DETERMINING THE LOAD AMOUNT AND TEXTILE TYPE AT THE CONDENSER TYPE TUMBLE DRYERS

by
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DETERMINING THE LOAD AMOUNT AND TEXTILE TYPE AT THE CONDENSER TYPE TUMBLE DRYERS

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ABSTRACT

DETERMINING THE LOAD AMOUNT AND TEXTILE TYPE AT THE CONDENSER TYPE TUMBLE DRYERS

In this project, the load amounts and types of textile in the condenser type tumble dryer was determined in order to automatically select the most suitable program cycle for drying of the laundry, and the sensing algorithm was developed. Two textile types such as cotton and polyester and five load amounts were examined for sensing studies. Many tests for different initial moistures were conducted in order to distinguish the differences between these load amounts and textile types at the condenser type tumble dryer. These tests were made with respect to proper heating algorithm that was created for these sensing studies. The data of drum outlet temperature and electrical resistance were used in order to differentiate the load in the drum. The sensing of the load amount and textile type were realized by responses of NTC temperature sensor and conductivity sensor. As a result of analyzing the temperature and electrical resistance data, the load amounts were able to be determined by temperature difference between the eighth and thirteenth minutes of the algorithm. On the other hand, cotton and polyester were sensed by using the knowledge of load amount. According to the load amount, two methods which were temperature analysis and average electrical resistance, were used to differentiate cotton and polyester textiles from each other. As a conclusion, sensing steps were combined into one algorithm.

ÖZET

KONDENSER TİPİ TAMBURLU ÇAMAŞIR KURUTMA MAKİNASINDA YÜK MİTARI VE TEKSTİL CİNSİ ALGILAMA

Bu proje kapsamında, kondenser tipi tamburlu çamaşır kurutma makinesinde çamaşırları kurutmak için en uygun programın otomatik olarak seçilmesi için yük miktarı ve tekstil tipi belirleme çalışmaları yapılmış ve algılama algoritması oluşturulmuştur. Algılama çalışmaları için pamuk ve polyester olmak üzere iki çeşit tekstil tipi ve beş adet yük miktarı seçilmiştir. Kondenser tipi tamburlu kurutuculardа, bu yük miktarları ve tekstil tipleri arasındaki farklılıkları incelemek için farklı giriş nemlerinde şartlandırılan tekstillerle kurutma testleri yapılmıştır. Bu testler, algılama çalışmaları için oluşturulmuş uygun ısıtıcı algoritması ile yapılmıştır. Çalışmanın başında yük miktarının ve tekstil cinsinin makine üzerinde bulunan mevcut NTC sıcaklık sensörü ve iletkenlik sensörü ile algılanılması amaçlandığı için, tambur içerisinde yer alan yükü tanımlayabilmek için tambur çıkış sıcaklığı ve elektriksel direnç verileri kullanılmıştır. Sıcaklık ve direnç verilerinin incelenmesi sonucunda, yük miktarı algoritmanın sekizinci ve on üçüncü dakikaları arasındaki sıcaklık artışı ile ayırt edilebilmiştir. Pamuklu ve polyester tekstil tipleri ise yük miktarına bağlı olarak sıcaklık analizi ve ortalama elektriksel direnç metodu olmak üzere iki farklı yöntem ile algılanmıştır. Sonuç olarak, algılama aşamaları tek bir algoritmada birleştirilmiştir.

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LIST OF SYMBOLS AND ABBREVIATIONS

DC	Direct current
LF	Load factor (1/kg)
m	Mass (kg)
NTC	Negative temperature coefficient
P	Power (W)
Q	Load factor of 4 kg (1/kg)
T	Temperature (°C)
t	Time (s)

1. INTRODUCTION

1.1. BACKGROUND

Historically, only heat source was the sun able to dry clothes. Drying clothes was time consuming and labor intensive process, also was usually all day event with washing clothes. Later, the first version of the tumble dryer was created by a Frenchman named Pochon in 1799 to become easier to process. It was a metal drum with holes in it which was cranked by hand, over an open fire. American Inventor George T. Sampson was granted a patent on June 7, 1892 for his version of the clothes dryer. It included a metal drum with a rack that held the clothes away from the heat source. Sampson's dryer was heated in a stove, rather than over an open fire, making his model was more efficient, and safer to use. The first electric tumble dryers appeared at the market in the 20th century, around 1915 [1].

Since the market penetration of tumble dryer, it has continued developing. At this developing process, firstly, in the late 1950s larger dryers emerged and a dryness sensor was invented. The sensor was able to determine when the clothes were dry, automatically shutting off the dryer at the correct time. The dryness sensor was a time and money-saver for many consumers. Furthermore, in 1974 a microelectronic controller feature was added to tumble dryers. Improving on the dryness sensor, this controller was created to control all aspects of a drying cycle; including dryness and length of time. In 1983, delayed start timers allowed for people to set their dryers to start at a certain time of day. This helped people to better monitor their energy use. In the 21st century tumble dryers have continually been perfected. Similar to any enhanced home appliance, new dryers come with LCD touch screens, rather than turn know controls [1].

With improving technologies, the studies about the tumble dryer have been carried out by white goods manufacturer since the tumble dryer penetration in Western Europe is in average at 34,4 per cent [2]. Moreover, in Europe, over 4 million tumble dryers are sold each year [3]. These studies were primarily about the energy efficiency but the comfort of consumer is the crucial as much as being eco-friendly appliances for market competition. When the

available technologies are taken into consideration, the auto- program feature at the tumble dryer is the demand for the users of tumble dryer. For the available tumble dryers, the appropriate program selection according to textile type is made by user from the potentiometer of the dryers. Additionally, there is not option about load amount selection. Although, some of the tumble dryers at the market are able to sense the load amount at the drum and correct the duration of the drying process, this feature is not available at Arçelik tumble dryers that were used in studies at this report. It was aimed that sensing either textile type or load amount will be possible at these tumble dryers.

1.2. DOMESTIC TUMBLE DRYERS

1.2.1. Air Vented Dryers

The air vented dryer consists of a drum, a fan, an electric heater, a motor to rotate the drum and some ducting to exhaust the moist air to the outside as shown in Figure 1.1 [4].

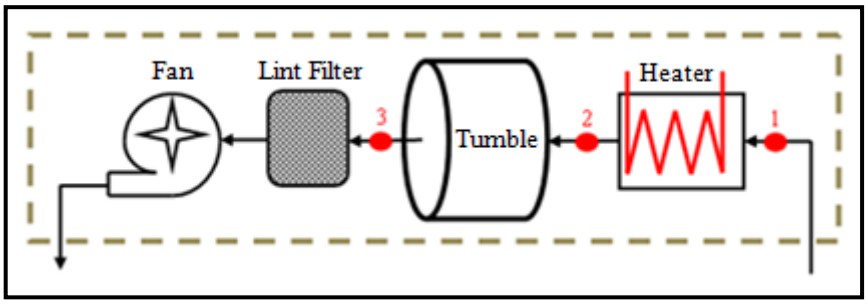

Figure 1.1. Components of air-vented dryer [5]

For drying wet clothes, a fan blows ambient air from the room and the air is heated at electric resistance heater. Hot air then enters the clothes drum, picks up moisture from wet clothes and the humid air eventually leaves the drum. The evaporation process of the moisture in the clothes realizes due to the difference in partial vapor pressures between the saturated air near the wet clothes and the hot relatively dry air in the drum. Increasing the temperature of the entering air increases the amount of evaporated water from clothes that is shown in Figure 1.2 as a psychometric chart. The humidification process is essentially an isenthalpic process as shown on the psychometric chart in Figure 1.2, where the enthalpy

of vaporization of moisture is supplied by the sensible cooling of air. For this reason, the temperature of the exiting humid air is always lower than the air temperature entering the drum [4].

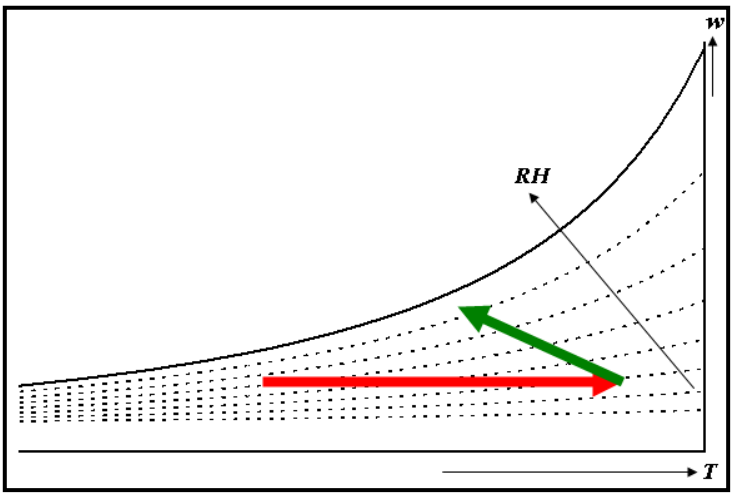

Figure 1.2. Thermodynamic process of an air vented dryer [5]

Air vented tumble dryers are technically simple, cheap, effective, reliable and relatively fast. The majority of dryers sold in the UK (60 per cent) are air-vented. There is a hidden added cost to running vented tumble dryers during cold weather, when additional heating is required [6].

1.2.2. Condenser Tumble Dryers

This system is of a closed cycle and does not require a venting duct to the exterior of the house. Therefore, consumers may place the dryer virtually at any location within their house. Today two types of condenser tumble dryers can be found on the market:

- Air condenser dryers
- Heat pump dryers

1.2.2.1. Air Condenser Dryers

An air condenser dryer consists of a heater, drum, filter, fan and condenser in the closed process cycle and also a secondary fan in the cooling cycle as shown in Figure 1.3 [4].

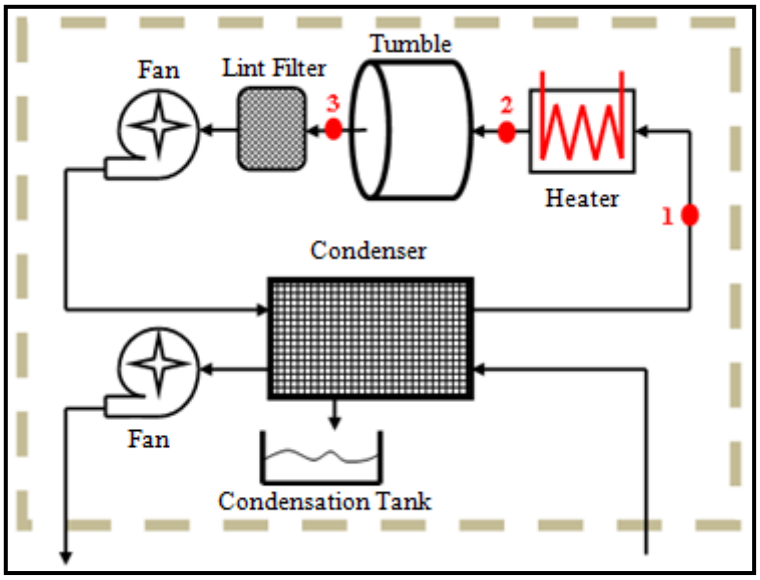

Figure 1.3. Components of air condenser dryer [5]

At the air condenser dryers, for drying wet clothes, process air is heated up by a heater before entering the tumble. As a result, its relative humidity decreases, and thus the evaporating potential of the process air increases as shown on the psychometric chart in Figure 1.4. In the tumble, the hot and dry air evaporates the moisture from the clothes. The humid process air that exits the tumble is blown to the condenser by a process fan after passing through the filter. In the condenser the humid process air is cooled by the ambient air which is blown by another fan, resulting in the condensation of the water vapor in the process air. The condensed water is either pumped to a holding tank for manual removal or directly pumped to drain so that users may not have to periodically empty the large condensate holding tank [4].

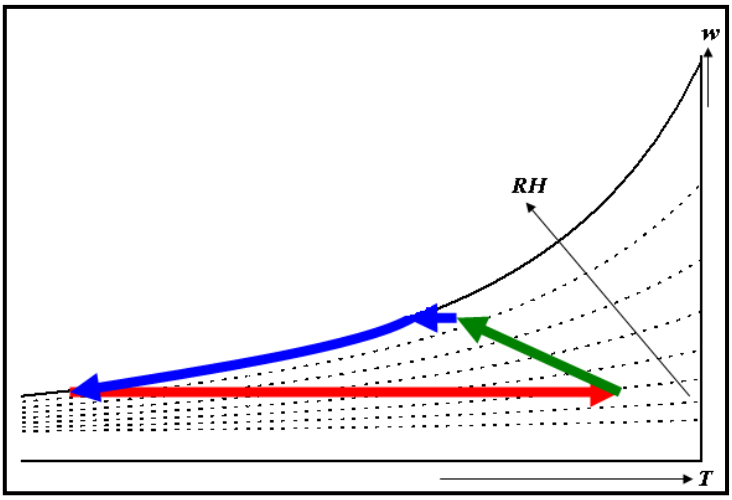

Figure 1.4. Thermodynamic process of an air condenser dryer [5]

Despite the disadvantages of being costly and requiring more regular maintenance such as manual water drainage and the removal of lint accumulated in the condenser, air condenser dryers have become a method more favored for automated drying in the EU. In today's world where energy resources are dropping at alarming rates due to the massive global demand, every little step toward improvement should be considered important for these huge energy consuming home appliances [6].

1.2.2.2. Heat Pump Dryers

A heat pump dryer basically consists of a drum, filter and fan within the process cycle; a condenser, evaporator, expansion valve and compressor within the cooling cycle as shown in Figure 1.5 [4].

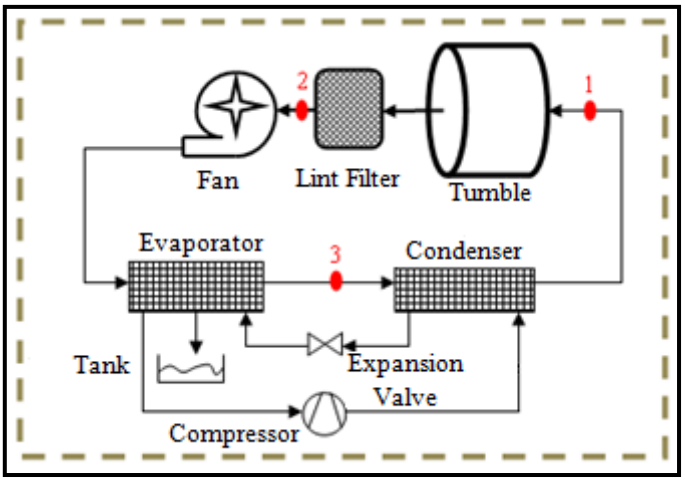

Figure 1.5. Components of heat pump dryer [5]

For drying wet clothes in heat pump dryers, after passing through the tumble and the filter, humidified air is blown to the evaporator where its temperature is reduced below the dew point and condensation occurs. After the evaporator, the process air goes through the condenser where it is heated before being blown back to the tumble [4].

Heat pump dryers can be up to 50 per cent more efficient than electrically-heated dryers but they are also the most expensive type of tumble dryer to buy. Because of the high prices based on the high manufacturing costs, however, its market share as of now could not reach even 1 per cent.

1.3. PROPERTIES OF POLYESTER AND COTTON TEXTILES

1.3.1. Cotton

Cotton is a soft white fibrous substance covering seeds of certain plants. Asiatic cottons first grew wild in East Africa. About 5000 years ago, the people in what is now Pakistan cultivated cotton [7]. Revolution in cotton processing was brought by the invention of cotton gin in 1793. Various types of cotton with improved features started to be produced with the growth of power loom in 1884 [8].

Figure 1.6. Cotton plant

The cotton fiber is primarily composed by cellulose; its average composition is 85 per cent cellulose, 5.5 per cent organic matter, 1.5 per cent mineral matter and 8.5 per cent humidity. The properties of the cotton fibers are depending on the length of the fibers. The longer the fibers the thinner they are and also the better the properties. As a result of heat action, yellowing of the fibers occur around 120°C – 150°C. Decomposition begins above 150°C – 200°C. Accordingly thermal properties, cotton burns like paper leaving light light-gray ashes. Moreover, cotton is conducting heat moderately well.

From naked eyes, cotton fibers are clear and silky, generally of white colors or are slightly tinted. From longitudinal observation under the optical microscope, each fiber is made of a single stretched cell with helicoidal circumvolutions from the growth of the plant. They are more important in the better quality cotton and disappear in the dead fibers. From transverse observation, the fiber presents fine walls surrounding a very broad, flattened and irregular central channel. The section form is bean like. The average diameter also varies according to the origin of the cotton and goes from 20 to 40 micrometers.

Moisture regain of the cotton fiber changes from 8.5 to 12 per cent. Also, moisture absorption rate is 14.2 per cent. Water is swelling the cotton and untwisting the fibers, but the circumvolutions are recreated during the drying. The tenacity is increasing when the fiber is wet (10 to 20 per cent).

1.3.2. Polyester

Polyester is the general name for any group of widely used synthetic products. Polyesters are strong, tough materials that are manufactured in a variety of colors, shapes and sizes. The first commercial production of polyester was by the du Pont de Nemours Company. It is the most used fiber in the United States.

The polyester is not a highly flammable fiber. When it is brought near to a flame, it starts to melt. In contact with the flame, it burns with fusion by leaving a hard black residue. The loss of tenacity under dry heat action is rather low. It has good thermal insulation.

Under the microscope, the longitudinal view shows a smooth surface of regular and homogeneous aspect. Granulations or pigmentations appear in the case of dull or semi-dull wire and in the case of dope dyed wire. The cross section is generally round and smooth with a possible internal pigmentation. There are also filaments with a multilobal cross section.

Moisture regain of the polyester fiber is 3 per cent under 20 ° C temperatures and 65 per cent relative humidity. Also, moisture absorption rate is 0.7 per cent. The moisture regain is very weak. This explains the great stability of the mechanical properties when wet and very fast drying.

2. PREVIOUS STUDIES

2.1. LITERATURE SURVEY

Researches on tumble dryers are insufficient in the literature. Most of these researches are about the performance and efficiency of dryer since the dryer is one of the white appliances that consume much energy. Therefore, researches about determining the load amount and textile type at the condenser tumble dryers was not found in the open literature. Although textile studies at the tumble dryers was not found specifically, there are some researches about water interaction of textiles, moisture gain and moisture transfer of textiles take place in the literature and they can explain drying behavior of textiles in the tumble dryer.

Drying properties of textiles were greatly influenced from wetting and wicking abilities of textiles and some researches were done about interaction of water of textiles [9-15]. Different drying properties and water interactions of cotton and polyester fabrics demonstrate the ability of sensing the textile type in the tumble dryer. There is general agreement that fiber type (e.g. hydrophobic, hydrophilic), fabric structure (e.g. dimensions of interstitial spaces, mass, thickness), fiber and/or fabric finishing treatments (e.g. mercerization, shrink proofing) have the potential to affect the wetting of a fabric [15]. Firstly, Kissa was described the wetting and wicking phenomena in their paper [9]. Wetting is the displacement of a fiber-air interface with a fiber-liquid interface. Textile fibers wetting phenomena are complicated by surface roughness, heterogeneity, and adsorption of liquids or surfactants with a consequent change of surface energy; since they do not have ideal surfaces. The wettability of fibers depends on the chemical nature of the fiber surface and fiber geometry, especially surface roughness. Moreover, wicking is the spontaneous flow of a liquid in a porous substrate, driven by capillary forces. Wicking is affected by the morphology of the fiber surface, and may be affected by the shape of the fibers as well. The common belief that the fiber shape does not affect wetting is valid only for the wetting of single fibers. The shape of fibers in an assembly such as yarn or fabric affects the size and geometry of the capillary spaces between fibers, and consequently the rate of wicking. The interaction of liquids and textiles depends on the wettability of fibers,

their surface geometry, the capillary geometry of the fibrous assembly, the amount and nature of the liquid and external forces.

In 1998, Crow and Osczevski examined the interaction between water and a range of fabrics because of claims that synthetic fibers such as polypropylene do not pick up moisture and so when made into active wear, leave the wearer warm and dry [10]. As a result of this study, they concluded that all fiber types , when made into fabrics, pick up water, with a strong correlation between a fabric' s thickness and the amount of water it picks up freely expressed in absolute terms rather than percent of its mass. Fabric structure, particularly the fiber-enclosed or intrafiber volume influences the amount of water a fabric picks up. Drying time and energy required to evaporate water from under and through a dry fabric or dry a wet fabric, depend on the amount of water the picks up, not fiber type. The amount of water wicked from one layer to another depends on pore sizes and their corresponding volumes. The actual amount of water held by the fabrics increased with the number of weft yarns. Furthermore, Prahsarn, Barker and Gupta investigated the ability of different knit materials to dissipate moisture vapor from a saturated clothing environment to the ambient atmosphere [11]. They used some methods to measure the moisture vapor transport behavior of polyester knit fabrics. As a conclusion of this research, yield parameters that are correlated and influenced primarily by the thickness of the fabric. The higher the air permeability of the fabric has the smaller the microclimate drying time. Fabric construction has an overriding influence on moisture vapor transport behavior, especially in low density open textile structures. A primary design criteria for a fabric for high moisture vapor transport performance is a structure that is both thin and open. However, both of the researches were stated that drying property of textiles were depends on water permeability and densities of textiles not textile type, the densities and water absorption properties of textiles that were used in this study were different [16]. The different drying and water interaction behavior of cotton and polyester textiles were described in the following journal.

Ching Iuan Su, Jun Xian Fang, Xin Hon Chen and Wen Yean Wu examined the water absorption capacity, diffusion rate, and drying rate of knitted fabrics made from the three composite yarns to shed light on their moisture absorption and release performance [12]. It was stated that, natural fibers such as cotton and wool are hydrophilic, meaning that

their surface has bonding sites for water molecules. Therefore, water tends to be retained in the hydrophilic fibers, which have poor moisture transportation and release. On the other hand, synthetic fibers such as polyester are hydrophobic, meaning that their surface has few bonding sites for water molecules. Hence, they tend not to get wet and have good moisture transportation and release. Neither natural nor synthetic fibers can perform well in both moisture absorption and release at the same time. In this study, composite yarns were compared according to water absorption capacity, diffusion capacity and drying rate. The experimental results of this study reveal that the use of profiled polyester fibers can enhance the diffusion rate and drying rate, leading to good moisture release. However, polyester fibers are hydrophobic and thus have poor water absorption capacity. This drawback can be overcome by adding cotton fibers, which are hydrophilic. Core and cover yarns containing profiled polyester filaments perform better in moisture absorption and release compared with polyester/cotton blend yarn.

Wang, Xu, Li and Cui studied on the electrical resistance of textiles under wet conditions [17]. They selected cotton and polyester to show the effects of fiber materials on the electrical resistance of fabrics. They stated that, absorbing mechanism of cotton is chemical absorption in which moisture is mainly absorbed by the fiber itself while polyester fabric absorbs moisture mainly by physical absorption, in which moisture is absorbed by the porous structure of the fiber, yarn, and fabric. The specific surface area of fibers shows great impact on water absorption, as the specific surface area of cotton is much larger than that of polyester, thus it absorbs a larger amount of water. Furthermore, the resistance of cotton fabric at each moisture regain point is much lower than that of polyester fabric. As a kind of hydrophilic material, cotton can absorb and diffuse water swiftly through the fiber itself. While polyester can hardly absorb water, the contained water in polyester fabric was discontinuously distributed in the interspaces of fibers and yarns, which made the water unable to diffuse and thus the conductivity of water was relatively low. When the fabrics were placed in a closed circuit, water in the cotton fabric was diffused more quickly than that in polyester fabric, and the electrical conductivity was higher than that of polyester. This was probably due to the higher moisture absorption and contact probability of cotton, in which more dissociative water molecules can be ionized and thus the electrical resistance is lower than that of polyester. These results suggest that fiber materials will affect the electrical resistance of the fabrics from which they are made.

As a result of experiments, the electrical resistance of fabrics decreases gradually that was shown in Table 2.1.

Table 2.1. Electrical resistance of fabrics with different testing distance and moisture regains

Sample	Moisture Regain (%)	Testing Distance (mm)					
		10	**20**	**30**	**40**	**50**	**60**
Knitted Cotton	142	11	20	26	25	30	31
	123	14	22	30	30	35	34
	91	22	30	38	40	42	48
	52	46	51	70	75	80	85
	32	50	85	100	110	120	120
	12	100	200	450	500	800	1000
Knitted Polyester	163	17	25	30	36	42	46
	142	20	30	36	40	44	48
	93	26	38	40	44	54	55
	59	44	55	60	70	80	85
	22	120	140	80	200	220	230
	7	400	500	800	1000	1000	1000

2.2. PATENT SURVEY

Patents related to sensing the load amount or textile type at the tumble dryer were examined. In this search "fabric type", fabric sense", "load type", "load sense", "cloth type", "garment type", "determining load", "determining type" and "load" were used as key words and D06F58 was used as International Patent Classification Number in the European Patent Office site. As a result of this research, forty six patents were found that are related to load and textile type sensing at the tumble dryer. Eleven of them were summarized in this report which was more relevant to study that was described in this report.

In this research, there was less amount of patent about textile type sensing. On the other hand, there was more number of patents about determination of load amount at the tumble dryer.

When the sensing patents were classified according to the companies, LG was the company that was applied to most of the patents related to sensing methods. The patents distribution according to companies was presented in Figure 2.1.

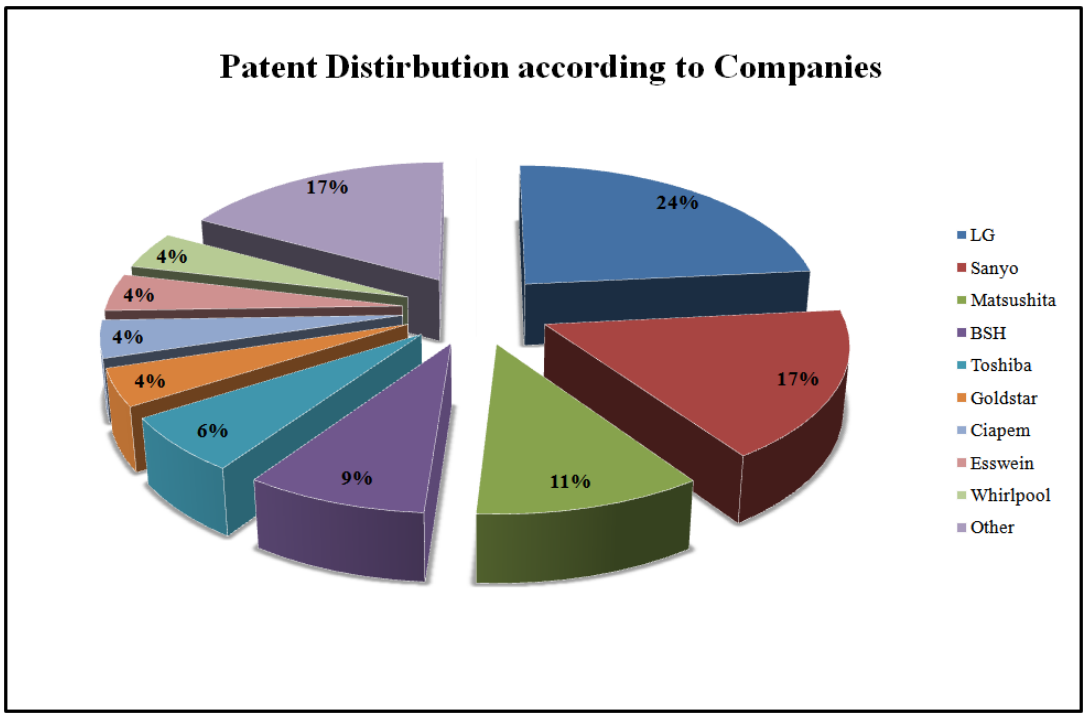

Figure 2.1. Patent distribution according to companies

Furthermore, the patents were classified accordingly methods which were thermodynamic, electrical and mechanical. Electrical and thermodynamic methods were major in the classification. The patents distribution according to methods was presented in Figure 2.2.

