INVESTIGATION OF HEAT FLOW CHARACTERISTIC IN AN INDUSTRIL OVEN USING ANSYS

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SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to supervisor and to the second examiner.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid).

Signature :...................................

Name of Supervisor : DR. MOHD ZAID BIN AKOP

Date :...................................

DEDICATION

This is for my ibu and ayah. The reason why am I still holding on what I should hold. The ultimate weapon for me to stand up eight times when I fall hard seven times.

Without them I am nothing. I love you.

ABSTRACT

Temperature uniformity is the most important factor to design an oven. There's various design of an oven in the industry. However, most design having the same problem which is the uniformity of the temperature distribution inside the oven. Temperature distribution depends on the hot air circulated inside the oven cavity. The geometry design of the oven also the main concern along the heating coil design and position. Circulated hot air inside the cavity drive by a fan. A fan will circulate the hot air. The position of the device also play an important role. The material used for each wall inside the oven also affecting the temperature distribution. A numerical investigation using Computational Fluid Dynamic(CFD) technique will help in the initial process to design an oven. This numerical will give an early predicted of what will happen inside the oven. This simulation also shows the behavior of the air inside the oven. The result can be compared with different model in order to have better cooking result. The simulation for both oven shows different result. Forced convection have better cooking condition than natural convection.

ABSTRAK

Untuk merekabentuk sesebuah ketuhar, keseragaman suhu merupakan faktor yang sangat penting. Pelbagai jenis rekabentuk ketuhar yang terdapat dipasaran. Walaubagaimanapun, kebanyakan rekabentuk menhadapi masalah yang sama iaitu keseragaman suhu di dalam ketuhar. Rekebentuk geometri sesebuah ketuhar merupakan faktor penting yang di ambil kira selain rekabentuk rod pemanas dan juga kedudukan rod pemanas diletakkan. Pergerakan udara panas didalam ketuhar di bantu dengan kehadiran kipas. Kipas akan menggerakkan udara panas diseluruh kawasan didalam ketuhar. Selain daripada itu, kedudukan peranti diletakakn juga boleh menjadi faktor penting. Bahan yang digunakan untuk setiap dinding didalam ketuhar juga boleh diambil kira. Kajian berangka menggunakan teknik Komputer Dinamik Bendalir akan memudahkan proses awal untuk merekabentuk sesebuah ketuhar. Kajian ini akan memberi ramalan awal tentang keadaan di dalam ketuhar. Simulasi ini juga membantu untuk mengkaji pergerakan udara didalam ketuhar. Hasil daripada simulasi yang dijalankan boleh membantu untuk membandingkan rekebentuk yang akan menghasikan kaedah memasak yang terbaik. Simulasi daripada kedua-dua ketuhar menunjukkan keputusan yang berbeza. Ketuhar daya perolakan menunjukkan keadaan memasak yang lebih bagus daripada ketuhar perolakan semula jadi.

ACKNOWLEDGEMENT

I would like to express my greatest appreciation to my supervisor Dr. Mohd Zaid Bin Akop for giving me this opportunity to do final year project with him. He never hesitated to give me advice and guidance whenever I confronted problems. I am thankful for his patience and advice while leading me in this project.

I would like to thank to Dr. Tee Boon Tuan and Dr. Fudhail for always spending their time to consult me doing CFD simulation. Thank you so much for always being patient with me.

And for my classmate, thank you for always being an understanding person whenever we are doing any other assignments. Most of it, thank you everyone for always being patient with me.

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LIST OF ABBEREVATIONS

CFD	Computational Fluid Dynamics
Re	Reynolds number
Ram	Modified Rayleigh number
Nu	Nusselt number
DTRM	Discrete transfer
S2S	Surface-to-surface
DO	Discrete Ordinate

LIST OF SYMBOL

μ	Dynamic viscosity
v	Kinematic viscosity
U	Velocity
ρ	Density
k	Turbulent kinetic energy
cp	Specific heat
P	Pressure
T	Temperature
ε	Turbulent dissipation
g	Gravitational acceleration
β	Coefficient of thermal expansion
ϕ	Porosity
Q	Heat flow
d_m	Material thickness
S_{ij}	Strain-rate tensor

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Non-uniform heat distribution is still one of the main concern that been taking as a main factor to improve the best baking condition for different type of heating system. This concern has been observed using different oven. In commercial usage, there a lot of type of oven. Commonly the type of oven was differentiating by the type of heating mode. The main mechanism of heat transfer is forced convection. In any type of ovens, heat will always have been forced using different type of heating mode. An oven usually has three types of heating mode, classic, fan and grilling. Thus, in this analysis there's only two types of oven will be used to compare with each other which is conventional oven and convection oven that usually been used at home.

Conventional ovens use radiant heat that been surrounding from the top and/or bottom surfaces to heat the oven chamber. By way of definition radiating heat is basically heating energy transmitted by electromagnetic waves in contrast to heat transmitted by conduction or convection. The result tends to produce hot and cold spots in the oven chamber which can often lead to uneven cooking results. For commercial cooking applications, this method of transferring heat can limit both cooking results and menu options by way of achieving an even cooking result.

Convection ovens deals with the problems of hot and cold spots and uneven like cooking result by using a fan to circulate air and keep the temperature steadier. When hot air is blowing onto food, as opposed to merely surrounding it, the food tends to cook more quickly. However, there's scientific explanation for this is that moving air speeds up the rate of heat transference that naturally occurs when air of two different temperatures converge. In short explanation, convection oven is an oven that using a fan that forced hot air which is circulated around the oven chamber and acting as a catalyst for faster heat transference and a more even cooking temperature.

In many cases, non-uniform heat distribution come from uneven heat transfer through each part of the chamber of the oven. Uneven heat transfer occurred due to poor temperature distribution and flow field in the ovens chamber. Due to this reason, the baking of cookies will not be same since some part of the cookies will burned caused by the temperature different in the oven chamber. This temperature different will be analyze using lumped system analysis.

Other than that, the cause of this concern maybe coming from the position and the design of heating of the heating coils of conventional ovens while the position of fan and also the design and position of heating coils will give different result of heat distribution in the oven chamber.

1.2 PROBLEM STATEMENT

Conventional oven was designed with the heating coils placed on top and bottom of the oven chamber with different design of heating coil. While the convection oven designed with different position of fan that will circulate the hot air that been heated by different design of heating coils that been placed either on top or bottom of the oven chamber. In this concern, non-uniform heat distribution appears only when the oven is used to bake cookies dough. However, when the ovens used to bake other type of food such as breadits show uniform heat distribution for both ovens.

