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Identifying the Amount of Heat Flux and Thermal Conduction through Fabrics with Appropriate Heat Equation

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ABSTRACT

Heat equations such as heat flux and thermal conduction were applied in this paper so that these values were obtained during heat setting. Cotton spandex woven fabrics have the properties of stretch ability like stretch, growth, elasticity etc. Due to controlling such types of properties heat setting is mandatory. The values of heat flux and thermal conduction would be beneficial to heat application the fabrics more accurately. A heavy weight stretched woven fabric of twill weave was used in this research. The width of the fabric was 60 inch and had a thickness of 2.5 millimeter. Fabric was heated in a stenter machine with adjusted industrial settings. Heat flux values and thermal conduction values of the clothes were investigated using equations stated in this paper. Overheat can damage the fabrics drastically and all the comfort properties are also influenced seriously. Using heat flux equation and thermal conduction equation, fabrics are heated preciously and all these things are practically analyzed, examined and investigated in this research. This research is trial based and the findings are useful to the employees functioning in textile factories who are in duty of heat setting the cotton spandex woven fabrics and to controlling of their all comfort characteristics.

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1. Introduction

This research is important since stretched fabrics are the first choice in today's fashion and modeling. Heat setting with the values obtained by appropriate heat equations can be beneficial in controlling of such properties [1]. Most often, heat setting is also applied to progress characteristics for succeeding procedures [2].

Heat setting can eradicate the propensity of unwanted torqueing. Both twist equilibrium and stabilization of decoration effect are results of the heat setting procedure. Heat setting aids staple yarns as well as bulked incessant filament (BCF) yarns [3].

Heat setting often reasons synthetic fibers to advance volume as well. This volume growing is commonly labeled as "bulk development". In the carpeting industry, the procedure is entirely called "heat setting" [4]. Figure 1 shows how temperature releases from human body.

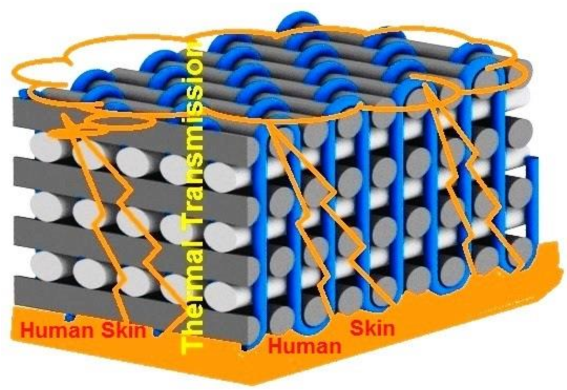

Fig. 1. Thermal conduction from human skin to clothes.

Thermal insulation can be attained with particularly engaged approaches, and with appropriate object forms and tools [5]. Flow of temperature is an unavoidable concern of contact among objects of altered temperature. Thermal insulation affords a section of insulation in which thermal conduction is condensed or thermal radiation is reproduced rather than captivated by the lower heated substances [6].

Low thermal conductivity is equal to high protecting ability. These cloths are produced with heat resistant threads and can be exposed to different handlings and coverings [7]. From standard weave structure for overall industrial uses to textiles woven with high-class weave structures and designs, different thermal conducting fabrics may be produced [8].

Mingling internal weaving expertise with a full series of high temperature strands provides the aptitude to come across with nearly any high temperature use [9]. So many thermal textiles are produced to retort to opposing situations in their environment and there by afford superior defense [10]. There has been widespread invention, for instance, in clothing fabrics that can deliver superfluous insulation in hot and cold situations [11].

When a substance alters phase with growing heat, from hard to fluid stage, a great amount of dormant heat is engrossed. This input of temperature is essential to change the solid substances to the water stage, and the alteration will happen at a nearly fixed heat of the melting state of the substance [12]. The temperature is, in result, stowed in the substance in its water state and is only free when the liquid is chilled back to its hard stage. This performance forms the foundation of stage alteration resources [13].

