ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Bahri DEMİR

DESIGN AND OPTIMIZATION OF MICROWAVE OVEN

DEPARTMENT OF MECHANICAL ENGINEERING

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ÇUKUROVA UNIVERSITY
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We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 21/09/2010.

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ABSTRACT

Msc THESIS

DESIGN AND OPTIMIZATION OF MICROWAVE OVEN

Bahri DEMİR

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF PLANT PROTECTION

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The hereby thesis was prepared in order to conduct the thermal calculations of the bakery ovens with rotating carts especially by examining the thermo-chamber. In the first section it was referred to detailed information regarding bread which was the material to be cooked, and the constitution process of bread was explained. In the following two sections the presentation of oven was introduced. Main groups of oven, security systems and vapor delivery systems were presented. And in the fourth and the last section all calculations were made. Firstly thermal calculations and then cost calculations were prepared. All these calculations were performed for each thermo-chamber anticipated to operate with three different fuel types and total fuel cost for same bread type was found.

Key Words: Bread, Bakery Oven, Microwave

ÖZ

YÜKSEK LİSANS TEZİ

MİKRODALGA FIRININ DİZAYNI VE OPTİMİZASYONU

Bahri DEMİR

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
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:Doç. Dr. Hüseyin AKILLI
:Yrd. Doç. Dr. Murat AKSOY

Bu tez döner arabalı ekmek fırınlarının özellikle ısı hücresi bölümünün incelenerek ısıl hesaplarının yapılması amacıyla hazırlandı. İlk bölümde pişirilecek malzeme olan ekmek hakkında detaylı bilgilere değinildi, ekmeğin oluşum süreci anlatıldı. Daha sonraki iki bölümde fırın tanıtımı yapıldı. Fırın ana grupları, emniyet sistemleri ve buhar verme sistemleri tanıtıldı. Dördüncü ve son bölümde ise bütün hesaplamalar yapıldı. İlk olarak ısıl hesaplar ve daha sonrasında maliyet hesapları yapıldı. Bütün bu hesaplamalar üç farklı yakıt ile çalışması öngörülen ısı hücresi için ayrı ayrı yapılarak bir adet ekmek için toplam yakıt maliyetleri bulundu.

Anahtar Kelimeler: Ekmek, Ekmek Fırını, Mikrodalga

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NOMENCLATURE

A	: Area (m^2)
λ	: Heat transfer coefficient (W/m.^oK)
R	: Thermal resistance
Q	: Heat Energy (W)
ΔT	: Temperature difference
m	: Mass (kg)
C	: Specific heat (kj/kg.^oC)
η_k	: gain efficiency
K_o	: furnace efficiency
K_z	: Yield surface
K_b	: Flue loss
I	: Enthalpy (Kcal/kg)
LHV	: Fuel Lower Heating Value (kcal/kg)
T	: Temperature (^oC)
B_h	: Hourly Fuel Consumption (kg/h)

1.INTRODUCTION

1.1.Specification of Bread

Bread is a product that is prepared by adding potable water, salt, yeast to 300 gr wheat flour and when required by adding only vitamin C, smeddum or fungal alpha amylase and that is made ready by kneading dough, processing in accordance with its technique, leaving for fermentation and then cooking.

In Turkey bread is generally made of wheat. At places where wheat is rare and expensive bread can be made by only barley meal, corn flour and mixed bread can also be made by adding these grains to wheat flour at a specific rate.

1.1.1. Bread Making Operations

Basically three operations involve in making bread. Kneading, yeasting and cooking. Kneading converts flour to dough. Yeasting causes the dough to ferment and puffs it up and cooking turns dough into bread.

1.1.1.1. Kneading

The first significant operation on the production of bread is the kneading of dough as to make all parts of mixture (dough) having the same elasticity and density.

1.1.1.2.Fermentation

After kneading dough should be yeasted (fermented) for a specific period. Because fermentation is required for slightly high volume quality bread production.

1.1.1.3.Cooking

As a result of this operation by means of heat dough turns to an aromatic product (bread) that can be easily ingested. Average cooking temperature of bread is T = 290 ^{o}C - 310 ^{o}C, and the cooking period is t = 18-20 minutes depending on the size of bread.

1.1.2.Specifications that Should be Available on the Outer Surface of Bread

Outer specifications of bread should be well cooked and puffed up when observed from outside and in specific appearance and odor its crust and color distribution should be homogenous as much as possible and it should not be flat and burned.

On the outer part no observable impurity and dough balls should exist and materials except flour such as bran and razmol used to prevent sticking should not be available. Bread can be long, round and in flower form and can be cooked as free or in pan.

1.1.3.Specifications that Should be Available on the Inner Part of Bread

- When the bread is cut, the inner part should have a spongy form.
- Pores should be homogenous as much as possible and no large air holes should be available.
- Dough should not be sticky.
- Flour and salt balls, any visible impurities should not exist.
- The color of bread should be white-cream and it should be homogenous.
- It should have specific taste and odor and no impurities, taste or odor should be observed.

  [ref : www.ankhalkekmek.com.tr/yayinlar.asp?sayfa=detay&id=61]

1.2. Definition of Oven

Bakery ovens are equipped by indirect heating, forced air circulation and rotating pan carts and are useful and economic ovens that provides cooking of the product in accordance with the required cooking specifications. Burners using diesel fuel or gas (natural gas and LPG) are being used in the ovens. Furthermore there are versions of oven available that operate with electricity.

Air inside the oven circulates from the outer surfaces of indirect air heater, which is heated up by the burner, through the circulation fan and leaves a part of the heat received from the heater through convection to vapor producers and a part over the product being cooked on the rotating cart and then arrives the heater inside the combustion chamber. Finally the air circulation continues after being reheated.

Security systems are designed for operation and maintenance in the oven. The outer surface coating plates of the oven are coated by an insulation material from inside. Oven cooking chamber, door and the combustion chamber are being manufactured of stainless plate. Moreover, all the front coating plates are being manufactured of patterned stainless plate.

On bakery ovens with rotating cart, easily loading and unloading of product to be cooked through cart is economic in respect of utilization. Rotating table is incited by a reducer chain system assembled on the upper side of the oven.

On bakery ovens with rotating cart, all the products on each pan are cooked homogenously due to the balanced heat transfer provided by convection. Required amount of vapor can be obtained inside the oven by the vapor producers on each side of the cooking chamber. Excess pressure and vapor composed inside the oven is being transferred to the funnel through flap pipe system.

For ease of service and maintenance the external surface elements of the oven are being equipped by plug-socket system. For the lighting of oven lamps resistant to 300°C are being used. Control panel of the ovens are on the left side from the front side of the oven. Panels are completely impermeable. Security door handle is designed on the oven to open the oven from inside in cases of emergency such as someone remaining inside. Again in this scope there is an “Emergency Stop Button” that halts all the operation of the oven in the case of emergency.

1.2.1.Main Groups of the Oven and Their Functions

Bakery ovens with rotating carts are composed of main groups such as combustion chamber, cooking chamber, circulation fan, vapor production units, rotating table reducer, burner, electricity panel, steam funnel aspirator, coating plates, doors of cooking and combustions chambers.

Circulation fan on the oven as being a multi flap fan assembled under the combustion chamber protection group it provides the circulation of hot air inside the oven.

Combustion chamber embodies the indirect air heater, burner and circulation fan of the oven. Indirect air heater is manufactured of stainless plate. The duty of the combustion chamber is to provide the heat requirement of the heated air being circulated inside the oven. The combustion chamber is equipped by security equipment against any over heating.

Rotating base disc of oven is being rotated through reducer on the upper side of oven and through chain gear mechanism.

Vapor production units are on the right and left of the cooking chamber. It produces the vapor required in order to provide the bread and bakery product to be cooked with thin crust and with better surface color.

Steam funnel aspirator provides the steam inside the oven to be evacuated to atmosphere through the hood after cooking of the product.

1.2.2.General Security System of the Oven

Security systems are developed inside the oven in order to prevent functional faults. Power circuits are protected against excess and thermic current. Burner will not be operated unless the circulation fan inside the oven does not operate. This measure is taken in order to prevent the overheating of the combustion chamber by the operation of burner. Another security measure is the availability of a security thermostat that can deactivate the burner in order to prevent over heating in the oven during a possible malfunction on digital thermometers. Security thermostat is set to 300°C. And the sensor element is connected to the steam gas funnel. When this temperature is exceeded that is set in any way inside the funnel (the reason of this could be the blockage or lack of suction of funnel) burner will be disabled and will not operate again unless the temperature of funnel decreases under the temperature set.

1.2.3.Vapor Delivery System

On bakery ovens with rotating cart, the vapor production units are placed on the right or left walls of the cooking chamber. Water pressure for vapor production should be set to a maximum of 3,5 bars. When the oven enters the regime that is when it reaches the temperature set on the digital thermometer which controlled through manual or automatic vapor delivery buttons.

When the bakery product is loaded in the oven, vapor obtained as plenty and saturated by spraying water on vapor production units for 15-20 sec is delivered for the forming of bakery product being cooked. Excess pressure due to over vapor inside the oven is prevented through the flap and pipe placed on the ceiling of oven.

It is recommended to place a water softening device on the main water inlet in order to prevent calcification of water system. When calcification occurs, sufficient amount of water is not sprayed through water spray pipes in other words, required amount of vapor for cooking process will not be available. Thus, in order to prevent decreases of efficiency of the system it is possible to overcome this problem by the periodic maintenance of pipes.

Water that is unable to evaporate in the vapor production unit during water spray is sent to the water chamber under the vapor production unit and then sent to the water pocket

1.3.Presentation of the System

Bakery ovens are generally composed of two sections. These are;

1. Heating section
2. Bread cooking section

1.3.1.Heating Section

The two sections as being independent from each other the fluids circulating in them do not mix up. Fuel inside the heating unit is burned by a burner. Hot gases heated up further by the flame composed in the section called the combustion chamber which is evacuated from the flame pipes funnel. The temperature of the funnel gases as being around 350 °C, it contains 3,5% O_2 and 4 ppm CO. The capacity of burner is set according to the capacity of oven that is the number of bread to be cooked.

1.3.2.Bread Cooking Section

Air used on the bread cooking operation is heated as being circulated by force of a circulation fan around the thermal chamber and flame pipes. The hot air enters homogenously by the assistance of flaps and clamps placed at the entrance section of the bread cooking chamber. At the entrance of heating units deflecting plates and pipes are being used for directing flow.

Breads are being cooked on aluminum trays aligned on a rack cart. The cart is placed on a rotating table and rotates slowly during the cooking process. The time for heating up the oven to the temperature of cooking is about 40–45 minutes. And the cooking process takes about 20 minutes. Air circulation inside the oven is shown in Figure 1.1.