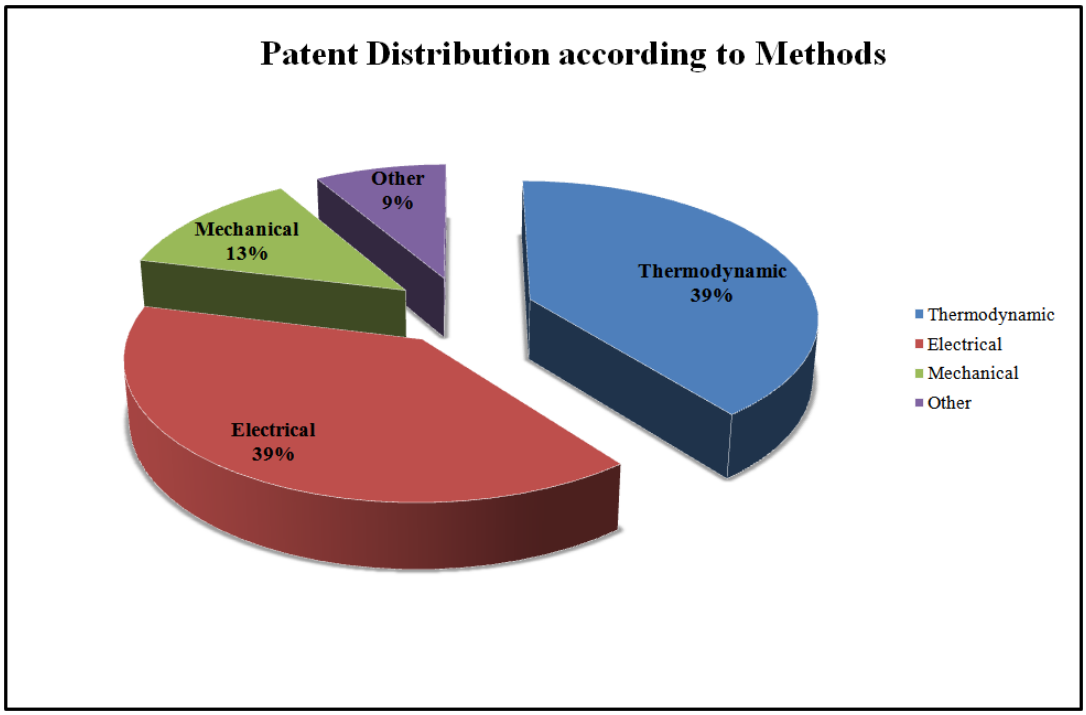

Figure 2.2. Patent distribution according to methods

In 2006, invention of LG was granted as KR100747589 B1 relates to a dryer that can sense a laundry amount and a dryness. There was a sensing unit for providing a pulse signal depending on contact to the drying object in the drum, a microcomputer for determining a load and dryness of the drying object with reference to the pulse signal from the sensing unit to control a general drying course. The microcomputer counts a number of pulses per unit time period from the sensing unit, to determine the load and the dryness according to a counted value, and controls an output capacity of the heater and a drying course finishing point according to the load and the dryness determined thus. It was aimed that using more accurate and safer system with a number of contact to the laundry. It was not used a direct contact system with the electrode sensor [19]. In Figure 2.3 the laundry amount with respect to count value was represented.

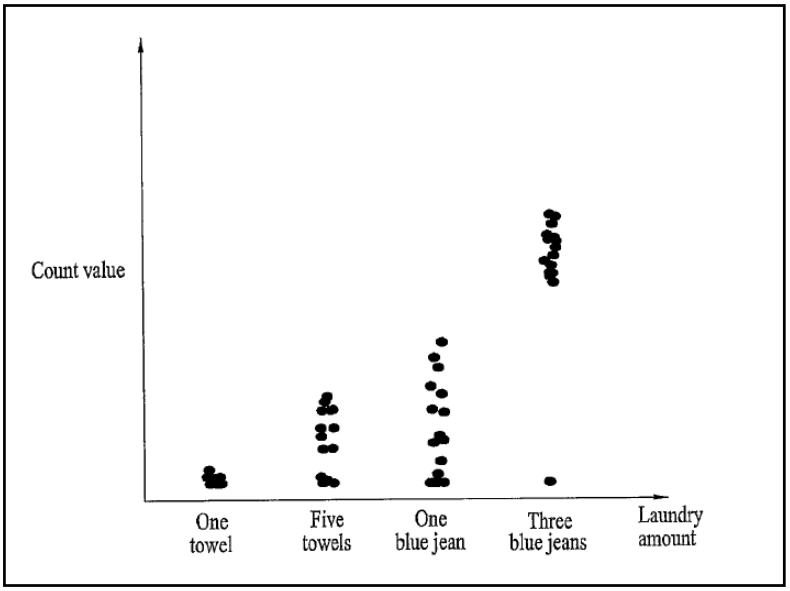

Figure 2.3. Schematic of KR100747589 B1 patent [19]

Zanussi within the patent which was published as EP0480387 B1, is aimed to identify the type of fabrics charged into the drum of the machine for being laundered or dried, and to automatically select the most suitable program cycle for the laundering or drying of the laundry. To determine the type of fabrics, the electrostatic charge of the laundry resulting from the friction of the different pieces of the laundry between one another was used. The internal walls of the drum is being rotated, was detected with the electrodes of which are each electrically connected to a sensor. Also, to differentiate the electrostatic charges, counter was connected to electrostatic discharge through processing and activating. Also, counter was adapted to count in an encoded form the duration from the start of accumulation of the electrostatic charges to their discharge through electrostatic discharge means. And to make a decision, comparator was connected to counter and, process through selector control unit to electronic program control unit as shown in Figure 2.4. The comparator was adapted in cooperation with selector control means. Electronic program control unit select different laundering or drying cycles in accordance with different types of fabrics to be laundered or dried, in response to the comparison, in an encoded form, of the count of duration to at least one reference count representative of a determined type of fabric [20].

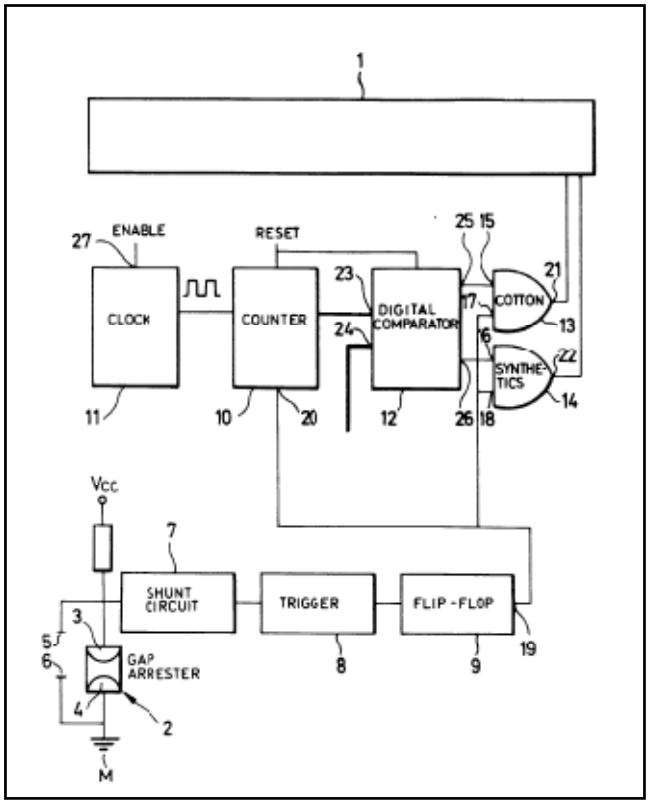

Figure 2.4. Schematic of EP0480387 B1 patent [20]

The patent application of Whirlpool that was published as EP1236826 A2, is about method for changing the program cycle of a household dryer while drying laundry, wherein the program can be changed and cancelled depending on the moisture of the laundry. In this method, the laundry comes into contact with moisture sensors during the drying process, moisture sensors that are attached to lateral grids provided between door and laundry drum at a level above the lowest point of the laundry drum as shown in Figure 2.5, record the contact frequency and moisture of the laundry. Those moisture sensors can determine the intervals between the individual contacts with pre-set minimum moisture from which the statistical means can be derived, and that the statistical means of the intervals that were obtained can be used to derive the changes of the program parameters, the display of the remaining drying time and the shut-off of the program [21].

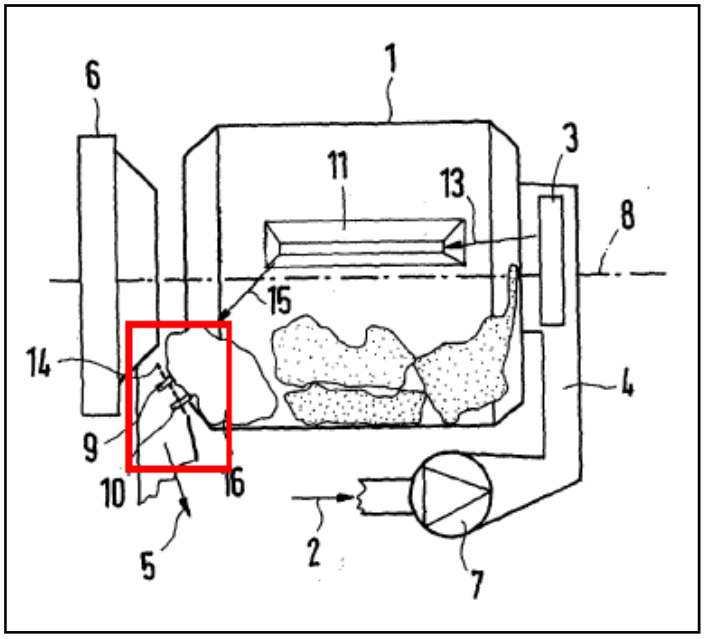

Figure 2.5. Schematic of EP1236826 A2 patent application [21]

The patent of Whirlpool that was published as KR100748963 B1, is related to drying control method for drying machines that is capable of calculating moisture content contained in the laundry. The method is the sensing the change in temperature of air before and after a heater during a drying operation of the drying machine to calculate moisture content contained in the laundry, thereby more accurately estimating drying time, and controlling the drying operation more efficiently corresponding to various load conditions. In the determination step; firstly, at least one of the temperature of air before being heated and the temperature of air after being were calculated. The load and moisture content contained in the laundry was calculated using a ratio of the change in temperature to the change in time. Drying operation was controlled according to the total load and the moisture content that was calculated. Schematic representation of method was presented in Figure 2.6 [22].

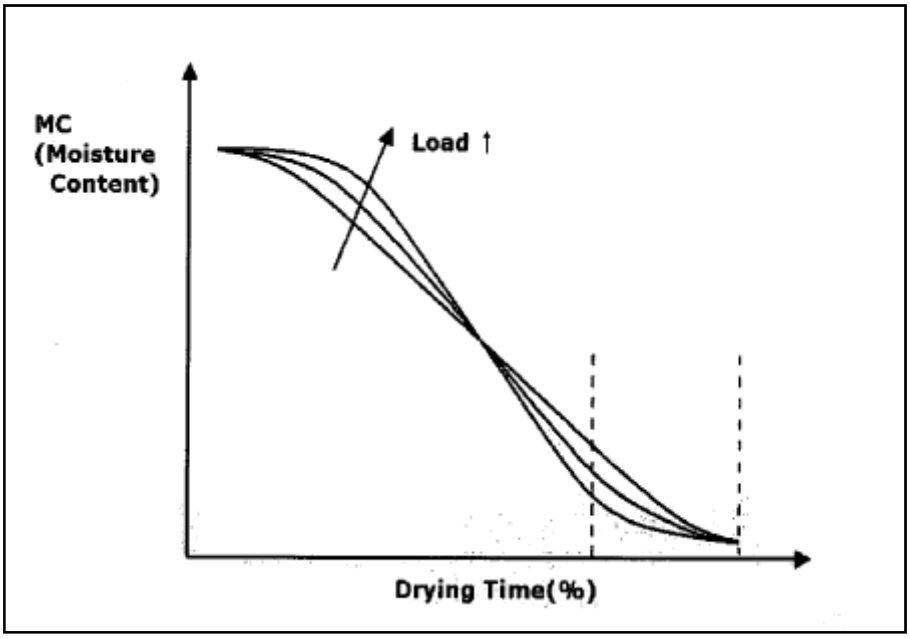

Figure 2.6. Schematic of KR100748963 B1 patent [22]

The patent of LG that was published as EP1507038 B1 is related to quantity of moisture contained in clothes in the drum of the clothes dryer displaying a residual clothes drying time on the basis of the detected moisture quantity. For sensing moisture content the resistance values were used. In this method, the pair of electrodes of the moisture detectors are contacted with the clothes rotated according to the rotation of the drum. Herein, both ends resistance value of the pair of the electrodes is varied according to a quantity of moisture contained in the clothes in the drum. A both ends resistance value of the electrodes of the moisture detector is in inverse proportion to a quantity of moisture contained in the clothes in the drum. In addition, the moisture detector converts both ends resistance value of the electrodes into a moisture detecting voltage and outputs the converted moisture detecting voltage to a controller, as shown in Figure 2.7. Hereinafter, a method and an apparatus for detecting a residual drying time of a clothes dryer capable of detecting a quantity of moisture contained in clothes accurately on the basis of a moisture detecting voltage value detected by the moisture detector and a drum outlet temperature value detected by the temperature detector and displaying a residual drying time according to the detected quantity of moisture [23].

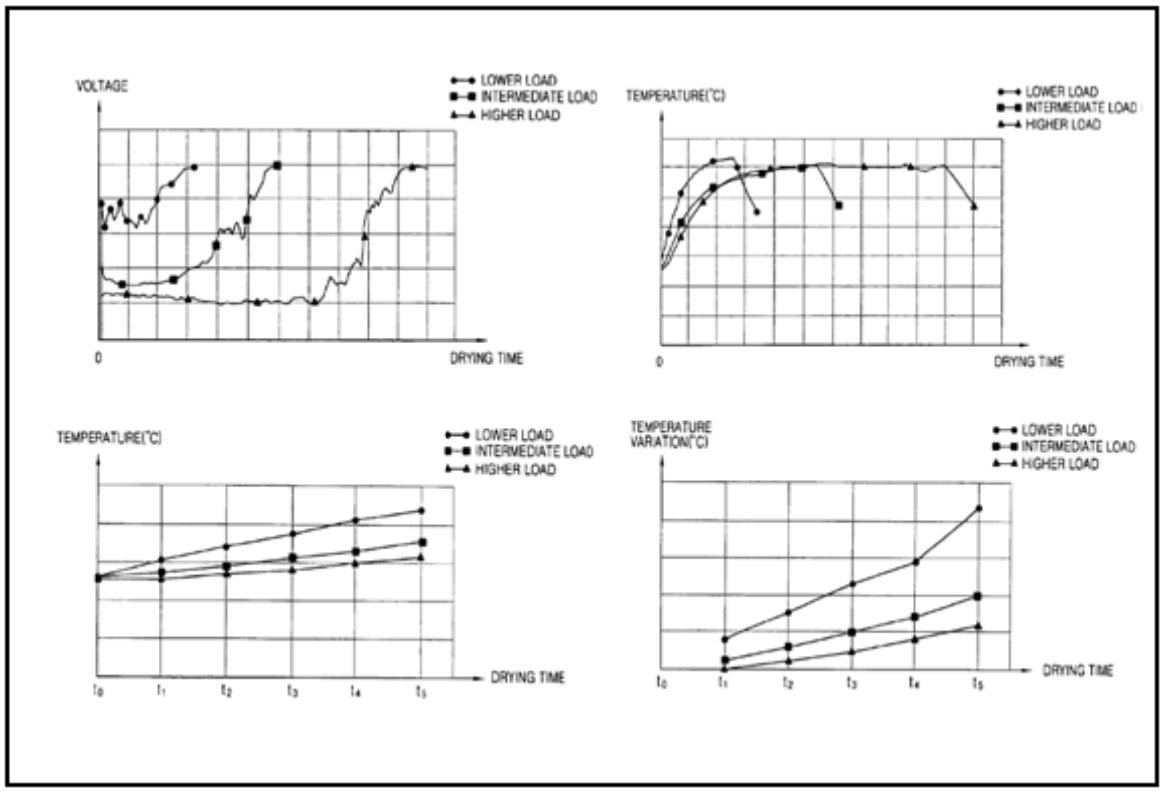

Figure 2.7. Schematic of EP1507038 B1 patent [23]

The patent application of General Electric that was published as US6122840 A is related to a closed loop fuzzy logic control for determining drying time. The system for determining drying time comprising; a first temperature sensor disposed in a first location for a first signal representative of temperature inside said drum and a second temperature sensor disposed in a second location for transmitting a second signal representative of exhaust air temperature. The mean of temperature difference between said first and second temperature signal was calculated and fuzzy logic controller determines membership in fuzzy sets representing clothes load in correspondence with said mean temperature difference signal, as shown in Figure 2.8. In conclusion, fuzzy logic controller for determining drying time as a function of the determined membership in fuzzy sets representing clothes load, as shown in Figure 2.9 [24].

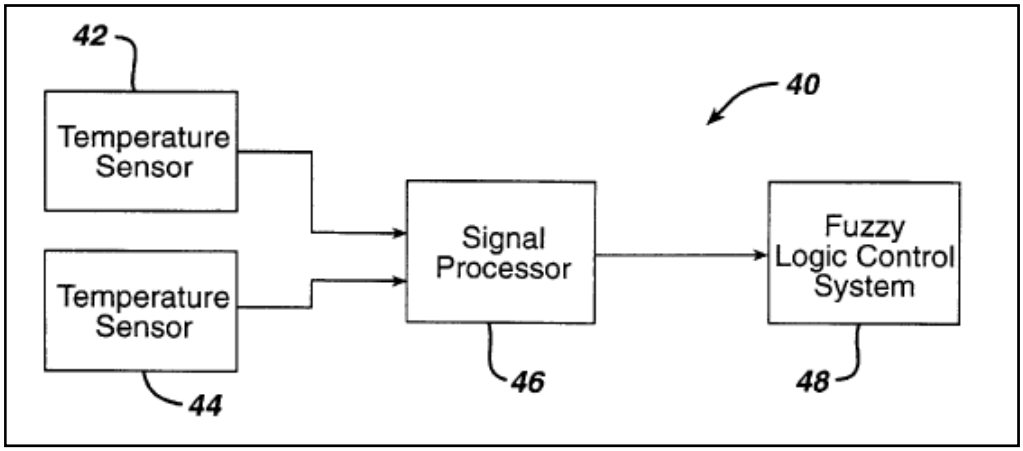

Figure 2.8. Schematic of US6122840 A patent application [24]

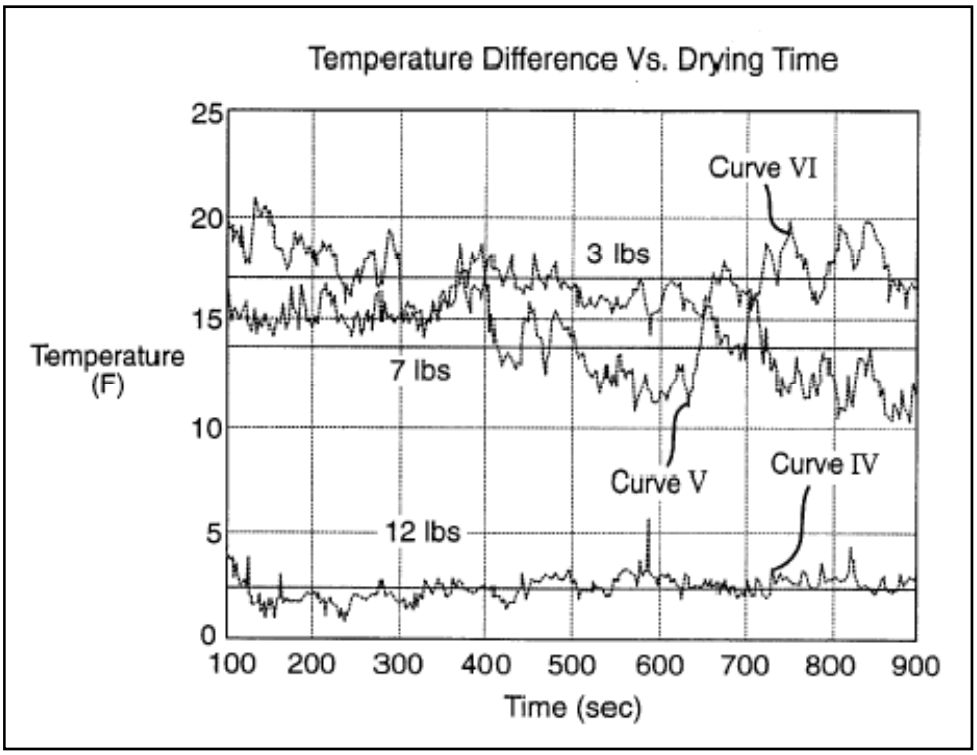

Figure 2.9. Schematic of US6122840 A patent application [24]

The patent of BSH that was published as EP0898009 B1 is related to a method for determining a load in a tumble dryer. Initially, laundry is moved in a laundry drum and the electrical conductivity of the laundry is determined by electrodes residing in the laundry drum. The method is distinguished by the fact that a range of fluctuation of the electrical conductivity is determined and serves as a measure of the load. The range of fluctuation is determined as the difference between the maximum and minimum values of the conductivity within a specific time interval. The maximum and minimum values of the measured conductivities are averaged and the range of fluctuation of the averages in each case is determined. By averaging, the influence of short-term interference is reduced, and the measurement certainty of the determination of the load is increased [25].

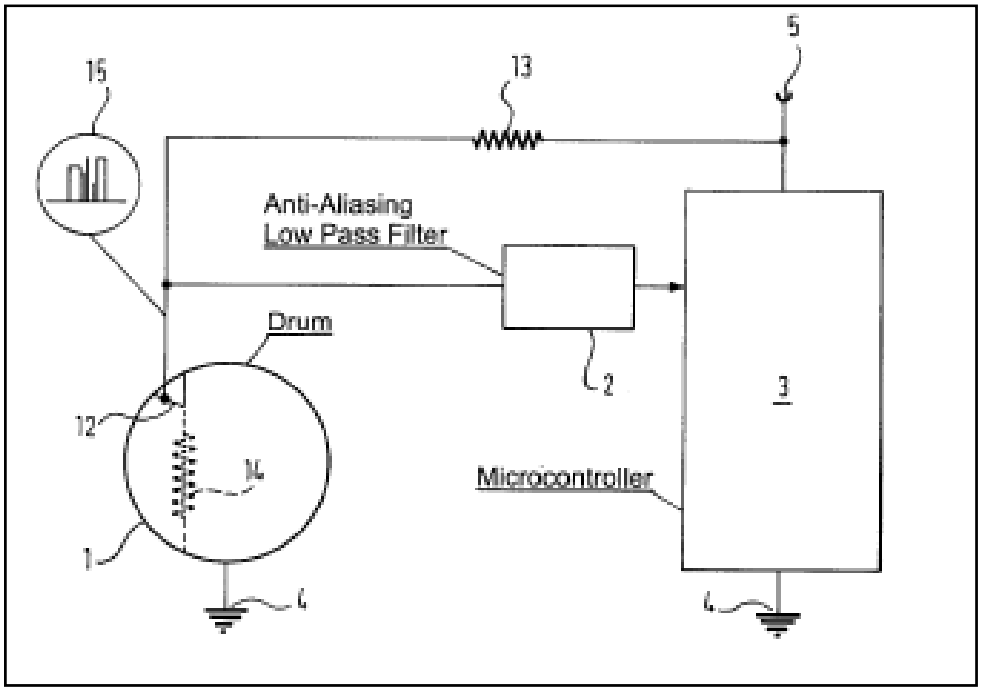

Figure 2.10. Schematic of EP0898009 B1 patent [25]

The patent of BSH that was published as EP0898008 B1 is related to a method for determining a load in a tumble dryer. There is provided a method for determining a load in a tumble dryer, which includes moving laundry in a laundry drum having electrodes; generating a pulsed conductivity measurement signal measuring electrical conductivity of the laundry as a result of contact occurring at least from time to time between the laundry and the electrodes of the laundry drum; and determining a frequency of the pulsed

conductivity measurement signal. The frequency serves as a measure of a load of the laundry. According to the invention, the frequency of the pulses in the measurement signal of the electrical conductivity of the laundry is determined and used as a measure of the load. The higher the frequency, the more frequently a piece of laundry touches the electrodes, and the greater is the load of the laundry in the dryer. This achieves the situation where the measure of the load is present in digital form, which significantly simplifies further processing with digital modules, in particular microcontrollers. The load can then be taken into account for controlling the drying process. Advantageously, the signal edges of the conductivity measurement signal are registered in particular by forming a time derivative (differentiation), and the frequency of the conductivity measurement signal is determined by determining the frequency of the registered edges. By registering the edges of the conductivity measurement signal, independent of its absolute level, the conductivity of the laundry is determined. Thus, a reliable determination of the load is possible even in the case of laundry of very low conductivity [26].

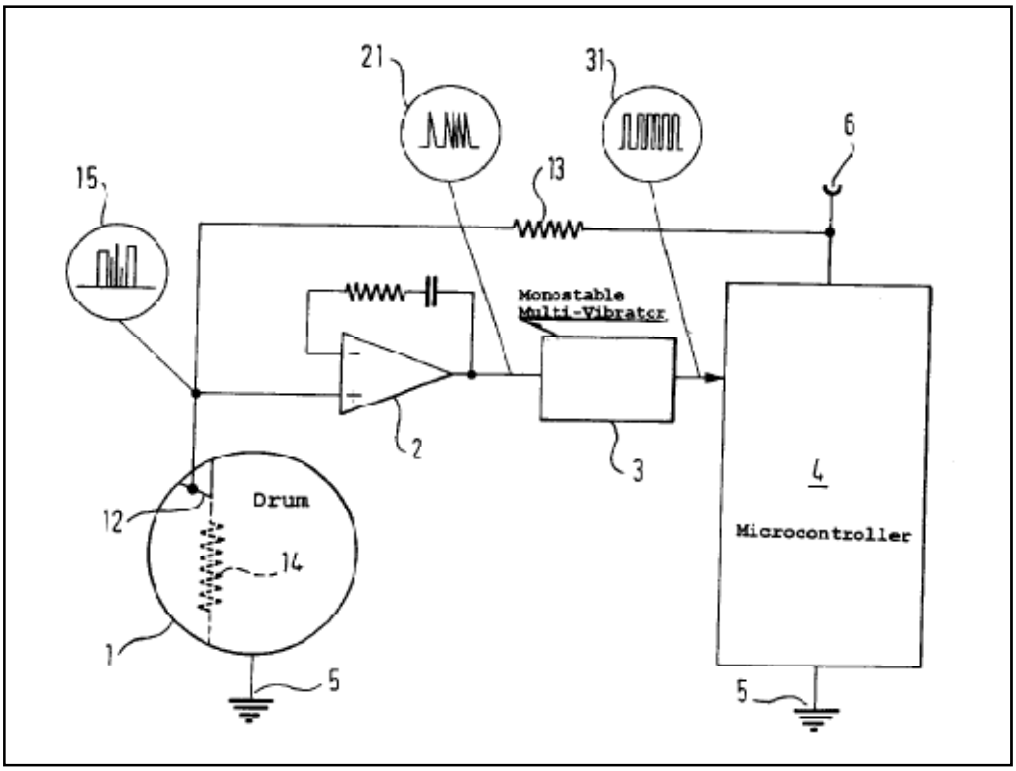

Figure 2.11. Schematic of EP0898008 B1 patent [26]

The patent of BSH that was published as EP1242665 B1 is related to a method for detecting properties of a textile. It is accordingly an object of the invention to provide a device for determining type and dampness of textiles, appliances applying the device, a method for detecting type and dampness of textiles, and a method for determining a filling level of a container. The device detects properties of textiles and includes a sending element, a receiving element, and an evaluation circuit as shown in Figure 2.12. The sending element sends electromagnetic radiation to a textile. The receiving element receives electromagnetic radiation that is transmitted through and reflected from the textile. The evaluation circuit connects to the receiving element and evaluates the electromagnetic radiation received by the receiving element. It decides the properties of a textile [27].

