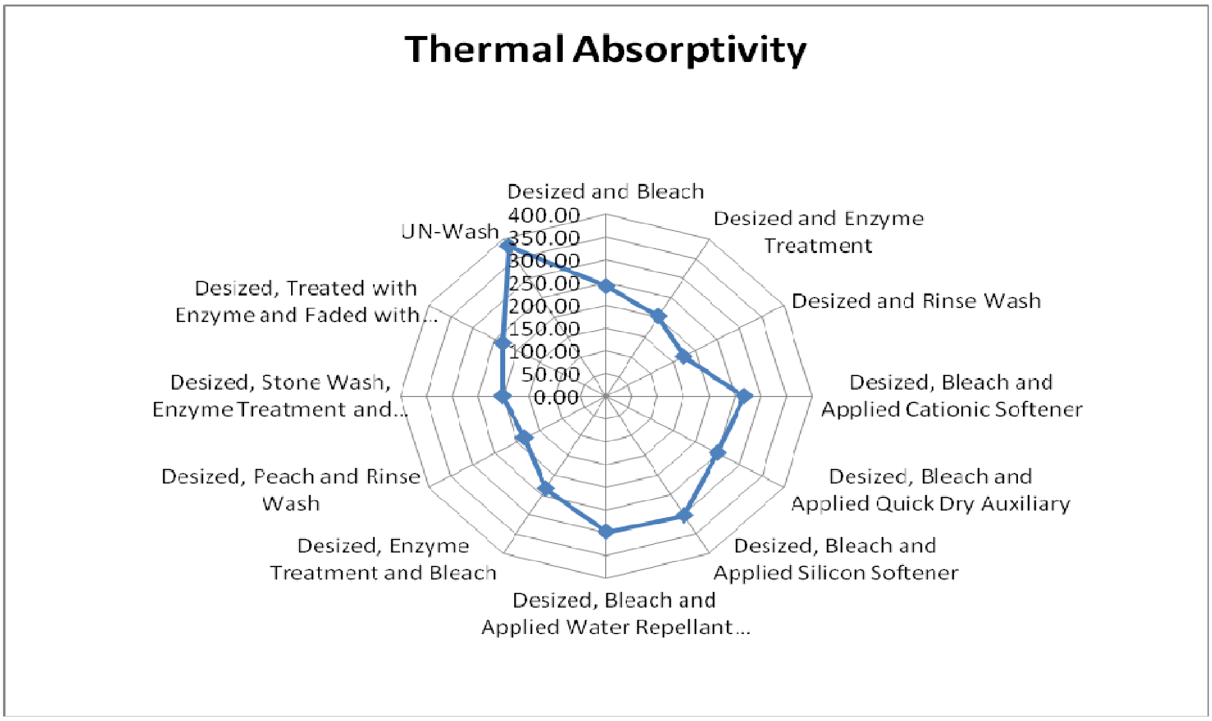

Figure 3 The effect of finishing on thermal absorbtivity of denim fabrics

Denim fabric is being subject to industrial washing aiming at receiving a required faded look. The second major objective is to have a certain hand feel [6]. These two aspects are quite easy to judge by the customer and are quite significant for marketing and as stated by a production department of denim manufactures. Denim apparel producers always try to have an edge on these issues from their competitors. It is obvious from the investment of denim apparel producers to have better machines and equipments for industrial washing. Furthermore, work of chemical manufacturing companies to provide special finishes to denim apparel producers is another convincing argument. On the other hand denim producers rarely consider its impact on the thermal comfort of their fabrics. This study provides a proof that different finishes have a significant impact on the thermal comfort of the denim fabric. This difference is not easy to judge without use of testing machines. However, wearer of denim apparel can experience these changes. This study can help denim producers in the selection finishes keeping in view its impact on thermal comfort, which is an integral part of overall comfort.

5. References

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