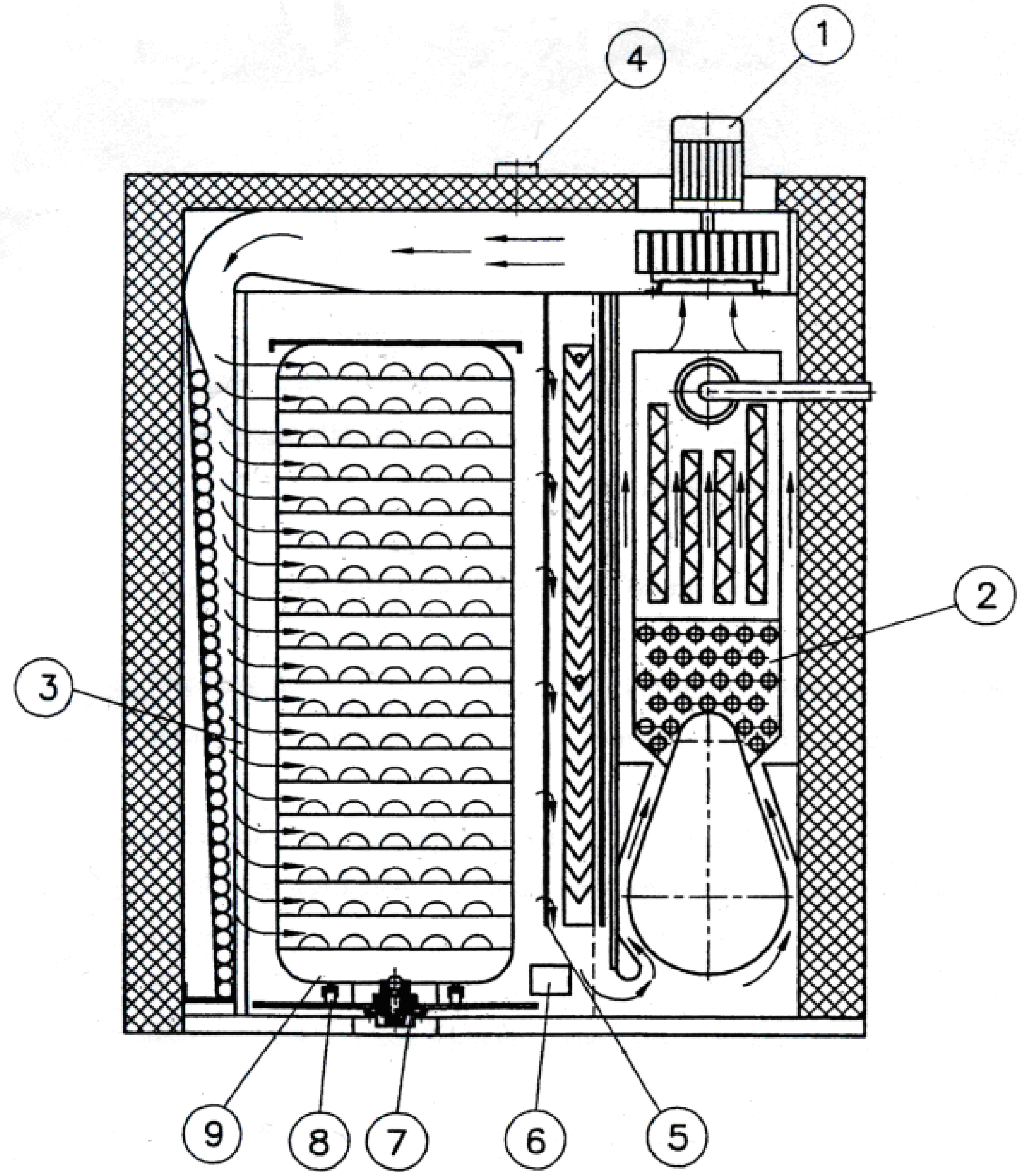

Figure 1.1. Air circulation scheme inside the oven. (1-Circulation fan 2-Air heater 3-Air blowing channels 4- Vapor output pipe 5- Suction plate 6-Vapor evacuation flap 7-Cart appliances 8 Cart wheel 9-Cart tray)

1.1.1 Delivering Vapor on Bread

Vapor is required to be supplied for the forming of dough while being kept in the conditioning room. Furthermore the necessary amount of vapor is supplied to the cooking section in order to obtain bread with bright surface.

Due to these requirements vapor production channels are available in the heating unit. Vapor is being produced by sending water inside the vapor box. The required energy for the production of vapor is being provided by the panel heated up by combustion gases. Vapor is sent on the bread as required through the adjustment plate.

1.3.4.Control of Oven

An automatic control system is available that regulates the enabling, disabling of elements and temperature during the operation of oven. When the start button is pressed burner enables and operates the mechanism moving the circulation fan and rotating table. Temperature of cooking chamber is measured by a thermal couple placed in the hot air entrance channel.

When the temperature of the cooking chamber exceeds 300°C the burner disables. When the temperature of the bread cooking chamber decreases below 300 °C the burner also enables again automatically.

The cooking of bread is briefly performed in this manner. By shaping the dough prepared and aligning on the trays, they are taken to the conditioning chamber and 25sec. - 30sec. vapor is given. Breads are kept in this chamber for about 30 minutes and the dough is yeasted as being puffed up. Then the trays are aligned in a cart and placed in the cooking chamber of the oven. Vapor is again given in the cabinet for a period of 15-20s. and the brightness of the surfaces of bread is provided. Breads are taken out of the oven by cooking approximately for 20 minutes

1.4.Microwave

Ovens cooking food by electromagnetic waves are called microwave oven. Microwave used in ovens is in between 2450 ± 50 Mhz. Ionization of a material by microwave is the distortion of material by splitting in (+) and (-) ions. And polarization of a material means splitting of molecules of the material composing its structure to (+) and (-) poles at specific rate. In polarization only one electrical or magnetic load is formed.

The new molecules vibrate, and do not distort. Frequencies of approximately 600 Thz and over can destroy the cells by ionizing the materials. And visible light and microwaves at lower frequencies causes polarization on materials, increase of molecule movement and arise of thermal energy due to friction. The arising heat cooks the food.

On microwave ovens electricity waves are converted to high frequency with short wavelength by the elements inside the oven such as high voltage transformer, condenser, diode. These waves are transferred to the oven space. It vibrates the molecules of food in the high frequency environment at high speed. The hereby vibration of molecules turns to heat. This heat provides the cooking of food without distorting its structure. Its difference from classical ovens is the heat being composed inside the food and not reaching from outside.

1.4.1.Standard Microwave Oven Accessories and Elements

1.4.1.1.Rotating Base Support

Rotating base support is placed on its location inside the oven. It is used under the glass plate. It is generally made of plastic (Figure 1.2)

Figure 1.2. Base Support

1.4.1.2.Glass Plate

Glass plate is placed on the rotating base support. It is used for all the cooking methods. It is shown in Figure 1.3.

Figure 1.3. Glass Plate

1.4.1.3.High Voltage Transformer

High voltage transformer is composed of primary and secondary coils such as other transformers. Secondary coil is two units. 220 V voltage is applied on the primary coil. Approximately 4000V is obtained from one of the secondary coils and 3. 3 V is obtained from the other. Transformer is shown in Figure 1.4.

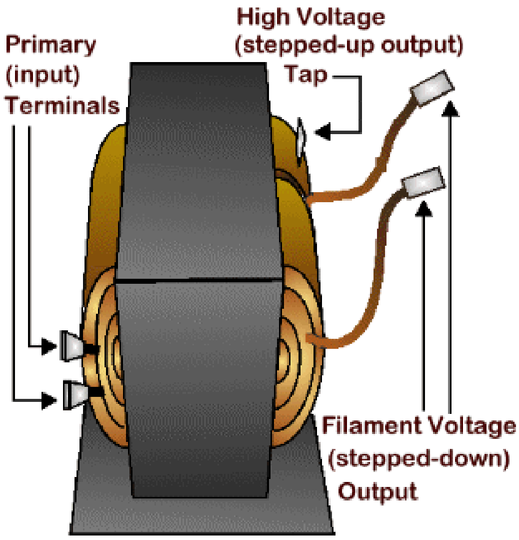

Figure 1.4. Transformer

1.4.1.4.High Voltage Diode

High voltage diode provides the magnetron to be given to the anode pole by converting the 4000V voltage from the high voltage transformer to direct voltage. It is shown in Figure 1.5.

Figure 1.5. High Voltage Diode

1.4.1.5.High Voltage Capacitor

High voltage capacitor is used for directing voltage along with the high voltage diode. Capacitor is shown in Figure 1.6.

Figure 1.6. High Voltage Capacitor

1.4.1.6.Rotating Table Engine

Rotating table engine is a small synchronous engine providing the rotation of the rotating table inside the oven. It is shown in Figure 1.7.

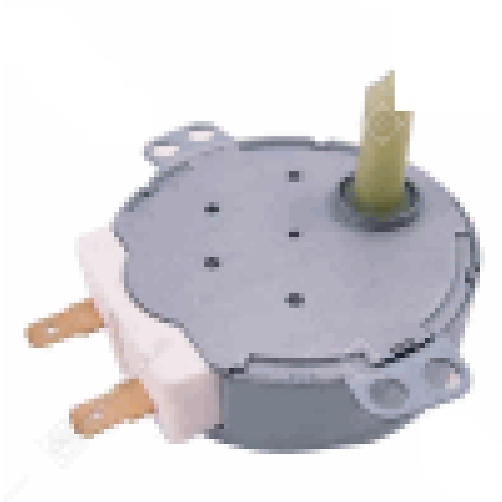

Figure 1.7. Table Engine

1.4.1.7.Magnetron

It is an element that produces high frequency. Alternative current (220 V) is applied on the primary of the high voltage transformer. Voltage (3.3V) comes out from one of the secondary coils and 4000 V voltage from the other. Voltage (3.3 V) is connected to the cathode poles of magnetron that is made of copper. Current flowing over cathode makes the cathode as incandescent. Split anode is available around the cathode.

A pole of the coil of the transformer with 4000 V is directed by passing through diode. (+) pole is connected to the anode. Other pole of the coil of 4000 V is connected to cathode. An attraction is composed among anode-cathode. Electrons ready to move on the cathode that became as incandescent conform the electrostatic attraction field and reaches the anode from cathode by passing through the air space. This movement of electrons causes polarization among splits of anode and composition of alternative current. Consequently high frequency intense electron movement starts. High frequency (2450 MHz) electron cell is sent inside the oven by an antenna connected to anode. Food inside the oven heats up or cooks as a result of vibration of molecules by remaining under the effect of high frequency. Magnetron is shown in Figure 1.8.

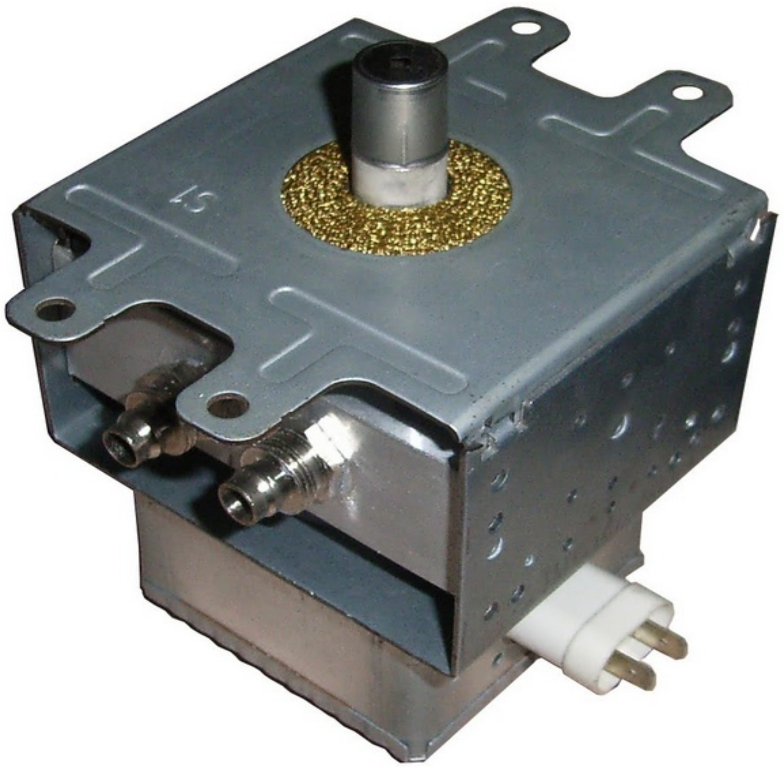

Figure 1.8. Magnetron

1.5. Calculations

1.5.1.Thermal Calculations

1.5.1.1. Thermal Losses in the Oven Section

Size of oven thermal transfer surface is shown in Figure 1.9.

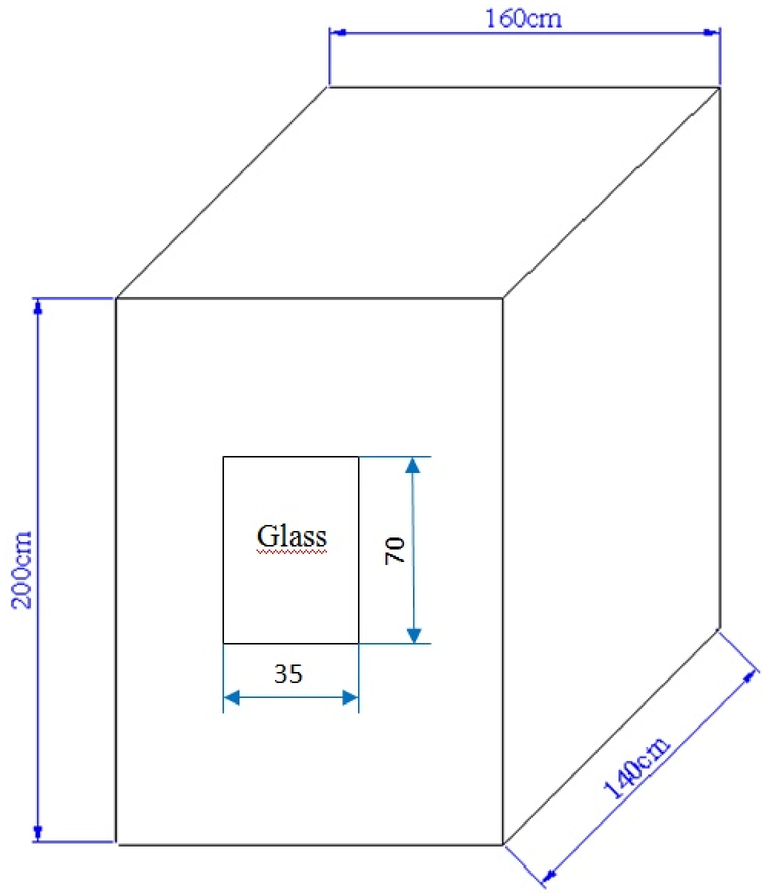

Figure 1.9. Size of Oven

Surface areas are shown in Figure 1.10 and calculation is shown in Table 1.1.