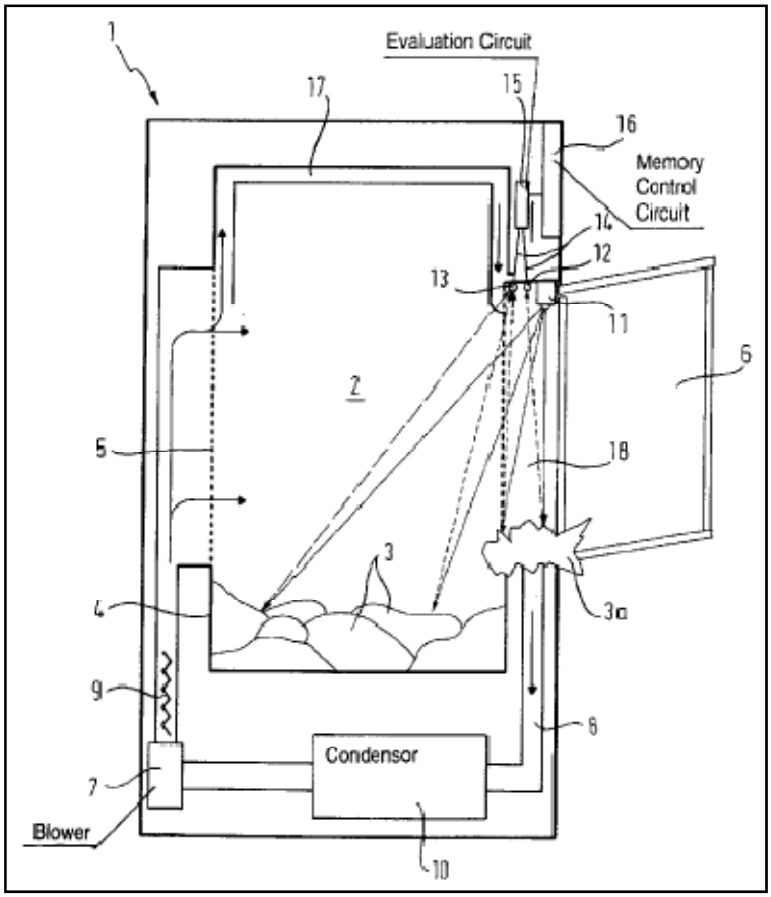

Figure 2.12. Schematic of EP1242665 B1 patent [27]

The patent application of LG that was published as US2004143992 A1 is related to a method for determining the amount of an object being dried. The method includes steps of initiating a drying procedure; measuring a temperature variation rate per unit time over the drying procedure; calculating an overall drying time based on the measured temperature variation rate per unit time; and performing the drying procedure for the calculated overall drying time. Accordingly, the laundry drier control method of the present invention determines the drying time after an increase in the temperature variation rate per unit time with respect to the rate at the time of initiating the drying procedure. Hence, the overall drying time can be dynamically controlled according to the amount and type of laundry in the drier. Schematic representation of method was presented in Figure 2.13 [28].

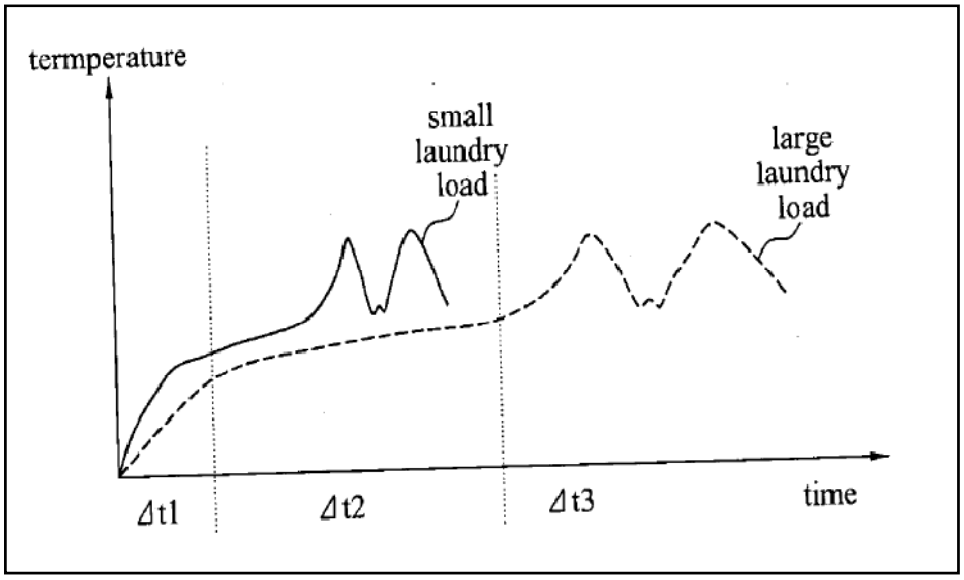

Figure 2.13. Schematic of US2004143992 A1 patent application [28]

The patent application of Sanyo that was published as JP7080194 A is related to a judging method for the type of the clothes. The kind of clothes is determined based on an output of this amount detection means of dust. The amount detection means of dust detects the quantity of dust, such as waste thread which comes out of clothing during desiccation. As an amount detection means of dust, the photo sensor which consists of a light emitting device and a photo detector is used. The photo detector counts the dust passes through between this light emitting device and photo detector as the light of the light emitting device is interrupted and the voltage of the photo detector will fall. When there is much

quantity of the detected dust, a judging means judges that clothing is a thing of a towel system, and when small, it is judged to be a thing of a jeans system [29].

3. EXPERIMENTAL SETUP

The determining of load amount and textile type studies were realized at the Arçelik condenser tumble dryer as shown in Figure 3.1. Moreover, in this tumble dryer, there is a 2500 W heater. At the studies, data were obtained from thermocouple, NTC sensor and conductivity sensor.

Figure 3.1. Arçelik condenser tumble dryer

3.1. THERMOCOUPLE

Temperature was measured with thermocouples at various locations of the tumble dryer. These locations are shown in Figure 3.2.

1. Outlet of drum
2. Inlet of drum
3. Outlet of condenser
4. Outlet of cooling fan

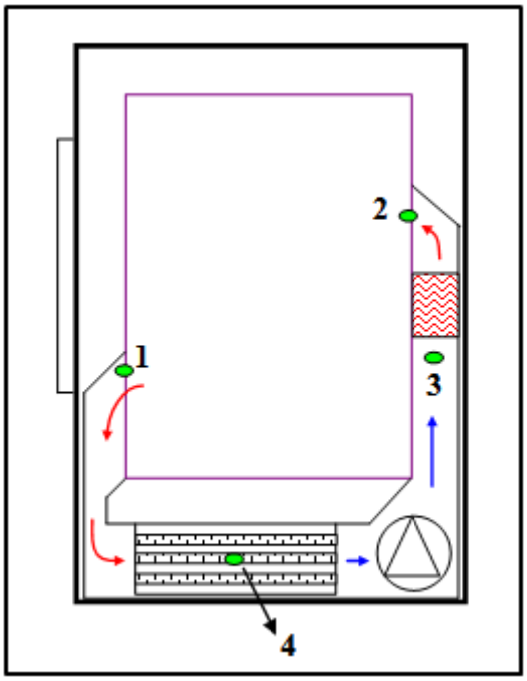

Figure 3.2. Locations of thermocouples at the tumble dryer

When the temperature measurements were examined during the preliminary tests, it was concluded that the drum outlet temperature was more appropriate than other locations because the temperature variations due to load amount and textile type changes could be observed more clearly at the drum outlet. Temperatures were measured from three different locations of drum outlet as shown in Figure 3.3 as numbered 1, 2 and 3. They are plotted in Figure 3.4. It is clear that the temperature variations are observed better from the first thermocouple which was close to the NTC temperature sensor on the dryer.

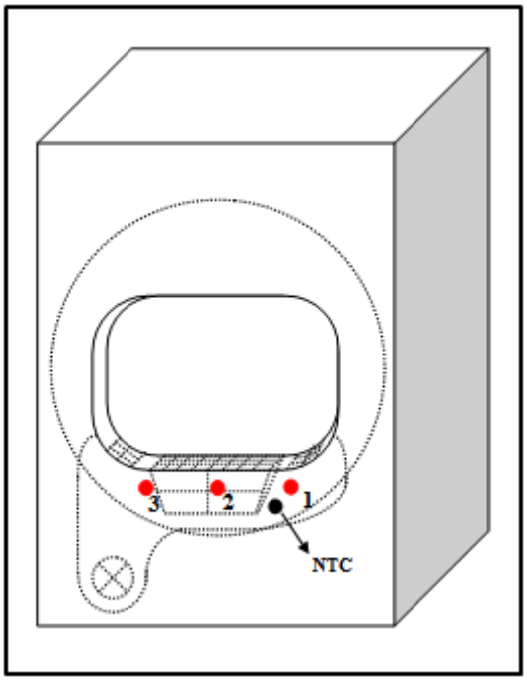

Figure 3.3. Locations of thermocouples at the outlet of drum

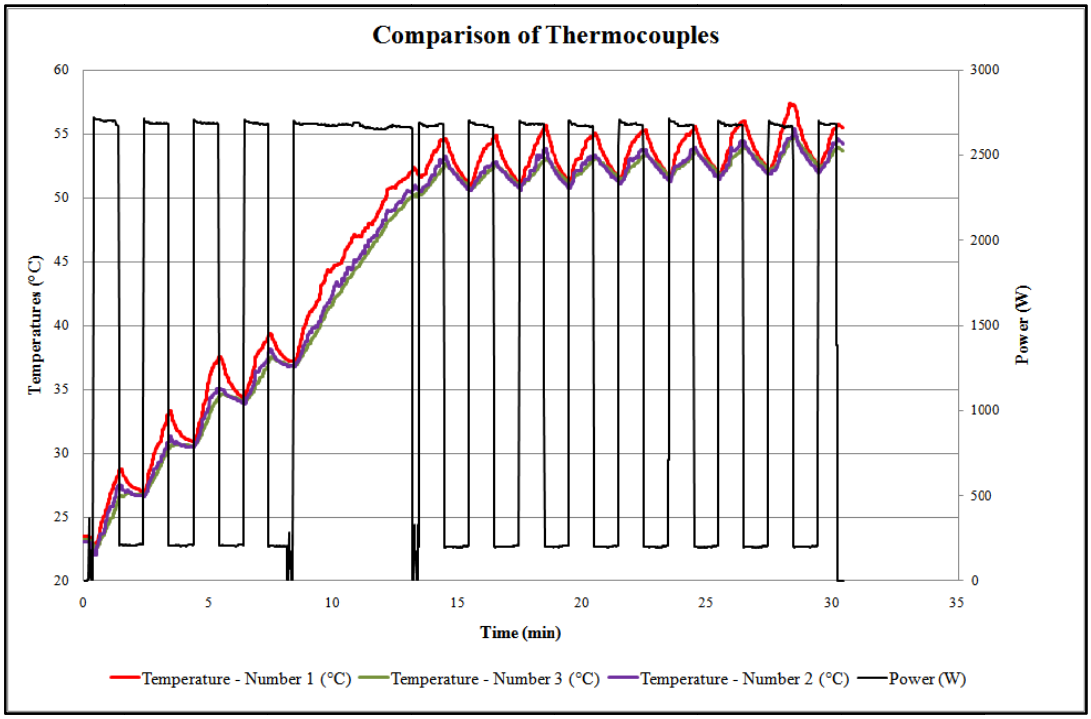

Figure 3.4. Comparison of thermocouple measurements at the different locations of drum outlet

At the experiment setup, the thermocouples were connected to the data acquisition system shown in Figure 3.5 and their temperature data could be read and recorded by the computer program of data acquisition system. Moreover, the voltage, current, power and energy information of the dryer were obtained with this program as shown in Figure 3.6.

Figure 3.5. Panel of data acquisition system

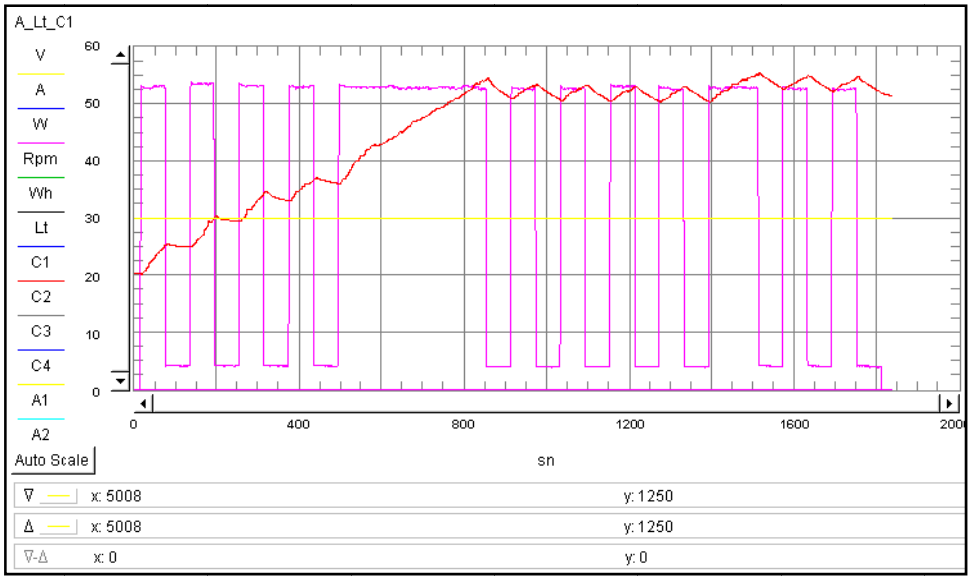

Figure 3.6. Interface of the computer program of data acquisition system

3.2. NTC

The drying programs were controlled according to temperature and electrical resistance information at the available condenser tumble dryers. The temperature values for controlling algorithm were obtained from NTC sensor. This sensor was located at the outlet of drum on the channel along the condenser as shown in Figure 3.7. NTC stands for negative temperature coefficient thermistor which is an electronic component that exhibits a large change in resistance with a change in its body temperature.

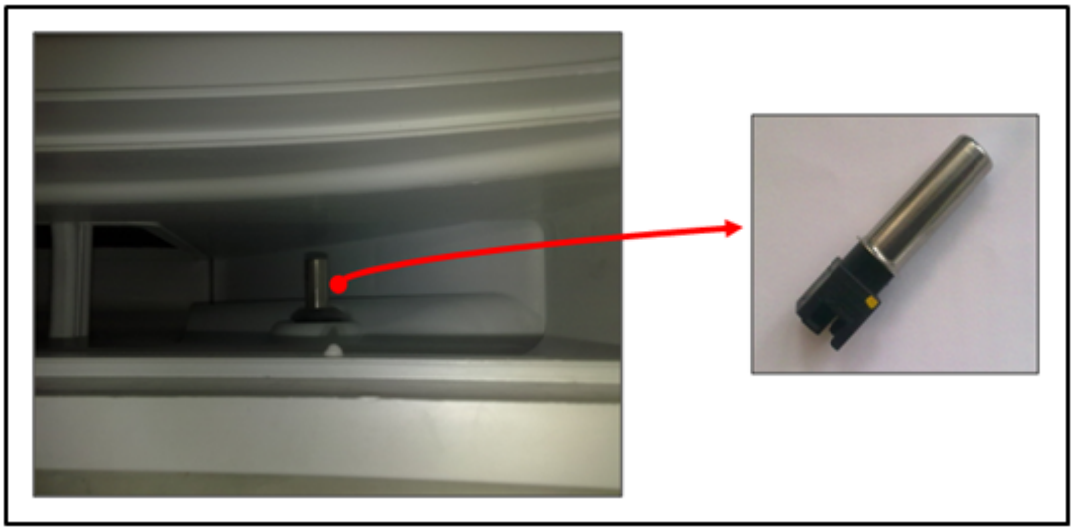

Figure 3.7. NTC thermistor at the tumble dryer

At the beginning of the project, it was aimed that the existing components on the dryer were used primarily at the sensing studies of load amount and textile type. Therefore, the temperature measurements of the NTC sensor were analyzed in addition to the thermocouple measurements.

During the drying process, temperature measured by NTC sensor was controlled by electronic card of the dryer. However, at the experimental setup, the data were transferred from the electronic card to the computer program of card data acquisition system. The temperature values could be read and recorded by the help of this program as shown in Figure 3.8.

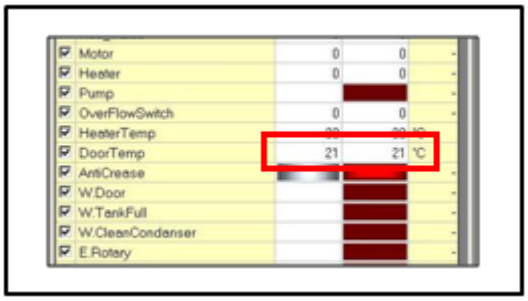

Figure 3.8. Interface of NTC temperature measurements at the computer program of card data acquisition system

3.3. CONDUCTIVITY SENSOR

Another component that provides to control the algorithm during the drying process is a conductivity sensor. According to the electrical resistance values that were obtained from the conductivity sensor, the drying operation is stopped at the end of the drying.

The conductivity sensor is placed between the door and drum of the dryer and it consists of two metal plates as shown in Figure 3.9. These plates are connected to the inlet of sensing circuit. Conductivity sensing circuit generates the DC signal whose value increases with increasing drying degree of textile. This DC signal is read by means of Analog-Digital Converter by microprocessor and the acquired digital value becomes an input for the dryness sensing algorithm. This sensor is called conductivity sensor, but the information that is get from this sensor is electrical resistance value.

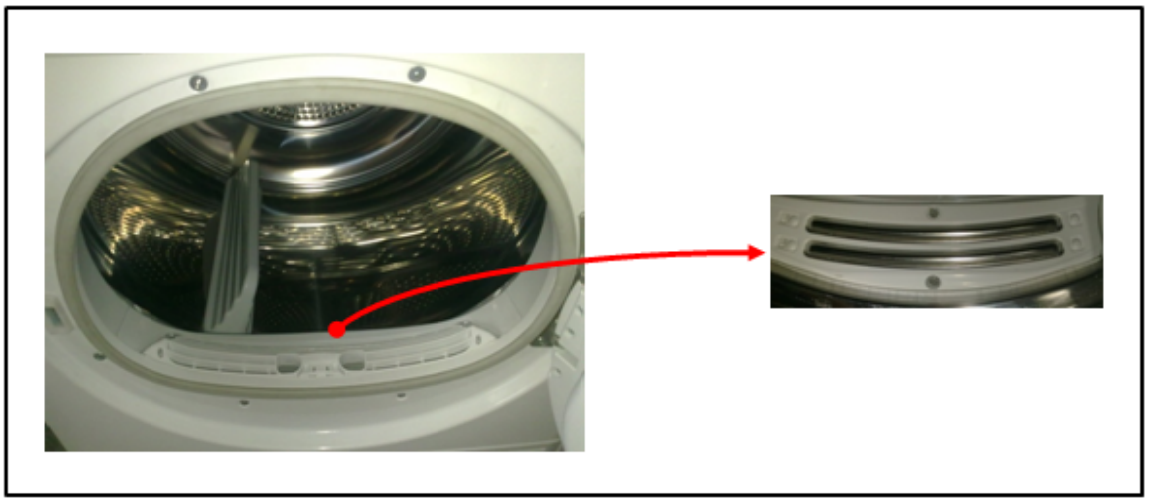

Figure 3.9. Location of conductivity sensor at the tumble dryer

Unlike the existing situation, at the sensing of load amount and textile type studies, the resistance values were used for differing load amount or textile type at the beginning of drying. At the experimental setup, the data were transfer from the electronic card to the computer program of card data acquisition system by the same connection which was used for NTC. Similarly, the resistance values could be read and recorded by the help of computer program of card data acquisition system as shown in Figure 3.10.

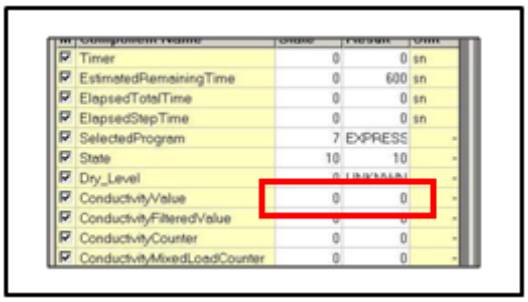

Figure 3.10. Interface of conductivity values at the computer program of card data acquisition

4. EXPERIMENTAL STUDIES

4.1. TEXTILE TESTS

For all types of dryers, there are cotton cupboard dry program for drying cotton textiles and synthetic cupboard dry program for drying polyester textiles. First of all, it was examined whether it is necessary for cotton and polyester textiles to run at different programs. Damages level of the polyester textiles were examined when they were dried at the cotton cupboard dry program and their results were compared with their own program that is synthetic cupboard dry. After synthetic and cotton cupboard dry programs of benchmark condenser tumble dryers were examined and their differences were determined, simulations of synthetic and cotton cupboard dry programs were built for Arçelik condenser tumble dryer. At these two conditions, the degree of textile damages was analyzed for 25 cycles. Following these tests, effects of textile damage were investigated at first benchmark condenser tumble dryer by comparing its own cotton and polyester cupboard dry programs.

4.1.1. Benchmarks

Heater algorithms and temperature profiles of cotton and synthetic cupboard dry programs of Arçelik and benchmark tumble dryers were analyzed to investigate the difference between these programs. To compare the cotton and synthetic cupboard dry programs of different companies, the X number was calculated. This number was developed newly in this project. X number consists of parameters that are temperature, time, heater power and load amount as shown in Equation 4.1 since it was expected that these parameters affect the damage of the textiles during drying process. Moreover, X number is an indicative to the degree of textile damage. X number states the work per kilogram that is necessary to increase the 1°C temperature of textile.

$$X = \frac{t \times (T - 60°C) \times P}{m} \left[\frac{\text{kW} \times °\text{C} \times \text{s}}{\text{kg}}\right] \tag{4.1}$$

X number was analyzed by dividing the drying process into three phases. The first phase is the heating phase of the dryer and textiles, the second phase is the steady state phase and the third phase is the drying phase of the textiles. Most of damage on the textile damage occurs during the third phase as it is mentioned in the literature. Buisson, Rajasekaran, French, Conrad and Roy have found that if the heat energy decreases at about 4 per cent moisture retention, heat damage may be diminished [18]. Therefore, the third phase should be analyzed carefully.

Comparison of different phases of the cotton and polyester programs were presented in Figure 4.1 according to the X number and different companies.

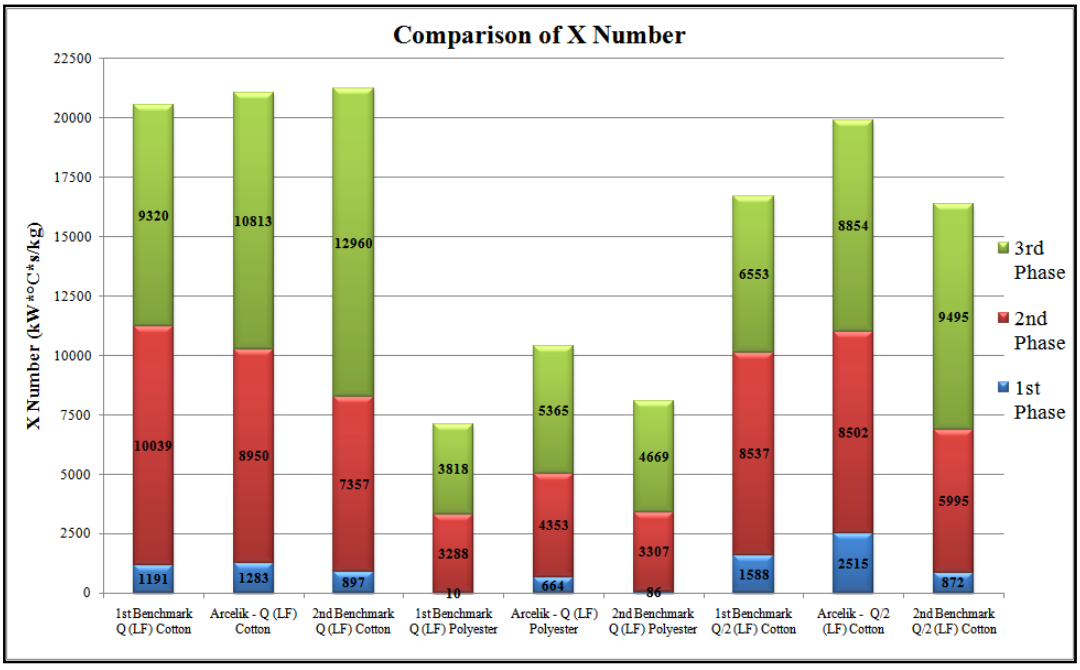

Figure 4.1. Comparison of X Number according to the Arçelik and benchmark tumble dryers

When the X numbers were compared for Arçelik and benchmark tumble dryers, X number values of cotton cupboard dry programs are higher than synthetic cupboard dry programs values for all types of tumble dryers. When only X numbers of synthetic cupboard dry programs were compared for different companies, it was found that Arçelik dryer has highest X number and first benchmark dryer has lowest X number for all phases.

4.1.2. Arçelik Tumble Dryer Tests

The tests were conducted in order to examine polyester textile damages for cotton and polyester cupboard dry program simulations.

Two programs were created that represent the maximum and minimum drying temperatures of the polyester textiles in the tumble dryer. Simulation of cotton cupboard dry program has the highest drum outlet drying temperature and simulation of synthetic cupboard dry program has the lowest drum outlet drying temperature. The temperature of the cotton cupboard dry program simulation was 10 - 15°C higher than that of the synthetic cupboard dry program simulation. However, the test duration of the synthetic cupboard dry program simulation task 15 minutes longer than that of the cotton cupboard dry program simulation to dry textiles at the same level, as shown in Figure 4.2.

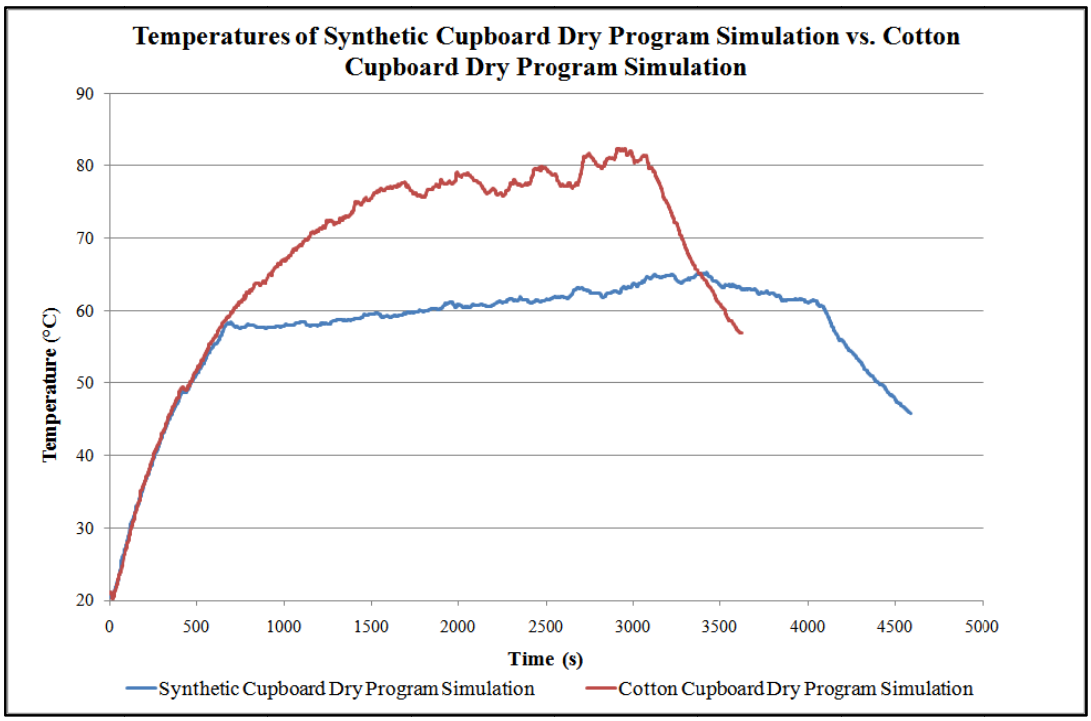

Figure 4.2. Comparison of temperatures of synthetic and cotton cupboard dry program simulations at Arçelik tumble dryer

Test setup and conditions consisted:

- Arçelik tumble dryer
- Rinsing: 800 rpm
- Initial moisture amount: 40 per cent
- Load amount: 4 kg with samples
- Contents of samples:
    - 100 per cent Polyester
    - 95/5 per cent Polyamide /Lycra
    - 65/35 per cent Viscose /Lycra

A set of 25 cycle tests were run for each simulation program. At the end of the five, ten, eighteen and twenty fifth cycles, the dimensions of the textile were measured. In this manner, the degree of the textile damages was compared for cotton and polyester programs.

At the end of the twenty fifth cycle, the height shrinkage of 100 per cent polyester textile was 10,26 per cent with the cotton cupboard dry simulation program and was 6,00 per cent with the synthetic cupboard dry simulation program. As shown in Figure 4.3, shrinkage of textiles that was dried at cotton cupboard dry simulation program was higher since from the first cycle to last cycle. Shrinkage tendency of other samples was similar to 100 per cent polyester textile.