In usual conditions, warmth will flow through the clothing to the external atmosphere. In this method a lively thermal obstruction is formed that is in totaling to the usual reflexive thermal barrier innate in the costumes design [14].

These constituents engage and relief heat for better luxury deprived of cooperating the cloth's inherent physiognomies [15]. The body itself adjusts its temperature from side to side a group of organic developments. When human body heat outspreads outside the limits of the thermo unbiased region, physical schemes function less competently, and when strapped to excesses can even result in passing away [16].

Hence, thermo-regulation is life-threatening both from a protection and enactment viewpoint. Definite mixtures of fabric structure, organic varnishes and garment shapes can also retain the body heater or chiller, dependent on the ecological circumstances. Habitually cloths are suited for one or the former [17]. Temperature moves from the heated place to the colder places [18]. Oppositely, deep climate garments must benefit evaporative temperature loss by amassed humidity association, and increasing the quickness of heat transmission through the substances [19].

Naturally, cloths do not fundamentally offer thermo regulation. Body loses temperature when he comes to the contact of clod climate [20]. The character of the cloth will be to permit air to flow everywhere the body and at the similar time deliver a bolster of insulation when the body necessities it [21]. The cloth must be capable to amend to the requirements of the surroundings [22].

If a fabric is manufactured with conductive materials such as copper, nickel or steel sheets, then these fabrics may be working as a conductive material [23]. It can do it by detecting how much power it is captivating from environment. The substantial guarantees this voltage level is preserved, confining temperature difference to within 1°C [24]. Clothes made up of carbon fibers are liable for the heating enactment, permits a more constant and enjoyable circulation of temperature than most predictable heated attires [25].

There are three chief features that have been perceived in constituents that deliver the property of thermo regulation [26]. Firstly is the moisture management or breathing capability [27]. When a cloth comes in the contact of water then it takes humidity and become damp in nature and can show some conductive characteristics [28]. The second most important property is insulation. The cloth must have a good isolation value to appendage the border layer on the exterior of the body [29].

There should be an appliance to vary the gradation of insulation. Lastly, the cloth must be as light as possible to attain supreme relaxation [30]. An extremely effective breathable cloth material permits the consumer to regulate body temperature [31]. The general consequence is to produce a more contented state on the skins exterior.

The insulating cloths are combined with the sentient or humidity managing finishes with high metal constituent in materials. Some fabrics can be turned as conductive by galvanizing process such as coating with some substances like copper or nickel those are conductive [32]. Clothing created with predictable polymers has negligible thermal insulation properties [33].

Carbon can be used as conductive materials. Cloths can be manufactured with conductive materials produced by ring or rotor spinning [34]. The carbon generates the conductivity and thus resistance. Generally, fabrics made up with cotton fibers are most often nonconductive if they are not wet in water [35].

Temperature is dispersed consistently over the whole surface of the textiles with resistance changing among different Ohm per square area of the surface. A type of substance providing improved insulation comprises the insulating cloths [36]. The fabrics those should be heated are produced with some special elastic materials called spandex. Spandex has some other names also like elastane [37].

During the expenditure of the substances, vapor is removed from each compartment by benefit of the bending of the cloth. With advanced movement of user, the impelling task is consistently amplified [38]. The enactment of substance is organized to contest with lower rate. These cloths can be used as covers or slack coatings consistent with user's desires [39]. The wideness of the protecting constituent differs from 3 to 7 mm, with oftenly applied being among 3 to 6 mm [40].

Spandex or elastane is used in fabrics to give them a stretchy appearance and these fabrics are most suited for the person whose are related to sports [41]. In winter, for instance when cool temperature is near about 0°C, insulated wear is suggested for confirming the wearer is adequately heated when quiescent [42].

Though human is engaged in concentrated action, the body heat upsurges with improved heat creation. To retain this upsurge inside restrictions, the body sweats for extracting vitality from wearer through evaporation [43]. If temperature cannot be moved from body through clothes, then temperature started to increase and these increased temperature started sweating [44].