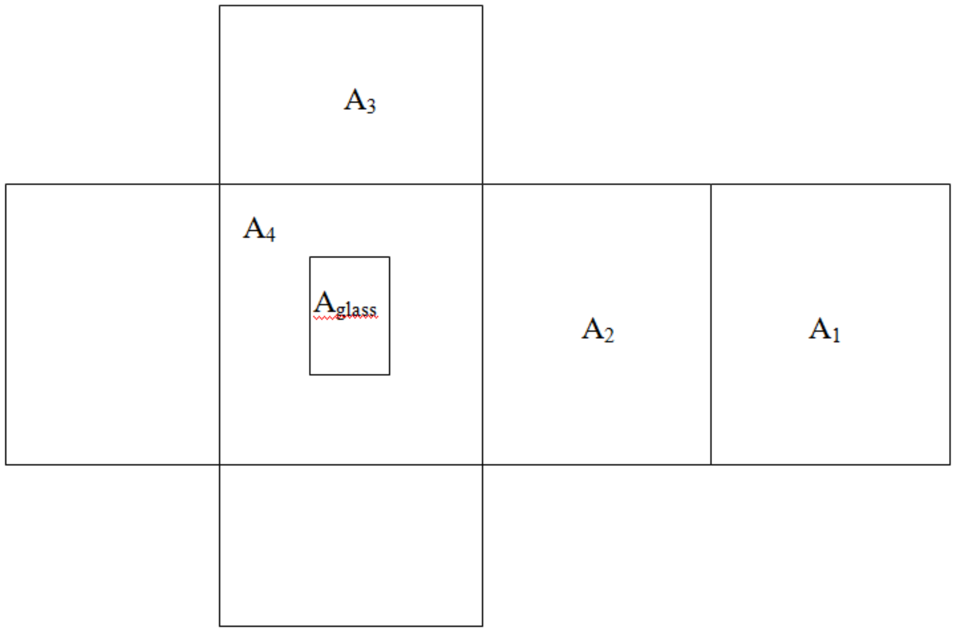

Figure 1.10. Oven surface area

Table 1.1.Calculation of surface areas

Side Wall Areas			
A_1	2 x 1,6	3,2	m2
A_2	2 x 1,4	2,8	m2
A_3	1,6 x 1,4	2,24	m2
A_4	(2 x 1,6) - (0,35 x 0,7)	2,96	m2
A_{gl}	0,35 x 0,7	0.24	m2

The oven coating materials chromium (304) is being used on inner and outer parts of the system for sterilization, longevity and endurance. Secondly in the middle part rock wool is being used as the insulation material whose thermal transfer coefficient is low and resistant against burning. Cross section of thermal transfer surface is given in Figure 1.11.

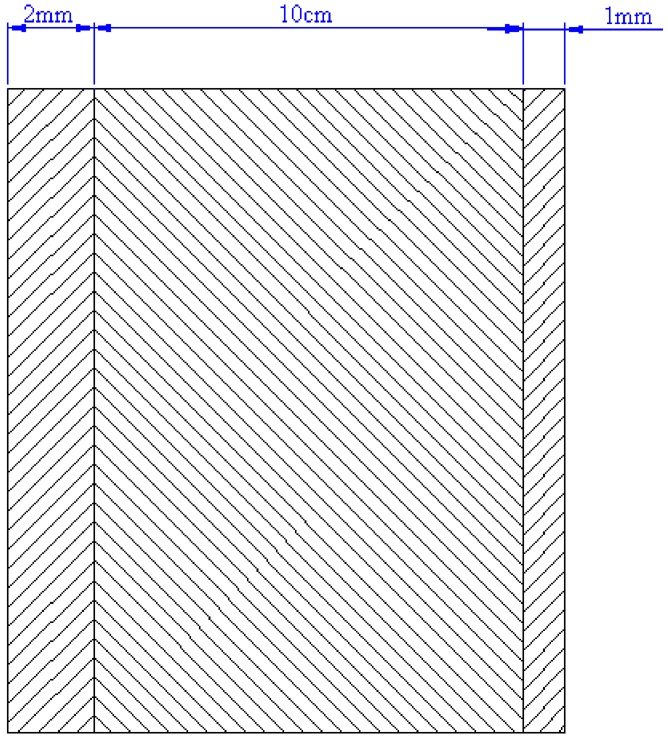

Figure1.11. Cross section of thermal surface

Thermal transfer coefficients of coating and insulation materials used on the walls of oven.

Insulation material $\lambda = 0{,}046 \, W/m.^{o}K$

Coating material $\lambda = 94 \, W/m.^{o}K$

Heat being transferred out on surface areas

In order to calculate heat being transferred, it is necessary to calculate different heat transfer coefficients composed due to different materials at those surface cross sections (Figure 1.12).

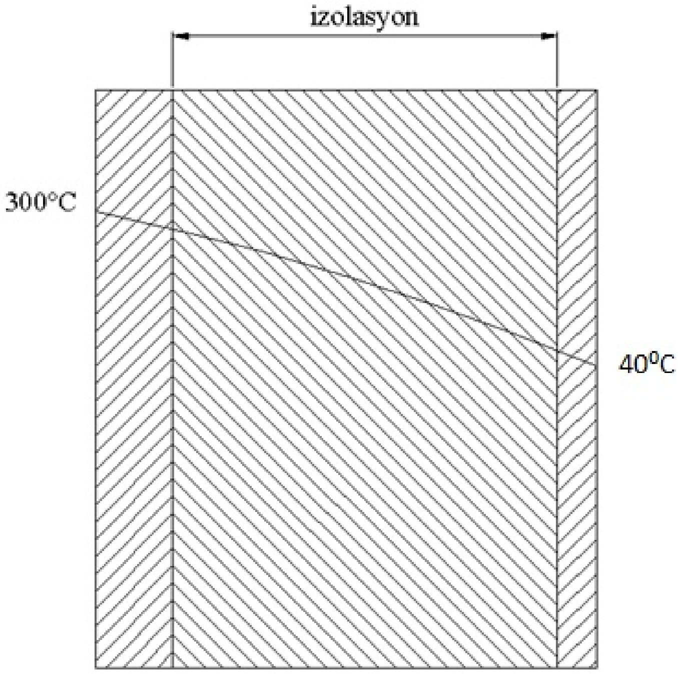

Figure 1.12. Cross section of thermal surface

For A_1 surface:

Internal surface material specifications $\lambda_1 = 1{,}9\, {W}/{m.^o K}$ $L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04\, {W}/{m.^o K}$ $L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9\, {W}/{m.^o K}$ $L_3 = 1mm$

As a resistance against heat transfer being different at each level, first of all thermal resistances for each level is found and then the total thermal resistance is found.

$$R_1 = \frac{L_1}{\lambda_1 x A_1} \quad R_2 = \frac{L_2}{\lambda_2 x A_1} \quad R_3 = \frac{L_3}{\lambda_3 x A_1} \tag{1.1}$$

$$R_1 = \frac{0{,}002}{1{,}9x3{,}2} = 3{,}28.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x3{,}2} = 0{,}7812 \quad R_3 = \frac{0{,}001}{1{,}9x3{,}2} = 1{,}64.10^{-4}$$

$$R_t = R_1 + R_2 + R_3 \tag{1.2}$$

$$R_t = 0{,}7817$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T} \tag{1.1}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q = \frac{260}{0{,}7817} = 332{,}5W$$

For A_2 surface:

Internal surface material specifications $\lambda_1 = 1{,}9 \, W/m.^o K$ $\quad L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04 \, W/m.^o K$ $\quad L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9 \, W/m.^o K$ $\quad L_3 = 1mm$

As a resistance against heat transfer being different at each level, firstly thermal resistances for each level are found and secondly the total thermal resistance is calculated.

$$R_1 = \frac{L_1}{\lambda_1 x A_2} \quad R_2 = \frac{L_2}{\lambda_2 x A_2} \quad R_3 = \frac{L_3}{\lambda_3 x A_2}$$

$$R_1 = \frac{0{,}002}{1{,}9x2{,}8} = 3{,}75.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x2{,}8} = 0{,}8928 \quad R_3 = \frac{0{,}001}{1{,}9x2{,}8} = 1{,}87.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 0{,}8934$$

As having two counter surfaces

$$R_T = \frac{0{,}8934}{2} = 0{,}4467$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q = \frac{260}{0{,}4467} = 582W$$

For A_3 surface:

Internal surface material specifications $\lambda_1 = 1{,}9 \, {}^{W}\!/_{m.^oK}$ $L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04 \, {}^{W}\!/_{m.^oK}$ $L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9 \, {}^{W}\!/_{m.^oK}$ $L_3 = 1mm$

As a resistance against heat transfer is different at each level, first thermal resistances for each level are determined and later the total thermal resistance is calculated.

$$R_1 = \frac{L_1}{\lambda_1 x A_3} \quad R_2 = \frac{L_2}{\lambda_2 x A_3} \quad R_3 = \frac{L_3}{\lambda_3 x A_3}$$

$$R_1 = \frac{0{,}002}{1{,}9x2{,}24} = 4{,}69.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x2{,}24} = 1{,}116 \quad R_3 = \frac{0{,}001}{1{,}9x2{,}24} = 2{,}34.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 1{,}1167$$

As having two counter surfaces

$$R_T = \frac{1{,}1167}{2} = 0{,}5583$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,{}^\circ K$$

$$Q = \frac{260}{0{,}5583} = 465{,}6W$$

For A_4 surface:

Internal surface material specifications $\lambda_1 = 1{,}9 \, {}^{W}\!/_{m.^oK}$ $L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04 \, {}^{W}\!/_{m.^oK}$ $L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9 \, {}^{W}\!/_{m.^oK}$ $L_3 = 1mm$

As a resistance against heat transfer being different at each level, first thermal resistances for each level are found and then the total thermal resistance is determined.

$$R_1 = \frac{L_1}{\lambda_1 x A_4} \quad R_2 = \frac{L_2}{\lambda_2 x A_4} \quad R_3 = \frac{L_3}{\lambda_3 x A_4}$$

$$R_1 = \frac{0{,}002}{1{,}9x2{,}96} = 3{,}55.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x2{,}96} = 0{,}84 \quad R_3 = \frac{0{,}001}{1{,}9x2{,}96} = 1{,}77.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 0.8451$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q_4 = \frac{260}{0{,}8451} = 307{,}6W$$

For A_{gl} surface:

Glass surface material specifications $\lambda_1 = 0{,}8\, W/m.K \quad L_1 = 6mm$

Since the heat transfer is different at each level, firstly thermal resistances for each level are found and later the total thermal resistance is determined.

$$R = \frac{L_1}{\lambda_1 . A_3}$$

$$R = \frac{0{,}006}{0{,}8x2{,}24} = 0{,}03125$$

Loss of heat at this surface:

$$Q = \frac{\Delta T}{R}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q_{gl} = \frac{260}{0{,}03125} = 8320W$$

Total loss of heat:

$$Q_F = Q_1 + Q_2 + Q_3 + Q_4 + Q_{gl} \tag{1.2}$$

$$Q_F = 332{,}5[W] + 582[W] + 465{,}6[W] + 307{,}6[W] + 8320[W]$$

$$Q_F = 10007{,}8[W] = 8605{,}2\left[kcal/h \right]$$

1.5.1.2. Thermal Losses in the Heat Cell Section

Sizes of heat transfer surface outwards from the heat cell (Figure 1.13). Surface areas are shown in Table 1.2.

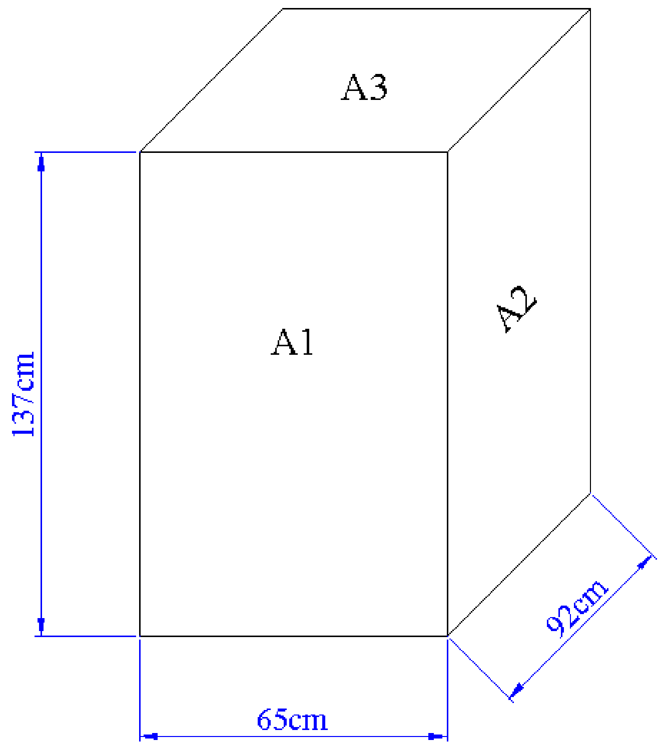

Figure 1.13. Size of Heat Cell Section

Table 1.2 Surface areas of heat cell section

Surface Areas			
A_1	2 x 1,6	3,2	m^2
A_2	2 x 1,4	2,8	m^2
A_3	1,6 x 1,4	2,24	m^2

As mentioned before, the external wall materials chromium is being used on inner and outer parts of the oven for sterilization, longevity and endurance. In the middle part a rock wool is being used as the insulation material whose thermal transfer coefficient is low and resistant against burning. Wall thicknesses of cross section of thermal transfer surface are shown in Figure 1.14.