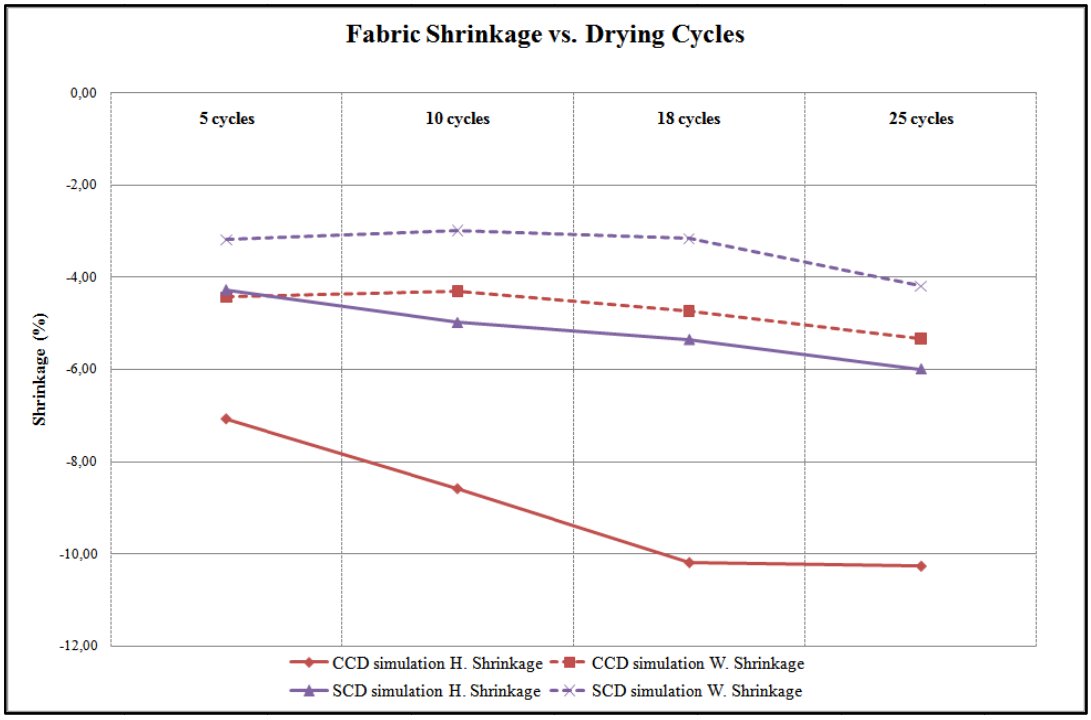

Figure 4.3. Comparison of polyester textile shrinkage between drying cycles

When the textile printings were analyzed visually, at the end of the fifth cycle, the printing on the 100 per cent polyester textile with the cotton cupboard dry simulation program was damaged as shown in Figure 4.4. The surrounding of the printing was wrinkled, so it appeared that it was damaged at high temperatures. However, at the end of the twenty fifth cycle, the level of wrinkles was equal for both the cotton and synthetic cupboard dry simulation programs.

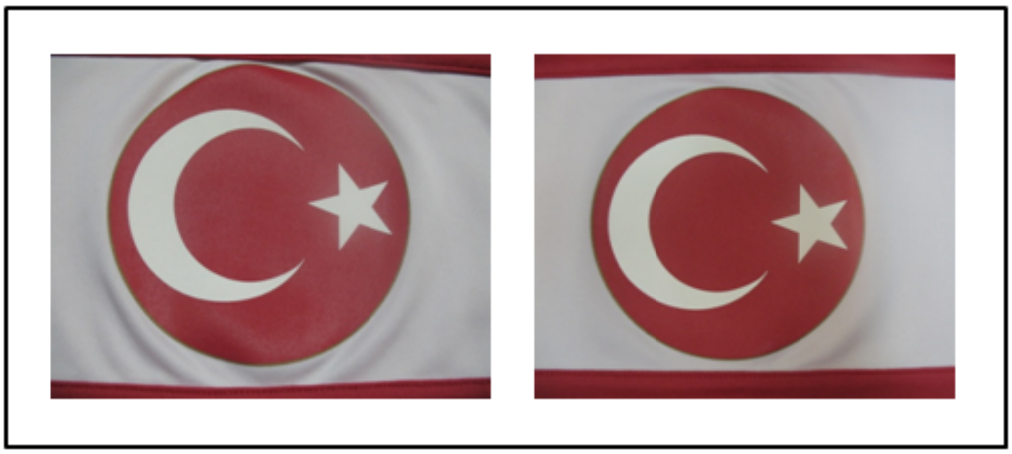

Figure 4.4. Visual comparison of textile wrinkles between cotton and synthetic drying programs

4.1.3. First Benchmark Tumble Dryer Tests

For the first benchmark tumble dryer, the tests were run in order to understand different effect of first benchmark cotton and synthetic cupboard dry programs on textile damage. The result of textile shrinkage was compared between cotton and synthetic cupboard dry programs. The reason for selecting first benchmark tumble dryer for tests was that drying temperatures of the cotton and polyester cupboard dry programs were close to each other which were about 70 - 75 °C as shown in Figure 4.5 and 4.6.

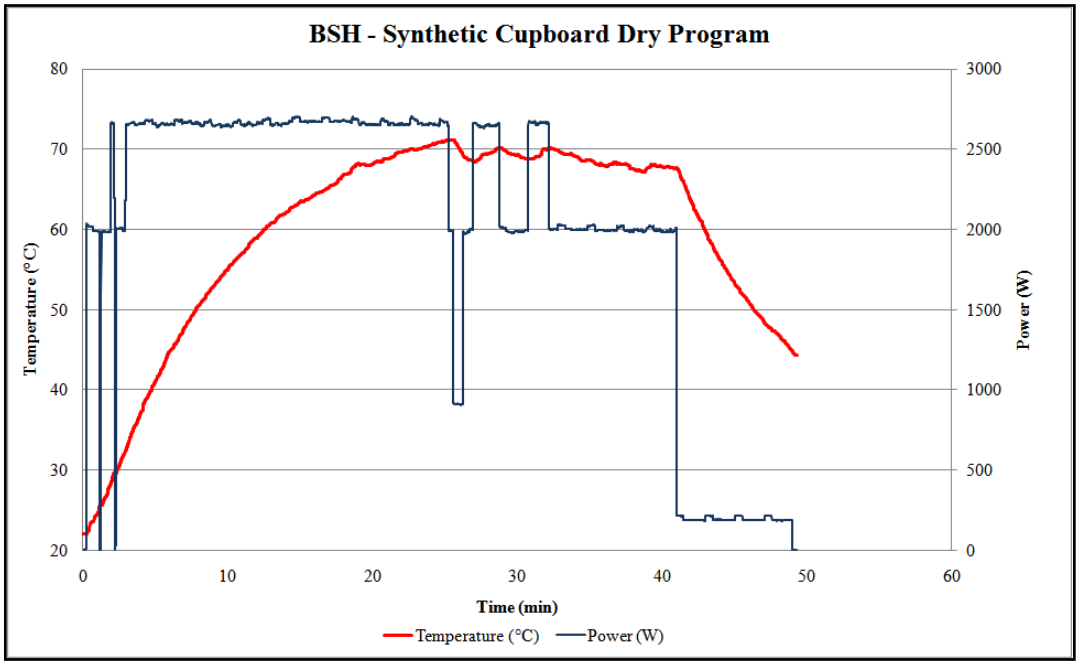

Figure 4.5. Temperature and power profile of synthetic cupboard dry program of first benchmark tumble dryer

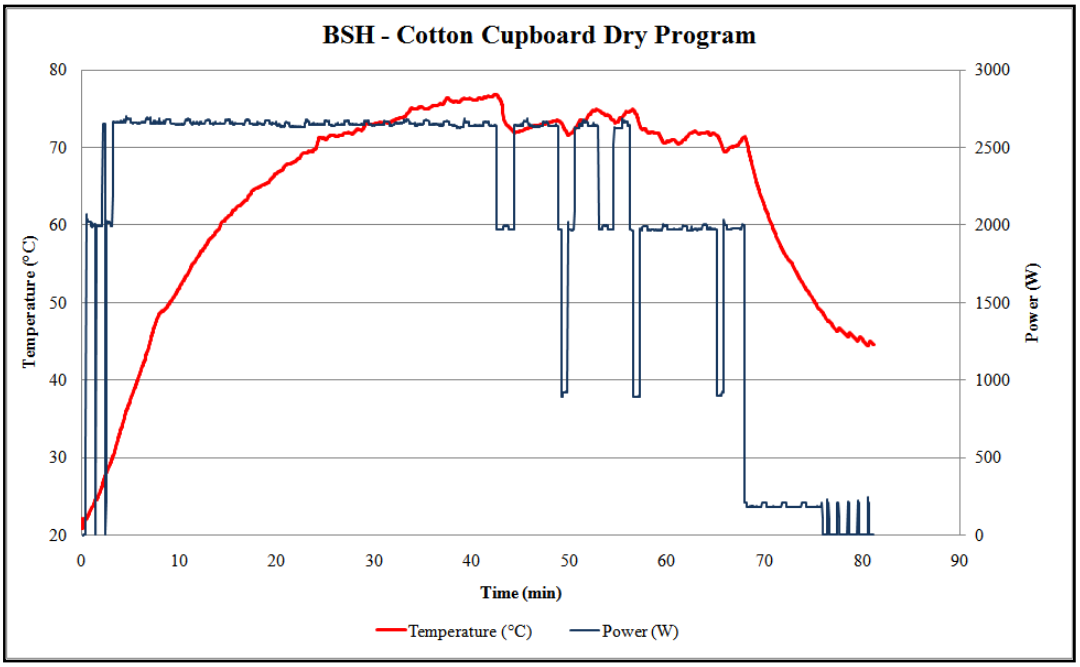

Figure 4.6. Temperature and power profile of cotton cupboard dry program of first benchmark tumble dryer

Five cycle tests were run for both cotton and synthetic programs. At the end of the fifth cycles, the dimensions of the textile were measured and shrinkage rates were calculated with respect to the first dimensions.

Differently from Arçelik tumble dryer tests, samples were cut to two pieces, and thus one of the identical pieces was dried with cotton cupboard dry program and other was dried with synthetic cupboard dry program. This is the minimize textile differences due to manufacturing errors and providing the comparison of different drying program effects without other factors.

Twelve samples were used in both of the test groups and all samples were 100 per cent polyester textiles. The results of the height shrinkage of the textiles were presented in Figure 4.7. At the end of the fifth cycle, for eight samples that were dried at cotton cupboard dry program, shrinkage values were higher than values of samples that were dried at synthetic cupboard dry program.

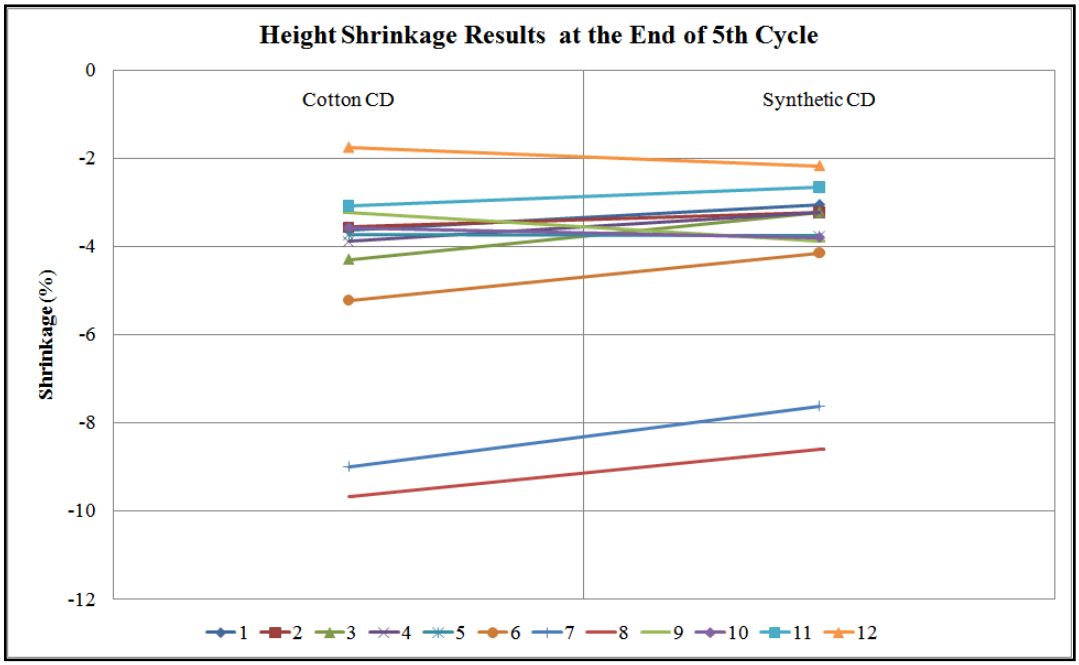

Figure 4.7. Comparison of height shrinkage results at the end of the fifth cycle according to the different samples

In Figure 4.8, proportional differences of textile shrinkage between textiles which were drying at cotton and synthetic cupboard dry programs were presented. The average of proportional difference of textile shrinkage values is 19.87 per cent as shown in Figure 4.8. Furthermore, the maximum value of shrinkage difference is 33.43 per cent and the minimum value of shrinkage difference is 10.22 per cent.

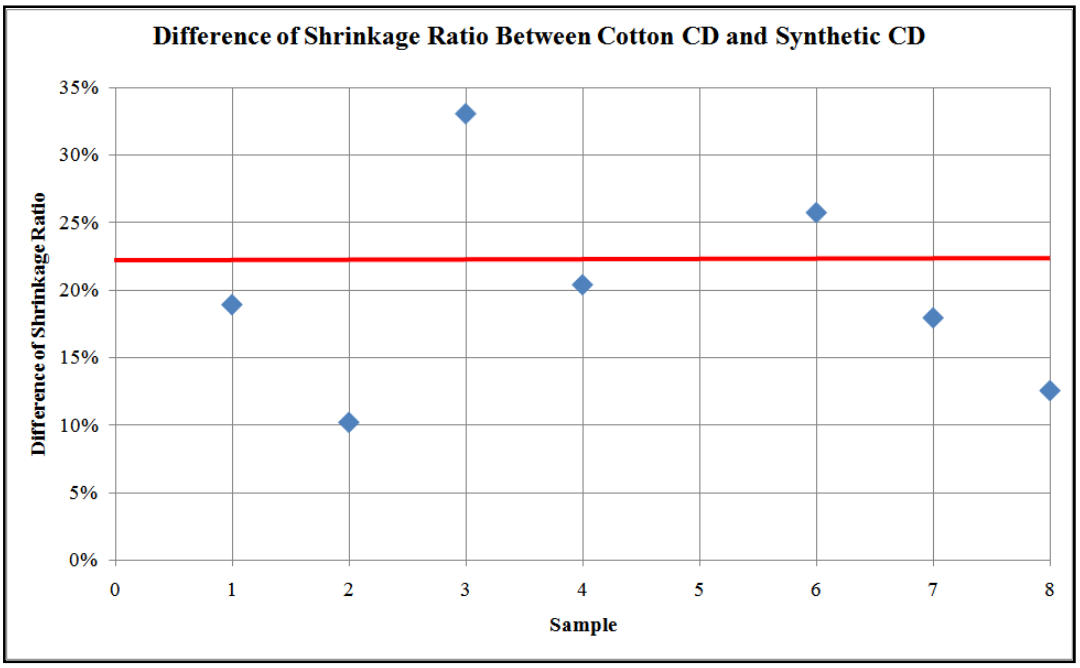

Figure 4.8. Comparison of shrinkage ratio between cotton and synthetic cupboard dry programs

As a conclusion of the tests, although drying temperatures of the cotton and polyester cupboard dry programs were close to each other, textile damage effects of cotton and polyester cupboard dry programs were different.

When the X numbers of first benchmark tumble dryer programs mentioned in Section 4.1.1 were compared, the results of the shrinkage differences between the programs were estimated since X number presented the program effects on textile damage. X number values for first benchmark cotton cupboard dry program was higher than values for synthetic cupboard dry program for all phases. Therefore, it was concluded that textiles that were dried with the cotton cupboard dry program damaged more. Test results confirmed the representation of damage level of X number values.

4.2. ALGORITHM

At the beginning of the sensing studies, various drying algorithms were attemped to create different responses for different textiles types against the temperature variation. Due to different specific heats of cotton and polyester and moisture absorption capacity, it was expected that the rate of temperature change for cotton and polyester would be different. Therefore, it was decided that, in the drying algorithm, the heater must be operated with the sequence of on and off positions at the sensing stage.

At the first algorithm, the heater was operated as one minute on and one minute off position during 30 minutes as shown in Figure 4.9. This algorithm was applied for cotton and polyester textile tests; as shown in Figure A.1 and A.2. As a result of tests, the temperature increase rate for cotton and polyester textiles were close to each other for the same load amounts. However, the temperature decrease rate was different for cotton and polyester textiles.

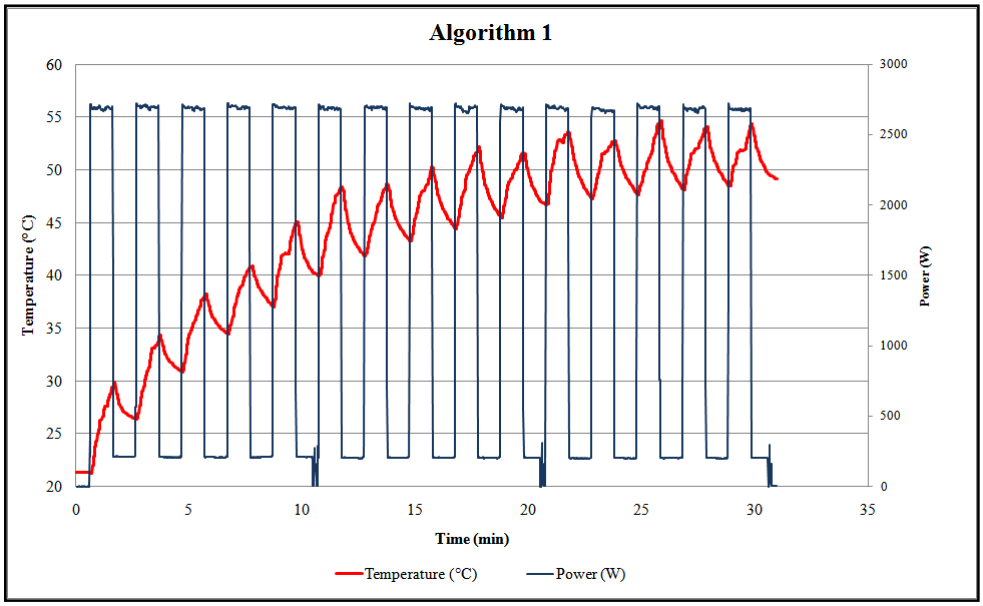

Figure 4.9. Temperature and power profile of first drying algorithm

After the first algorithm was analyzed, it was modified to the second algorithm in order to observe the temperature increases more clearly. In this manner, at the second algorithm, the heater was fully on during the first five minutes. After five minutes the heater was operated as one minute on and one minute off position until the end of drying algorithm as shown in Figure 4.10. As a result of cotton and polyester textiles tests results that were shown in Figure A.3 and A.4, however the temperature variations were not distinct enough for polyester and cotton textiles unlike with the first algorithms.

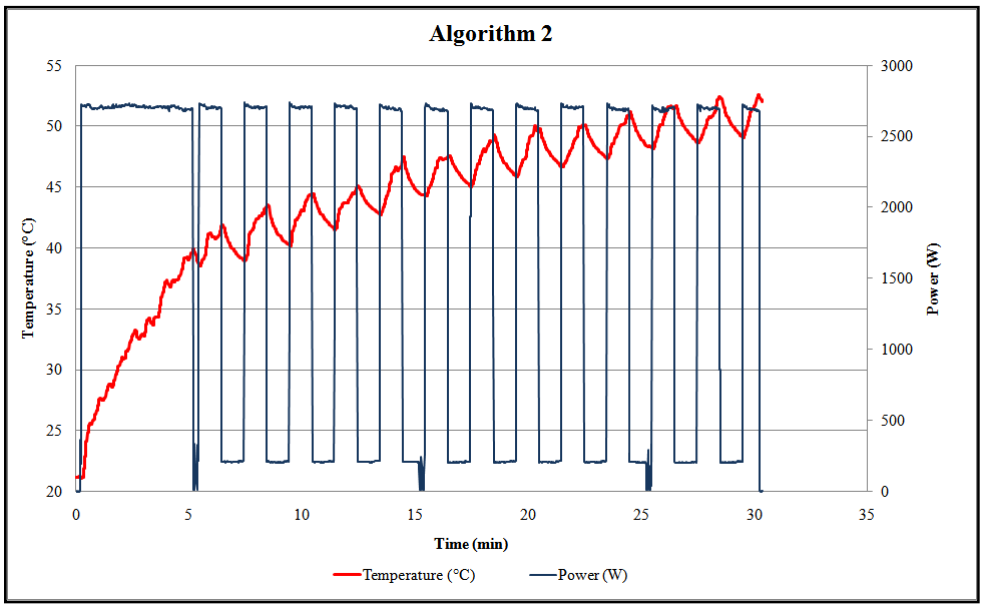

Figure 4.10. Temperature and power profile of second drying algorithm

The test results of the first and second algorithms were interpreted and the third algorithm was developed a result of feedback of these algorithms. It was clear that the temperature variations were different at the beginning of the heating phase. For this reason, in the third drying algorithm, heater was operated as one minute on and one minute off position at first eight minutes, then at on position fully during the next five minutes and again at one minute on and one minute off position until the end of algorithm. The third algorithm was presented in Figure 4.11. At this algorithm, the temperature variations were more distinctive for cotton and polyester textiles as shown in Figure A.5 and A.6. Therefore, this algorithm was used along the load and textile type sensing studies. And at sensing studies, it was aimed that, temperature increase and decrease differences between

textile types were determined at the first eight minutes and the temperature increase differences between load amounts were determined between eighth and thirteenth minutes.

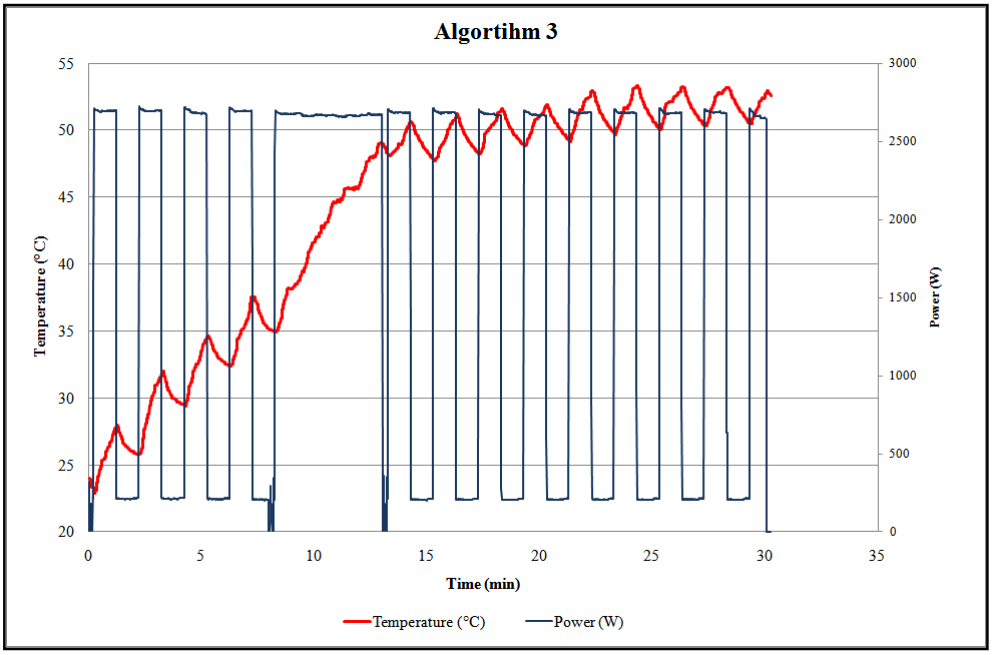

Figure 4.11. Temperature and power profile of third drying algorithm

4.3. SENSING METHODS

The methods were developed to analyze the test results. All tests that were made in sensing studies were interpreted according to these methods. It was aimed that the different load amounts and textile types would be differentiated by these methods. Moreover, the load amounts were compared in terms of load factor (LF). The load factor is the one over load amount in the tumble dryer during drying:

$$LF = \frac{1}{m} \tag{4.2}$$

The load factor for 4 kg was defined as Q and other load factors of other load amounts were presented according to load factor Q.

$$Q = \frac{1}{4\ kg} \tag{4.3}$$

4.3.1. Temperature Difference between Eighth and Thirteenth Minutes

Temperature variations were measured by the NTC sensor that exists on the tumble dryer and thermocouples that were placed externally during the drying tests. Since it was aimed that the sensing studies were made by existing components on the tumble dryer, the temperature difference between eighth and thirteenth minutes was calculated by values that were obtained from NTC sensor. Temperature increases at this stage were compared for all sensing tests by the help of this method. The representation of method was shown in Figure 4.12.

$$\Delta T = T(13) - \mathrm{T}(8) \tag{4.4}$$

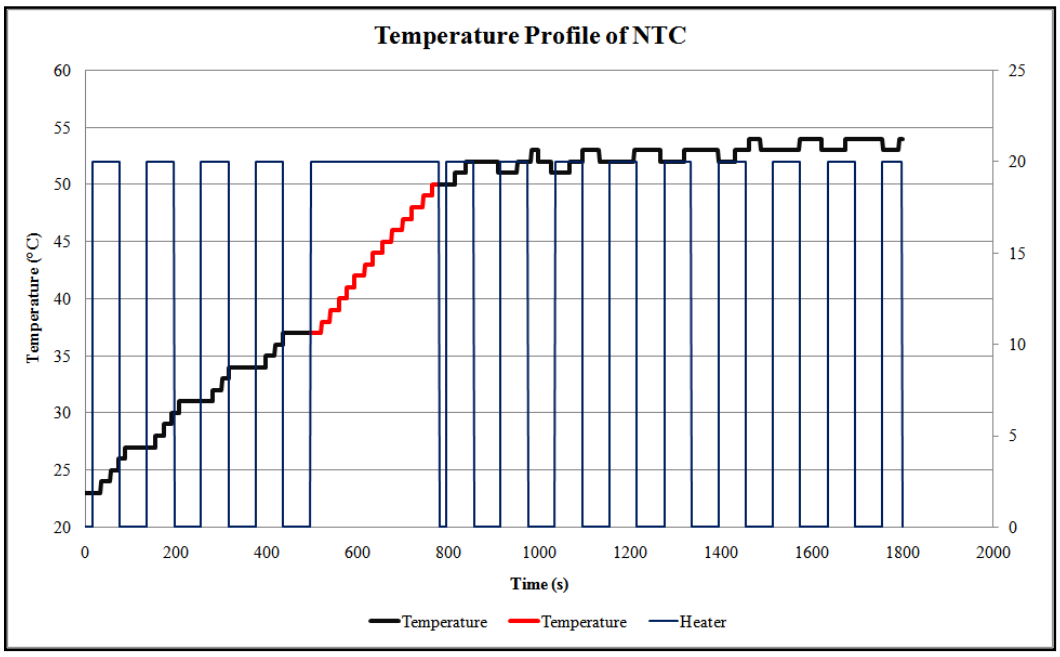

Figure 4.12. Profile of temperature measuring with NTC thermistor

4.3.2. Temperature Analysis with Thermocouple

The temperature variations as increases and decreases at the first eight minutes were analyzed by temperature values that were obtained from either thermocouples or NTC sensor. In Figure 4.13, the temperature profile obtained from thermocouple is presented. Increases or decreases of the temperature depend on heater operation condition. Absolute value of these temperature increases and decreases was summed at the method of temperature analysis with thermocouple. It was assumed that the total temperature variations were distinct for different textile types and so, temperature profiles of all tests were compared by the help of this method.