Clothing manufactured from dead fibers is obviously isolating. Deadly fibers have a distinct feature that indicate they may gather air interior thus producing a usual insulation [45]. For producing a cold cloth for tempered weather, the length of the yarns is highly twisted concluding to the echoing core and decreasing insulation [46]. For the cloths of cold season, yarns with less twist are applied.

The excellence of insulation in clothing will be expansively ruled by the depth and compactness of its constituent materials. Choosing of clothes differs from person to person and it also differs from places to places. For an example, the people of cold countries needs heavy clothes and the people of hot countries need light clothes [47]. Therefore low compactness is also significant for enlightening insulation. Temperature moves through the hollow places in between the yarn and interlacement. Exterior heats also disturb the efficacy of insulator [48].

The clothes those are used by some forces like army, naval forces or air forces are manufactured with some special materials to protect them some adverse environment. Some of them are produced with smart materials to give some extra advantages [49]. A number of smart materials and fabrics are obtained nowadays [50]. Aerogels are created through the formation of gummy constructions and then exclusion of all liquid without permitting any shrinkage [51].

The fabrics those have open holes are dried in air by air circulation through the holes in the clothes [52].

When a cloth's hole are filled with some materials such as wax, oil or some other materials, then this fabric cannot pass any air and also cannot convey temperature. When a fabric can pass air, then it can also pass temperature with it [53].

Core spandex yarns are produced with using the spandex in the central, which is wrapped by cotton or some other fibers to provide elastic stretchy characteristics [54]. If spandex yarns are using in the central position then it can easily give some stretchily. These fabrics are mostly used by the swimmers, athletics, sportsman, cricketer, footballer etc [55].

When special ingredients are initiated in clothes, the air holes amid neighboring layers of dress are enlarged, to provide improved insulation [56]. The combination of resources into clothes thus converses greater adaptability in the defense that the clothing offers against excesses of warmth or cold [57].

If the after uses of the clothes are known, then they should be prepared in such a way that, they would be very suited for fulfilling the end purpose. The dresses of the sports man should be prepared with such materials those can provide stretchy and comfort properties wearing which, a sportsman can move easily. For controlling all these properties, heat setting is must either during the fabrics manufacturing stages or during the finishing stages [58].

2. Materials and method

2.1. Materials used

Table 1 shows a material that is used for experimentation purpose in this research. Elastic clothes were tempered to alleviate the flexible sections with natural cotton and to guarantee all the stretched features. During heating the stretched fabrics, their hotness was calculated in Joule with the equations detailed underneath.

Table 1
Cotton Spandex Woven Fabrics used in this Experiments.

Fabric Construction	Fiber Composition	Fabric Weight (g/m^2)	Thickness (mm)	Weave Structure	Fabric Width (")
10×(10+70D)/ 80×60	97% Cotton 3% Spandex	350	2.5	3/1 LHT	60

This fabric was prepared with combining the percentage of cotton and spandex was 97:3. This fabric has the weight of 350 g/m^2, thickness of 2.5mm, weave structure of 3/1LHT and the width of 60". 10Ne warp and (10+70D) weft interlaced each other in 3/1 LHT wise to weave the fabric. The yarn count for warp is 10Ne and weft is (10+70D) Ne. Spandex of 70D Denier is inserted with the weft yarn in this type of cloth.