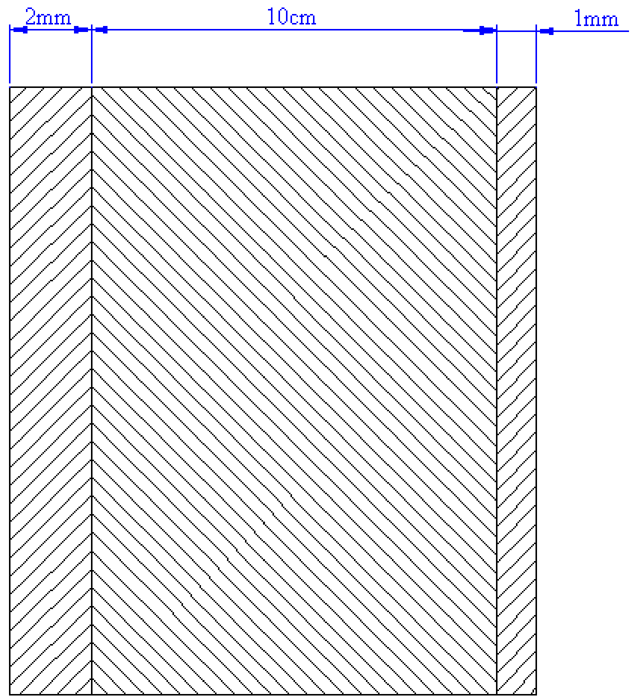

Figure 1.14. Cross section of thermal surface

Thermal transfer coefficients of coating and insulation materials used on the walls of heat cell. Temperature differences of cross section to be used on calculation (Figure 1.15)

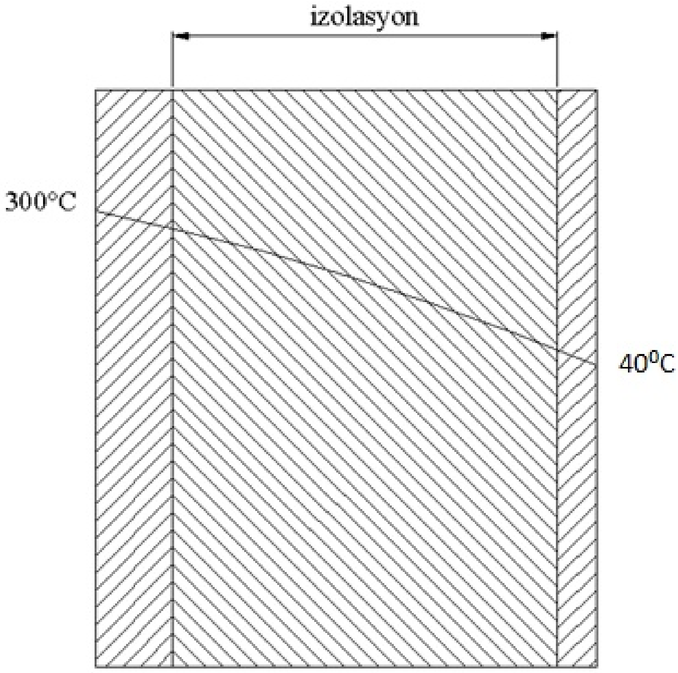

Figure 1.15. Cross section of thermal surface

For A_1 surface:

Internal surface material specifications $\lambda_1 = 1{,}9\, W/m.^{o}K$ $\quad L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04\, W/m.^{\circ}K$ $\quad L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9\, W/m.^{\circ}K$ $\quad L_3 = 1mm$

It is known that resistance against heat transfer is different at each level. For this reason, thermal resistances for each level are first found and then the total thermal resistance is calculated.

$$R_1 = \frac{L_1}{\lambda_1 x A_1} \quad R_2 = \frac{L_2}{\lambda_2 x A_1} \quad R_3 = \frac{L_3}{\lambda_3 x A_1}$$

$$R_1 = \frac{0{,}002}{1{,}9x0{,}89} = 11.82.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x0{,}89} = 2{,}80 \quad R_3 = \frac{0{,}001}{1{,}9x0{,}89} = 5{,}91.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 2{,}8091$$

As having two counter surfaces

$$R_T = \frac{2,8091}{2} = 1,404$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q_1 = \frac{260}{1,404} = 185,1W$$

For A_2 surface:

Internal surface material specifications $\lambda_1 = 1,9\, W/_{m.°K}$ $L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0,04\, W/_{m.°K}$ $L_2 = 10cm$

External surface material specifications $\lambda_3 = 1,9\, W/_{m.°K}$ $L_3 = 1mm$

First of all thermal resistances for each level are calculated later the total thermal resistance is figured out.

$$R_1 = \frac{L_1}{\lambda_1 x A_2} \quad R_2 = \frac{L_2}{\lambda_2 x A_2} \quad R_3 = \frac{L_3}{\lambda_3 x A_2}$$

$$R_1 = \frac{0,002}{1,9x1,26} = 8,35.10^{-4} \quad R_2 = \frac{0,10}{0,04x1,26} = 1,98 \quad R_3 = \frac{0,001}{1,9x1,26} = 4,17.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 1,9847$$

As having two counter surfaces

$$R_T = \frac{1,9847}{2} = 0,9923$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q_2 = \frac{260}{0,9923} = 261,9W$$

For A_3 surface:

Internal surface material specifications $\lambda_1 = 1{,}9 \, W\!/_{m.°K}$ $L_1 = 2mm$

Specifications of insulation material $\lambda_2 = 0{,}04 \, W\!/_{m.°K}$ $L_2 = 10cm$

External surface material specifications $\lambda_3 = 1{,}9 \, W\!/_{m.°K}$ $L_3 = 1mm$

After all thermal resistances for each level are determined, the total resistance is computed.

$$R_1 = \frac{L_1}{\lambda_1 x A_3} \quad R_2 = \frac{L_2}{\lambda_2 x A_3} \quad R_3 = \frac{L_3}{\lambda_3 x A_3}$$

$$R_1 = \frac{0{,}002}{1{,}9x0{,}598} = 17{,}6.10^{-4} \quad R_2 = \frac{0{,}10}{0{,}04x0{,}598} = 4{,}18 \quad R_3 = \frac{0{,}001}{1{,}9x0{,}598} = 8{,}8.10^{-4}$$

$$R_t = R_1 + R_2 + R_3$$

$$R_t = 4{,}1832$$

As having two counter surfaces

$$R_T = \frac{4{,}1866}{2} = 2{,}0916$$

Loss of heat at these surfaces:

$$Q = \frac{\Delta T}{R_T}$$

$$\Delta T = 573 - 313 = 260\,°K$$

$$Q_3 = \frac{260}{2{,}0916} = 124{,}3W$$

Loss of heat at these surfaces:

$$Q_H = Q_1 + Q_2 + Q_3$$

$$Q_H = 185{,}1 + 261{,}9 + 124{,}3 = 571{,}4W$$

$$Q_H = 571{,}4[W] = 491{,}3\left[kcal\!/_{h}\right]$$

1.5.1.3. Total Required Power

According to the law of conservation of energy, energy transferred to air through heat cell is being used for cooking bread, for heating the metals inside (pan and cart), for the compensation of heat being transferred from the walls of oven by conduction and for covering the heat being transferred by conduction from the wall of heat cell. The equation of this energy conservation:

$$Q_h = Q_b + Q_{ek} + Q_T + Q_C + Q_F \tag{1.3}$$

Q_h: energy transferred by air
Q_b: energy required for vapor
Q_{ek}: energy required for cooking bread
Q_T: heat spent for heating the pan and cart
Q_C: heat escaping from the walls of heat cell
Q_F: heat escaping from the walls of oven

As the vapor amount to be composed inside the oven is very low compared to other energy amounts, it can be ignored. If we consider that 60 gr of the weight of dough is water and remaining part is wheat and that the temperature of dough reaches T = 100 ^oC during cooking and as 192 units of dough of 260 gr could be cooked inside the oven in 20 minutes;

$$Q_{ek} = m_s x C_s x \Delta T_s + m_B x C_B x \Delta T_B \tag{1.4}$$

$$m_s = 192x0{,}06x3 = 34{,}56\, kg/h \tag{1.5}$$

$$C_s = 4{,}18\, {}^{kj}\!/_{kg.C}$$

$$\Delta T_s = 100 - 13 = 87^o C$$

$$C_B = 1{,}5\, {}^{kj}\!/_{kg.C}$$

$$\Delta T_B = 100 - 13 = 87°C$$

$$m_B = 192x0{,}200x3 = 115{,}2\, kg/h$$

$$Q_{ek} = 34{,}56x4{,}18x87 + 115{,}2x1{,}5x87 = 27601{,}6\left[{kj}/{h}\right] = 6603{,}2\left[{kcal}/{h}\right]$$

Heat spent to suite the pan and pan cart to the oven conditions;

$$Q_T = m_T x C_T x \Delta T_T$$

Total mass of cart and pans entering oven within an hour:

$$m_T = m_A + m_t = (69 + 72)x3 = 423\,{kg}/{h} \tag{1.6}$$

$$C_s = 0{,}45\,{kj}/{kg.C}$$

$$\Delta T_s = 300 - 24 = 276(°C)$$

$$Q_T = 423x0{,}45x276 = 52536{,}6\left[{kj}/{h}\right] = 12568{,}56\left[{kcal}/{h}\right]$$

Total energy required for cooking bread during the operation of oven;

$$Q_{Top} = Q_{ek} + Q_T + Q_C + Q_F \tag{1.7}$$

$$Q_{Top} = 6603{,}2 + 12568{,}56 + 491{,}3 + 8605{,}2 = 28268{,}26\left[{kcal}/{h}\right] = 32{,}87\left[KW\right]$$

1.5.2.Total Thermal Energy Required by the System

1.5.2.1.System Operating by Natural Gas

Efficiency of boiler: η_k

$$\eta_k = 1 - (K_o + K_z + K_b) \tag{1.8}$$

K_o: Efficiency of oven: 0,01

K_z: Surface efficiency: 0,02

K_b: Funnel loss

$$K_b = \frac{I_{ta} - I_{tu}}{LHV}$$

I_{ta} : funnel gas enthalpy

I_{tu} : enthalpy of environmental conditions

LHV: Fuel Lower Heating Value 8250kcal/m^3 =11619,7 kcal/kg

λ: air over plus coefficient 1,1

T_{ta}: funnel gas temperature: 350 ^oC

I_{ta} : 1500 kcal/kgY

I_{tu} : 25 ^oC for environmental temperature 100 kcal/kgY

$$K_b = \frac{I_{ta} - I_{tu}}{LHV} = \frac{1500 - 100}{11619,7} = 0,12$$

$$\eta_k = 1 - (0,01 + 0,02 + 0,12) = 0,85$$

The energy required

$$Q = \frac{Q_{top}}{\eta_k} = \frac{28268,26}{0,85} = 33256,77 \left[kcal/h \right] = 38,67 \left[KW \right]$$

1.5.2.2.System Operating with Diesel Fuel

Efficiency of boiler: η_k

K_o: Efficiency of oven: 0,01

K_z: Surface efficiency: 0,02

K_b: Funnel loss

$$K_b = \frac{I_{ta} - I_{tu}}{LHV}$$

I_{ta} : funnel gas enthalpy

I_{tu} : enthalpy of environmental conditions

LHV: Fuel Lower Heating Value 10200 kcal/kg

λ: air over plus coefficient 1,1

T_{ta}: funnel gas temperature: 350 ^oC

I_{ta} : 1500 kcal/kgY

$$K_b = \frac{I_{ta} - I_{tu}}{LHV} = \frac{1500 - 100}{10200} = 0,13$$

$$\eta_k = 1 - (0,01 + 0,02 + 0,13) = 0,84$$

The energy required

$$Q = \frac{Q_{top}}{\eta_k} = \frac{28268,26}{0,84} = 33652,69\left[{kcal}/{h}\right] = 39,13\left[KW\right]$$