$$Total\ Temperature\ Variation = \sum_{n=0}^{8} |T_{n+1} - T_n| \tag{4.5}$$

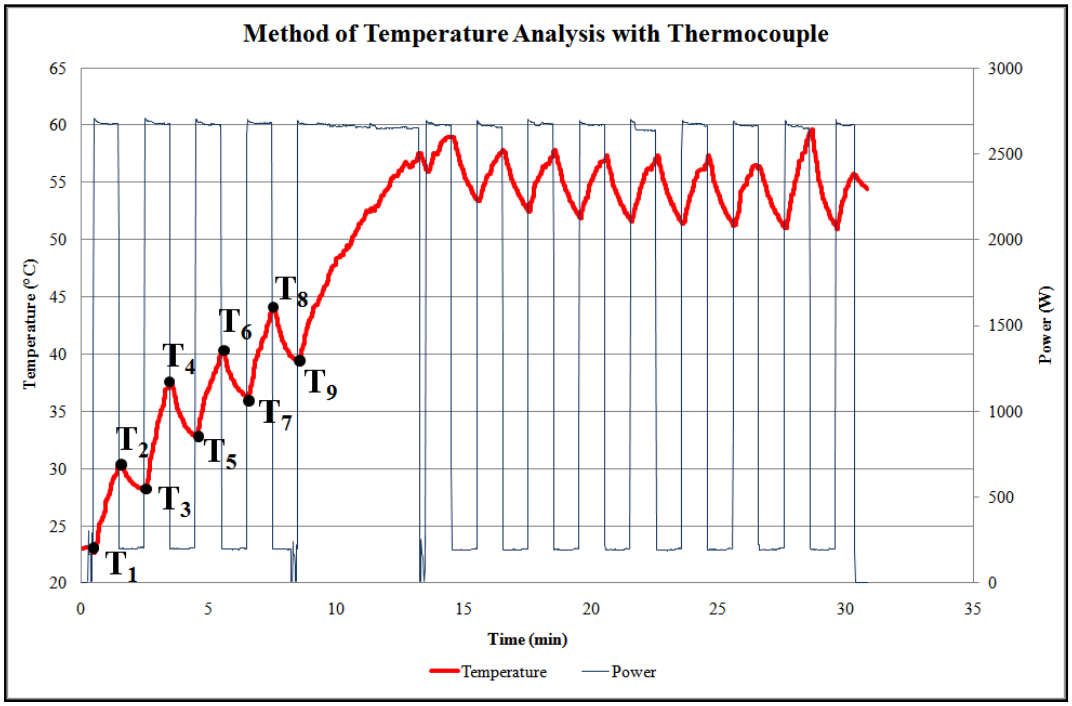

Figure 4.13. Profile of temperature measuring with thermocouple

4.3.3. Temperature Analysis with NTC

During the first eight minutes, the temperature variations that could be seen at temperature profile obtained from thermocouples were not the same with profile that from the NTC sensor as shown in Figure 4.14. The temperature decreases for polyester textiles could not be observed in the temperature profile obtained by NTC sensor; as shown in Figure A.7 and A.8. At the preliminary tests for sensing studies, it was determined that the temperature of cotton was stable or decreased during heater at off position, on the other hand temperature of polyester textiles increased. Therefore another method was formulated as temperature analysis with NTC to analyze temperature variations at first eight minutes. In this method, since the temperature profiles at the first eight minutes were differentiated with the heater off position, the absolute value of temperature of this period were summed:

$$Total\ Temperature\ Variation = \sum_{n=1}^{4} |T(2n) - T(2n-1)| \tag{4.6}$$

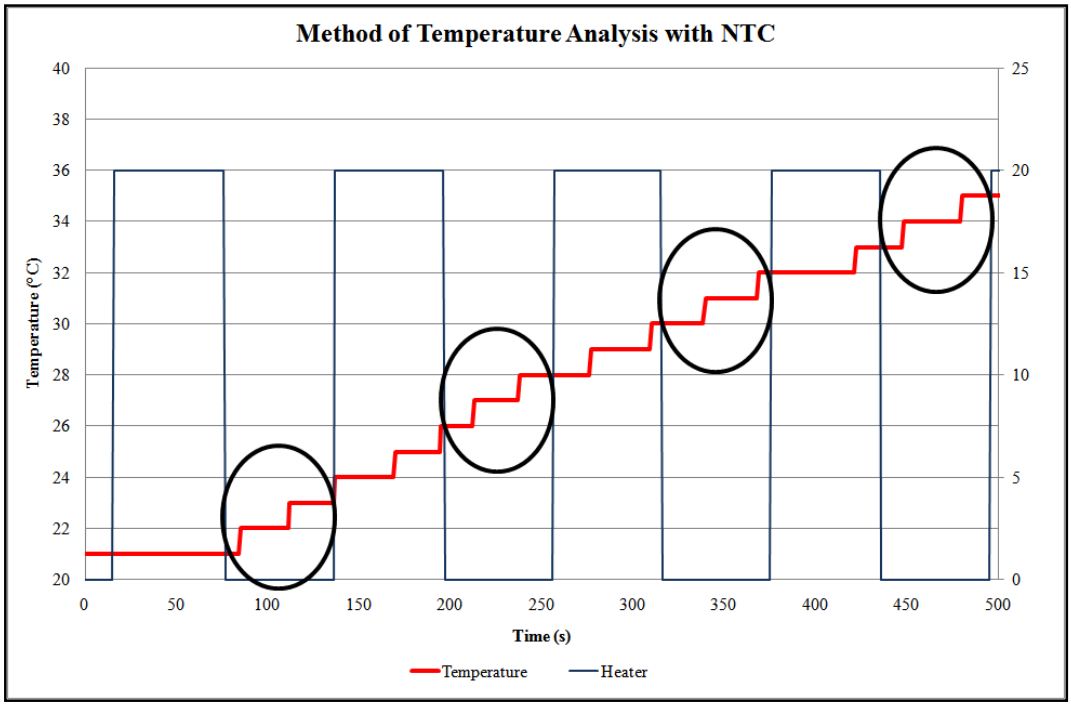

Figure 4.14. Temperature changes during the heater at off position

4.3.4. Average Electrical Resistance

Electrical resistance values that were obtained from existing conductivity sensors on the tumble dryer were examined as average electrical resistance method. At this method, the electrical resistance values between the one hundredth and five hundredth seconds were averaged and the results were compared for all tests as shown in Figure 4.15.

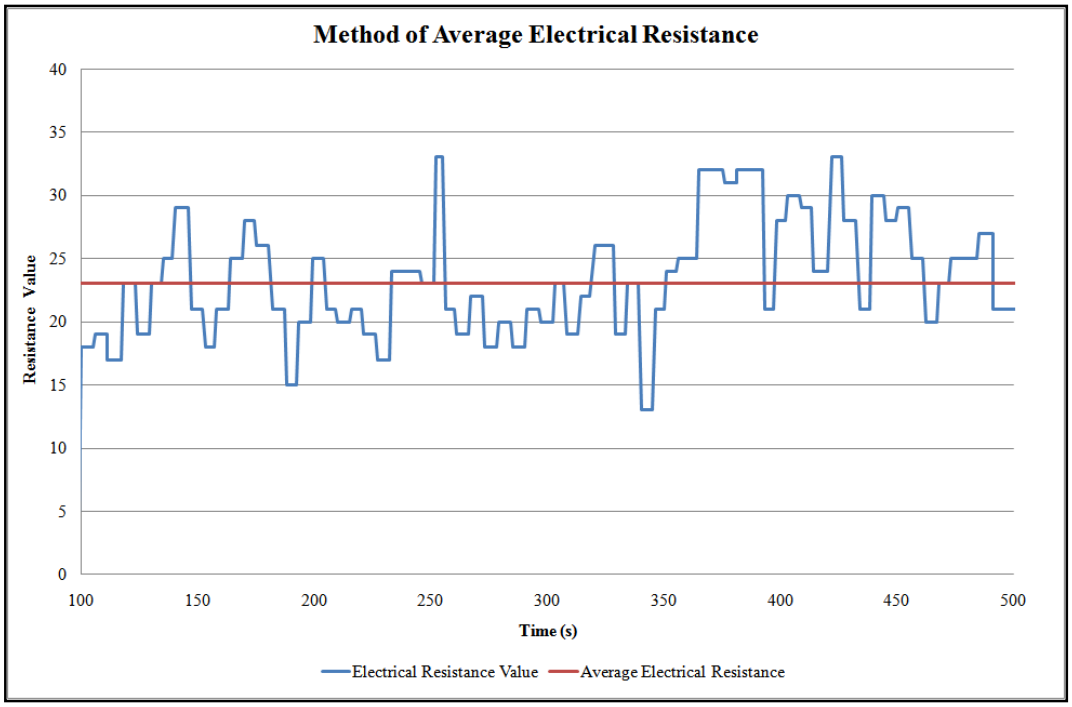

Figure 4.15. Electrical resistance value and average between the one hundredth and five hundredth seconds

4.4. COTTON TEXTILE TESTS

Dryer tests were made with 100 per cent cotton textiles which are defined in EN 61121 standard. Cotton textiles were tested according to different load factors and initial moisture contents. Q/2, 2Q/3, Q, 2Q and 4Q load factors were selected to sense. Moreover, the initial moisture contents were established as 50, 60 and 70 per cent for cotton textiles since the cotton textiles have high moisture absorption capacity. For all conditions three tests were made. For each load factor, nine tests were made and the values that were obtained were given as an interval at figures.

As a result of the tests, when the temperature difference between eighth and thirteenth minutes were examined, the load factors are directly proportional to temperature increases as shown in Figure 4.16. In other words, the the temperature difference between eighth and thirteenth minutes increases with load factor Q.

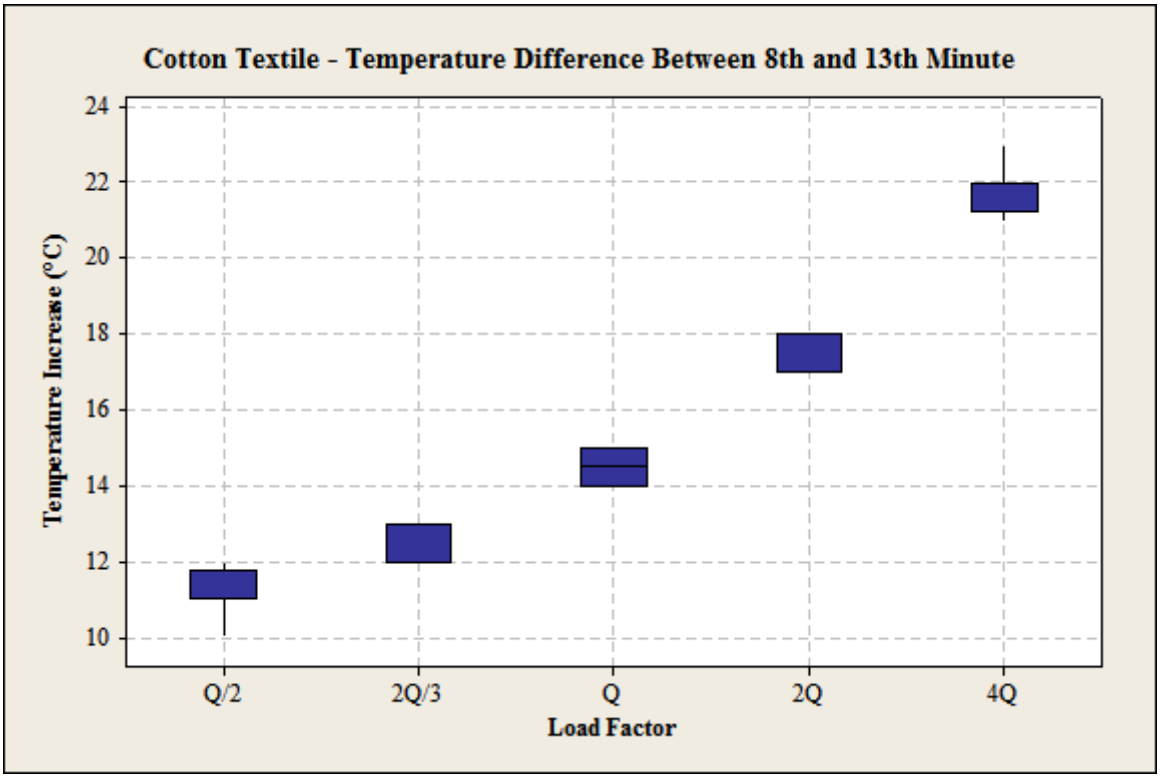

Figure 4.16. Comparison of temperature increase of the cotton textile for different load factors

When the thermocouples measurements were analyzed for first eight minutes, the load factors are directly proportional to total temperature variation as shown in Figure 4.17. The values of total temperature variation are similar only for load factors of Q/2 and 2Q/3. For load factors Q, 2Q and 4Q, the values of total temperature variation are different from each other.

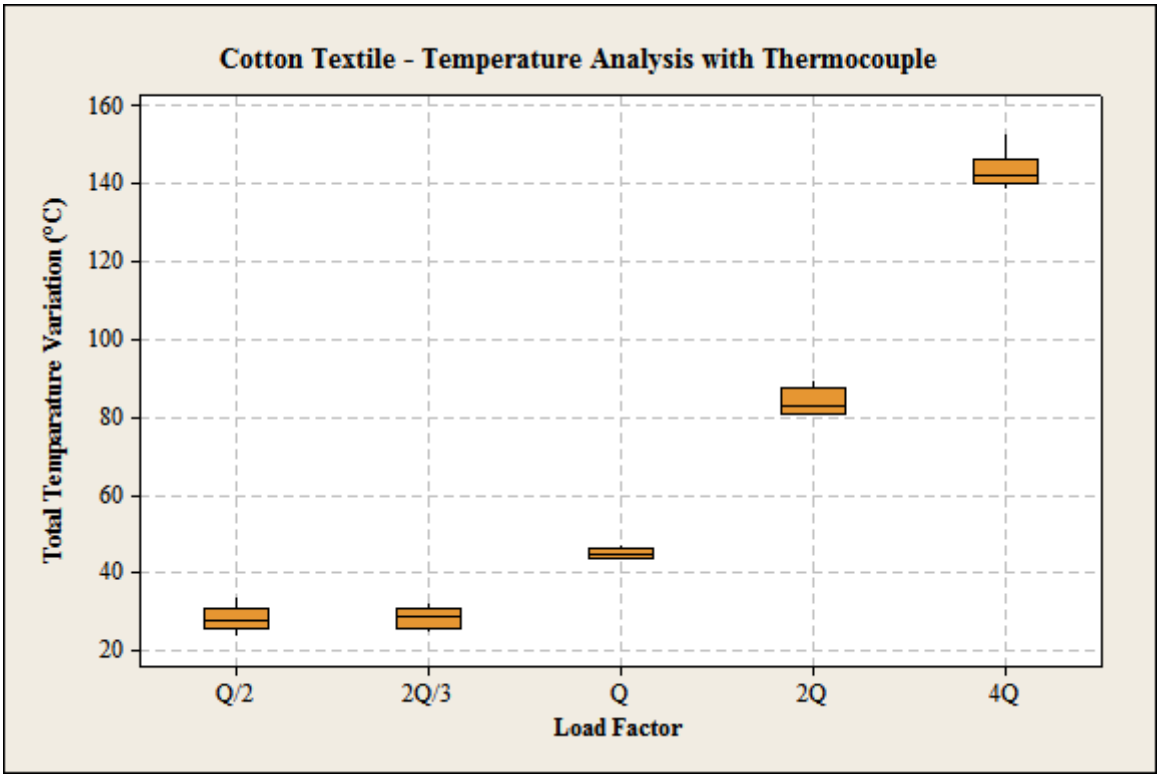

Figure 4.17. Comparison of thermocouple temperature analysis results of the cotton textile for different load factors

The values of total temperature variations measured with NTC were examined at the time of heater-off positions at the first eight minutes, as shown in Figure 4.18. The temperature variations are similar for load factors of Q/2, 2Q/3, Q and 2Q. Total temperature variation of 4Q has negative values and different from other load factors. It can be said that the value of total temperature variations has a decreasing tendency for high load factor Q's.

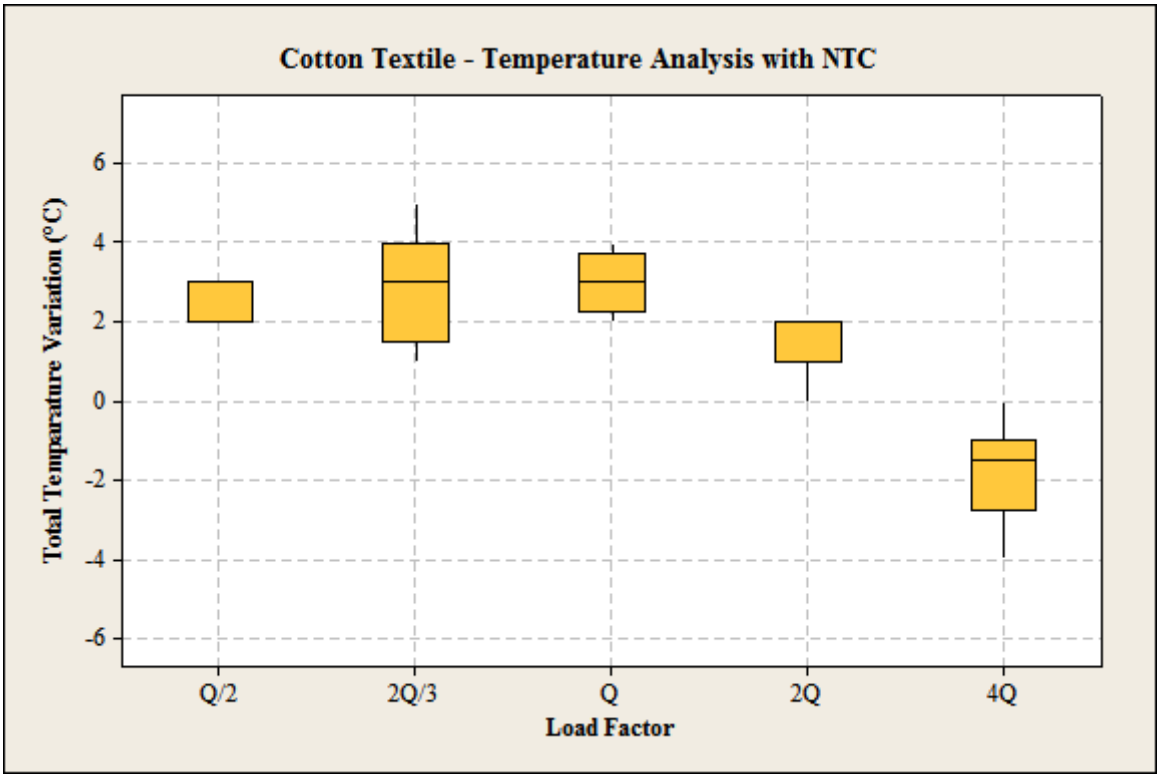

Figure 4.18. Comparison of NTC temperature analysis results of the cotton textile for different load factors

When the average electrical resistance values were examined between one hundred and five hundred seconds, the average electrical resistance values for Q/2, 2Q/3 and Q load factors are close to each other as shown in Figure 4.19. The average electrical resistance values are different for 2Q and 4Q load factors. Also their values are higher than Q/2, 2Q/3 and Q load factors. It is clear that average electrical resistance values increase with higher load factor Q's.

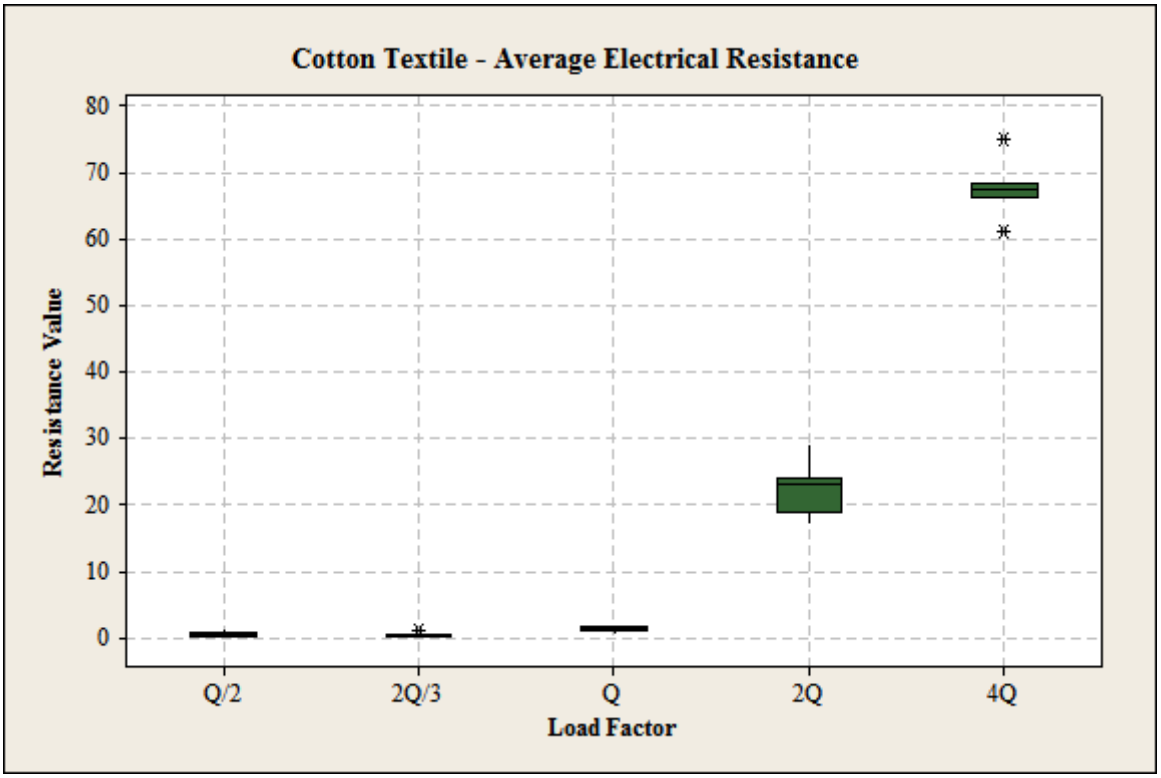

Figure 4.19. Comparison of average electrical resistance of the cotton textile for different load factors

4.5. POLYESTER TEXTILE TESTS

Dryer tests were made with 100 per cent polyester textiles. Polyester textiles were tested for different load factors and initial moisture contents in the same manner with cotton textiles. Q/2, 2Q/3, Q, 2Q and 4Q load factors were selected to sense. Moreover, the initial moisture contents were established as 30, 40 and 50 per cent for polyester textiles since the polyester textiles have lower moisture absorption capacity than cotton textiles. For all conditions three tests were made. For each load factor, nine tests were made and the values that were obtained were given as an interval at figures.

As similar with cotton textile, when the temperature difference between eighth and thirteenth minutes were examined, the load factors are directly proportional to temperature increases for polyester textiles as shown in Figure 4.20. The values of temperature increase are different for Q, 2Q and 4Q load factors. The values of temperature increase for Q/2 and

2Q/3 load factors can not be distinguished from each other but their values are different from other load factors.

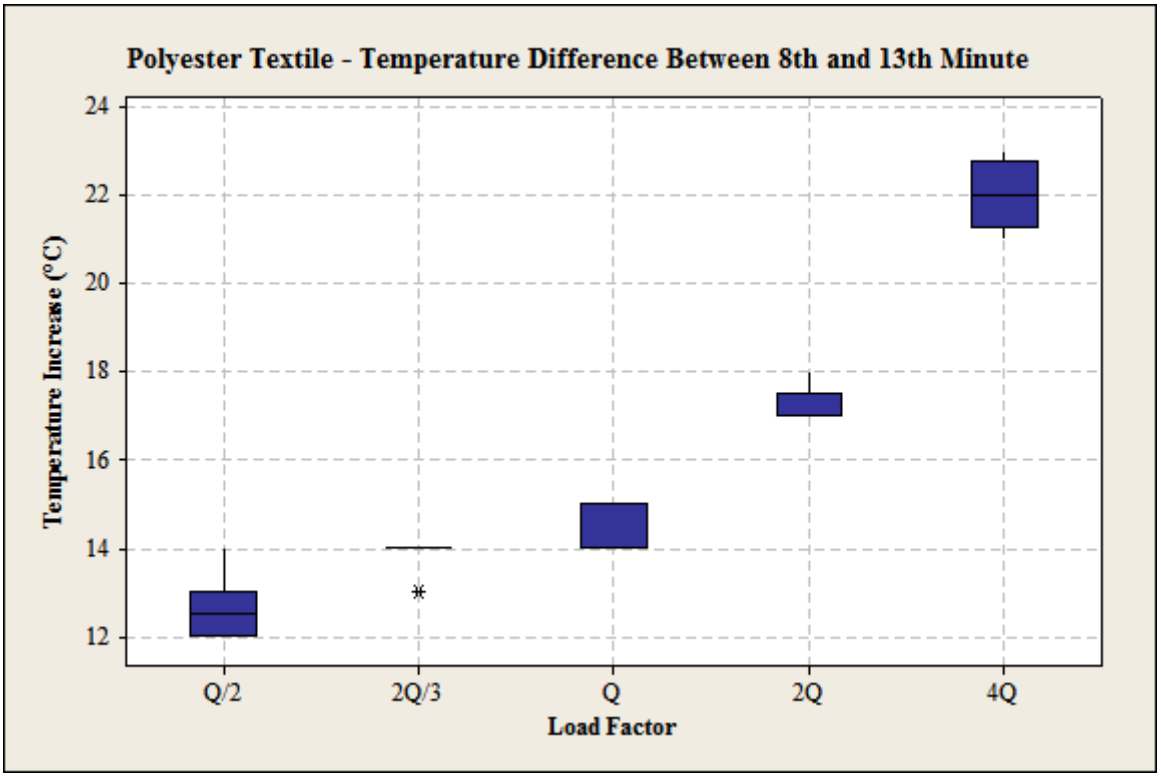

Figure 4.20. Comparison of temperature increase of the polyester textile for different load factors

The comparison of the results of the temperature analysis with thermocouples measurements for different load factors is shown in Figure 4.21. Total temperature variations are directly proportional to load factor Q's and different for each load factor. But the values of Q/2 and 2Q/3 are very close to each other.

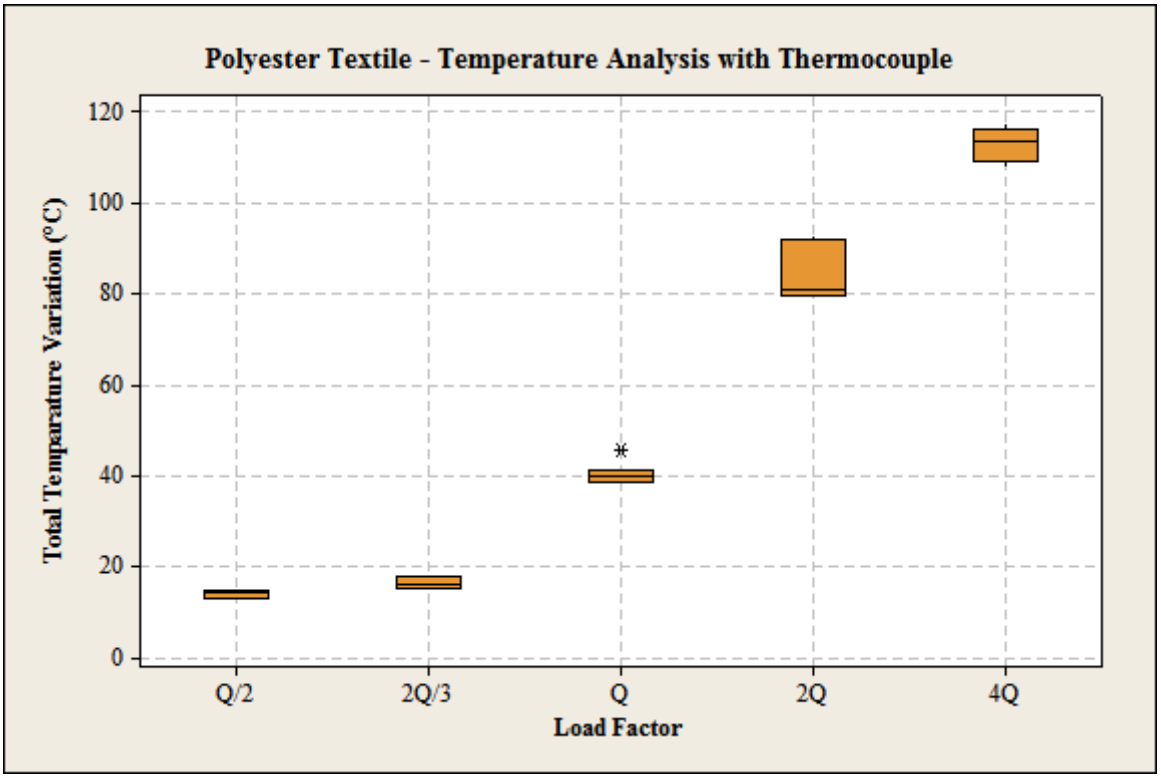

Figure 4.21. Comparison of thermocouple temperature analysis results of the polyester textile for different load factors

The values of total temperature variation with the heater at off position that are result of the temperature analysis with NTC measurements are inversely proportional to load factors as shown in Figure 4.22. For polyester textiles, total temperature variations are different for various load factors.