Figure 1.1 : Conventional Oven

Figure 1.2 : Convection Oven

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To investigate the flow of heat transfer in conventional and convection ovens.
2. To analyse the flow of heat transfer in conventional and convection ovens.
3. To compare the temperature distribution and velocity in convectional and convection ovens.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. Only heating mode classic will be analyzed of both ovens that will gave a comparison which oven is better for cookies baking.
2. Conventional oven will be analyzed with heating coil placed on top and bottom of the oven.
3. Convection oven will be analyzed with a fan place only at the back side of the oven and heating coil placed of top of the oven.

CHAPTER 2

Literature Review

2.1 Mechanism of Heat Transfer

Heat is a form of energy that can be transferred from one system to another system. There are three different ways for heat to be transferred which is: conduction, convection and radiation (A. Cengel, 2015). A temperature distinction is required for these methods of heat transferred to happen, and the heat dependably exchanges from areas of high temperature to lower temperature. The amount of heat transferred during the three process is denoted by Q while the heat transferred rate is denoted by $\dot{Q}$ which is define as heat transfer "per unit time". The heat transfer rate has the unit J/s which is equivalent to W(watt).

If the rate of heat transfer is available, the total amount of heat transfer Q during the time interval can be find from

$$Q = \int_0^{\Delta t} \dot{Q}\, dT \tag{2.1}$$

Provided that the variation of with respect to time is known. If the is constant, the equation above will be reduced to

$$Q = \dot{Q}\,\Delta t \tag{2.2}$$

2.1.1 Conduction

Conduction is the transfer of heat as a result of interactions between different particles (A. Cengel, 2015). Conduction can occur in solids, fluids and gases. In gases and fluids, conduction caused by collisions and diffusion of molecules during their random motion of movements. In solids, it is caused by vibrations of molecules in a lattice and the energy transport of free electrons. Steady one dimensional heat conduction is defined as

$$\dot{Q} = -kA\frac{dt}{dx} \tag{2.3}$$

which is also known as Fourier's law. Here A is the heat transfer surface area, which is always normal to the direction of heat transfer, and k is the thermal conductivity of the given material.

2.1.2 Convection

Convective heat transfer takes place in fluids in the presence of fluid motion (A.Cengel, 2015). Convective heat transfer is divided into natural and forced convection. In forced convection, the fluid motion is initiated externally, e.g. by a fan or a pump, while in natural convection it is caused by density differences in the fluid due to temperature gradients. Convective heat transfer from a solid surface to the surrounding fluid is defined as

$$\dot{Q} = hA(T_s - T_\infty) \tag{2.4}$$

which is known as Newton's law of cooling. Here h is the convection heat transfer coefficient, A is the heat transfer surface area, T_s is the temperature of the surface and $T\infty$ is the temperature of the fluid sufficiently far away from the surface.

2.1.3 Radiation

Radiation is a process where energy is emitted by matter in the form of electromagnetic waves (A. Cengel, 2015). Radiation does not, unlike conduction and convection, require a medium in order to transfer energy, it works just as well in vacuum. The relevant type of radiation for heat transfer studies is thermal radiation, which is emitted by all bodies at a temperature over absolute zero. The net radiative heat transfer is calculated as

$$\dot{Q} = \varepsilon\sigma A(T_S^4 - T_{Surr}^4) \quad (2.5)$$

where ε, A and T_s is the emissivity, surface area and absolute temperature, respectively, of a body and T_{surr} is the absolute temperature of the surrounding surface. The Stefan-Boltzmann constant σ, is equal to 5.67 × 10−8W ($m^2 \cdot K^4$).

2.2 Natural Convection oven

Heat that is transferred by natural convection is accompanied by radiation of comparable magnitude except for low emissivity surface. For an oven, natural convection relay on the temperature distinction within the hot air in the oven to the baking material. Heat that is supplied by the heating coil is not generated by any external sources (pump, fan, suction device) but the differences of the density between the hot air and the baking material due to temperature gradient. To have a uniform distribution of temperature the heat supplied from electric heaters or heating coils must be well designed and to determine the quality of the device the temperature field must be as uniform as possible. (Jacek, 2013).

Not only convection heat transfer occurs, radiation heat transfer also one of the factor that been study to optimize the distribution of temperature and velocity. The study about natural convection with or without presence. With presence of radiation, the temperature ratio of the heat transfer between both ways decrease slightly, for aspect ratio increase from unity and will increase drastically as the aspect ratio decrease from unity. While without presence of radiation, the ratio increased by increasing the absolute temperature (Abdulmaged, 2013).

Figure 2.1 : Natural Convection Oven (http://www.alamy.com)

2.3 Forced Convection Oven

Forced convection oven worked by the heat is transferred from the heating element via conduction, convection and radiation with the existed forced air by the external force device in the oven chamber (Sakin, 2008; Martin, 1997). Using a fan or jet impingement hot air is forced to circulate in the chamber. Uniformity of the temperature and velocity across the oven chamber is important to ensure that heat is equally transferred in the oven chamber. These two factors will result to the quality of the baking product. To maintain the uniformity of these factors, high air pressure is created in the plenum that provide the banks of the nozzles (Khatir, 2011).

Figure 2.2 : Forced Convection Oven (http://ovenreviewshq.com)

2.4 Governing Equation

The following equations are used in order to mathematically describe fluid flow in oven cavity.

2.4.1 Continuity equation

This is the three dimensional and unsteady continuity equation for a compressible fluid. The first term describes the rate of change in time of the density and the second term describes the net flow of mass out of the element boundaries.

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho U_j}{\partial x_j} = 0 \tag{2.6}$$

2.4.2 Momentum Equation

This is the momentum equation, or Navier Stokes equation, written in tensor notation. The momentum equation is obtained by applying Newton's second law to a fluid particle.

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \rho}{\partial x_i} + \frac{1}{\rho}\frac{\partial}{\partial} + g_i \tag{2.7}$$

2.4.3 Energy Equation

The energy equation for incompressible flow with constant C_p reads:

$$\rho \frac{du}{dt} = -p\frac{\partial U_i}{\partial x_i} + \Phi + \frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right) \tag{2.8}$$

where Φ is defined as

$$2\mu S_{ij} S_{ij} - \frac{2}{3}\mu S_{ii} S_{kk} \tag{2.9}$$

and S_{ij} is the strain-rate tensor

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \tag{2.10}$$

2.5 Dimensionless Number

The relevant dimensionless numbers that will be observed in the flow assumption in the oven are described below.