2.2. Equation used for heat flux

It is experimental that, cloths have characteristics of conductivity, for that reason thermal energy is progressed by the carnal transferal progression in different places. It shows in the way that, it appears hot fluid in a container and warm up a fabric in fickle navigational waves. Equation 1 was used to measure the thermal hydraulics, where ϕ_q is refereed as heat flux, ϑ *is* refereed as velocity, ρ is refereed as density, c_p is refereed as heat element, ΔT showed heat.

$$\phi_q = \vartheta \rho c_p \Delta T \quad (1)$$

2.3. Equation of thermal conduction

Textile materials such as fabrics are thermal conductive and their conductivity was be calculated with equation 2 as detailed below. In this equation, Q denoted thermal conductivity, t denoted time, d denoted thickness, A denoted area, T denoted temperature and K denoted conductivity constant. With these mentioned terms, thermal conductivity of the fabrics could be defined.

$$\frac{Q}{t} = \frac{kA(T_{hot} - T_{cold})}{d} \quad (2)$$

2.4. Machine used

Temperature application of the fabrics was carried out with “Montex Stenter Frame 6500”. It is an engine, which is prepared in 1992. This apparatus is particularly generated to heat setting the woven fabrics industrially. It is 72” wide and 120 meter long. This engine has dualistic stenter shackles with pinches at the side to clutch the fabrics from container [46]. Figure 2 displays a stenter machine when heat setting was on.

Fig. 2. Heat setting is carried out with stenter machine.

3. The Experimentation

Stenter machine used to heat setting the fabrics. The machine collected cloths from container and prior to heat application, it makes condition of the cloths. By conditioning the fabrics, it was collected from container and entered into the machine. This engine collected fabrics towards inside direction with its stenter pins at the edge that griped to the selvedge area of cloths.

Fabrics were dampened in water prior to heat setting, so that it moderate the chances to be spoiling down caused by temperature application. The water batch contained 5g/l of acetic acid to control the level of pH after heat application because spandex fabrics have a provability to raise the level of pH after being burnt or heated. Machine tracks at 30 m/min speed. Gas burner increased the amount of heat inside the machine.

Gas burner released hot air flow. This machine heated the fabrics at 170°C, 180°C, 190°C, 200°C, 210°C, 220°C and 230°C with different engineering setting. Clothes immersed into water to avoid burning chances in temperature before heat setting.

3.1. Experimentation for heat flux

Heat flux of the fabrics was measured with equation 1 mentioned above. Fabrics have some thermal properties because of that reason; thermal energy is developed by the opulent transferal progression in places. Equation 3 helps to measure the heat flux, where ϕ_q is refereed as heat flux, $\vartheta\ is$ refereed as velocity, ρ is refereed as fabric's density, c_p is refereed as specific heat of heating element, ΔT is refereed as the adjustment in heat.

$$\phi_q = \vartheta \rho c_p \Delta T \tag{3}$$

ΔT is the difference of hot (200°C) and cold (30°C) temperature.

$$\Delta T = T_{hot} - T_{cold}$$

Therefore,

$$\Delta T = (200 - 30)°C$$

$$\Delta T = 170°C$$

$Applying\ \Delta T$ Value in equation 1,

$$\phi_q = \vartheta \rho c_p \times 170°C$$

The value of specific heat c_p of the cotton spandex woven fabric is 1505 $\frac{J}{kg.K}$. Using $C_p$value in equation,

$$\phi_q = \vartheta \rho \times 1505 \frac{J}{kg.K} \times 170°C$$

If we put the value of fabric's density $\rho = 640 \frac{kg}{m^3}$ in the equation, then it would be

$$\phi_q = \vartheta \times 640 \frac{kg}{m^3} \times 1505 \frac{J}{kg.K} \times 170°C$$

The velocity of the fabric is 30 meter per minute or 0.5 meter per second. Thus $\vartheta = 0.5 \frac{m}{s}$

$$\phi_q = 0.5 \frac{m}{s} \times 640 \frac{kg}{m^3} \times 1505 \frac{J}{kg.K} \times 170°C$$

Separating the units,

$$\phi_q = 0.5 \times 640 \times 1505 \times 170 \times \frac{m \times kg \times J \times °C}{s \times m^3 \times kg \times K}$$

After multiplication,

$$\phi_q = 8.19 \times 10^7 \times \frac{m \times kg \times J \times °C}{s \times m^3 \times kg \times K}$$

Multiplying the units,

$$\phi_q = 8.19 \times 10^7 \times \frac{J \times °C}{s \times K \times m^2}$$

$$\phi_q = 8.19 \times 10^7 \times \frac{W}{m^2}$$

Therefore, the heat flux is measured as $8.19 \times 10^7 \frac{W}{m^2}$. With all the techniques over the mathematics, we can conceivably find out the heat flux values ϕ_q using 170°C temperature to 230°C temperature.

