## 1- Introduction:

Over the last years the comfort parameters became essential in clothing. The word comfort is defined in the Webster's [1] dictionary as circumstances that give ease of body or mind. The clothing comfort was anciently divided into three categories; Psychological, tactile and thermal comfort [2]. Recently the ergonomic comfort was defined as the comfort related to comfort shapes, forms and facility of movement [3]. The thermal comfort is related to the cloth ability to keep body temperature constant and dry by allowing the transfer of the perspiration produced by the body through the fabric and to the surrounding atmosphere. This means the involvement of four main fabric properties which are; thermal conductivity, air permeability, water vapor and liquid water permeability [4].

Several research works have been carried out on the effect of different textile processes and properties on the thermal comfort. Behera at al. [4] compared different fabrics made from ring, rotor and friction spinning from the comfort point of view. They found that fabrics woven from the ring-spun yarn has the best tactile comfort, while fabrics, made from the friction spun yarn, had the best thermal comfort. Schacher et al. [5] compared the thermal properties of classical and microfibers polyester fabrics. It was found that fabrics made of microfibers have lower heat conductivity and higher thermal insulation and that the microfibers fabrics gave a warmer feeling than the classical fabrics.

For medical textiles Jose et al. [3] studied the thermal comfort for surgical gown as a result they designed a new material for gowns which compiles the comfort parameters.

The wide use of knitted fabrics in under wear clothing made the study of the comfort parameters of knitted fabric essential due to its direct contact with the body surface. Ozcelik et al [6] compared the thermal properties of inter-lock knitted fabrics produced from different textured yarns. Results shows that the thermal resistances of the textured fabrics are higher than the fabrics produced with non-textured filaments and those false-twist textured yarns showed the highest cover factor due to the increased bulkiness of the yarns. Since the thickness of the fabric increases by texturing, air permeability decreases. This decrease in air permeability was more evident in false-twist textured fabrics.

Marmarali et al [7] investigated the thermal comfort of knitted fabrics made from new generation yarns (tetra-channel polyester, high functional polyester and patented blend of natural and synthetic fibers), with three different tightness (tight, medium and loose fabrics). Results shows that the looser fabrics pass higher insulation and air permeability and gives warmer feelings.

Ozdil et al. [8] investigated the thermal properties of 1 × 1 rib knitted fabrics produced from different yarn counts, twist factor and combed, carded yarns. It was found that finer yarns had less thermal conductivity and higher water vapor permeability due to open structure of the 1 × 1 rib fabrics. Moreover, the studied fabrics gave warmer feeling property due to the lower thermal absorptivity values. When the yarn twist used for 1 × 1 rib fabrics was increased, thermal absorptivity and water vapour permeability increased, which gave cooler feeling. On the other hand, thermal resistance values decreased as the twist coefficient of yarn was increased. It was found that yarn twist value is insignificant on the fabric conductivity. Thermal resistance values of fabrics knitted with combed cotton yarns were lower than the fabrics knitted with carded cotton yarns. Thermal conductivity, thermal absorptivity and water vapour permeability values of the fabrics knitted with combed yarns were higher.

Bhattacharjee and Kothari [9] predicted the steady-state and the transient thermal properties using two types of neural networks; forward feed and back propagation. They used a three layer networks in both cases and compared the results obtained from both cases with the experimentally obtained results of 86 cotton fabrics. It was found that the neural network can be used as a tool to predict the thermal behavior of fabrics satisfactory.

## 2- Material and Methods :

### 2-1 Material:

In this research work two types of yarns, of the same count Ne 30, (100% cotton and 50%-50% Cotton –Modal, TPI 20.4 and 18.5, respectively) were used to produce single jersey knitted fabrics with constant loop length 2.82mm, using two different yarn input tension 14 cN and 6 cN. Table (1) shows the specifications of produced fabrics.