2.5.1 Modified Rayleigh number

The modified Rayleigh number, Ra_m, usually used in flow situations involving natural convection in porous media. It can be represented as a measure of the driving forces for natural convection, and is defined as

$$Ra_m = \frac{\rho c_{pg} \beta d_m K \Delta T}{v k_m} \tag{2.11}$$

2.5.2 Nusselt Number

The Nusselt number is the ratio between heat flux where convection is existed and heat flux without convection for the same situation. A Nusselt number represents heat transfer by pure conduction, while a Nusselt number larger than one means that convection has started. The larger the Nusselt number is, the more dominant convection is:

$$Nu = \frac{q_{with\ convection}}{q_{without\ convection}} \tag{2.12}$$

2.5.3 Reynolds number

The Reynolds number is defined as the ratio of the inertia forces to the viscous forces in a fluid. A large Reynolds number means that the inertia forces, which are proportional to the density and velocity of the fluid, are large compared to the viscous forces. Since laminar flow is dominated by viscous forces and turbulent flow by inertia forces, the Reynolds number can be used to characterize whether a flow is laminar or turbulent. The Reynolds number where the flow becomes turbulent is called the critical Reynolds number, the value for this is different for every geometry.

$$Re = \frac{intertia\ force}{viscous\ force} = \frac{UL}{v} = \frac{\rho UL}{\mu} \tag{2.13}$$

2.6 Modeling oven in Computational Fluid Dynamic(CFD)

Computational Fluid Dynamic allow us to do prediction of any time of flow in any condition or situation. In Khatir *et al.* (2010, 2011) previous work, the prediction of CFD modeling for temperature distribution in the oven have given the influences in bread quality. Other than that, to maximize the usage of CFD modeling, the study of the temperature profile along the oven chamber to reduce moisture loss (Therdthai *et al,* 2002) optimized temperature, heat transfer coefficient,and bread radius for improving quality (Purlis, 2011) and oven design optimization in bread-baking industry (Khatir, 2011) have been conducted.

The CFD method to predict the temperature uniformity distribution and velocity fields in the oven have been validated by Jacek Smolka (2013) for CFD modeling for a heating oven with natural air circulation. In the study, general temperature and flow fields, validation of the temperature field and velocity field and temperature uniformity have been obtained by using 3-dimensional analysis of CFD model.

In order to make sure the CFD giving an accurate result, experimental and numerical analysis have been done. A.M. Najib (2015) doing both experimental and numerical analysis of 3d gas flow field in infrared heating reflow oven with circulating fan. The experiment was developed to get the spatial temperature across the oven using a set of industrial standard thermocouple that been attached in various position in the oven chamber. The numerical modeling has been identified using FLUENT modeling and User Defined Function (UDFs). The model was developed to predict the thermal profile of the oven. Other than that, the temperature contour and air circulating in the oven also have been identified. Both experimental and numerical result giving satisfactory result for temperature uniformity in the oven.

While Jacek Smolka (2013) presented, the experimental validation of CFD model for heating oven with natural convection. The experiment has been done to determine the analysis of the flow and thermal processes using a heating oven with natural circulating air and the numerical has been carried out to investigate the temperature boundary condition along the U-shaped heating coil and the emissivity of the internal and external wall to gain the radiative heat fluxes. The result of the experimental and numerical giving a satisfactory outcome for temperature values and computational velocity.

2.7 Turbulence Model

Following to most previous study, the fluid flow in both ovens was predicted to be turbulent flow. Turbulence indicated the present of Reynold number in high value. Air flow in the oven also can be predicted using steady-state Reynolds Averaged Navier-Stokes (RANS) equation for three-dimensional flow. In RANS equation, the continuity and momentum equation can be written as:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0$$
$$\frac{\partial}{\partial x_i}(\rho u_i) + \frac{\partial}{\partial x_i}(\rho u_i u_j) = -\frac{\partial}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right] + \rho\bar{g} + \frac{\partial}{\partial x_i}(-\rho\bar{u}_i'\bar{u}_j') \tag{2.14}$$

where ρ and u_i representing the air density and velocity components in direction x, p is pressure, and $\bar{g}$ is representing the gravitational acceleration due to gravity.

2.7.1 Standard *k*-ε model

Two variables that can be used to describe turbulence flow: *k* (turbulent kinetic energy) and ε (turbulent dissipation) that allow the computation of turbulent stress and turbulent viscosity. These variables also used to describe as the realizable *k-ε* transport model that also can describing the turbulence model (Khatir, 2011 and Boulet,2010). The realizable *k-ε* was approached by the RANS. The improvement of the standard k-ε model is represented by realizable *k-ε* model that can be used for more complex geometry. The improved model consists these follows two transportation equation:

$$\frac{\partial}{\partial x_i}\left(\rho k_{U_i}\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_1}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon \tag{2.15}$$

$$\frac{\partial}{\partial x_j}\left(\rho\varepsilon_{U_j}\right) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_1}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + \rho C_1 S_i - \rho C_2\frac{\varepsilon^2}{k + \sqrt{v\varepsilon}} \tag{2.16}$$

2.8 Radiation model

Not only turbulence model should be analyzed in oven, radiation model must be taking into consideration of prediction the heat flow in an oven. Since the heat was transferred from heating coil to the baking product, radiation is one of the heat transfer mechanism that been involve. There is five radiation model that been provided in ANSYS Fluent: Discrete transfer (DTRM), P-1, Rosseland, Surface-to-Surface (S2S) and discrete Ordinates (DO).

Study have been conduct to observe the most appropriate radiation model for natural convection oven. Discrete ordinate model working very well with the full range of optical thicknesses and a great solution of radiation for semi-transparent wall. The model has been tested to over-prediction of biscuits temperature surface (Zlatko, 2011).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to obtain the data for heat transfer analysis for conventional and convection ovens. The flow chart of the project is shown in Figure 3.1. This project starts by studying and understand how the oven works and the characteristic of an oven. Different type of oven has different characteristic. To understand the oven more, various journal and thesis of previous study have been studied. After that a study of how to simulate CFD using software called ANSYS-FLUENT and to study the correct way to obtain correct and validate measurement data. In the software, the obtained data will using analysis system called Fluid Flow (Fluent) or more familiar with name Computation Fluid Dynamic (CFD). After designing both oven, the simulation to analyse heat flow characteristic in this oven will performed.

3.2 General Simulation Setup

Figure 3.2 shows the general simulation setup to obtain the result of the analysis. Simple drag from the left tool box will pop-up the analysis that will be used to obtain the simulation result.