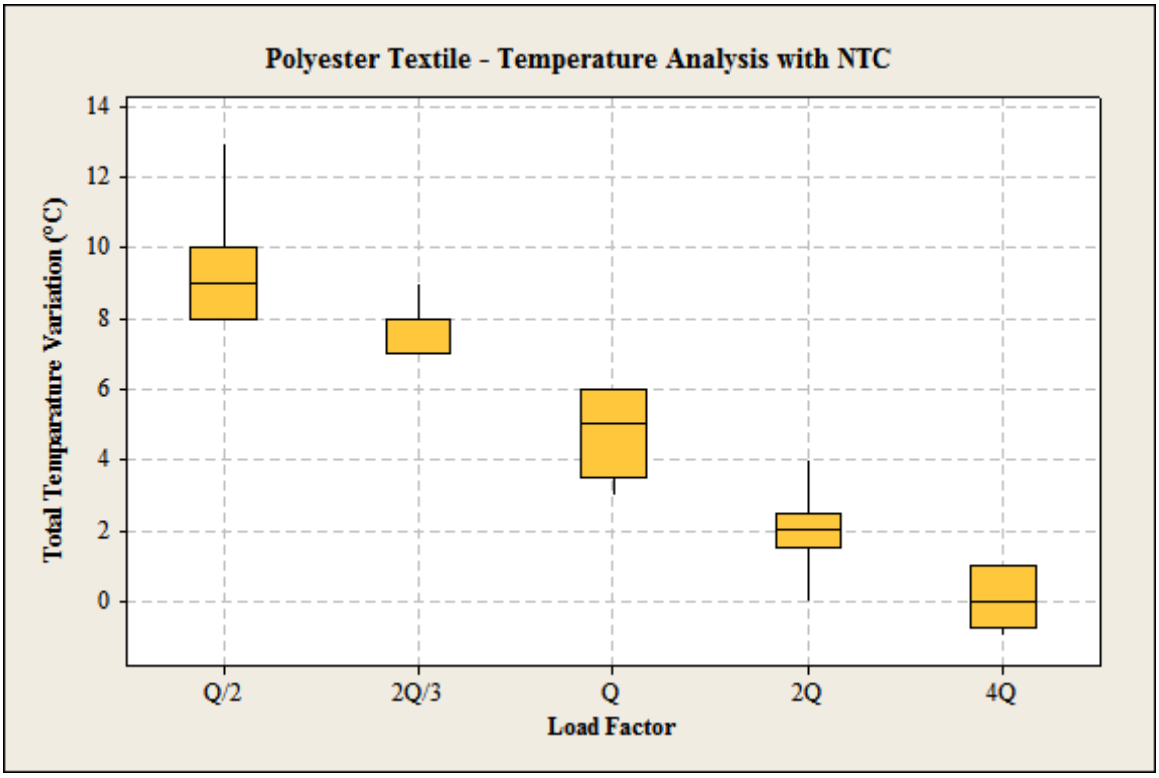

Figure 4.22. Comparison of NTC temperature analysis results of the polyester textile for different load factors

When the values of average electrical resistance were examined, they are directly proportional to load factors as shown in Figure 4.23. Furthermore, the resistance values of 2Q/3 are similar with either load factor of Q/2 or Q.

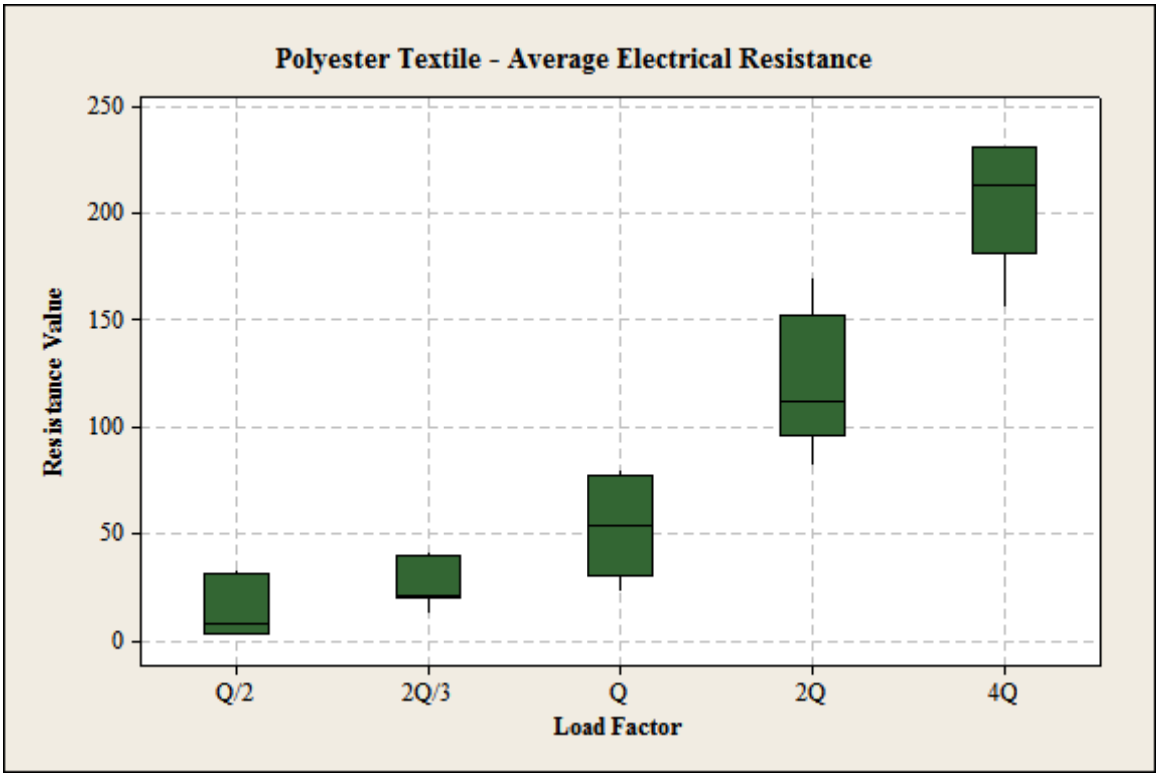

Figure 4.23. Comparison of average electrical resistance of the polyester textile for different load factors

4.6. COMPARISON OF COTTON AND POLYESTER TESTS

The test results of the cotton textiles and polyester textiles were compared. Firstly, the temperature increase values were compared at the test time between the eighth and thirteenth minute with the continuos operation of the heater. The values of the temperature increase were independent from the different initial moistures as shown in Figure 4.24. The temperature increase values of the different textile types are similar to each other for the same load factor. The temperature difference between the eighth and thirtennth minutes do not affect from the textile type. Temperature incerease of Q, 2Q and 4Q load factors can be differentiated in the case of independent from textile type. On the other hand, the values of the Q/2 and 2Q/3 load factors are similar to each others and can not be differentiated from each other. As a resut of the test results, load factors can distinguish as Q/2-2Q/3, Q, 2Q and 4Q according to the temperature difference between eighth and thirteenth minutes.

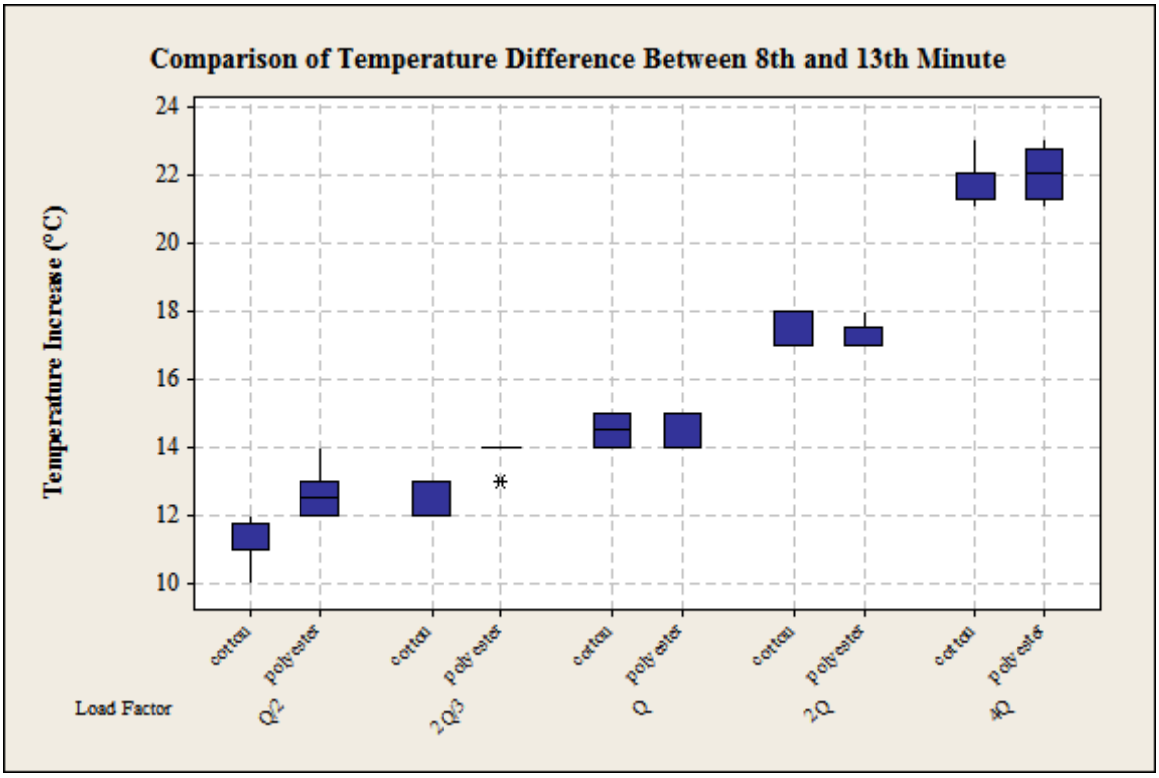

Figure 4.24. Comparison of temperature increases of the cotton and polyester textile for different load factors

In the Figure 4.25, the results of the temperature analysis with thermocouple were examined for different load factors with different textile types. The values of total temperature variation of Q, 2Q and 4Q load factors are diffrent from each other. Transversely, the values of the Q/2 and 2Q/3 are very close to each other. When the results are analyzed by the side of textile type, for Q/2, 2Q/3 and 4Q load factors, the total temperature variation values of the different textile types are different from each other. For Q/2, 2Q/3 and 4Q load factors textile type can be determined to be as cotton or polyester if the load factor is known.

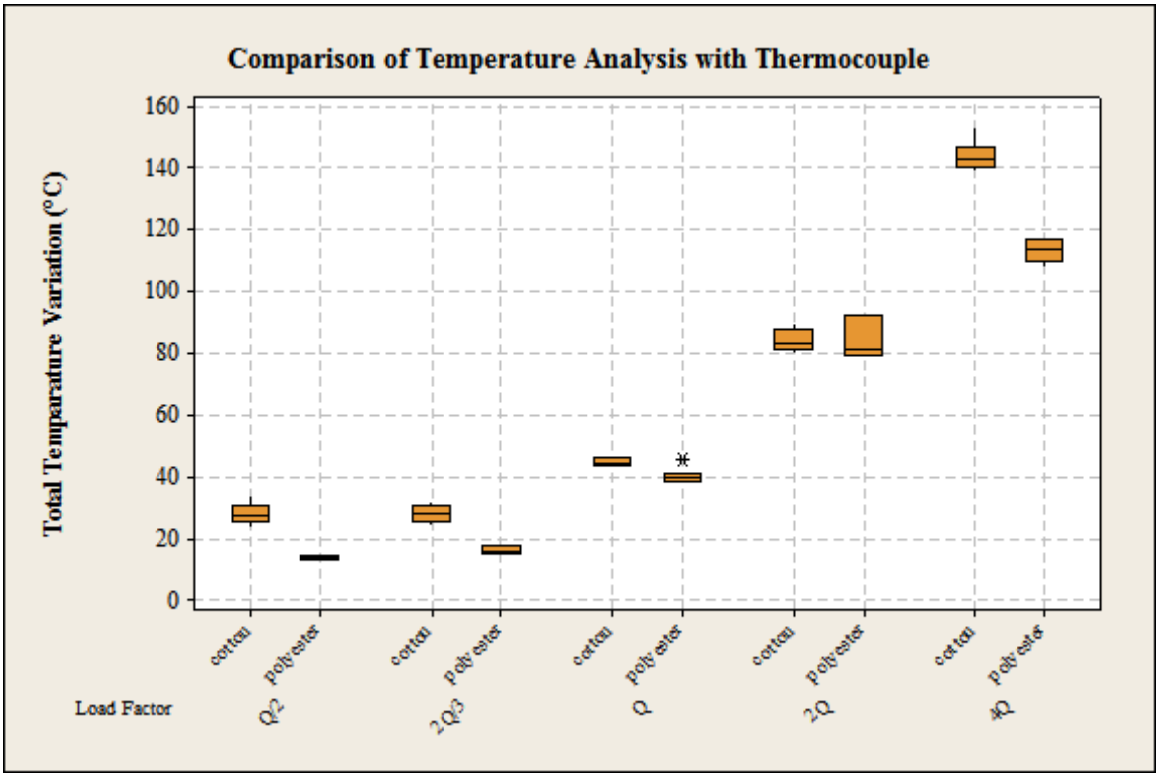

Figure 4.25. Comparison of thermocouple temperature analysis results of cotton and polyester textile for different load factors

The total temperature variations of the different textiles were examined in Figure 4.26 when the heater was not operated at the temperature increasing region. The temperature variation values of the different textiles at the heater-off positions are very close to each other for Q, 2Q and 4Q load factors. At the tests that were made for these load factors, the total temperature variations are similar for cotton and polyester textiles. For Q/2 and 2Q/3 load factors, the total temperature variation values are different for cotton and polyester. For all tests, the total temperature variation values of the cotton textiles are generally lower than the polyester textile's values but for Q/2 and 2Q/3 load factors, the difference between cotton and polyester is much larger.

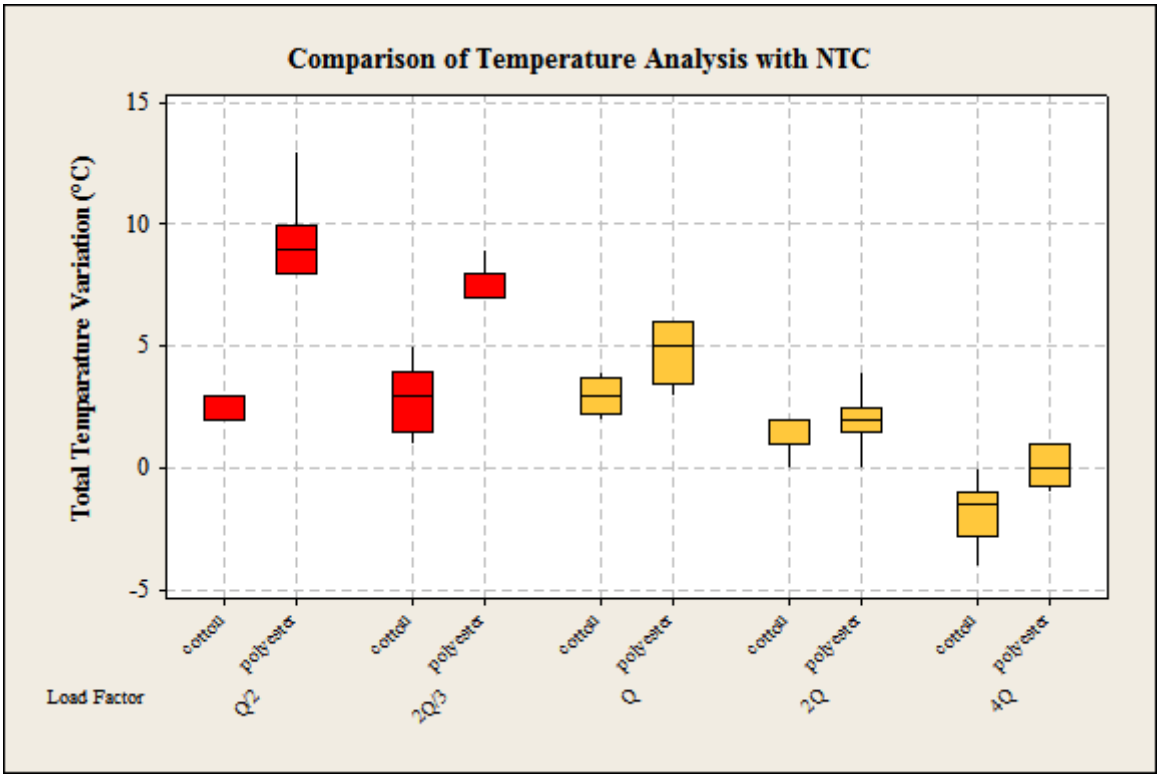

Figure 4.26. Comparison of NTC temperature analysis results of cotton and polyester textile for different load factors

Comparison of the average electrical resistance values of the different textile types is presented in Figure 4.27. For 2Q/3, Q, 2Q and 4Q load factors, the average electrical resistance values for cotton and polyester textiles are different from each other. The average electrical values of the polyester textile are higher than those of cotton textile. While load factor Q values are increasing, the difference of the average electrical resistance values' between cotton and polyester is increasing. Only the average electrical resistance values of the Q/2 are similar for cotton and polyester textiles. For all load factors except for Q/2, when the load factor is known, the textile type can be determined.

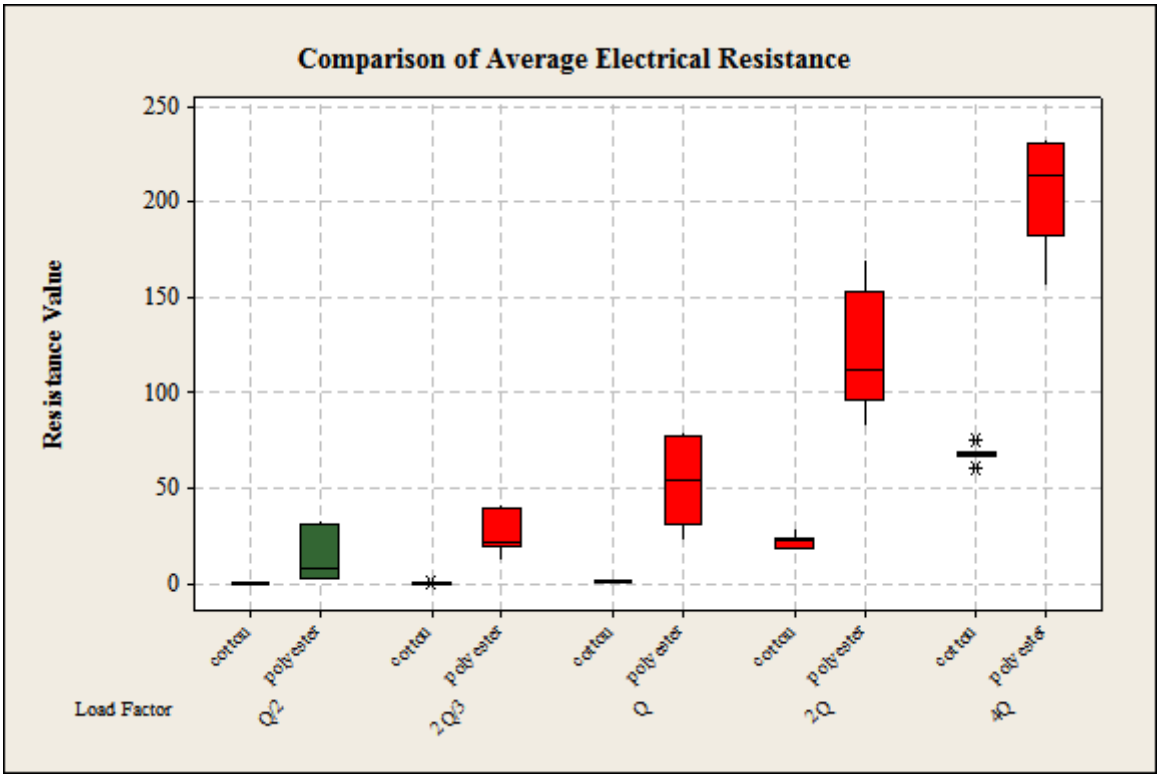

Figure 4.27. Comparison of average electrical resistances of cotton and polyester textile for different load factors

4.7. MIXED TEXTILE TESTS

Mixed textiles are defined in the EN 61121 standard for testing the easy-care textiles. The mixed textiles are polyester/cotton blended textile with the proportion of (65 ± 3) per cent polyester. At these test series, it was aimed to investigate the behaviour of the mixed textiles. Accordingly, only two load factors Q/2, Q and one initial moisture 50 per cent was selected. As a result of the test, temperature and electrical resistance values were examined and compared to all test results of the polyester and cotton textiles.

In Figure 4.28, the temperature increase values of mixed textiles were compared for cotton and polyester textiles. The temperature differences between eigthth and thirteenth minutes of mixed textiles are similar for cotton and polyester textiles at both load factors. The test results show that the effect of the mixed textiles does not change the temperature increase tendancy.

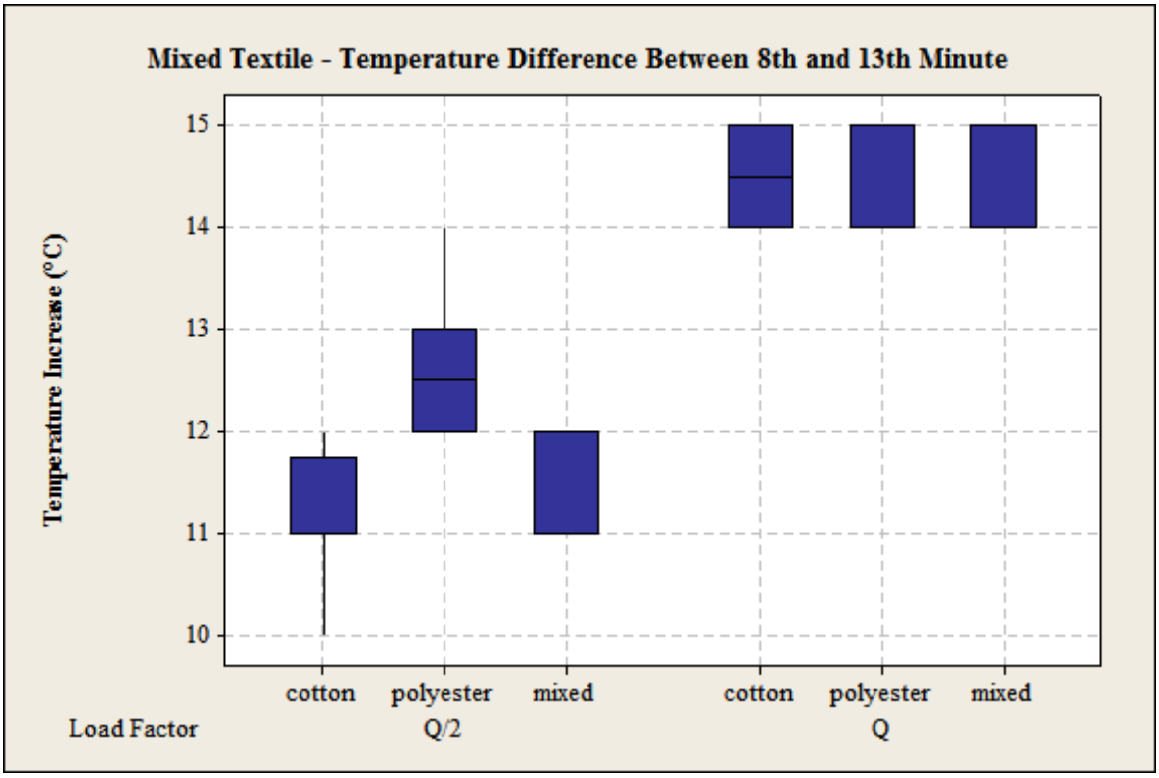

Figure 4.28. Comparison of temperature increase of the mixed textile for different load factors

The results of tests were examined by the additional analysis with thermocouple. The comparison of the mixed textiles test results with the cotton-polyester textiles is presented in the Figure 4.29. For Q/2 load factor, total temperature variations of the mixed textiles are different from other textile types but their values are close to the values of polyester textiles.

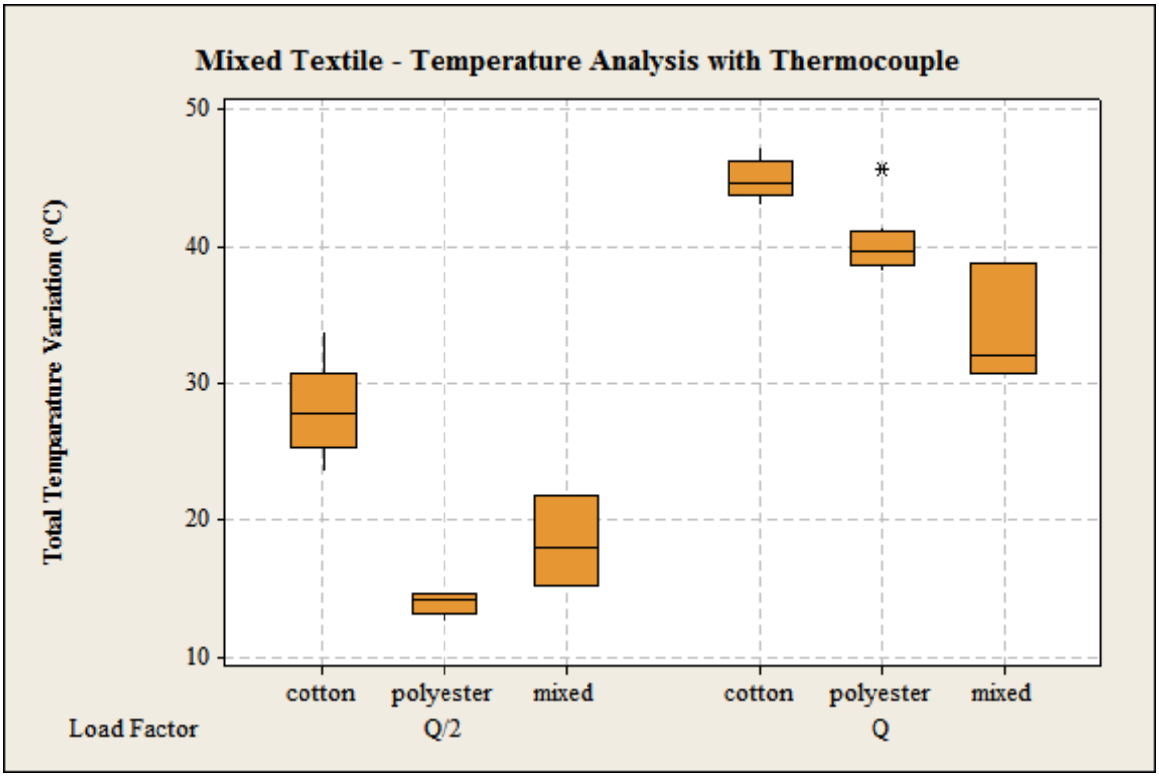

Figure 4.29. Comparison of thermocouple temperature analysis results of the mixed textile for different load factors

The total temperature variations of the mixed textiles as a result of the temperature analysis were compared in Figure 4.30. Values of the mixed textiles are close to cotton textiles values for Q/2 load factor. For other initial moistures' of the mixed textiles, total temperature variations values can be similar to cotton textiles and they can not be differentiated between each others. It is desired to distinguish the mixed textile from cotton textile. It was desired that the mixed textiles values are close to polyester textiles like the result of the temperature analaysis with thermocouple. On the other hand values of the cotton, polyester and mixed textiles values are similar to each other for various load factors.

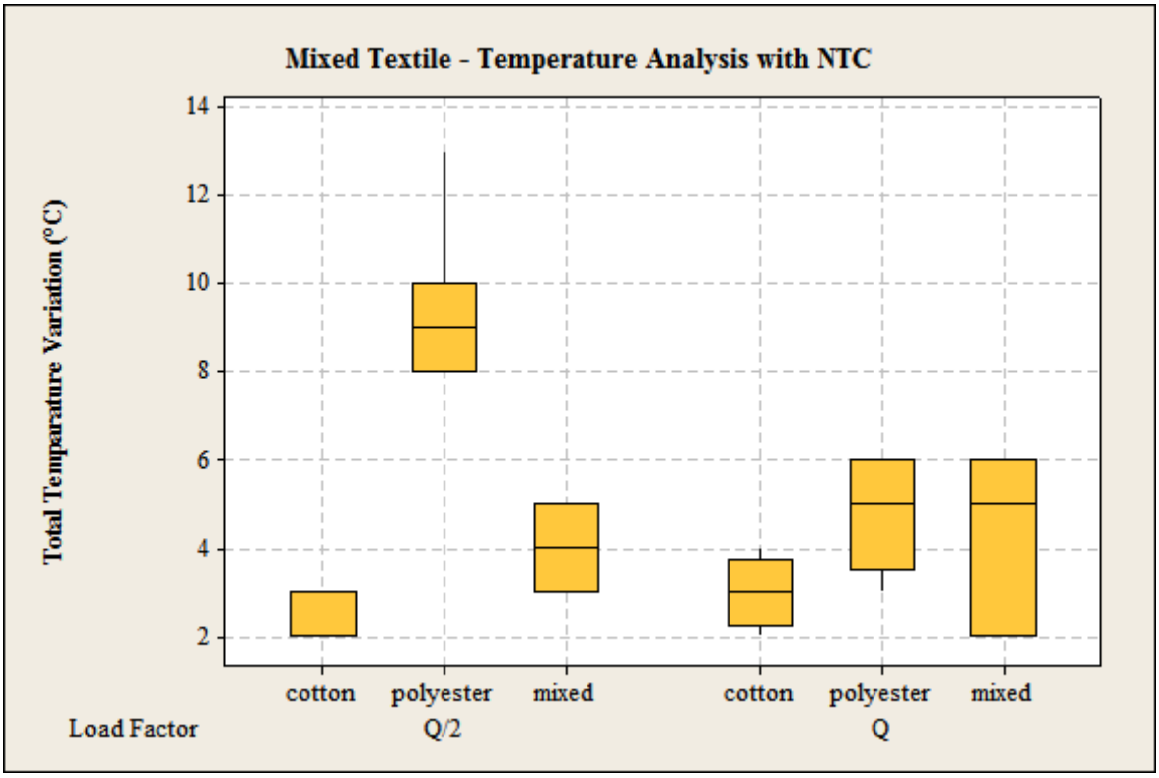

Figure 4.30. Comparison of NTC temperature analysis results of the mixed textile for different load factors

When the average electrical resistance values were compared as shown in Figure 4.31, it is concluded that for the resistance values of the mixed textiles are between the cotton and polyester textiles values. Therefore, mixed textiles can be distinguished from other types for load factor Q at these test conditions.