Table (1) the knitted fabric specification

| Sample No. | Yarn tension (cN) | Courses/ cm | Wales/cm | Fabric Weight (g/m2) | Loop Length (mm) | Thickness (mm) |
|---|---|---|---|---|---|---|
| 1 | 14 | 20.4 | 13.2 | 131 | 2.82 | 0.62 |
| 2 | 6 | 20.4 | 13.6 | 130 | 2.84 | 0.6 |
| 3 | 14 | 20.4 | 13.6 | 130 | 2.83 | 0.67 |
| 4 | 6 | 20.4 | 14.2 | 128 | 2.82 | 0.68 |
| 5 | 14 | 20.4 | 14.8 | 134 | 2.81 | 0.55 |
| 6 | 6.2 | 20.4 | 14.4 | 134 | 2.82 | 0.54 |
| 7 | 14 | 20.8 | 14.8 | 135 | 2.82 | 0.62 |
| 8 | 6.2 | 20.4 | 14.8 | 134 | 2.82 | 0.6 |

### 2-2 Fabric Manufacturing:

All the fabrics were produced on the same knitting machine; Mayer and Cie, S4-3.2 single jersey circular knitting machine. Then the fabrics were finished in two different methods (open width form and closed width form).

### 2-3 Methodology:

In order to study the effect of the yarn blend ratio, input tension and the finishing method on the thermal properties. A two level, three factor design of experiment was carried as shown in Table (2) where:

Finishing process: 1= open width form, 0= close width form

Blend ratio: 1=50% Modal, 50% Cotton and 0=100% cotton.

Yarn tension: 1=14 cN, 0 =6 cN measured by the using MLT WESCO device.

Table (2) Design of Experiment

| Sample No. | Finishing Process (F) | Blend Ratio(B) | Yarn Tension(T) |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 0 |
| 3 | 1 | 0 | 1 |
| 4 | 1 | 0 | 0 |
| 5 | 0 | 1 | 1 |
| 6 | 0 | 1 | 0 |
| 7 | 0 | 0 | 1 |
| 8 | 0 | 0 | 0 |

## 2-4 Fabric testing:

### 2-4-1 Thermal properties:

The thermal properties of the 8 fabric samples were measured using the Alambeta testing instrument. Figure (1) shows a sketch diagram for the Alambeta device. In this device the fabric is placed between a hot and a cold plate. The amount of heat flow from the hot plate to the cold plate through the fabric is measured by heat flux sensors. Also the thickness of the fabric is measured (h), which is used to determine the thermal resistance(r) $r = \frac{thickness(h)}{\text{thermal conductivity}(\lambda)}$, and the thermal absorptivity $b = \sqrt{\lambda \times density \times specific\ heat}$ [8]