3.2.1 Modeling

In order to start the simulation, simplified oven geometry have to be design in the Design modular or Geometry section. All the simplified model of prediction the heat flow has to be design clearly in order to have the simplest model. The modeling can be done either in 2-dimensional or 3-dimensional design of oven. Figure 3.3 shows the design that have been done in design modular. The figure show the simplified design or an assumption of natural convection oven with heating coil place at bottom and lower of the oven chamber.

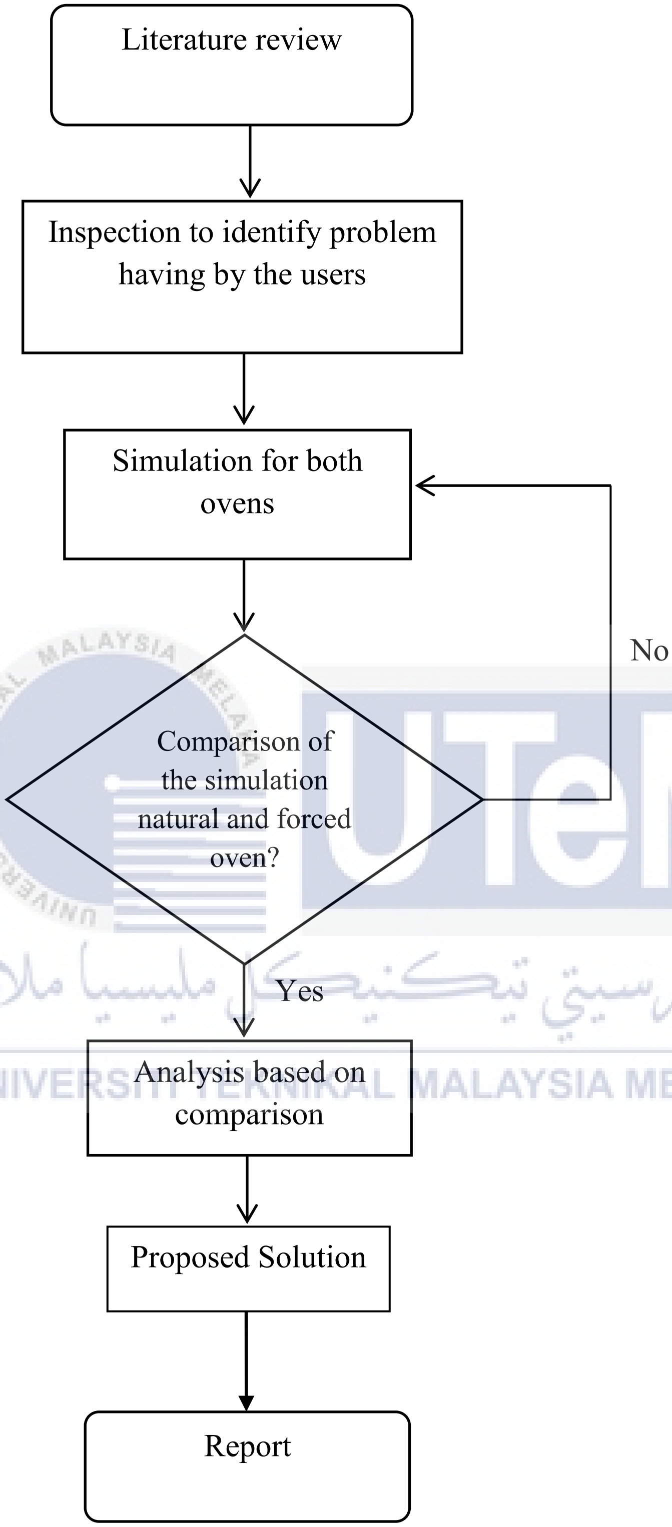

Figure 3.1: Flow chart of the methodology.

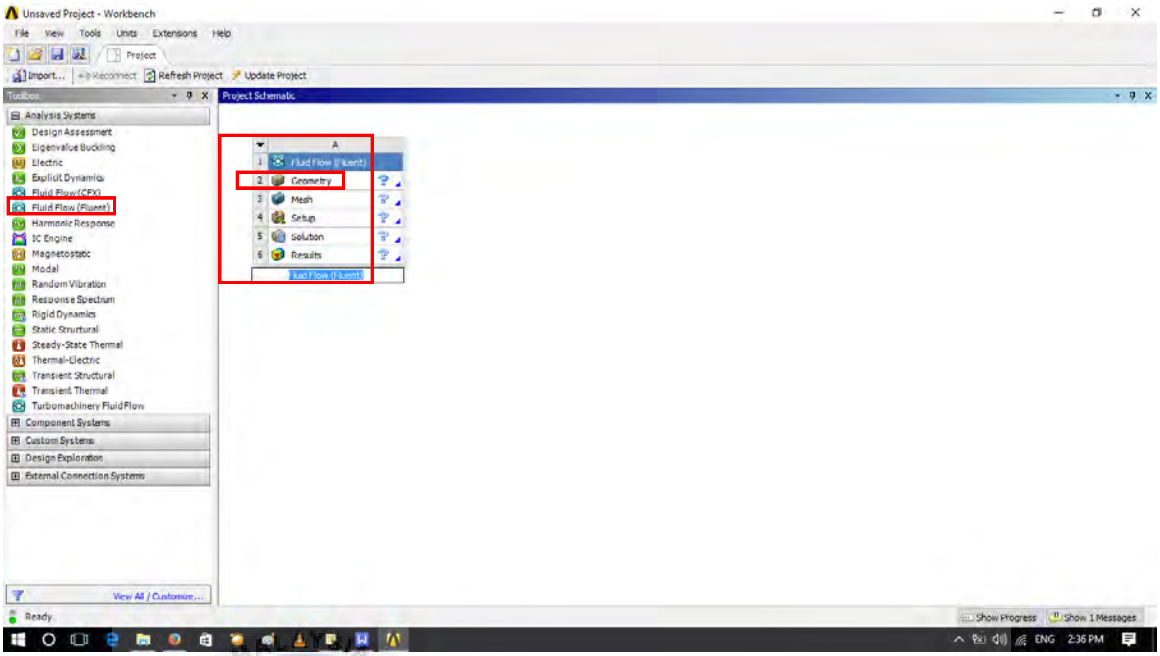

Figure 3.2: ANSYS Simulation set up.