3.2. Experimentation for thermal conductivity of fabrics

The thickness of the clothes is always an obstacle for the thermal transmission or thermal conduction. Applying equation 2 cloth's thermal conduction was evaluated. In this equation, t is referred for time or duration, T is referred for temperature, K is referred for thermal conductivity of the clothes and A is referred for the area of the clothes, K is referred for the thermal conductivity constant, Q is referred as heat conduction and d is referred for thickness of the clothes.

In table 1, fabric's width became 60" or 1.524 meter and the thickness is found to be 2.5mm or 0.0025 meter. The experimented clothes were 1000 meter long. Fabric's thermal conductivity constant K is found to be $0.25 \frac{J}{s.m.C}$. Clothes were in store room (30°C) and heated in 170°C to 230°C. Heating machine was entirely 120 meter long where space heating chamber is measured as 90 meter.

30 meter in the stenter machine is given as extra for backing along with the batcher. Fabric went into the stenter machine gradually at the persistent speed of 30 MPM and was applied

temperature at the exposure of 90 meter area. Hence, the quantity of temperature (J) was estimated with equation 2.

$$\frac{Q}{t} = \frac{kA(T_{hot} - T_{cold})}{d}$$

$$Q = \frac{tkA(T_{hot} - T_{cold})}{d}$$

This machine covers heat at 90 meter. Machine's constant speed was 30 MPM (meter per minute). Thus, temperature was applied on clothes by 3 minutes for the period of heat setting. Henceforward, heating time (t) is 3 minutes or (3×60 seconds) or 180 seconds.

$$Q = \frac{180s.k.A.(T_{hot} - T_{cold})}{d}$$

Fabric's thermal conductivity constant K is $(0.25\frac{J}{s.m.C})$.

$$Q = \frac{180s \times 0.25\frac{J}{s.m.C} \times A \times (T_{hot} - T_{cold})}{d}$$

The area measurement of the clothes A is, A= 1.5748m × 100,000m = 1,57,480 m^2

$$Q = \frac{180s \times 0.256\frac{J}{s.m.C} \times 1{,}57{,}480\, m^{2} \times (T_{hot} - T_{cold})}{d}$$

Room temperature or Normal temperature is termed as cold temperature of fabrics was T_{cold} 30°C and hot temperature of the clothes, termed as T_{hot} was 200°C.

$$Q = \frac{180s \times 0.25\frac{J}{s.m.C} \times 1{,}57{,}480\, m^{2} \times (200°C - 30°C)}{d}$$

Detracting temperature's values, the equation be

$$Q = \frac{180s \times 0.25\frac{J}{s.m.C} \times 1{,}57{,}480\, m^{2} \times 170°C}{d}$$

Value of d is 2.6 mm or 0.0026 meter

$$Q = \frac{180s \times 0.25\frac{J}{s.m.C} \times 1{,}57{,}480\, m^{2} \times 170°C}{0.0025m}$$

$$Q = \frac{180 \times 0.25 \times 1{,}57{,}480 \times 170}{0.0025} \times \frac{s \times \frac{J}{s.m.C} \times m^{2} \times °C}{\text{m}}$$

$$Q = 4.82 \times 10^{11} \times \frac{s \times \frac{J}{s.m.C} \times m^{2} \times °C}{\text{m}}$$

Calculating the units, we found the unit value for Q is Joules (J), therefore the values of Q is $Q = 4.82 \times 10^{11}\ Joule$

Therefore, we can say that, 4.82×10^{11} Joule temperature is needed to heat setting the clothes of 1,00,000 meter with 200°C temperature. Henceforth, each meter cloth could be tempered with $\frac{4.82\times10^{11}}{100000}$ or 4.82×10^{6} Joules. With all the ways through the mathematics, we can possibly find out the thermal conduction values (Q) for 170°C temperature to 230°C temperature applying equation 2.