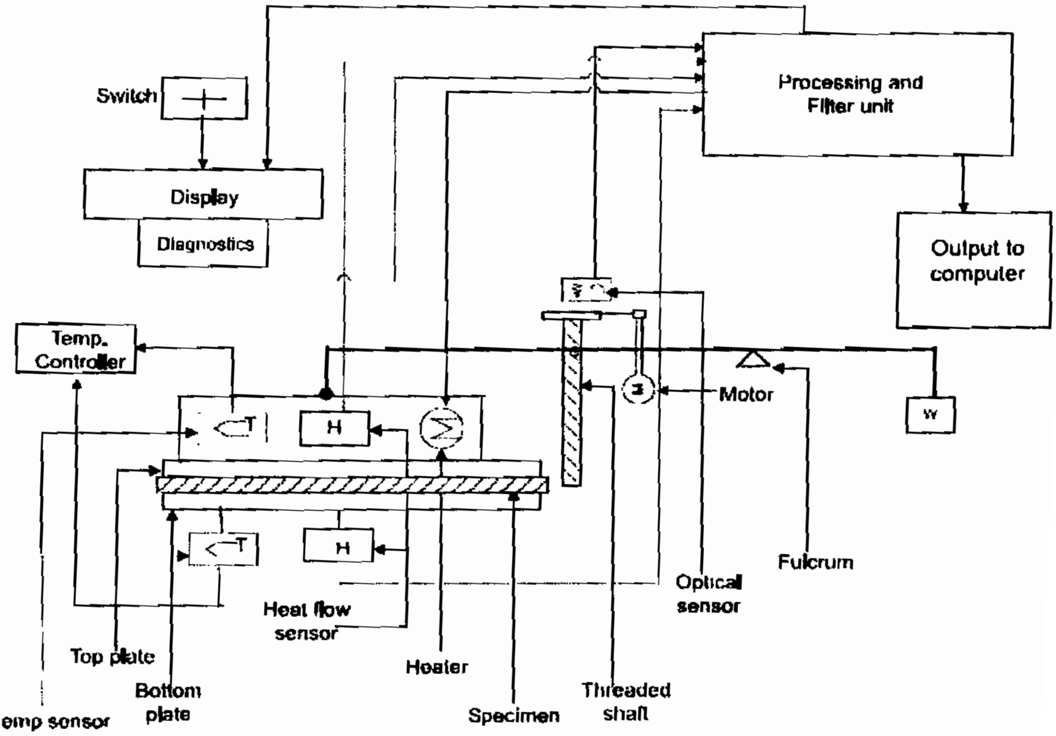

Figure (1) Sketch diagram for the Alambeta [9]

### 2-4-2 Water absorption properties:

Although, the water absorption and air permeability properties are not considered as thermal properties of the fabric, but they are essential form the comfort point of view [2]. Therefore, they were studied in this research to be a start to study the comfort behavior in the futur.

The wicking behavior of the studied samples was measured using a 0.2% soap solution. The samples were dropped from 1cm into the solution [10]. The time taken for complete sinking of the sample was measured in minutes. Four readings were taken for each sample (Sample dimension 1×1 inch). Also the percentage gain of the studied fabrics were measured by taking a 20cm × 20cm sample and dipping it into water for five minutes and then the sample was hung vertically to allow extra water to drip for another five minutes. Finally the percentage gain in the weight of the samples was calculated [11].

### 2-4-3 Air permeability:

The air permeability of the studied samples was measured according to the ASTM D 737

## 3- Results and Discussion

The following table (3) shows the results obtained for the knitted fabrics.

Table (3) Values of thermal properties of knitted fabrics

| Sample No. | Thickness(h) (mm) | thermal conductivity( $\lambda$) ($W.m^{-1}k^{-1}$) | Thermal Absorptivity (b) ($W.m^{-2}s^{1/2}k^{-1}$) | Thermal Diffusivity(a) ($m^2s^{-1}$) | Gain(g) % | Immersion time(i) (min) | Air permeability(p) ($ft^3m^{-1}s^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1 | 0.68 | 42.57 | 105.67 | 0.158 | 300.2 | 19 | 349 |
| 2 | 0.67 | 42.5 | 105.13 | 0.167 | 298.7 | 20.2 | 319 |
| 3 | 0.6 | 41.83 | 119.67 | 0.126 | 278.3 | 6.2 | 234 |
| 4 | 0.62 | 41.97 | 121.67 | 0.120 | 286.5 | 3.5 | 219 |
| 5 | 0.6 | 46.5 | 120.67 | 0.149 | 311.5 | 24 | 321 |
| 6 | 0.62 | 46.77 | 139 | 0.116 | 298.2 | 25.1 | 302 |
| 7 | 0.54 | 43.03 | 140 | 0.094 | 264.9 | 2.3 | 174 |
| 8 | 0.55 | 41.93 | 127.33 | 0.108 | 274.3 | 3.3 | 185 |

In order to investigate the effect of the factors under study (blend ratio, yarn input tension and finishing process) on the thermal comfort the following regression equations were estimated according to the given mathematical modal; $Y=a_0+a_1F+ a_2B+ a_3T+ a_1\ a_2F\ B+ a_1\ a_3F_1\ T+ a_2\ a_3B\ T$, where: F: Finishing process, B: Blend ratio and T: yarn tension

### 3-1 Thermal Conductivity:

The following regression equation was estimated to determine the factors that affect this property with $R^2$ 0.988

$$\text{Conductivity}= 43.36 - 2.34F+ 2.39B \quad (1)$$

*P-value* 2E-08 0.037 0.034

Where: F: Finishing process; 1= open width form, 0= close width form. B: Blend ratio; 1=50% Modal, 50% Cotton and 0=100% cotton.