Figure 3.3 : Oven Geometry

3.2.2 Meshing the Geometry

Geometry have been modeling to present the boundary condition and fluid domain in the analysis. The next step after completing the geometry modeling is to mesh the edges and surface. Fluent offers the user many choices with the number of nodes on the edges. Fluent allowing the user to create very fine mesh of area of interest or where the flow assumption need to be analyzed in very detailed analysis. In meshing modular, user also have to define Named Selection of the surfaces or edges in order to define boundary condition of the model. Once completed, the meshing can be generated. Figure 3.4 show the meshing of the oven and table 3.1 shows the meshing information for both model.

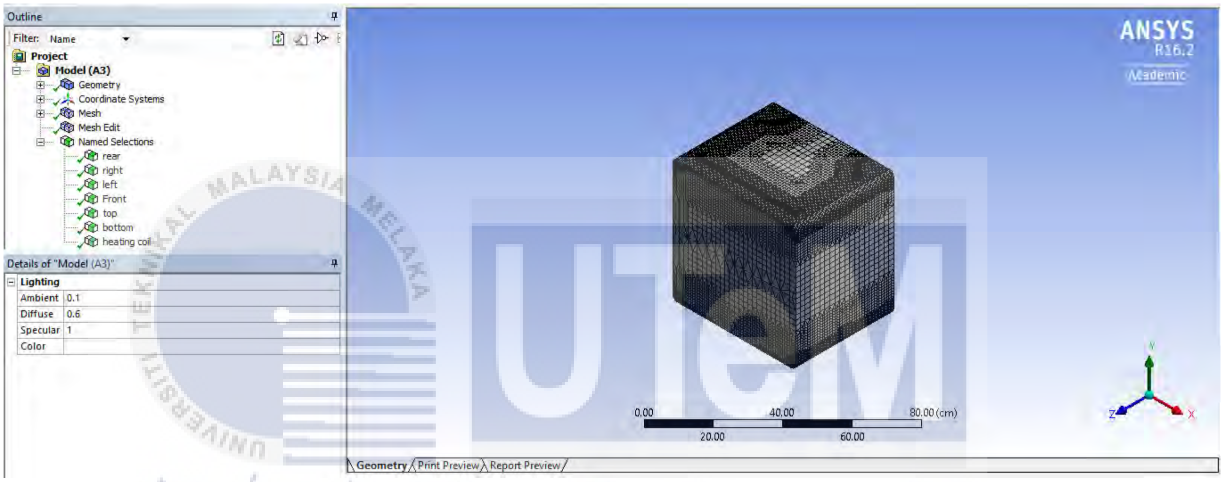

Figure 3.4 : Meshing of the oven

Table 3.1 : Meshing Information

	Scewness	Orthogonal Quality	Nodes	Element
Forced	0.89972	0.1971	1689892	1097089
Natural	0.86545	0.16366	794349	2800963

3.2.3 FLUENT Solver

To start the calculation the first step in the Fluent in to check the grid or meshing of the geometry to make sure it is suitable to analyzed. If the any problem with the meshing, the model must be re-meshed in order for the Fluent to accept. Fluent is using segregated solution method to solve the conservation equations using control volume technique. Figure 3.5 shows the solver that using a loop method to solve the equation. While Figure 3.6 shows the FLUENT solver setup window. In Fluent solver window, user have to setup type of model, boundary condition, material properties used and type of solver. Table 3.2 shows the material properties that have been used. Table 3.2 shows the boundaries condition and material properties used.

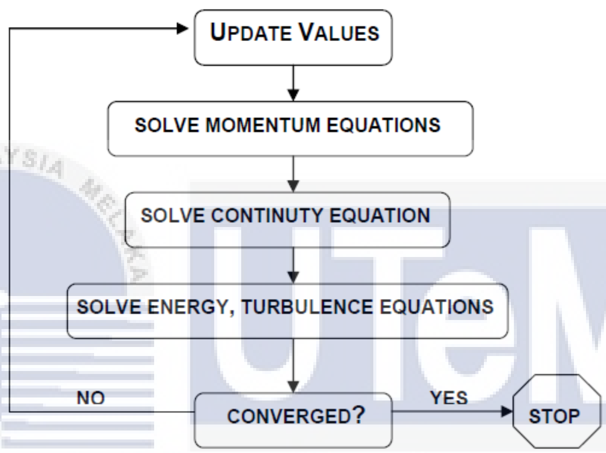

Figure 3.5 : Fluent Solver

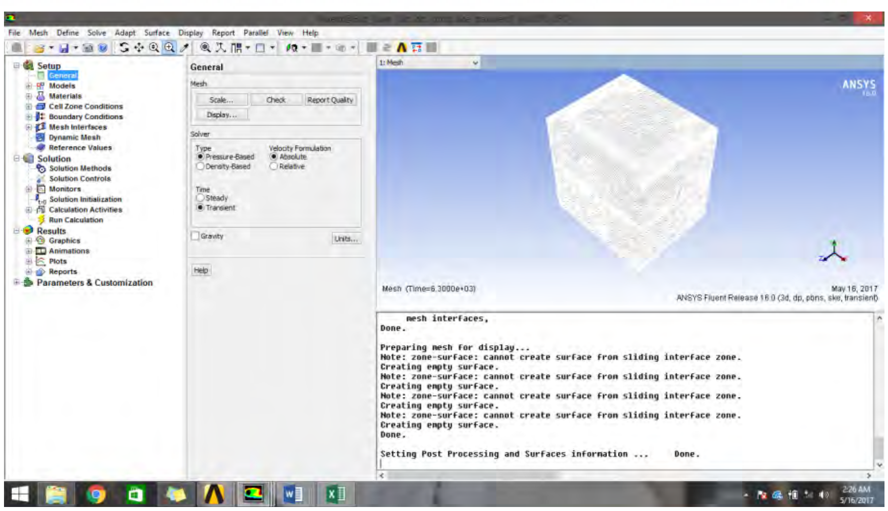

Figure 3.6 : Setup Windows

Table 3.2 : Boundary condition

Boundary Condition	Initial temperature, K	Initial Velocity, m/s^2	Type of interface
Upper Wall	300	N/A	Wall
Bottom Wall	300	N/A	Wall
Right Wall	300	N/A	Wall
Left Wall	300	N/A	Wall
Rear Wall	300	N/A	Wall
Front	300	N/A	Wall
Tray	300	N/A	Wall
heating coil	300	N/A	Wall
Cookies	300	N/A	Wall
Air Inlet	N/A	1.2	Exhaust Fan
Air Outlet	N/A	0	Outlet vent

Table 3.3 : Material Properties 1

	Density	Specific Heat	Thermal Conductivity
Cookies	1075	3365	0.452
Steel	7850	465	44
Glass	2700	840	0.76
Aluminium	2700	869	229
Air	1.255	1006.43	0.0272

CHAPTER 4

RESULT, ANALYSIS AND DISCUSSION

4.1 Simulation Result

The aim of the result is to study and compare of the temperature and velocity distribution inside both ovens. Both model have been simulated in transient mode. The simulation results will show the condition of the temperatures and velocity inside the oven after an hour.