1.5.3.Calculation of Fuel Amount Spent in one Hour

1.5.3.1.System Operating with Natural Gas

B_h: Fuel amount spent in a hour

$$B_h x LHV x \mu_k = Q_{Top} \tag{1.9}$$

LHV: Fuel Lower Heating Value 8250kcal/m^3 =11619,7 kcal/kg

µk: 0,85

$$B_h = \frac{Q_{Top}}{LHV x \mu_k} = \frac{28268,26}{11619,7x0,85} = 2,86\,kg/h$$

1.5.3.2.System Operating with Diesel Fuel

B_h: fuel amount spent in a hour

$$B_h x LHV x \mu_k = Q_{Top} \tag{1.10}$$

LHV: Fuel Lower Heating Value 10200 kcal/kg

µk: 0,84

$$B_h = \frac{Q_{Top}}{LHV x \mu_k} = \frac{28268,26}{10200x0,84} = 3,26\,kg/h$$

1.5.4. Investment Cost

1.5.4.1. Cost Analysis of Heat Cell Operating with Natural Gas

A metal material amount used for the internal part of heat cell is in total of 150 kg. The terms of 1kg of this material is 10 TL

The total cost is 150x10= 1500 TL

The total amount of metal material amount used for the external part of heat cell is 180 kg. The cost of 1kg of this material is 10 TL:

The total cost is 180x10= 1800 TL

In the same manner rock wool amount used for insulation is 350 kg. The price of rock wool is 1.5 TL/kg

The total cost is 350x1.5= 525 TL

The cost of burner selected as a heat cell igniter 1200 € = 2367 TL (€=1.97 TL)

Workmanship used for the construction of heat cell:

- For cutting of ready pipe one worker works for / four hours / one day
- For the preparation of bend pipes cutting from plate, two workers work for / eight hours / one day
- For the plates with 71 - 55 hole, 26 - 55 hole, 52 - 55 hole in which the pipes are placed, one worker works for / eight hours / one day
- For cutting bending and welding of body and general assembly and completion of welding, two workers work for / eight hours/ three days.
- For placing the heat cell insulation material in between walls, two workers work for / four hours / one day.

In generally, 84 hours of work is required in total. The monthly expense of a master working with the daily minimum wage of a worker is 724 TL. If we consider that the master works for four weeks, five days a week and eight hours a day:

Hourly wage of the master is $= \dfrac{724}{4.5.8} \cong 4{,}5TL$

Workmanship cost for one heat cell = 84x4,5 =378 TL

Total cost of a furnace fire box that will operate with natural gas is 4203TL.

Total cost=4203+2367=6570 TL

1.5.4.2. Cost Analysis of Heat Cell Operating with Electricity

The total amount of metal material used for the external part (side) of the heat cell is 180 kg. The cost of this material is 10 TL:

Its cost 180x10= 1800 TL

Rock wool amount used for insulation is 350 kg. The terms of rock wool is 1,5 TL/kg

The price of rock wool is 350 x 1,5= 525 TL

Workmanship used for the construction of heat cell:

- For the general assembly of heat cell and for placing resistances, two workers work for / eight hours / two days.
- For placing the heat cell insulation material in between walls, two workers work for / four hours / one day.

40 hours of work is required in total. The monthly expense of a master working with the daily minimum wage of a worker is 724 TL. If we consider that the master works for 4 weeks in a month, five days a week and eight hours a day:

Hourly wage of the master is $= \dfrac{724}{4.5.8} \cong 4{,}5TL$

Workmanship cost for one heat cell = 40x4.5 =180 TL

Only 63,3 KW electricity power is required to be used in the heat cell as not having funnel and thus funnel loss. And for this power utilization of 43 units of resistances as each being 1,5 KW is convenient.

As the price of one unit of resistance is 9 €;

Total resistance price is 9x43=387 €=762,4 TL.

Total cost of this furnace fire box which will operate with electricity energy except the resistances is 2505 TL.

In this case total cost

Total cost is 2505+762,4=3267,4 TL

1.5.4.3. Cost Analysis of Heat Cell with Diesel Fuel

A metal material amount used for the internal and external parts of the heat cell is about 330 kg. As mentioned before price of metal material is 10 TL

The total terms is 330x10= 33000 TL

Rock wool needs for one heat cell is about 350kg. The unit price of rock wool is 1,5 TL/kg

The cost of rock wool is 350x1,5= 525 TL

The terms of burner selected as heat cell igniter 1000 €=1970 TL(1€=1,97TL)

Workmanship used for the construction of heat cell:

- For cutting of ready pipe, one worker works for / four hours / one day
- For the preparation of bend pipes cutting from plate, two workers work for / eight hours / one day
- For the plates with 71 - 55 hole, 26 - 55 hole, 52 - 55 hole in which the pipes are placed, one worker works for / eight hours / one day
- For cutting bending and welding of body and general assembly and completion of welding, two workers work for / eight hours/ three days.
- For placing the heat cell insulation material in between walls, two workers work for / four hours / one day.

In generally 84 hours of work is required in total. The monthly expense of a master working with the daily minimum wage of a worker is 724 TL. If we consider that the master works for 4 weeks a month, five days a week and eight hours a day:

Hourly wage of the master is $= \frac{724}{4.5.8} \cong 4{,}5TL$

Workmanship cost for one heat cell = 84x4,5 =378 TL

Total cost of a furnace fire box that will operate with natural gas is 4203 TL.

P=4203+1970=6173 TL

1.5.5.Operation Costs

Consider that an oven is cooking each day in the morning, noon and night for one hour. In one hour it can cook three cart of bread each with 20 minutes.

1.5.5.1. Cost Analysis of Heat Cell Operating with Natural Gas

Heat cell operating with natural gas spends;

$\mathrm{B_h} = 2{,}86\,\mathrm{kg}/h \cong 4{,}31\,{m^3}/{h}$ fuel.

As amount of 1 M^3 natural gas being 0,544353 TL/m3;

2,35 TL fuel cost is realized in one hour.

If we consider that we produce 3 carts in one hour each of 140 breads, we can produce about 420 breads in an hour.

In this case in order to cook 3 carts of bread 2,35TL fuel cost is realized. In order to bring the cooking cabinet to 300^{o}C condition the system should operate by full capacity for 40 minutes. In this case the amount of fuel required to bring the oven to convenient conditions is:

$$\frac{2{,}35.2}{3} = 1{,}56TL$$

For one bread $\frac{1{,}56 + 2{,}35}{420} = 0{,}009TL$ fuel cost is being realized.

1.5.5.2. Cost Analysis of Heat Cell Operating with Electricity

Heat cell operating with electricity operates with electricity energy of 32,87 KW.

As the unit price of electricity is 0,22957 TL/KWh

7,54 TL fuel cost is realized in an hour.

We produce 3 carts in one hour each of 140 breads, and produce about 420 breads in an hour.

The cost of fuel is 7,54 TL for three carts. In order to bring the cooking cabinet to 300^{o}C condition the system should operate by full capacity for 40 minutes. In this case the amount of fuel required to bring the oven to convenient conditions is:

$$\frac{7{,}54.2}{3} = 5{,}02TL$$

For one bread $\frac{(7,54+5,02)}{420}=0,029TL$ fuel cost is being realized.

1.5.5.3. Cost Analysis of Heat Cell Operating with Diesel Fuel

Heat cell operating with diesel fuel spends;

$B_h = 3,26\text{kg}/h = 3,91 l/h$ fuel.

The amount of 1 liter of diesel fuel as being 3,07TL/lt;

12 TL fuel cost is realized in one hour.

As mentioned before we produce 3 carts in one hour each of 140 breads, and produce about 420 breads in an hour.

In this case in order to cook 3 carts of bread 12 TL fuel cost is calculated. To bring the cooking cabinet to 300^{o}C condition the system should operate by full capacity for 40 minutes. In this case the amount of fuel required to bring the oven to convenient conditions is:

$$\frac{12.2}{3}=8TL$$

For one bread $\frac{(12+8)}{420}=0,047TL$ fuel cost is being realized.

Investment cost of heat cell for each fuel and operation cost are shown in Table 1.3.

Table 1.3. Costs of heat cell and investment

	Fuel		
	Natural Gas	Electricity	Diesel
Investment Cost of Heat Cell	6570 TL	3267,4 TL	6173 TL
Operation Cost of Energy	0,009 TL/Bread	0,029 TL/Bread	0,047 TL/Bread

2. PREVIOUS STUDIES

G. Sumnu et al.(2005) were compared the effects of different baking methods Microwave, IR and IR microwave combination. They concluded that microwave baked cakes had some quality defects such as lack of color. They have found that by using IR-microwave combination baking, the time saving advantage of microwave baking was combined with the surface browning advantage of IR heating. They also showed that IR-microwave combination oven can be used in the baking industry not only for cakes but also for breads and biscuits.

S.Lakshmi et al. (2007) studied energy expenditure of cooking rice with microwave and comparison with other appliances. They also compared the performance of microwave oven with alaectic rice cooker and pressure cooker. They summarized microwave cooking offered the advantage of shorter cooking time amongst the various methods of cooking.

J. Zhang, A.K. Datta (2006) were developed a mathematical model for baking bread. The model displayed when the oven temperature increases from 150 ^{o}C to 230 ^{o}C, bread volume decreases due to shortened yeast activity period. They also showed that microwave in baking heats the bread dough more uniformly, thus does not create a dry and hard surface as in conventional baking. They suggested if microwave is combined with hot air in baking, the internal dough temperature increases faster than without using microwave and yeast activity is reduced.

N. Therdthai et al. (2002) aimed to establish an optimal temperature profile for white-sandwich bread to achieve the best product quality. Their experiments were conducted by a multi-level partial factorial design, where dough was baked in a process with four equally divided zones (Figure 2.1).

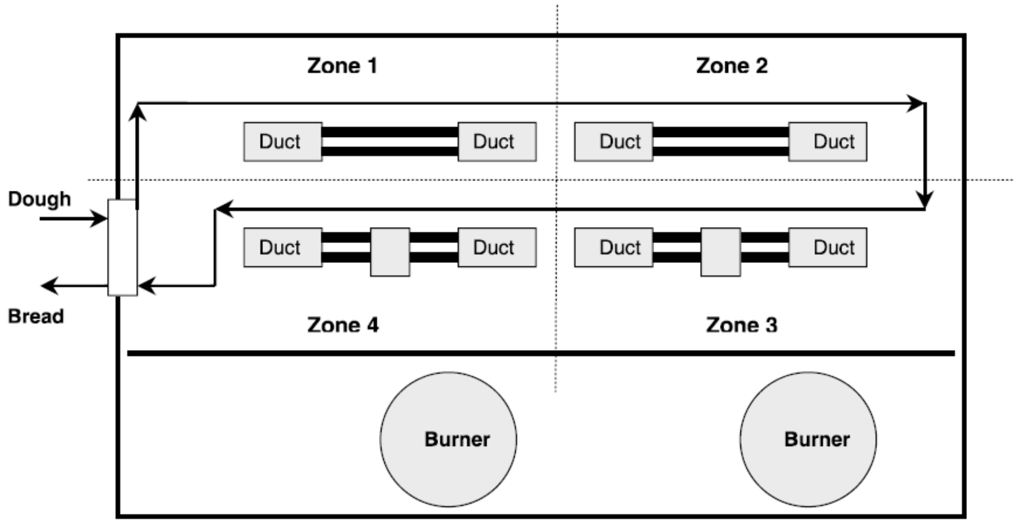

Figure 2.1. Schematic diagram of an industrial baking oven.(N. Therdthai et al.2002)

They determined that dough should be baked for 27.4 min with the weighted tin temperatures at 115, 130, 156 and 176 ^oC for zones for 1, 2, 3, 4, respectively.

S.S.R. Geedipalli et al. (2007) studied the role of a carousel in improving heating uniformity of food in a microwave oven. They developed a physics based computational model coupling the Maxwell's equations for electromagnetic and energy equation for heating inside a microwave oven food load. The compared the uniformity in temperature of a stationary food and rotating food. They concluded that with rotating food increase 37–43% of the temperature uniformity.

G. Sumnu et al.(2003) compared the effects of halogen lamp-microwave combination baking on quality of breads with other baking methods. They also aimed to improve the quality of microwave baked breads by using combination oven. They stated that by using halogen lamp, microwave combination oven solve especially the crust color problem of microwave naked breads.

B. M. Shaughnessy and M. Newborough (2000) were designed and constructed a prototype low emissivity oven and made performance comparisons with previous experimental low emissivity ovens. They concluded that a low-emissivity oven design offers substantial energy savings over both natural and forced convection mode of high-emissivity ovens.

A. Mondal, A.K. Datta (2008) reviewed published literatures on experimental and mathematical studies on bread baking during the last two decades. The article has six topics; basic ingredients, baking technology, properties of bread, experimental studies on crust and mathematical modeling.