As it can be seen from equation (1) that as the blend ratio % (B) increases the thermal conductivity increases; this is due to the high thermal stability of Modal fibers due to its high crystallinty and orientation [12].Also the close width form gives higher conductivity. Figure (2) shows the effect of blend ratio and finishing process on conductivity. It is clear from the figure that the yarn tension has no effect and that as the ratio of modal increases the conductivity increases too and the close width gives higher conductivity.

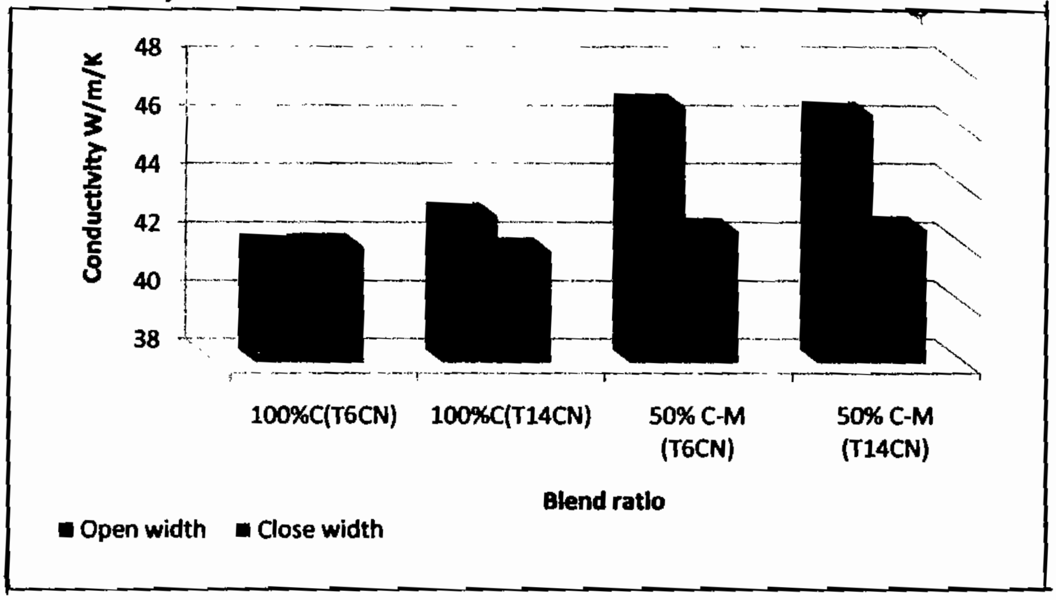

Figure (2) relation between blend ratio and Conductivity

## 3-2 Thermal Absorptivity:

The thermal absorptivity (b) reflects the hot or cold feeling of the fabric. the following equation was estimated to determine the thermal absorptivity (b) with $R^2$0.642

absorptivity b=128.1-22.7FB (2)

*P-value* 3E-08 0.017

Where: F: Finishing process; 1= open width form, 0= close width form. B: Blend ratio; 1=50% Modal, 50% Cotton and 0=100% cotton.

As it can be seen form equation (2) that both the finishing processes (F) and the Modal %( B) effects the thermal absorptivity.

Figure (3) shows the relation between blend ratio and the studied factors on absorptivity. It is clear from the figure that the yarn tension has no significant effect and that as the cotton fabrics gave higher absorptivity than the 50% -50% Modal- cotton fabrics. Also the open width finishing process gave less absorptivity, this agrees with equation (2).