The model mode is radiation with Discrete ordinate (DO) mode and k-ε standard model. The reason why using DO model instate S2S, DTRM and Rosseland is because DO is the only model that can simulate semi-transparent body. The front wall of both model using glass material, therefore DO is the most suitable mode for these types of simulation.

4.2 Temperature Distribution

The temperature distribution will show the temperature contour of the hot air scatted inside the oven cavity. The boundaries condition temperature contours of the model also have been observed. All the results will be compared between the two models. The result is expected to different between the model since the forced convection oven has fan that help to circulate the hot air inside the oven cavity.

4.2.1 Natural Convention

Figure 4.1 shows the temperature distribution at boundaries condition of the oven.

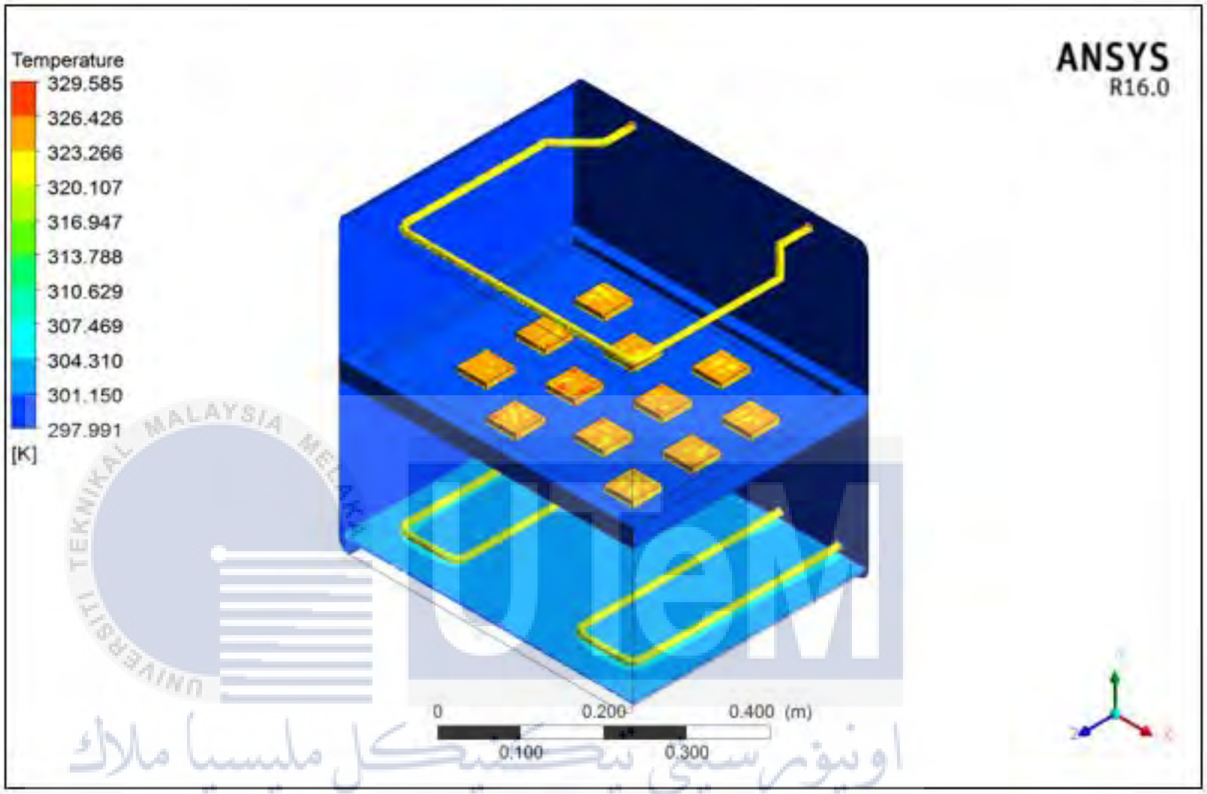

Figure 4.1: Temperature Distribution at Boundaries Condition.

While Figure 4.2 show the temperature distribution at critical part of the oven, which are the heating coil, cookies and tray. Since the temperature different of the cookies and the tray is smaller, Table 4.1 shows the temperature recorded after one hour and maximum temperature that all boundaries condition can reach but the time is unknown.