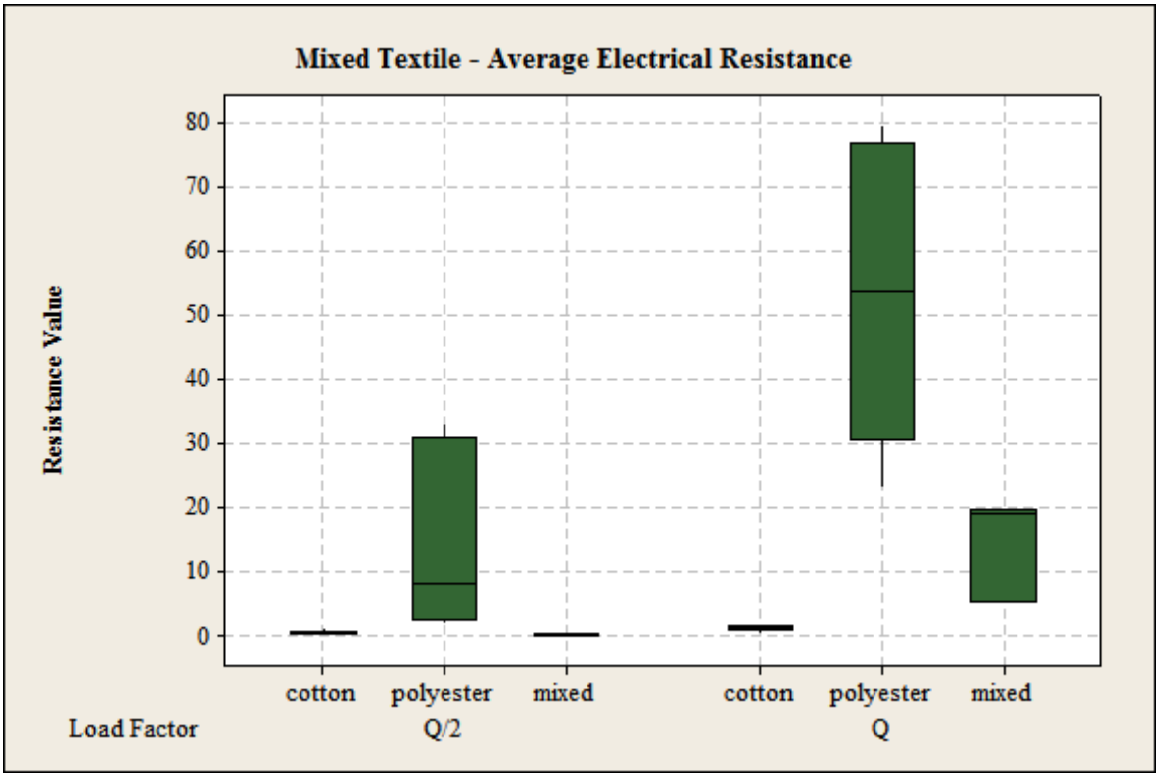

Figure 4.31. Comparison of average electrical resistance of the mixed textile for different load factors

4.8. TESTS AT DIFFERENT AMBIENT TEMPERATURE

Cotton, polyester and mixed textiles tests were made an the standard ambient conditios. The temperature of the standard ambient is (23 ± 2) °C; the standard ambient humidity is (55 ± 5) per cent according to European Standard EN 61121 . It was aimed to observe the effect of the different ambient temperatures on temperature increases, variations and electrical resistance values. All tests were run in the conditioned room. By considering the maximum and minimum temperature at which the tumble dryer can be operated, the temperature of the conditioned room was regulated between 10°C and 35°C. Polyester textiles, cotton textiles and Q/2, Q and 2Q load factors were used in the test series; the 50 per cent initial moisture was selected as a test condition.

The effect of the different ambient temperatures on temperature increases was shown in Figure 4.32. For all load factors that were tested, the temperature difference between eighth and thirteenth minutes is not affected critically by the 10°C and 35°C ambient temperatures. Temperature incresing values are independent of the different ambient temperatures at the heating phase of the dryer.

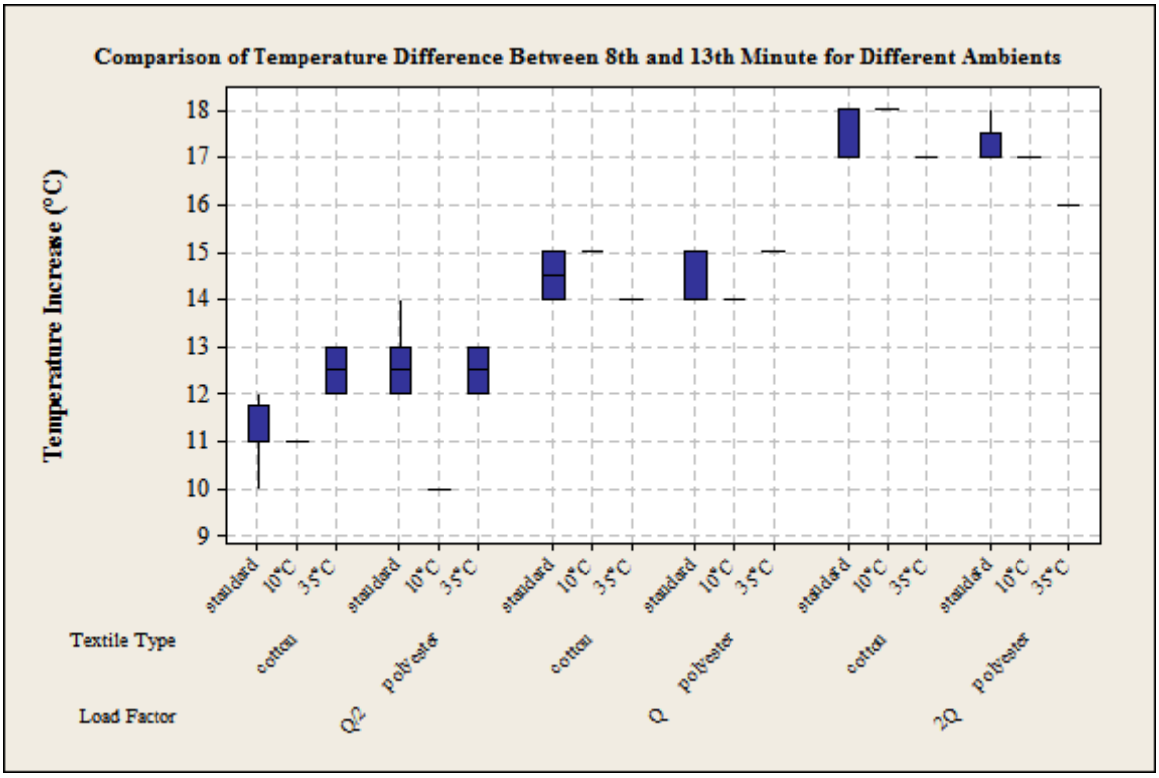

Figure 4.32. Comparison of temperature increases of the cotton and polyester textile for different ambient temperatures and load factors

In Figure 4.33, the comparison of the total temperature variation values between the different ambient temperatures and the standard condition is presented. For Q and 2Q load factors, the results of the temperature analysis with NTC are similar for all ambient temperatures. Like the standart ambient tempeature results, total temperature variation values can not be differentiated between cotton and polyester textiles for these load factors. On the other hand, for Q/2 load factor, total temperature variation values are different between cotton and polyester textiles. Different ambient temperatures do not affect the distinction between cotton and polyester textiles by the temperature analysis with NTC values for Q/2 load factor.

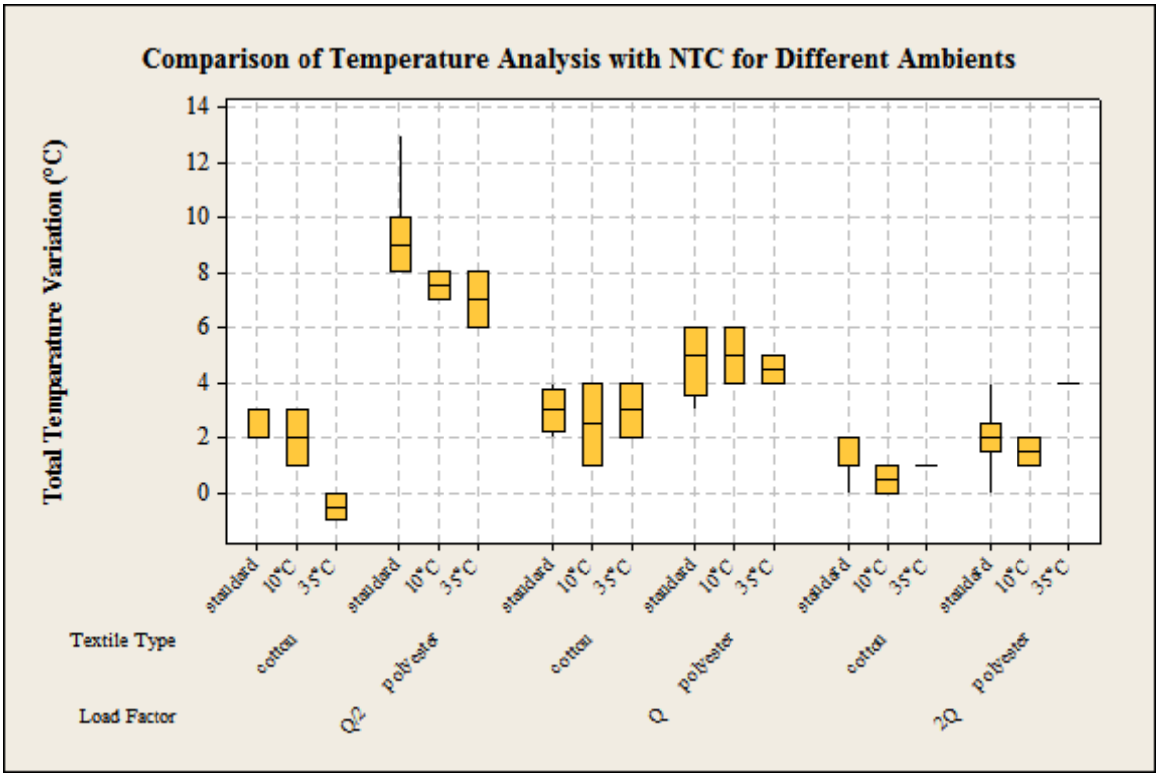

Figure 4.33. Comparison of NTC temperature analysis results of cotton and polyester textile for different ambient temperatures and load factors

The average electrical resistance values of the different ambient temperatures were compared in Figure 4.34. Only for load factor 2Q, the difference between values of cotton and polyester textiles is significant. At 10°C and 35°C ambient temperatures, the distinction between textile types is negligible for Q/2 and Q load factors. But at the standard ambient condition, the average electrical resistance values were different between cotton and polyester textiles for load factor Q. Different ambient condition affects the distinction of the textile types for Q load factor.

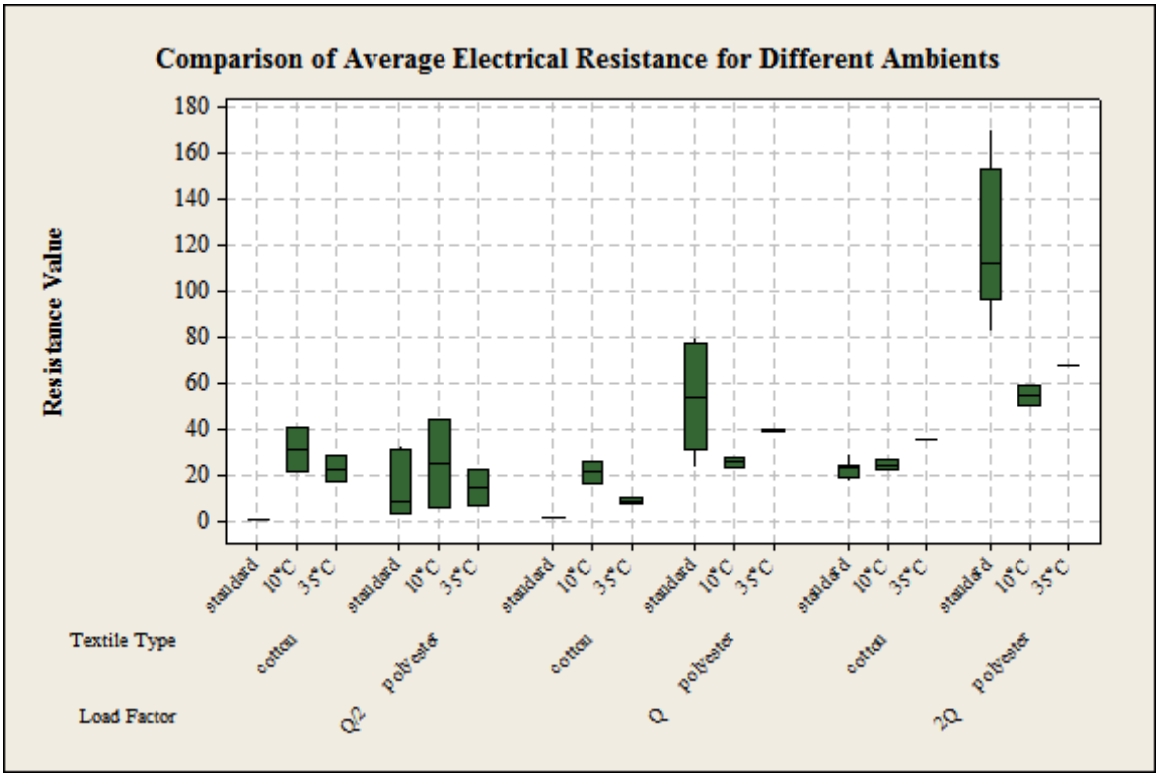

Figure 4.34. Comparison of average electrical resistances of cotton and polyester textile for different ambient temperatures and load factors

4.9. ELECTRICAL RESISTANCE TESTS

Electrical resistance of the textiles was measured by the conductivity sensors on the drying machine at the preceding sensing tests. These measurements were affected by the factors such as rotation of the drum, dimension of textiles, load amount and electronic card design. Resistivity measurements were made with the conductivity sensor and polyester textiles at the ambient that was independent from dryer by eliminating these factors. It was aimed to prove that the resistance value of polyester changes with moisture gain. The setup consisted of 2410 source meter, conductivity sensor and 100 per cent polyester textiles. The conductivity sensor was connected to the source meter by conductive cables and the metal plate side of the sensor contacted to the textiles to realize measurements. Also, the conductivity sensor was fed by source meter with 21 V and current values were recorded.

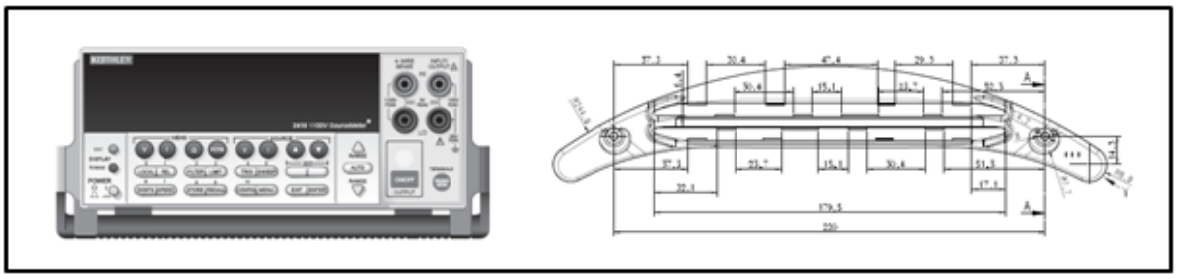

Figure 4.35. 2410 Source meter and conductivity sensor plate

Resistivity measurements were made from six different locations of the textiles because of the different moisture distribution along the textiles. Measurement locations were presented in Figure 4.36 as red dashed lines. Dimensions of the standard polyester samples used in measurements were 30x30 cm. As a result of the measurements, average of the different locations was accepted as electrical resistance of the textile.

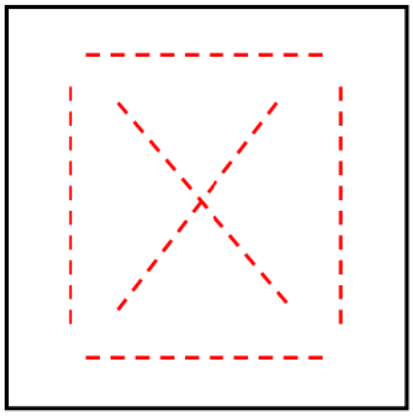

Figure 4.36. Locations of measurements at the polyester textile

At each measurement location, 12 current values were recorded and total, 72 data were recorded for one measurement. And then these current values were averaged. Finally, these values were converted to the resistance values.

Polyester textiles were conditioned as 30, 40 and 50 per cent initial moistures. For different polyester samples, the results of the measurements were shown in Figure 4.37. The resistance value of the polyester textiles is linearly decreasing when moisture regain of the textile is increasing. Moreover, the electrical resistivity values are close to each others for high moisture regain values.

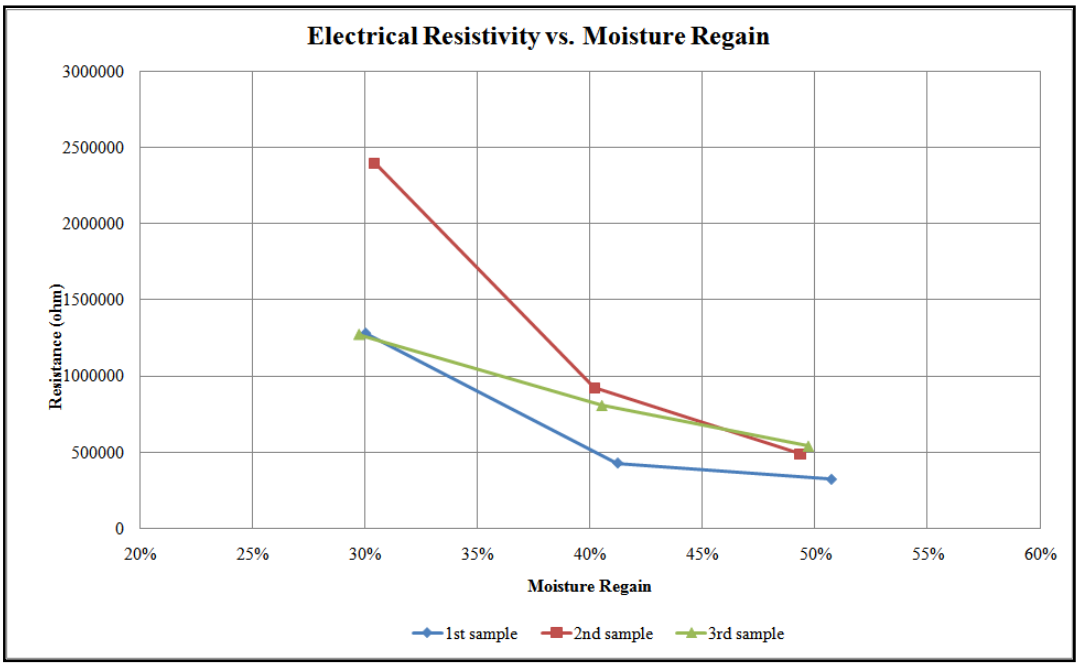

Figure 4.37. Comparison of electrical resistivity values of different polyester samples for different moisture values

As it was mentioned before at the "Literature Survey" section, there was a study about the electrical resistance of textiles under wet conditions. The results similar to the literature were obtained at this study. The study [17] shows that, the electrical resistance of polyester textiles decreases gradually when moisture regain increases as shown in Figure 4.38.

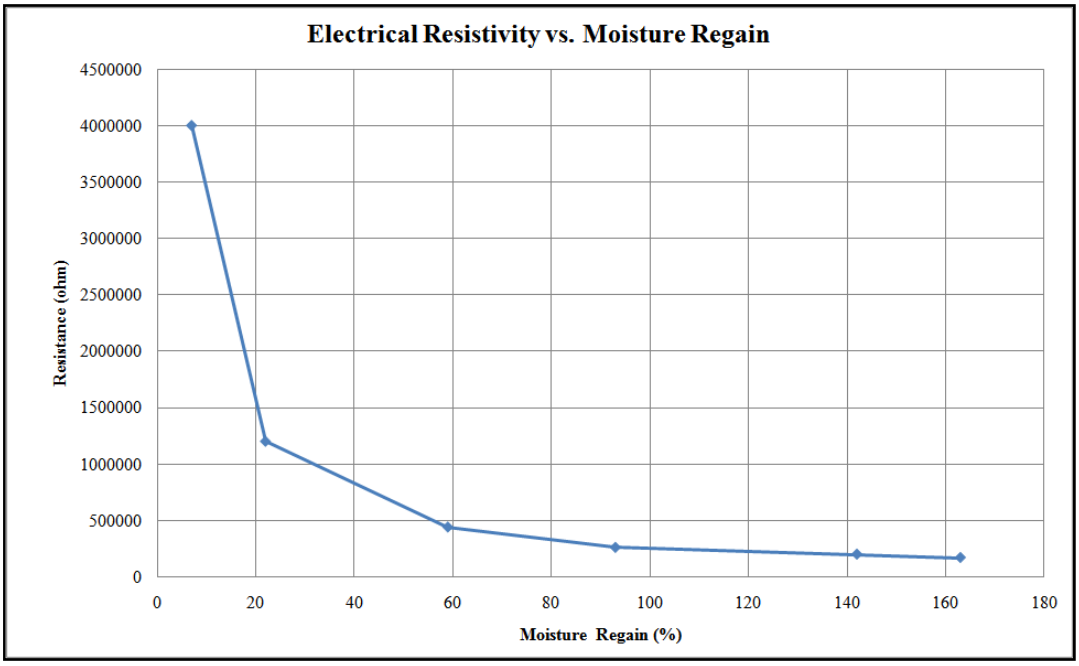

Figure 4.38. Comparison of electrical resistivity values for different moisture regains [17]

4.10. SENSING ALGORITHM

As a result of the tests results, an algorithm has been created that contains methods of sensing load factor of textile quantity and textile type during drying. First of all, it was aimed that the sensing operation was to be made with components which already exist in the dryer. Therefore, the values of NTC measurements were preferred to temperature measurements with thermocouple. Moreover, while the algorithm was being created, the last sensing operation was limited with cotton and polyester textiles at standard ambient conditions for all load factors that was tested, since the mixed textile result shows difficulty in differing mixed textiles from other textile types.

When the all test results were analyzed, temperature increase between eighth and thirteenth minutes was the best method to sense the load factor of textile quantity. Temperature increases of cotton and polyester textiles were presented in Figure 4.39 according to load factors. Distinction between Q, 2Q and 4Q load factors was realized but Q/2 and 2Q/3 load factors were not differed from each other. Furthermore, for Q and 2Q/3 load factors, value of temperature difference intersects at the temperature increase of 14°C as shown in Figure 4.39. The reason that they share the common temperature increase of

14°C may be due to the same amount of water in the textiles. In Figure 4.40, temperature increases and water amount of the textiles was compared.

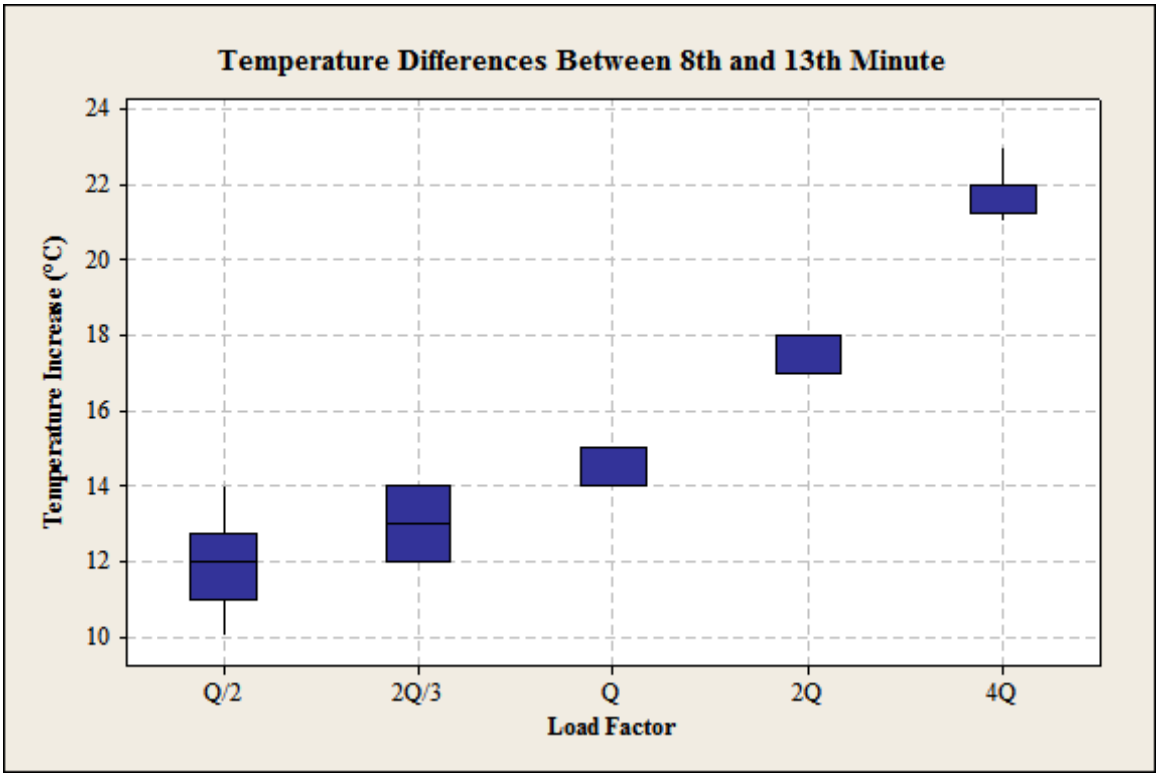

Figure 4.39. Comparison of temperature increases different load factors

Temperature increase values are inversely related to the amount of water in the textiles as shown in Figure 4.40. For instance, at the temperature increase of 14°C, the textile whose load factor is 2Q/3 has 1800 g water and the textile with the load factor of Q has 1600 g or 2000 g water. Their water amounts are close to each other. As a result, temperature increase value is affected from textile mass and amount of water in it, in other words, the total mass of textile.

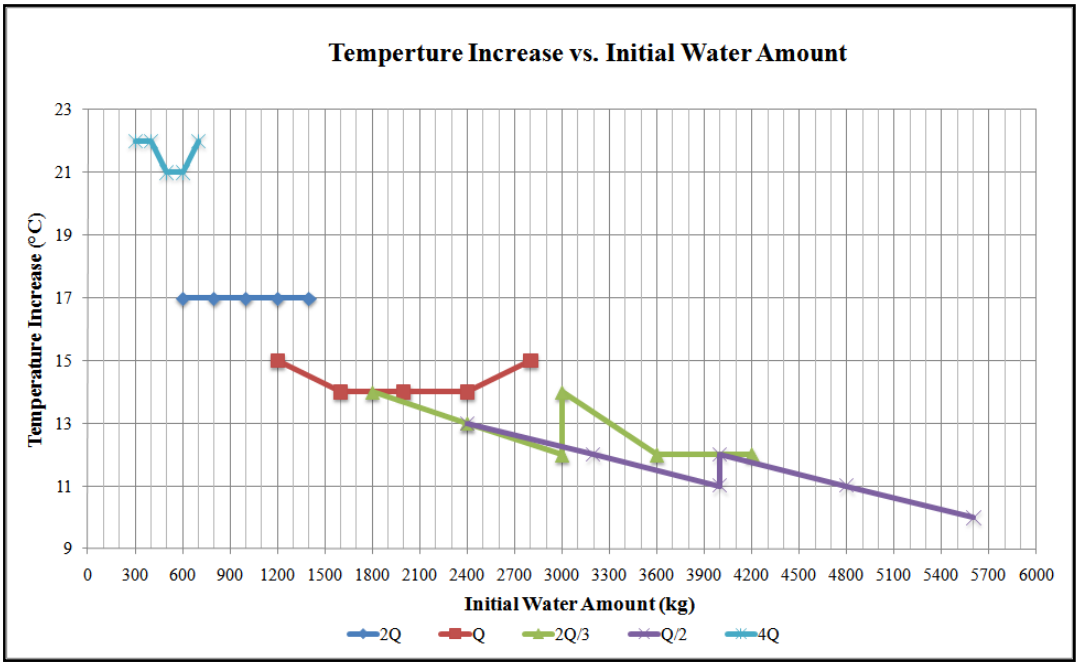

Figure 4.40. Comparison of the initial water amount of textiles and temperature increase

When Figure 4.39 and Figure 4.40 were analyzed together, it is concluded that load factors of textile quantity can be distinguished as small, medium and large (Q/2-2Q/3, Q, 2Q-4Q), independent of textile type and initial moisture quantity of textiles.