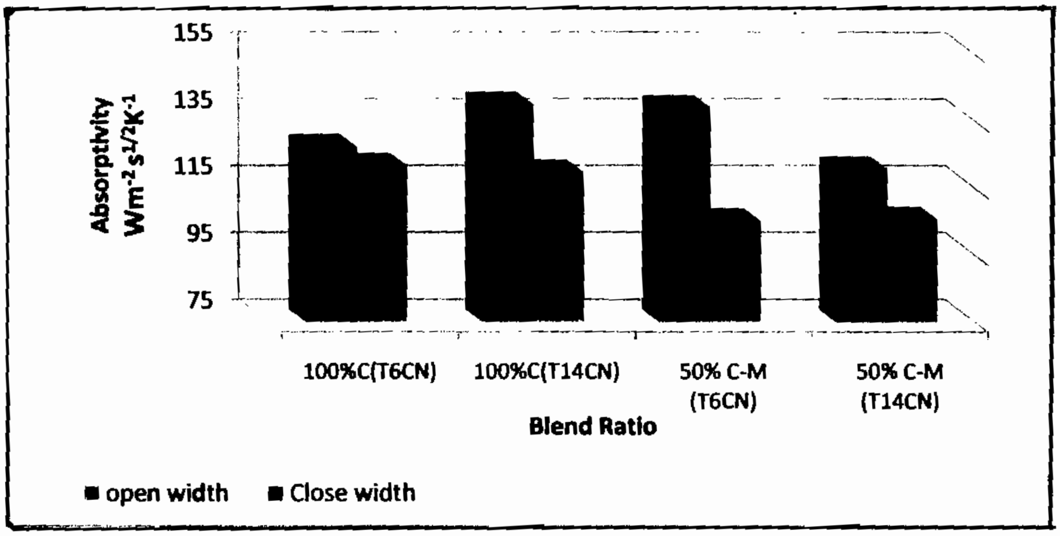

Figure (3) Relation between blend ratio and absorptivity

### 3-3 Thermal diffusivity:

The following equation with $R^2 0.843$ was estimated to determine thermal diffusivity (a).

$$\text{thermal diffusivity } a = 0.099 + 0.026F + 0.035B \quad (3)$$

| *P-value* | 4E-05 | 0.028 | 0.009 |
|---|---|---|---|

Where: F: Finishing process; 1= open width form, 0= close width form. B: Blend ratio; 1=50% Modal, 50% Cotton and 0=100% cotton.

Since the,

$$\text{thermal diffusivity} = \frac{\text{thermal conductivity}}{\text{density} \times \text{Specific heat}}$$

and the specific heat and the density are constant for the same material. Therefore the material will have the same trend as in the case of the thermal conductivity, this is clear from equations (1) and (3) that the coefficient of the B is positive in both equations. On the other hand, the Finishing process gave a different affect on diffusivity. This indicates that the finishing process is of great importance to the thermal properties of the fabric and that it affects the comfort of the body.

### 3-4 Water absorption properties:

First the wicking behavior of the sample was studied. The following equation (4) shows the factors affecting the immersion time (min) for complete immersion of samples, with $R^2 0.987$

$$\text{Immersion time} = 3.843 + 20.7B - 4.95FB \quad (4)$$

| *P-value* | 0.002 | 1E-05 | 0.015 |
|---|---|---|---|

Where: F: Finishing process; 1= open width form, 0= close width form. B: Blend ratio; 1=50% Modal, 50% Cotton and 0=100% cotton.

It can be seen that as the 50% cotton 50% Modal fabric (B=1) gave higher immersion time, due to the high absorption capability of the modal fibers [13]. Figure (4) shows the relation between blend ratio and the studied factors on the immersion time. It is clear from the figure that the 50% -50% Modal- cotton fabrics gave higher immersion time. Also the close width finishing process gave higher immersion time.