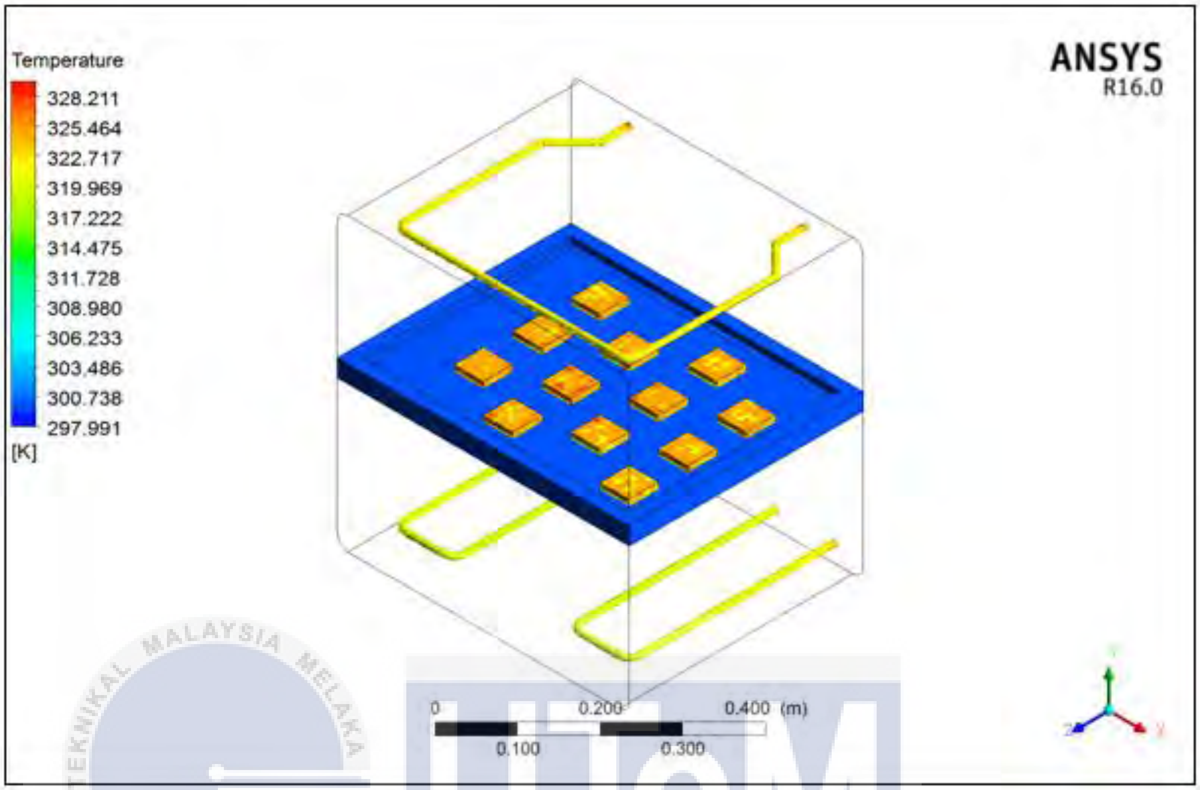

Figure 4.2 : Critical Boundary Condition

Table 1: Temperature of Boundaries Condition

	Temperature After 1 Hour, °K	Maximum Temperature, °K
Upper Wall	302.238	316.302
Bottom Wall	302.703	316.460
Right Wall	301.992	316.465
Left Wall	301.992	316.462
Rear Wall	302.761	431.205
Front Wall	301.873	341.765
Tray	301.883	316.462
Cookies	322.665	329.584
Heating coil	330.722	348.548

Figure 4.3 and 4.4 shows the temperature distribution on the tray and the cookies. The temperature distribution on the tray shows that the edge of the tray has higher temperature then the middle of the tray.