Megahey et al. (2005) were examined microwave baking characteristics of madeira cake. They concluded that microwave baking allowed for up to a 93% reduction in baking time in comparison with convective baking at 200^{o}C. They found that surface temperature was lower than centre temperature (at all moisture contents) for the microwave-baked cake. The reverse was observed for the convective baked cake.

E.T. Thostenson, T.-W. Chou (1999) reviewed the fundamentals of electromagnetic theory, dielectric response and applications of microwave heating to materials processing. They determined that the ability of microwaves to couple energy directly to the material is the primary advantage of microwave processing as compared to conventional techniques. They explained that the volumetric heating ability of microwaves allows for more rapid, uniform heating, decreased processing time, and often enhanced material properties. They conclude that the application of microwave and radio frequencies for processing of materials can have advantages over traditional heat transfer.

M.E Williamson, DJ. Wilson (2009) aimed to develop, test and optimize the design of a novel gas-fired burner for tunnel ovens. They used Computational fluid dynamics (CFD) simulations to model the burner and baking chamber environment. With experimental studies they constructed o new burner that has equipment capital cost saving, heat losses through the oven walls and factory floor space reduction benefits.

N. Uysal et al. (2009) investigated the possibility of using microwave infrared combination oven for roasting of hazelnut. Microwave – infrared combination oven was used for their experimental studies (Figure 2.2) .

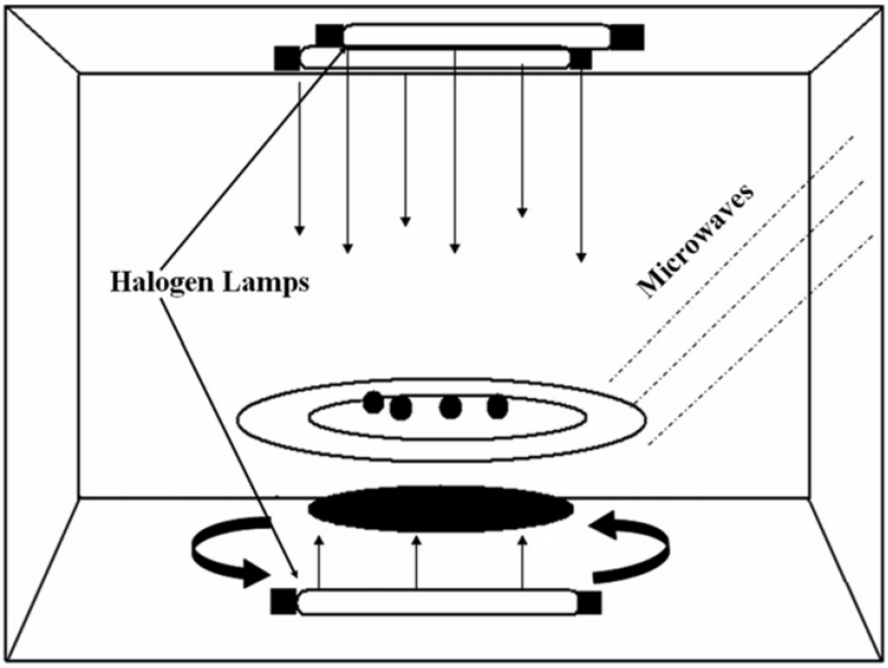

Figure 2.2. Schematic diagram of microwave–infrared combination oven.

They conclude that the roasting time of hazelnuts was significantly reduced and recommended a microwave infrared combination oven for roasting of hazelnut and other nuts.

D.D. Dincov et al. (2004) presented computational results for intensive microwave heating of porous materials. They achieved the agreement between calculated values for penetration depth and the distribution of the heating function inside the sample as dielectric properties change.

A.K. Datta, H. Ni (2002), were studied the temperature and moisture profiles for infrared and hot air-assisted microwave heating of food using a multiphase porous media transport model for energy and moisture in food. They conclude that the hot air can reduce surface moisture and increase surface temperature, but not as effectively as infrared heat, due to the lower surface flux for hot air as compared to the infrared energy.

3. MATERIAL AND METHOD

3.1.Material

3.1.1. Dough

Dough is the mixture of a specific amount of flour, water, salt and yeast and a preparation by keeping the mixture under convenient conditions. The composition in which wheat flour is used and kept for fermentation for 2 hours is in the form of 50% flour, 25% water, 2% salt, 3% yeast and additives (Figure 3.1).

Figure 3.1: Dough

3.1.2.Oven

The idea of cooking with microwaves firstly started by Percy Spencer in 1945's as the "magnetron" planned to be used as radar was discovered. In 1947 he had the patent of this invention of him and designed the first microwave oven at length of 1,8 meters and weight of 340 kg.. But it did not attract attention very much commercially. The first microwave ovens used in houses was started to be sold by the company Tappan in 25^{th} October 1995.

There is an important reason of using of this frequency. 2.54 Ghz is the resonance frequency of the water molecules. As all foods include water, they should warm, the plates appropriate to microwave oven should not warm as they do not include water. The water molecules should also warm thanks to this resonance, the substance itself should also be cooked.

The microwave is produced with the vacuum tube named magnetron in ovens. Magnetron turns the right current electricity energy to microwaves, the microwave oven starts to operate in this way. The power intensity of radiations (microwaves) spread by the microwave ovens decreases fast at opposite rate with the distance's square.

The features of these microwaves could be listed as followings;

- Absorbed by water, sugar and fats,
- Turns to atomic warm once it is absorbed,
- Most of them are not absorbed by plastic, glass and porcelain,
- They are reflected by metals

Microwave and convention combined oven was used for experiments (Figure 3.2).

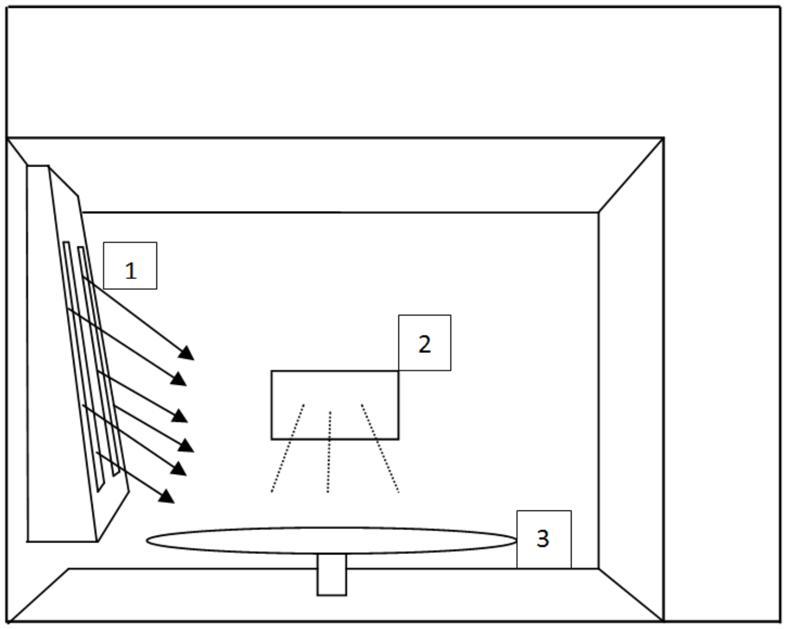

Figure 3.2. Illustration of microwave - conventional combination oven. (1) Heatedair, (2) Microwaves, (3) Turntable.

There was a rotary table in the oven to improve heating uniformity of samples. Samples was placed at the centre of the turn table. Microwave can be operated at 2450 MHz and at 900 W power and operation period of microwave can be changed by the external control unit. Three resistances having length of 32 cm, each power of 1000 w had been used. As the air is warmed by help of resistances, it is sent to the cooking part. Oven sizes as being 215x340x350 mm and a fan is available inside the oven. System has two parts control panel and combined oven (Figure 3.3).

(a)

(b)

Figure 3.3: (a) Microwave and conventional system combined oven b) Control panel

3.2.Method

Cooking of bread by microwave and convectional systems is a new application. In this study it is intended to search for the cooking of previously prepared dough kept under convenient conditions to be fermented by using microwave and conventional method. Readymade dough for cooking is experimented by changing the temperature and time parameters.

Experiments compose of following steps: firstly the oven is heated up to the required temperature by using resistances. Secondly dough is placed inside the oven. Then vapor is obtained by adding 150 ml water. Then the microwave is enabled (opened) and operated during the determined period. During the experiment only magnetron is operated as the temperature did not decrease to values below the starting value.

It is aimed to obtain the bread in the conditions wished of its external part through the warm air by help of resistances, to bake the bread with microwave energy.

The trial's results were evaluated in accordance with the following criterions.

-Its color should be brown, whole part of bread should have the same color, it should not have dark and light tones, and also speckled.

- The sides and bottom of the bread should be toasted smoothly and symmetrically.
- It should be thin and breakable easily.
- When the bread is cut, the pores should be thin, ellipse shape, homogeneous and have thin walls.
- Inside of the bread should be white and bright color and uniform.
- Should not be doughy, much dry, hard or sticky.

Experimental temperatures and periods were applied as follows:

- t = 4 min – T = 240 ^{o}C, 250 ^{o}C, 260 ^{o}C, 270 ^{o}C, 280 ^{o}C
- t = 5 min – T = 240 ^{o}C, 250 ^{o}C, 260 ^{o}C, 270 ^{o}C, 280 ^{o}C
- t = 6 min – T = 240 ^{o}C, 250 ^{o}C, 260 ^{o}C, 270 ^{o}C, 280 ^{o}C
- t = 7 min – T= 240 ^{o}C, 250 ^{o}C, 260 ^{o}C, 270 ^{o}C, 280 ^{o}C

4. RESULT AND DISCUSSIONS

4.1.Four Minutes Experiments

In four minute experiments dough were cooked with different temperatures such as T = 240 ^{o}C, 250 ^{o}C, 260 ^{o}C, 270 ^{o}C, 280 ^{o}C for four minutes period of time in the prototype microwave oven.

In first experiment in the prototype, the dough was baked at T = 240 ^{o}C for t = 4 minutes in combined oven as seen in Figure 4.1. The color of crust of the product is determined as white. It is seen that there is no glow at sides and bottom of bread. It is determined that the composition of crust is weak and that the pore structure is not completely composed. The examination of inner structure is shown that it is dough-like and not cooked.

Figure 4.1. Picture of baked bread cooking time period; t = 4 min. and T = 240 ^{o}C

Secondly dough cooked at T = 250 ^{o}C for t = 4 minutes is determined that the color of the product is yellow close to white shown in Figure 4.2 . Sides and bottom of bread were also not glowing smoothly. The composition of crust is weak. When the inner structure is controlled it is shown that it is bright white but not well cooked.

Figure 4.2. Picture of baked bread cooking time period; t = 4 min. and T = 250 ^{o}C

Thirdly the color of the product which cooked at T = 260 ^{o}C for t = 4 minutes is between yellow and brown and sides and bottom of bread were not glowing smoothly as seen in Figure 4.3. It is determined that the composition of crust is weak and the pore structure is not completely composed. When the inner structure is examined, it is seen that it is bright white but not well cooked.

Figure 4.3. Picture of baked bread cooking time period; t = 4 min. and T = 260 ^{o}C

Then the color of the product cooked at T = 270 ^{o}C for t = 4 minutes is brown and sides and bottom of bread were not glowing smoothly as seen in Figure 4.4. It is determined that the composition of crust is thin and the pore structure is not completely composed. The inner structure is examined and found that it is bright white but not well cooked and remained dough-like.

Figure 4.4. Picture of baked bread cooking time period; t = 4 min. and T = 270 ^oC

Lastly the color of the upper side of the product cooked at T = 280 ^oC for t = 4 minutes is dark brown and appointed that sides and bottom of bread were not glowing smoothly and partially burned shown in Figure 4.5. The composition of crust is thick and the pore structure is not completely composed. The inner structure is bright white but not well cooked except the part close to crust and remained dough-like.

Figure 4.5. Picture of baked bread cooking time period; t = 4 min. and T = 280 ^{o}C

As the effect period of the microwave is not enough, the interior part of bread had not reached to the necessary qualities by the result of trials of four minutes, become doughy in general. It was fixed that a shell structure not homogenous and sometimes burning, showing regional differences through examination of the external surface of dough was formed at high temperatures where the period of four minutes does not allow the shell's formation at low temperatures. The best of four minutes experiments is also 270 ^{o}C but it isn't good enough when compared with baked in conventional oven bread (Table 4.1).