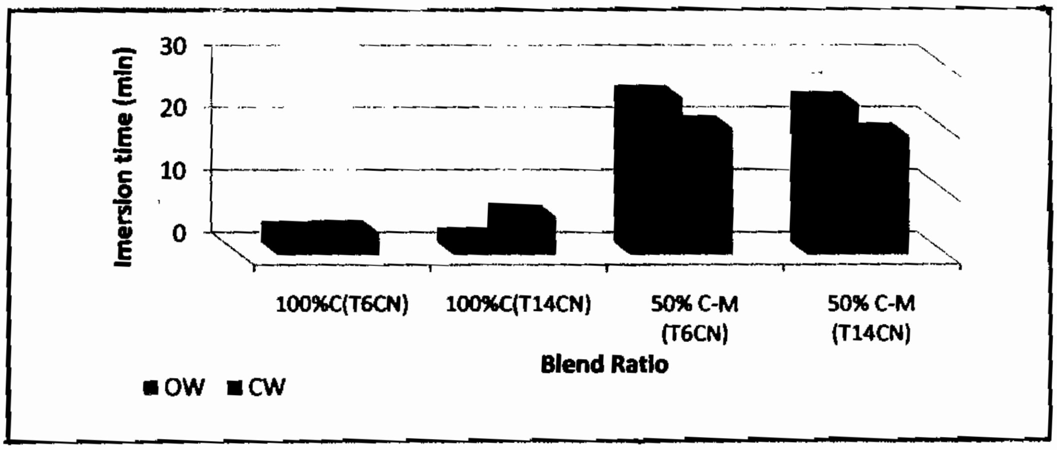

Figure (4) Relation between blend ratio and immersion time

Similarly, the percentage gain was calculated with $R^2$ 0.792

Gain %= 276 + 26.17B

*P-value* 5E-10 0.003

As it can be seen it has the same trend as the immersion time, accept for the Finishing process has no effect in this case. This is clear from figure (5)

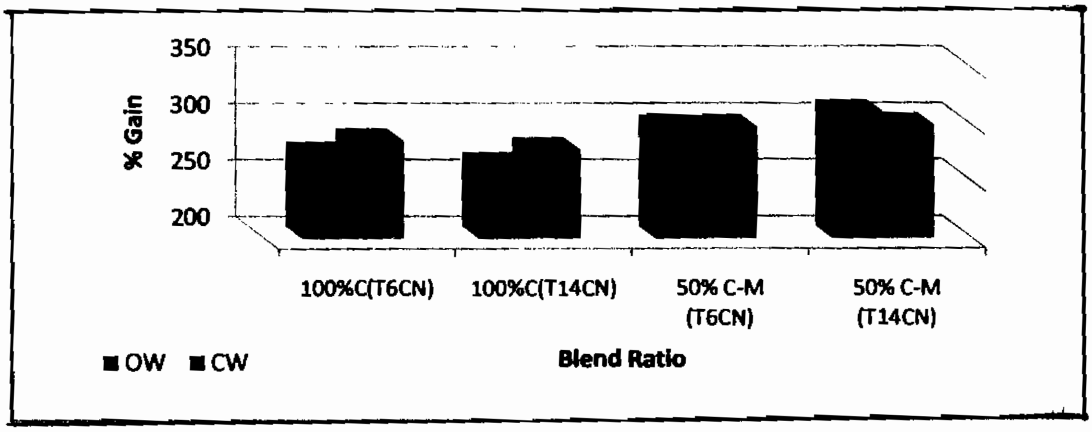

Figure (5) Relation between blend ratio and Gain %

## 3-5 Air Permeability:

Finally, the air permeability can be estimated from the following equation with an $R^2$ 0.966

Air permeability= 185.6 + 34.75F + 119.8B

*P-value* 5E-06 0.021 9E-05

Where: F: Finishing process. B: Blend ratio.

As it can be seen the modal fabric gave higher air permeability due the smooth surface of the modal fabric and the low hairiness which allows more amount of air to pass through the same area, and also the high packing factor of modal fibre compared with cotton fibre, this agrees with the results obtained in previous research [14]. Also the open width form gave more air permeability; this is due to the open structure of the fabric during this finishing process.

## 4-Conclusions:

In this research work thermal properties of knitted fabrics produced from 100% cotton and 50%cotton/50%Modal fibres were studied. Also, the water absorption and air permeability properties were studied, although they are not thermal properties, but they are of great importance from the comfort point of view. Results show that as the blend ratio % of modal fibre increases in the fabric, the thermal conductivity, diffusivity, immersion time, gain percentage and air permeability increases. Also, the finishing process was found of great importance to the thermal properties of the fabric, in case of cotton –modal blended fabric, which means that it affects the comfort of the body. Finally, the yarn input tension has no affect on the thermal properties of the fabrics.

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