4. Results and discussion

This section discussed the results of heat flux and conduction. If thermal conduction is happened to the clothes to a specific limit, there has been a remarkable change to the other physical properties of the clothes. These heat properties of the clothes were investigated to measure the exact amount of heat transferred through the clothes.

4.1. Results of heat flux

Stream of heat energy in a unit area of fabric is heat flux. In SI unit the results are obtained in watt per square meter (W/m^2) in this examination. Apply heat variance to find the results. Accurate values can provide actual results. Here, in this experiment, without using thermal resistance, but using temperature measurements on each surface of the fabric the heat flux was directly calculated.

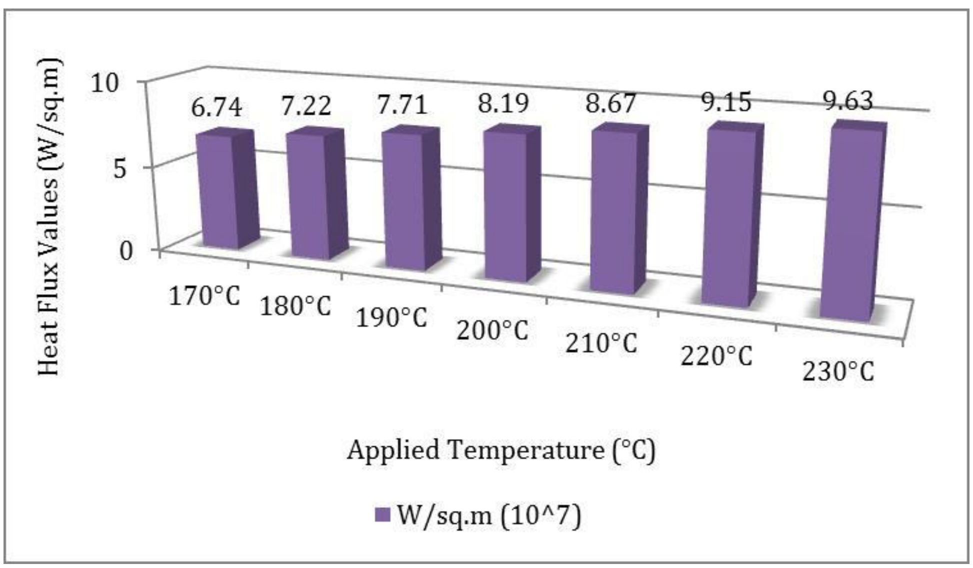

Fig. 3. Heat flux values $\left(\frac{W}{m^2}\right)$ against different applied temperature.

Results of heat flux were placed in figure 3. Values of heat flux were inspected for the different temperature difference mentioned in the same equation. Different heat flux results were gotten based on applied temperature of 170°C to 230°C. It seems from the figure 3 that, while heating the fabric at 170°C, the heat flux value was 6.74×10^7 W/m^2. While heating the fabric at 180°C, the heat flux value was 7.22×10^7 W/m^2.

While heating the fabric at 190°C, the heat flux value was 7.71×10^7 W/m^2. While heating the fabric at 200°C, the heat flux value was 8.19×10^7 W/m^2. While heating the fabric at 210°C, the heat flux value was 8.67×10^7 W/m^2. While heating the fabric at 220°C, the heat flux value was 9.15×10^7 W/m^2. While heating the fabric at 230°C, the heat flux value was 9.63×10^7 W/m^2.