Table 4.1. Results of four minutes experiments

	4 Minutes				
	240 ^oC	250 ^oC	260 ^oC	270 ^oC	280 ^oC
Color of Crust	-	-	-	+	-
Evenness of Bake	-	-	-	-	-
Character of Crust	-	-	-	-	-
Pore structure	-	-	-	-	-
Color of crumb	+	+	+	+	+
Chewability	-	-	-	-	-

4.2.Five Minutes Experiments

The dough was cooked in the prototype oven at temperatures of T = 240 ^oC, 250 ^oC, 260 ^oC, 270 ^oC, 280 ^oC respectively in its trials of five minutes experiment.

At first the dough was baked at T = 240 ^oC for t = 5 minutes is determined that the color of crust of the product is yellow which is close to white shown in Figure 4.6. It is seen that there is no complete glow at sides and bottom of bread. It is observed that the composition of crust is weak and that the pore structure is not completely composed. When the inner structure is examined it is found that it is dough-like and not cooked.

Figure 4.6. Picture of baked bread cooking period; t = 5 min. and T = 240 ^oC

Secondly the dough was baked at T = 250 ^oC for t = 5 minutes in combined oven as seen in Figure 4.7. The color of the crust of the product is determined as brown close to yellow and that sides and bottom of bread were not glowing smoothly. The composition of crust is good and the pore structure is not completely composed. The examination of the inner structure is shown that it is bright white but not well cooked.

Figure 4.7. Picture of baked bread cooking period; t = 5 min. and T = 250 ^{o}C

Thirdly the color of the product which cooked at T = 260 ^{o}C for t = 5 minutes is between yellow and brown shown in Figure 4.8. Sides and bottom of bread were not glowing smoothly. It is determined that the composition of crust is convenient and that the pore structure is not completely composed. The inner structure is controlled it is seen that it is bright white but not well cooked.

Figure 4.8. Picture of baked bread cooking period; t = 5 min. and T = 260 ^{o}C

Later it is observed that the color of the product cooked at T = 270 ^{o}C for t = 5 minutes is brown and that sides and bottom of bread were not glowing smoothly as seen in Figure 4.9. It is determined that the composition of crust is convenient and that the pore structure is not completely composed. The inner structure is bright white but not well cooked and remained dough-like.

Figure 4.9. Picture of baked bread cooking period; t = 5 min. and T = 270 ^{o}C

Finally the color of the upper side of the product cooked at T = 280 ^{o}C for t = 5 minutes is dark brown and appointed that sides and bottom of bread were not glowing smoothly and partially burned shown in Figure 4.10. The composition of crust is thick and that the pore structure is not completely composed. When the inner structure is examined it is found that it is bright white but not well cooked except the part close to crust and remained dough-like.

Figure 4.10. Picture of baked bread cooking period; t = 5 min. and T = 280 ^{o}C

As the period affected by the microwave is not enough as in the trials of the trials of four minutes, the interior structure of the product cooked did not reach to the values wished and stayed doughy in also the trials of five minutes. When the external structure is looked, it was seen that it was better than the trials of four minutes but the shell’s color was not brown homogenously wished when it was compared to the bread cooked with the traditional method but the shell’s structure was smooth in general. The best of five minutes experiments is 270 ^{o}C but it isn’t good enough when compared with baked in conventional oven bread (Table 4.2).

Table 4.2. Results of five minutes experiments

	5 Minutes				
	240 °C	250 °C	260 °C	270 °C	280 °C
Color of Crust	-	-	-	+	-
Evenness of Bake	-	-	-	-	-
Character of Crust	-	+	+	+	-
Pore structure	-	-	-	-	-
Color of crumb	+	+	+	+	+
Chewability	-	-	-	-	-

4.3. Six Minutes Experiments

In five minute experiments dough was cooked T = 240 °C, 250 °C, 260 °C, 270 °C, 280 °C for six minutes in the prototype microwave oven.

Firstly, the color of crust of the product cooked at T = 240 °C for t = 6 minutes is in between yellow and brown as seen in Figure 4.11. It is seen that there is no complete glow at sides and bottom of bread. It is determined that the composition of crust is weak and that the pore structure is convenient. The examination of inner structure is shown that it is bright white and well cooked.

Figure 4.11. Picture of baked bread cooking period; t = 6 min. and T = 240 ^oC

Secondly the product cooked at T = 250 ^oC for t = 6 minutes is brown and that sides and bottom of bread were not glowing smoothly shown in Figure 4.12. It is seen that the composition of crust is normal and that the pore structure is convenient. When the inner structure is examined it is found that it is bright white and well cooked.

Figure 4.12. Picture of baked bread cooking period; t = 6 min. and T = 250 ^{o}C

Thirdly the dough baked at T = 260 ^{o}C for t = 6 minutes is brown and that sides and bottom of bread were glowing smoothly as seen in Figure 4.13. The composition of crust is controlled and it is seen that it is normal and that the pore structure is convenient. The inner structure is examined and found that it is bright white and well cooked.

Figure 4.13. Picture of baked bread cooking period; t = 6 min. and T = 260 ^{o}C

The color of the product cooked at T = 270 ^{o}C for t = 6 minutes is dark brown and that sides and bottom of bread were not glowing smoothly (Figure 4.14). It is observed that the composition of crust is normal and that the pore structure is convenient. The inner structure is checked it is shown that it is bright white and well cooked.

Figure 4.14. Picture of baked bread cooking period; t = 6 min. and T = 270 ^oC

Lastly the color of the upper side of the product which cooked at T = 280 ^oC for t = 6 minutes is dark brown and sides and bottom of bread were not glowing homogenously and partially burned (Figure 4.15). It is checked that the composition of crust is thick and that the pore structure is convenient. When the inner structure is controlled it is found that it is bright white and well cooked.

Figure 4.15. Picture of baked bread cooking period; t = 6 min. and T = 280 ^{o}C

In the trials of six minutes as different than the trials of five minutes and four minutes it was observed that the interior part of bread was cooked appropriately because the microwave’s effect period was enough, the poles were thin, have a ellipse shape, homogeneous. It was fixed that the external structure of bread was T = 250 ^{o}C, close to ideal one and had the ideal shape at T = 260 ^{o}C. The best of six minutes experiments is T= 260 ^{o}C and it is as good as bread which baked in conventional oven (Table 4.3).

Table 4.3. Results of six minutes experiments

	6 Minutes				
	240 ^oC	250 ^oC	260 ^oC	270 ^oC	280 ^oC
Color of Crust	-	+	+	-	-
Evenness of Bake	-	-	+	-	-
Character of Crust	-	+	+	+	-
Pore structure	+	+	+	+	+
Color of crumb	+	+	+	+	+
Chewability	+	+	+	+	+

4.4.Seven Minutes Experiments

In this last trial series the dough was cooked at temperatures of T = 240 ^oC, 250 ^oC, 260 ^oC, 270 ^oC, 280 ^oC respectively as in the previous trial series.

First of all, the color of crust of the product cooked at T = 240 ^oC for t = 7 minutes is brown close to yellow shown in Figure 4.16. It is seen that there is no complete glow at sides and bottom of bread. The determination of the composition of crust is shown that it is weak and that the pore structure is convenient. The inner structure is examined and found that it is bright white and well cooked.

Figure 4.16. Picture of baked bread cooking period; t = 7 min. and T = 240 ^{o}C

Second of this turn, the dough was baked at T = 250 ^{o}C for t = 7 minutes in combined oven (Figure 4.17). The color of the product is brown and sides and bottom of bread were not glowing homogenously. It is determined that the composition of crust is normal and that the pore structure is convenient. The examination of inner structure is shown that it is bright white and well cooked.

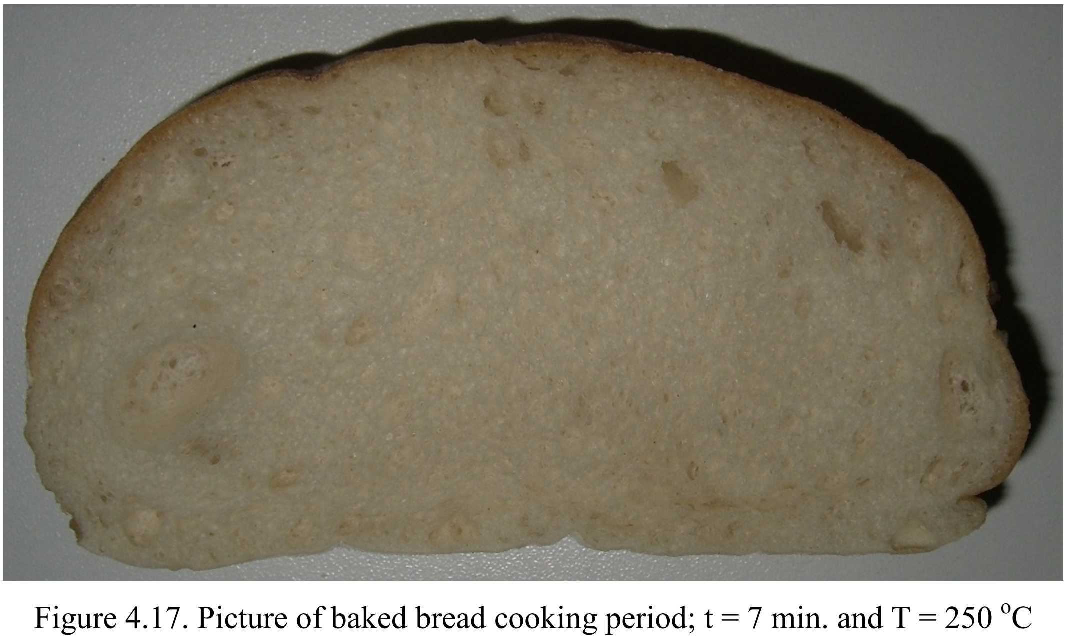

Figure 4.17. Picture of baked bread cooking period; t = 7 min. and T = 250 ^{o}C

Thirdly the color of the product which cooked at T = 260 ^oC for t = 7 minutes is dark brown and that sides and bottom of bread were glowing smoothly as seen in Figure 4.18. It is observed that the composition of crust is thick and that the pore structure is not composed normally at section close to crust. When the inner structure is examined it is found that it is bright white and well cooked.

Figure 4.18. Picture of baked bread cooking period; t = 7 min. and T = 260 ^oC

The color of the product cooked at T = 270 ^oC for t = 7 minutes is determined as dark brown and sides and bottom of bread were observed as not glowing homogenously and some parts are burned (Figure 4.19). The composition of crust is thick and that the pore structure is not convenient. When the inner structure is examined it is found that it is bright white and well cooked.

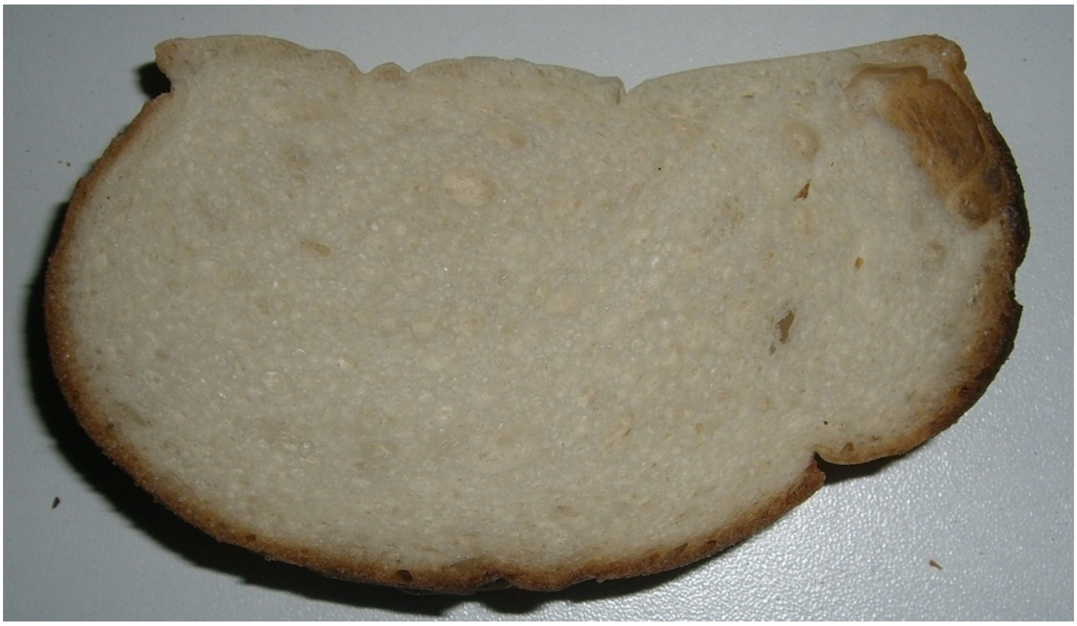

Figure 4.19. Picture of baked bread cooking period; t = 7 min. and T = 270 ^{o}C

At the end the product cooked at T = 280 ^{o}C for t = 7 minutes as seen in Figure 4.20. The color of the upper side of the product is dark brown and sides of bread were not glowing smoothly and partially burned. The composition of crust is thick and that the pore structure is not convenient. When the inner structure is examined it is found that it is bright white but the section close to crust is dry and that it is over cooked in general.