As a result of the tests results, for sensing the textile type two different methods must be used according to the load factor of textile quantity. Firstly, the results of temperature analysis are used for load factor of Q/2 and 2Q/3 because textile types cannot be differed by average electrical resistance values for Q/2 load factor. Although either average electrical resistance values or temperature variation values of 2Q/3 load factor were different for cotton and polyester textiles, common method must be used for Q/2 and 2Q/3 load factors since the load factors of Q/2 and 2Q/3 could not be differed from each other. Secondly, for load factor of Q, 2Q and 4Q the method of average electrical resistance is used because their temperature variation values were not different for cotton and polyester textiles.

The results of the temperature analysis method were presented in Figure 4.41. This method can only used for sensing the textile type of Q/2 and 2Q/3 load factors. The temperature variations of polyester textiles were higher than cotton textiles for Q/2 and

2Q/3 load factors. In other words, when the heater was off between first and eighth minutes, temperature of the polyester textiles continued to increase but temperature of the cotton textiles was stable or decreased at these load factors.

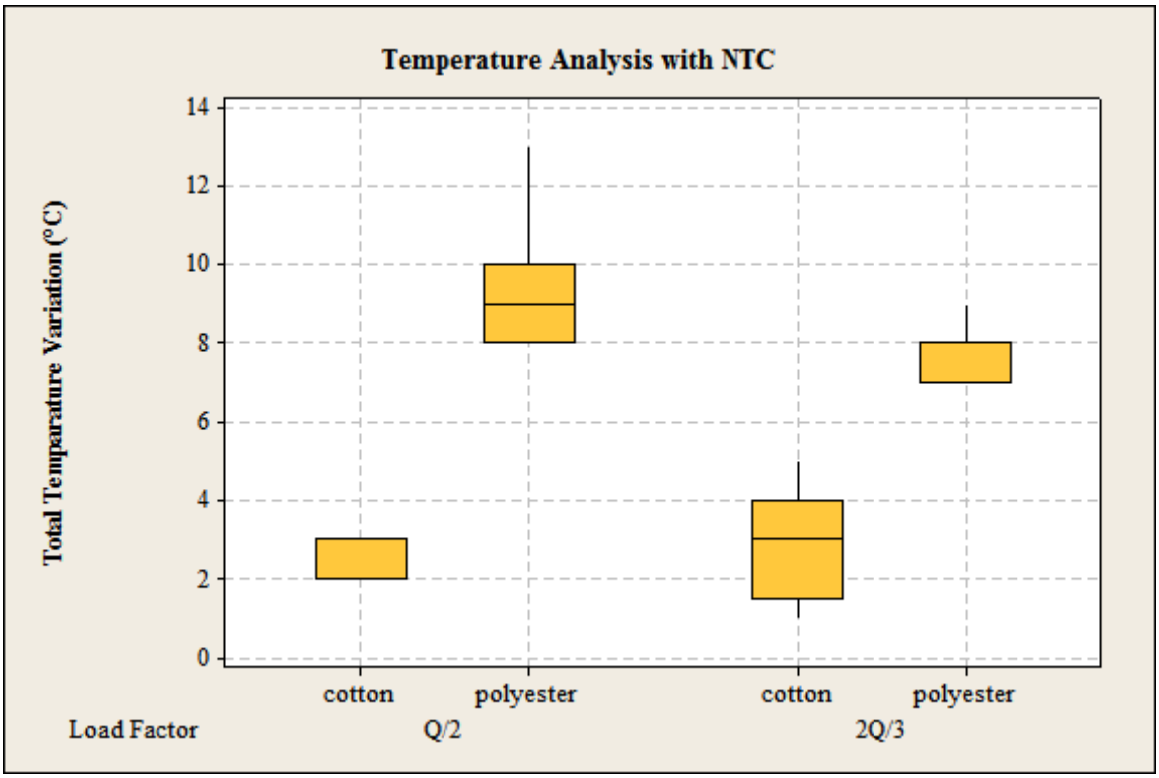

Figure 4.41. Comparison of NTC temperature analysis results of cotton and polyester textile for Q/2 and 2Q/3 load factors

The average electrical resistance values of Q, 2Q and 4Q load factors were shown in Figure 4.42. When the load factor is known as Q, 2Q or 4Q, the cotton and polyester textiles can be differentiated by average electrical resistance values as seen in Figure 4.42. Average electrical resistance values of polyester textiles were higher than those of cotton textile independent from load factors and initial moisture content of textiles.

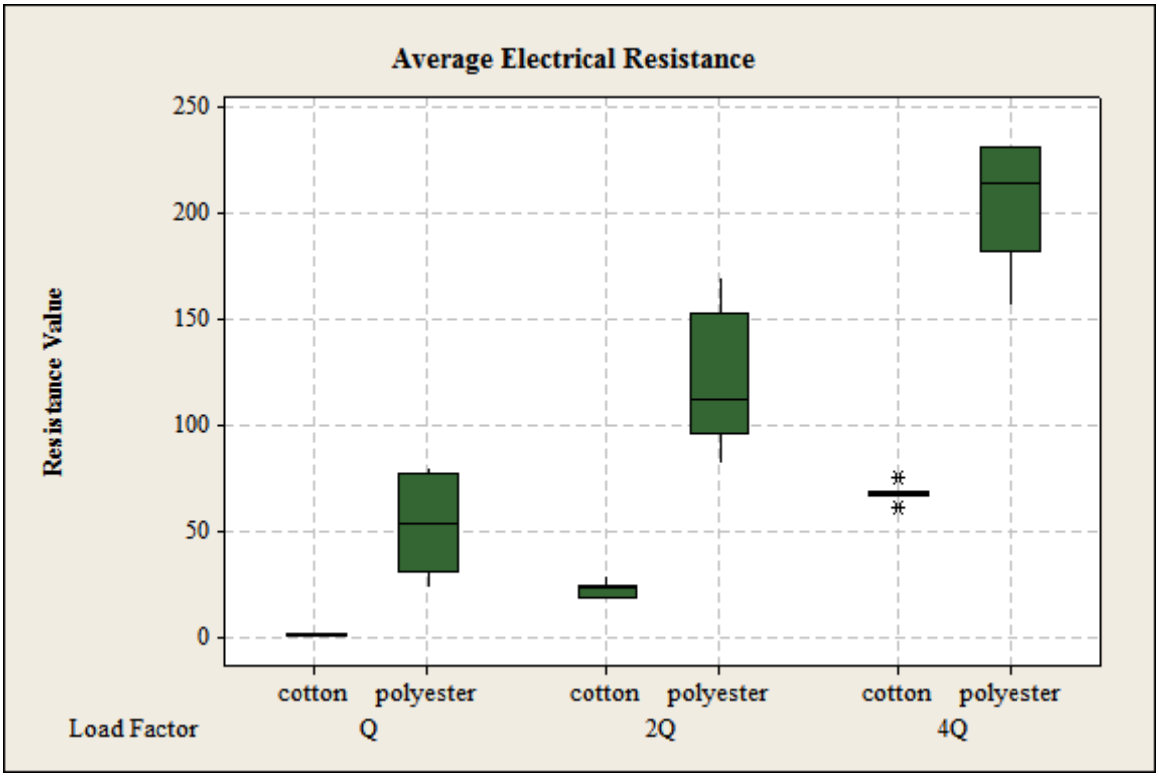

Figure 4.42. Comparison of average electrical resistance of cotton and polyester textile for Q, 2Q and 4Q load factors

When the results of the all methods were summed, one algorithm was formulated to sense the load factor of textile quantity and textile type. This algorithm combined heater profile of dryer and sensing methods. In this algorithm, the heater was operated one minute on - one minute off at the start of the drying process for the first eight minutes. At this stage, when the heater was not operated, the temperature variations were summed and recorded. Also, the electrical resistance values were averaged between one hundred and five hundred seconds and were recorded. Subsequently, heater was operated on position continuously between eighth and thirteenth minutes. In this interval, temperature difference was calculated and firstly the value of load factor was decided according to this temperature increase value. After deciding the load factor, textile type sensing method determined according to this load factor. If the load factor is Q/2-2Q/3, the temperature variation value will be compared with the reference value D. If the load factor is Q, 2Q or 4Q, the average electrical resistance value will be compared with the reference value A, B or C in respect of load factor value. Consequently, if the temperature variation value or the average electrical resistance value is higher than the reference value, the textile type is

decided as polyester. If they are lower than the reference value the textile type is decided as cotton.

5. CONCLUSION AND FUTURE WORK

5.1. CONCLUSION

At the present time, with improving technology, consumers have more expectation from the appliances used in daily life. Like most of sectors that serve for consumers' needs and comfort, the sector of white goods considers it important to improve user friendly products. As a result, one-touch washing machine and dish washer are available in the market. This project, in order to compete in the area of tumble dryers market, aims to provide the basis for one-touch tumble dryers.

Within the scope of this project, for condenser tumble dryers, the sensing study of the load amount and textile type in the drum was conducted. Appropriate sensing algorithm that includes heater profile and sensing methods was developed.

By the side of consumers' satisfactions, the technical need for sensing load amount and textile type at the tumble dryer was investigated. Comparing the benchmark and Arçelik tumble dryers tests with respect to X Number, the necessity of sensing the types of textiles was proved. X number was created newly in this project with parameters such as time, temperature, heater power and load amount which are effective on textile damage. It is an indicative to the degree of textile damage.

At the start of the project, it was aimed to sense the cotton and polyester textiles as a textile type and to sense the Q/2, 2Q/3, Q, 2Q and 4Q load factors as a representation of load amounts. Firstly, the proper heater algorithm was developed in order to observe different temperature response to different textile types and load factors. The experiments were conducted for different initial moisture of these different textile types and load factors by using this heater algorithm. Additionally some experiments were made in order to observe the effect of mixed textile and different ambient temperatures.

Three methods were used to analyze the test results for different textile types and load amounts: namely (1) temperature difference between eighth and thirteenth minutes, (2) temperature analysis and (3) average electrical resistance. Because of their availability on tumble dryer, the data of NTC thermistor and conductivity sensor plates were analyzed. As a result of the tests results, after analyzing with sensing methods, the load factors were differentiated according to temperature increase between the eighth and thirteenth minutes. Although the data of Q/2 and 2Q/3 load factors were similar to each other, the data of Q, 2Q and 4Q load factors were different from each other. Therefore, load amounts could be categorized as minimum, medium and maximum load. Furthermore, once the load factor was determined, the method of sensing the textile type was decided, depending on the load factor. If the load factor was Q/2 or 2Q/3, the textile type was sensed with the temperature variations at first eight minutes when the heater was not operated. This method was named as temperature analysis method with NTC. On the other hand, if the load factor was Q, 2Q or 4Q, the textile type was sensed with average electrical resistance between the hundred and five hundred seconds.

As a consequence of this project, the load factors of Q/2, 2Q/3, Q, 2Q, 4Q as a representation of load amount and cotton and polyester as a textile type were able to sense independent from the initial moisture of the textiles. The knowledge of load factor was used to determine the appropriate method for sensing the textile types. At the first thirteenth minutes, decision on the load amount and textile type was able to made.

5.2. FUTURE WORK

Sensing the textile type and load amount at the tumble dryer and realizing the one-touch tumble dryer were the main motivation of this project. As a future work, it is necessary to sense the standard mixed textiles and also the textiles that are widely used in daily life by consumers. The tests must be repeated with textile samples in the market that represent the consumer clothes. Furthermore, in order to increase the sensing precision, a better temperature sensor may be used in the tumble dryer. Moreover, the sensing duration may be decreased from thirteen minutes to less time interval.

APPENDIX A: GRAPHICS OF DRYING TESTS ON TUMBLE DRYER

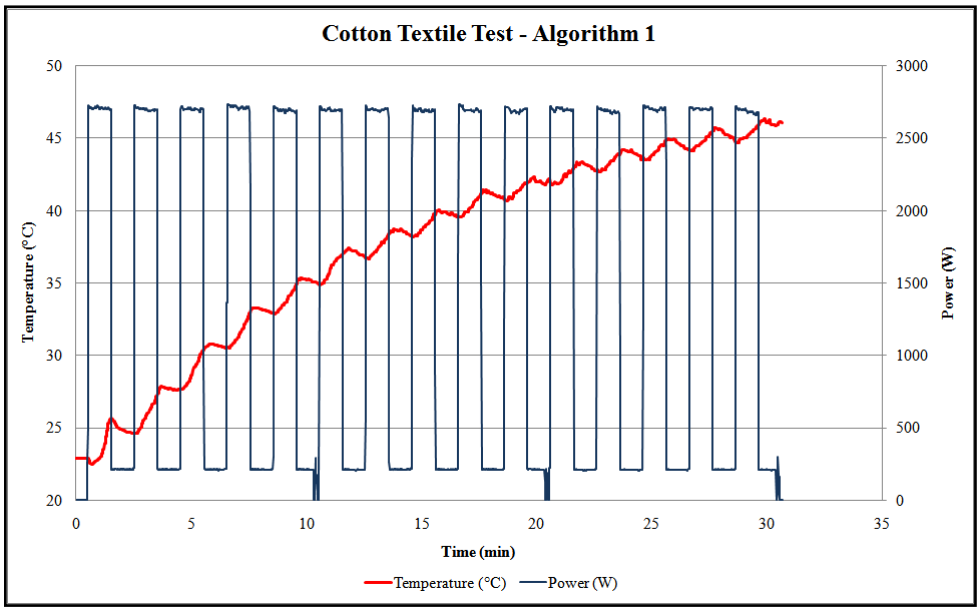

Figure A.1. Temperature and power profile of cotton textile drying with first algorithm

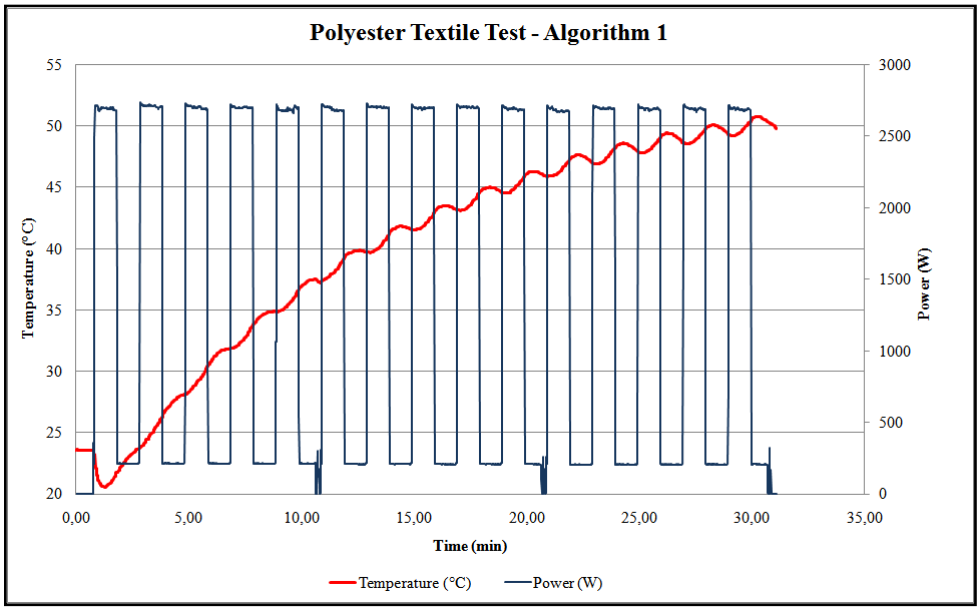

Figure A.2. Temperature and power profile of polyester textile drying with first algorithm

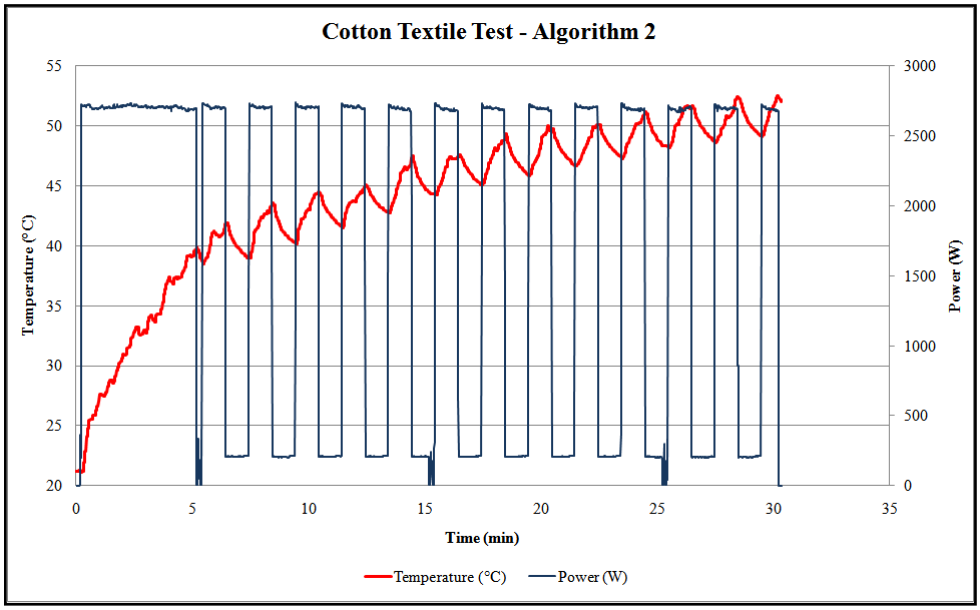

Figure A.3. Temperature and power profile of cotton textile drying with second algorithm

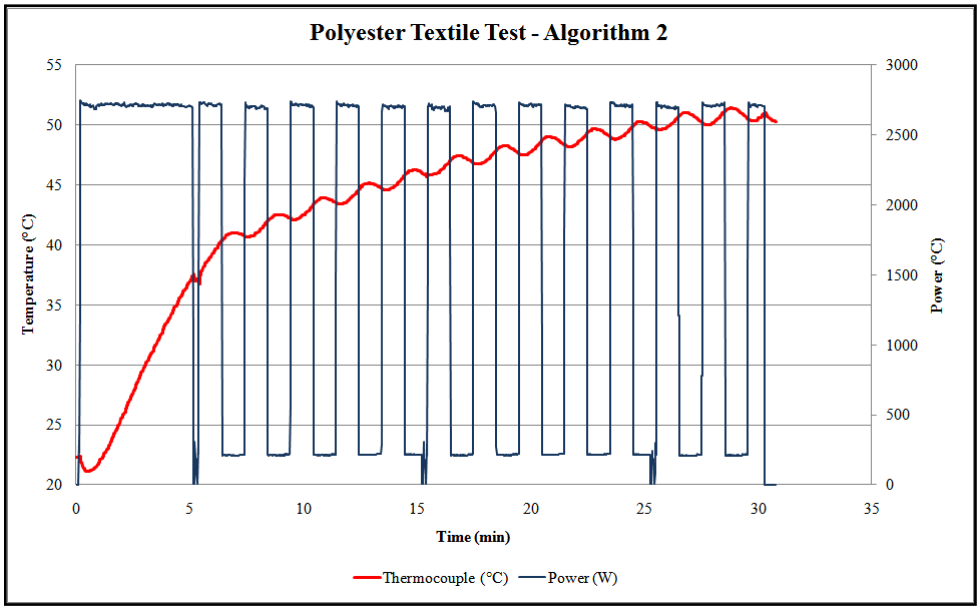

Figure A.4. Temperature and power profile of polyester textile drying with second algorithm

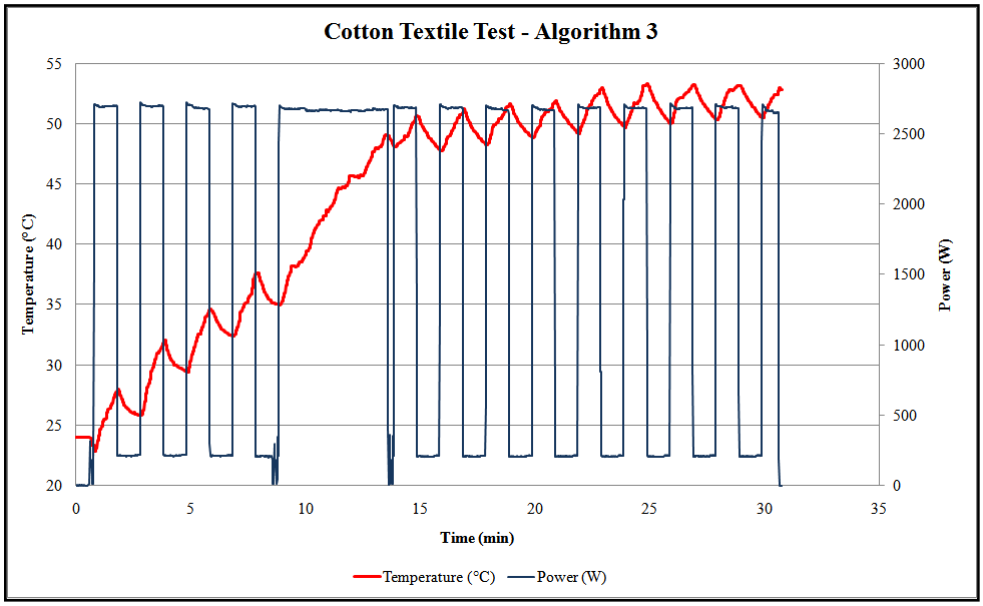

Figure A.5. Temperature and power profile of cotton textile drying with third algorithm

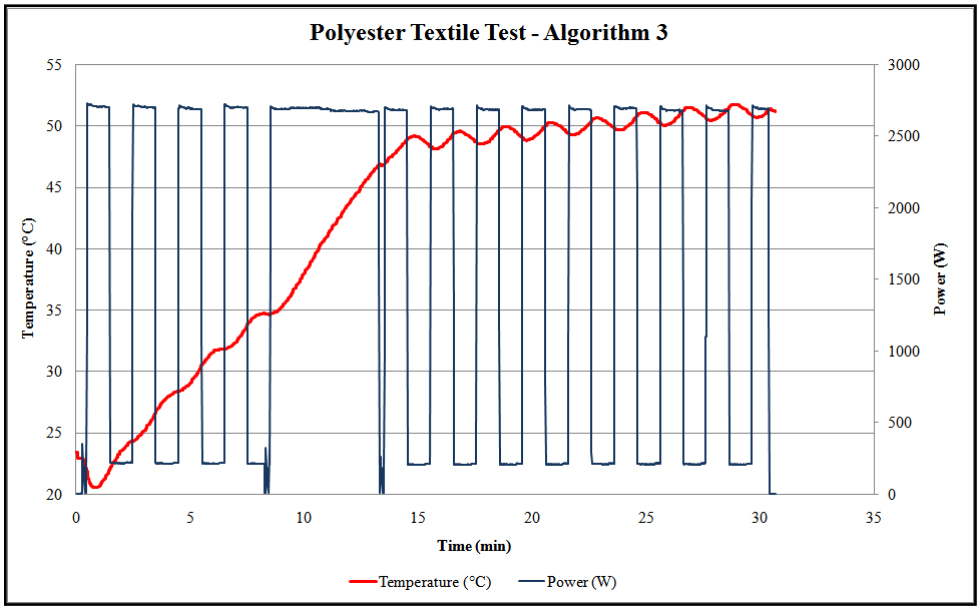

Figure A.6. Temperature and power profile of polyester textile drying with third algorithm

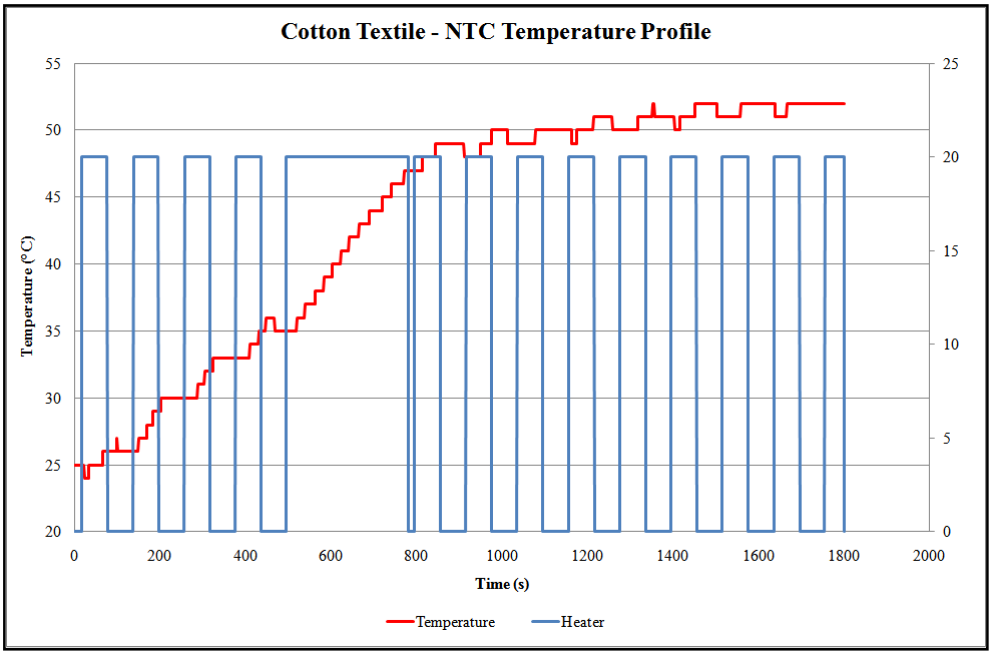

Figure A.7. Temperature power profile of cotton textile measuring with NTC thermistor

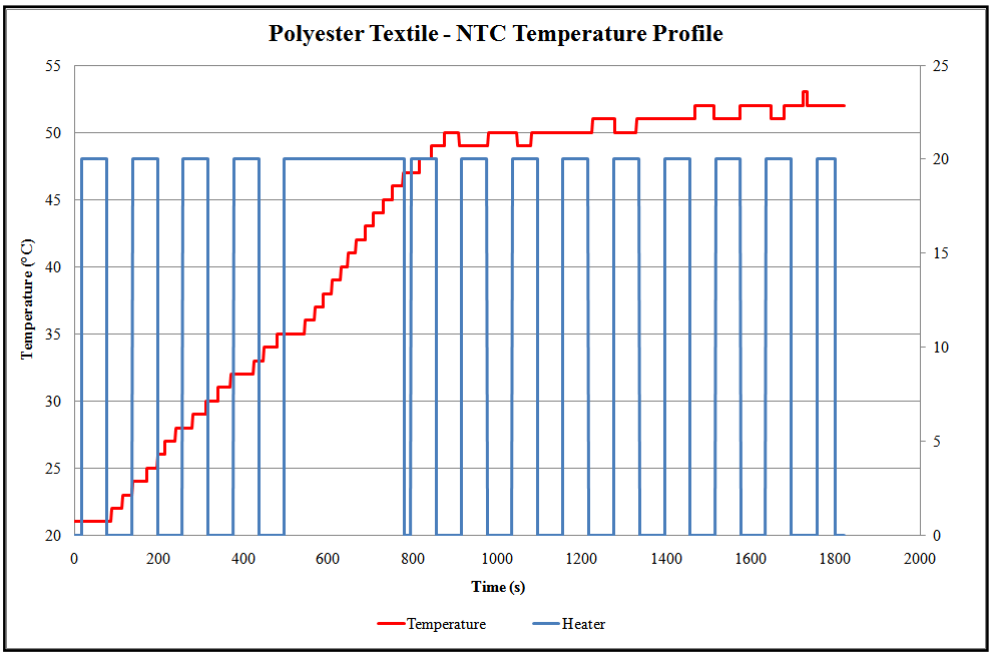

Figure A.8. Temperature power profile of polyester textile measuring with NTC thermistor

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