4.2. Thermal conductivity of fabrics

Basically, thermal conductivity is referred as the heat transfer rate by conduction process in a unit's cross section area of fabric, when a temperature gradient exits vertical to the region. Heat transmission happens at a lower rate in fabrics of low thermal conductivity than in materials of high thermal conductivity. Fabrics of high thermal conductivity are extensively applied in heat applications, and the fabrics of low thermal conductivity are applied as lower thermal insulation.

Fabric's thermal conduction is known as the carriage of heat energy due to the haphazard molecular motion, through a temperature gradient. It is different from energy transportation by convection and molecular exertion in that it does not include work execution of inner strains.

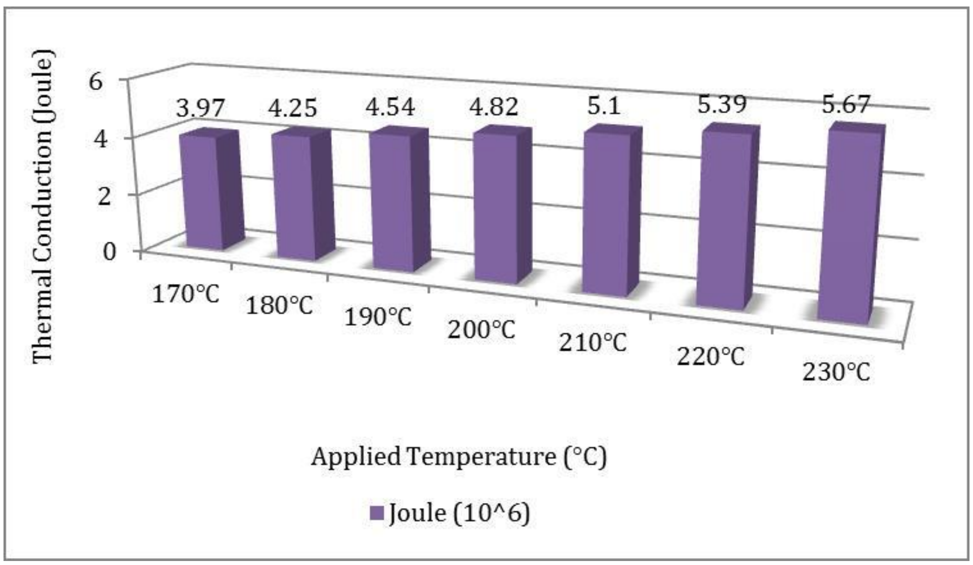

Fig. 4. Fabric's thermal conduction values (J) at different temperature point.

Applying equation 2 the thermal conduction values were acquired and positioned in figure 4. Thermal conduction values were acquired for the different temperature points stated in the similar equation. Thermal conduction values were acquired based on the applied heat from 170°C to 230°C temperature. It seems at figure 4, while the cloth was tempered at 170°C, the thermal conduction value was 3.97×10^6 J. While the cloth was tempered at 180°C, the thermal conduction value was 4.25×10^6 J.

While the cloth was tempered at 190°C, the thermal conduction value was 4.54×10^6 J. While the cloth was tempered at 200°C, the thermal conduction value was 4.82×10^6 J. While the cloth was tempered at 210°C, the thermal conduction value was 5.10×10^6 J. While the cloth was tempered at 220°C, the thermal conduction value was 5.39×10^6 J. While the cloth was tempered at 230°C, the thermal conduction value was 5.67×10^6 J.

5. Conclusion

The thermal conduction values and the heat flux values were investigated in this research with some appropriate heat equations. Fabrics were heated using a stenter machine preciously and the amount of temperature conduction through fabrics was measured using those heat equations. Cotton spandex woven fabrics are stretchable and their stretching characteristics could be obtained when they are heated preciously. Thermal conduction calculated the applicable heating amount. Temperature was applied on elastic fabrics to stabilize the spandex percentages in cotton fibers and to confirm full immovability with all stretching performances. In this research, heat flux and thermal conduction equations were disclosed in direct application form to apply. This paper would be beneficial for further experimentations on numerous heat equations and their applications consistently.

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