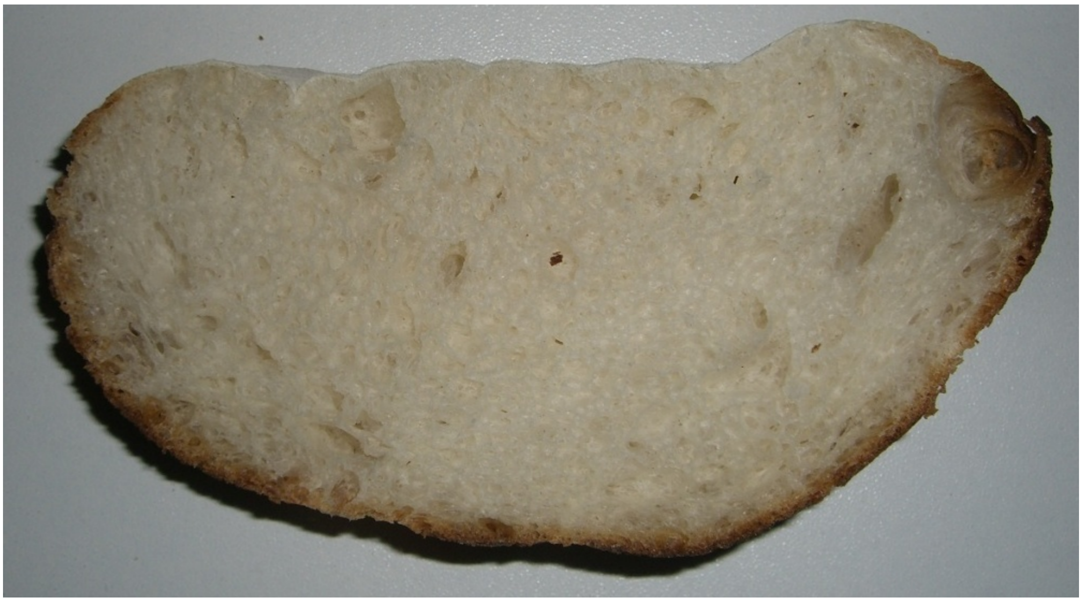

Figure 4.20. Picture of baked bread cooking period; t = 7 min. and T = 280 ^oC

In these last trials it was seen that the interior structure of dough was appropriate, homogenous and had a thin structure in the trials except 7 minutes 280 ^oC due to insufficient effect period of microwave. It was fixed that the shell's color wished, smooth toasting could not be obtained in general when its external part was examined. The best of seven minutes experiments is also 250 ^oC but it isn't good enough when compared with baked in conventional oven bread (Table 4.4).

Table 4.4. Results of seven minutes experiments

	7 Minutes				
	240 ^oC	250 ^oC	260 ^oC	270 ^oC	280 ^oC
Color of Crust	-	+	-	-	-
Evenness of Bake	-	-	+	-	-
Character of Crust	-	+	-	-	-
Pore structure	+	+	+	-	+
Color of crumb	+	+	+	+	-
Chewability	+	+	+	+	-

5. CONCLUSION

In this study convectional method and microwave, the cooking of bread by the traditional oven and the combined application of convectional method is examined. Application of combined system has advantages in terms of energy saving. The cooking of bread becomes possible in lower temperatures and in shorter period of time.

When the conventional system is examined it is observed that the funnel losses are high. In order to prevent these losses, a part of the lost energy can be gained by placing a heat exchanger at the outlet of funnel in order to recover heat from the exhaust gas. Turbulator can be used in order to increase the efficiency of combustion part. When the system is examined it is determined that the largest heat loss is being realized from the surveillance glass on the front side. This heat loss can be reduced by applying double or triple glass for the surveillance glass.

Experiments shown that the inner structure of bread gets better as time increase and the color of crust gets darkens as heat increase.

Results of four minutes experiments are observed that there is no sufficient period for the inside of bread to be cooked and that the outer part does not glow under low temperatures and that it darkens very much under high temperatures. In this experimental studies, the time and the temperature condition of t = 4 minute and T = 270 ^{o}C is found to be the most convenient criteria.

Five minutes experimental studies results indicate that the inner part of bread is not cooked and that the pore structure did not reach convenient conditions. The outer part of bread becomes yellow at low temperatures and becomes first brown and then dark brown as the temperature increases. Temperature and time period of t = 5 minutes and T = 270 ^{o}C is found to be the most convenient criteria.

Six minutes experiments results show that the inner part of bread is cooked and that the pore structure occurs at convenient conditions. It is observed that the outer part of bread is light brown at low temperatures and becomes dark at high temperatures as it would burn. In six minutes experiments the period of t = 6 minutes and T = 260 ^{o}C is found to be the most convenient criteria.

In seven minutes experiments, it is determined that the inner part of bread is cooked in general and that the pore structure is normal. It is observed that the outer part of bread is over darkened and partially burned. In this application the period of t = 7 minutes and T = 250 ^{o}C is found to be the most convenient criteria.

If we compare the present results to the traditional method by considering the cooking periods, the bread cooked in t = 18-20 minutes with the traditional cooking method. But same bread is cooked in a period of t = 6 minutes with the present system. When we evaluate by considering heat energy for cooking process, the same result is obtained with the combined oven at T = 260 ^{o}C while cooking the bread with the traditional method at T = 300 ^{o}C. As a result, it was fixed that the combined oven was more advantageous both from the aspect of time and energy for cooking. But as the trials are made with little prototype and it is not known that what kind of problems will occur in a large scale prototype, as it cannot be estimated that the microwave's affection distance is a positive function with the distance's square what kind of contraction problems may cause, it may be required to perform more comprehensive works for a large scale hybrid oven in order to mention about its applicability commercially.

When all the data of experiments are evaluated, it is found that sufficient conditions occur in the oven where the microwave and convectional systems are used as a combined oven, for the time period of t = 6 minutes and at T = 260 ^{o}C temperature and that it is more advantageous in respect of time, energy and operations costs compared to the conventional cooking methods.

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CURRICCULUM VITAE

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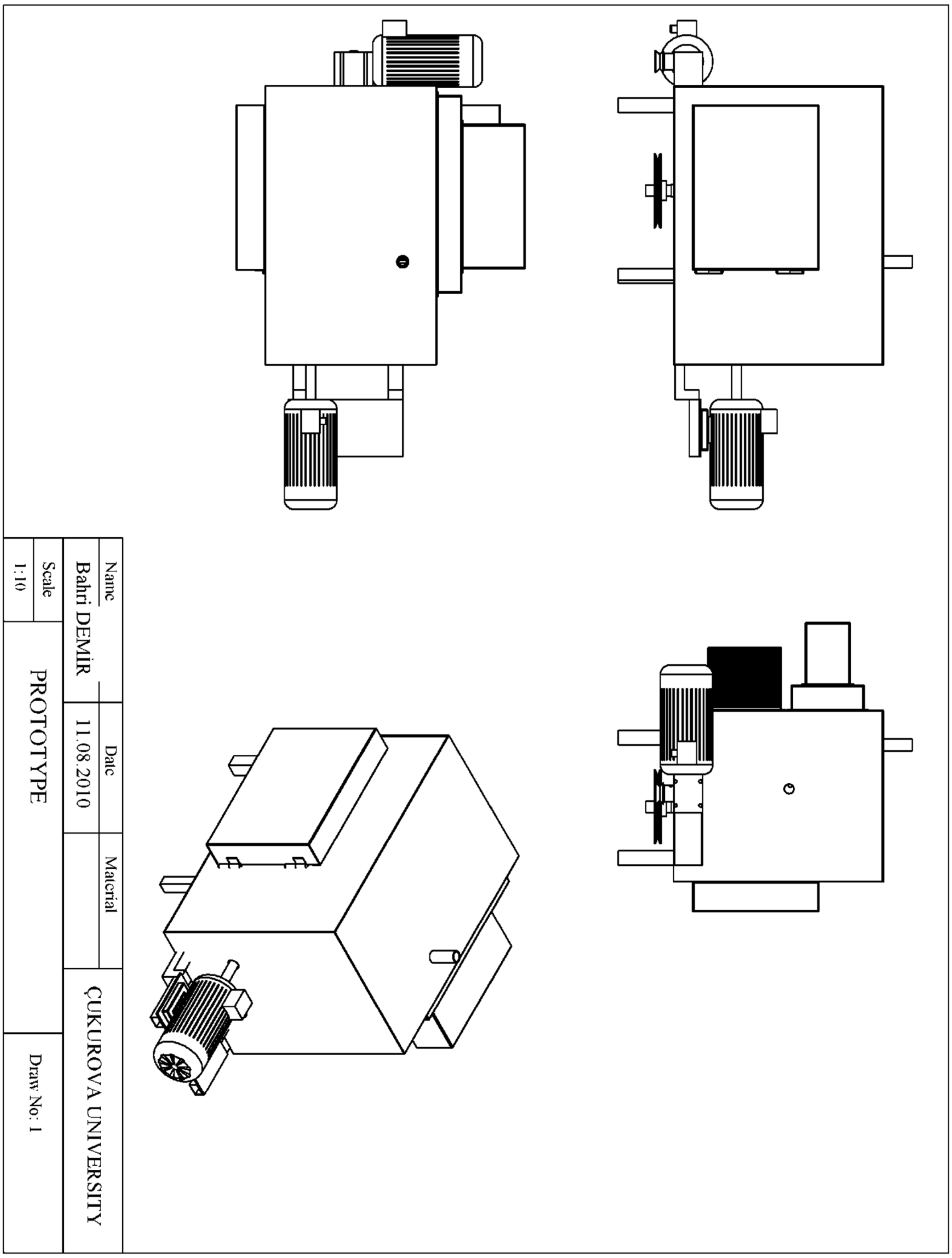
APPENDIX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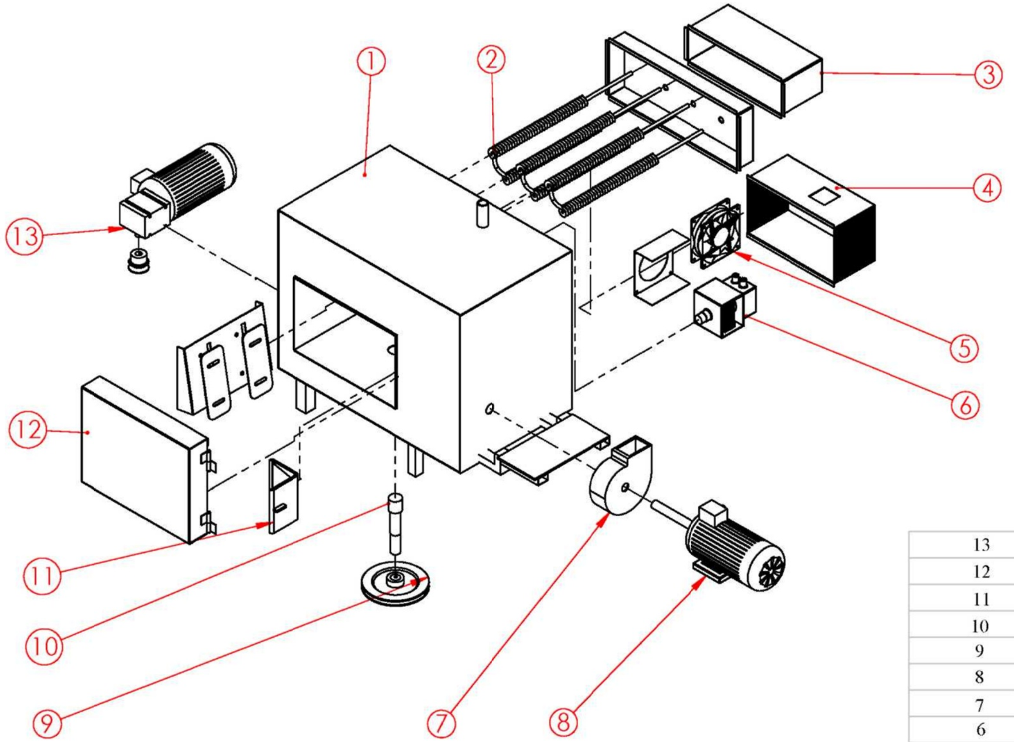

Item	Description
13	Reduction Gear Box
12	Oven Door
11	Steam Generator
10	Shaft
9	Pulley
8	Fan Engine
7	Circulation Fan
6	Magnetron
5	Magnetron Cooling Fan
4	Magnetron Cover
3	Resistance Cover
2	Resistance
1	Base Body

Name	Date	Material	ÇUKUROVA UNIVERSITY
Bahri DEMİR	10.08.2010		
Scale	PROTOTYPE (Explode)		Draw No: 2
1:10			