Figure 4.3 : Temperature Distribution of Tray

Figure 4.4 : Temperature Distribution of Cookies

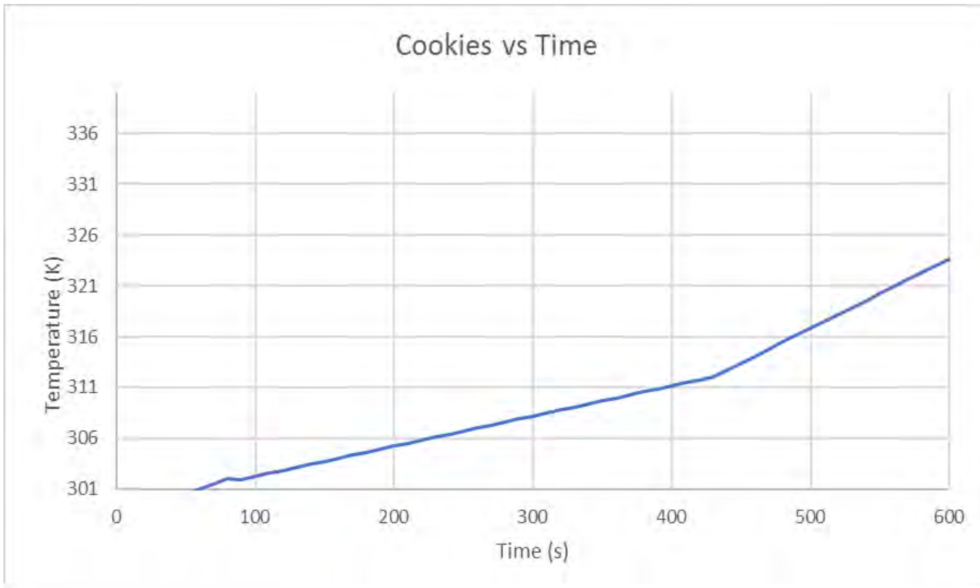

Figure 4.5 : Graph Cookies Temperature vs Time

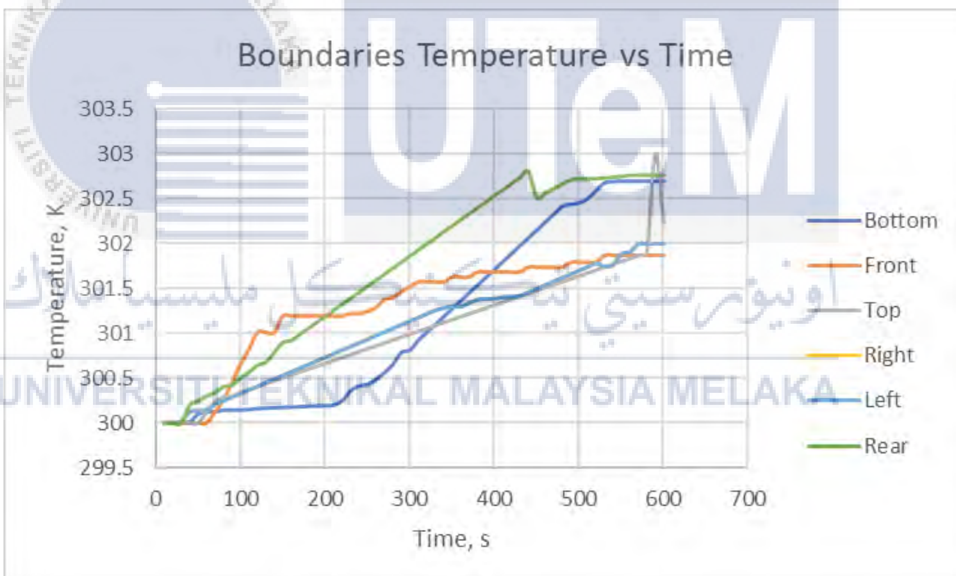

Figure 4.6 : Graph Walls Temperature vs Time

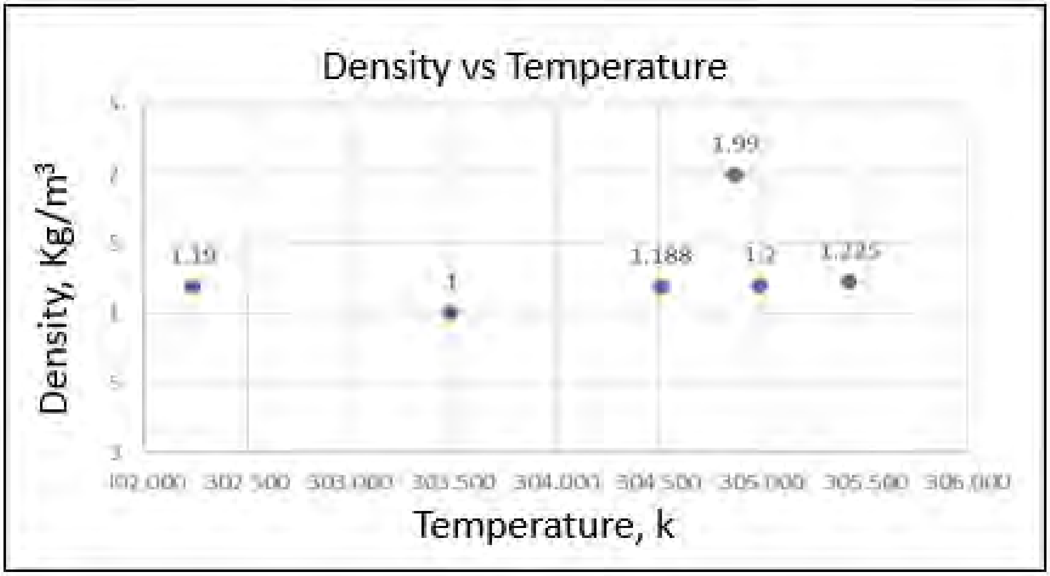

Figure 4.7 : Graph Density Position Inside the Oven

4.2.1.1 Analysis and Discussion of Temperature Distribution

The uniformity of the temperature distribution is an important design goal for an oven to produce a good baking result. The overall temperature profile after an hour of the oven shows in figure 4.1. The figure shows that, the majority temperature in the oven between 300.4 K to 320.722 K and it shows the uniformity inside the oven.

The oven temperature was initially setup at room temperature and the heating coil acting as heating element at 423 K since it is an actual temperature to bake cookies for an hour. After an hour, the cookies temperature rises to 323.66 K. The increments only 7.31% after an hour that meant that the cookies half way to the cooking condition.

Table 4.1 shows the temperature of all boundaries condition in the oven after an hour and maximum temperature that all boundaries condition can be reached. The values are different since the maximum temperature is calculated by the Fluent, but the time taken to reach the temperature is unknown. However, maximum temperature of the cookies is

329.584 K that will satisfy the baking condition of the cookies in slow cook mode and will give poor cooking product. However, it will take a lot of time to reach the desire temperature. But, the cookies are predicted to be cooked in short of time if the temperature is set at more higher temperature.

Due to the position of the heating coil the heating coil the temperature of bottom wall and upper wall seem to have highest value after an hour. However, the temperature value between these walls is not proportional increase between each other, since the area of the heating coil covered is not the same. While left and right wall increasing temperature increasing in the same rate, since the area covered by the heating coil is the same.

Since natural convention reacted to the value of density, Figure 4.3 shows the density value of the position inside the oven. It shows that the density from cookies to the upper heating coil are different. As the position approaching the heating coil, the density shows minor changes that will be effected to the temperature. The temperature increase as the density increase.

The temperature distribution at cookies shows a lot of temperature rising, however the tray temperature arise was so small. Due to the differences of the materials the distinction of the temperature was large. Tray was made from aluminium metal, while cookies is combination of mixture of non-metal materials. Therefore, the temperature differences will be in large value.

4.2.2 Forced Convention

Figure 4.1 shows the temperature distribution inside the oven after an hour. While figure 4.2 shows the temperature field of critical position inside the oven.

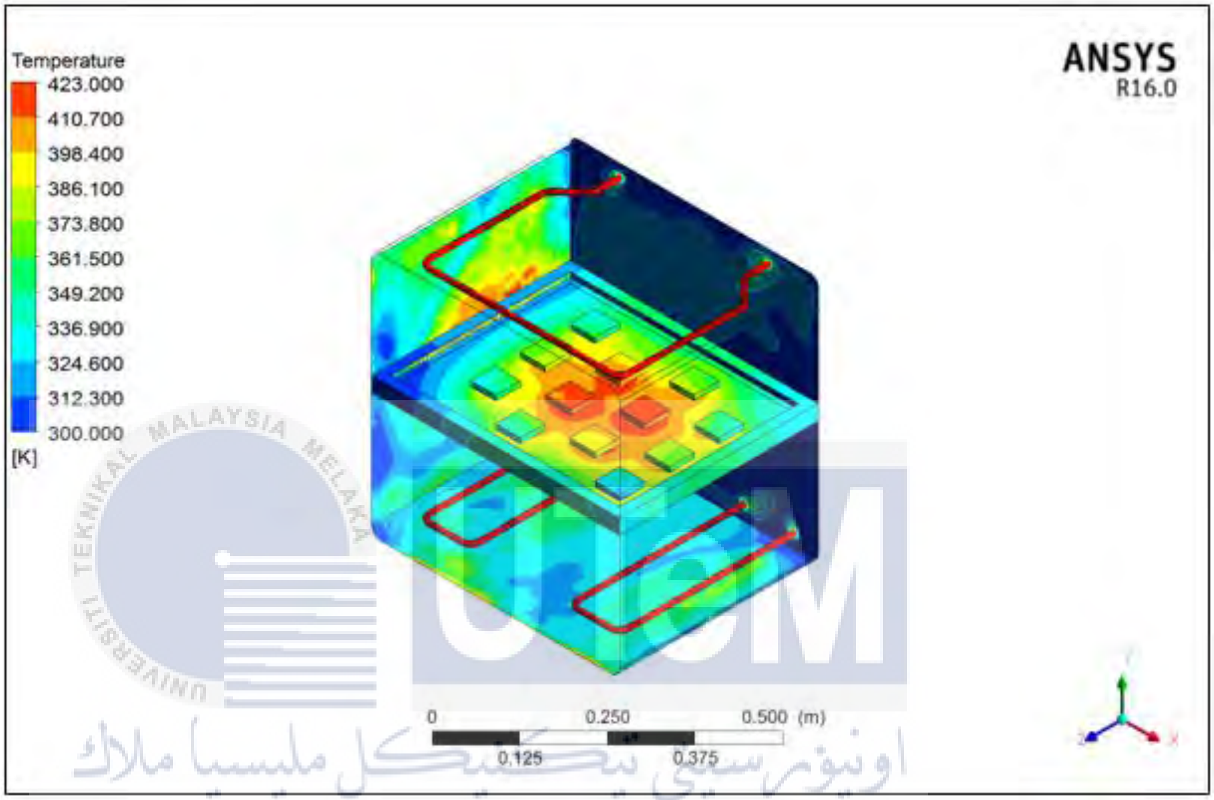

Figure 4.8 : Temperature Distribution at Boundaries Condition.

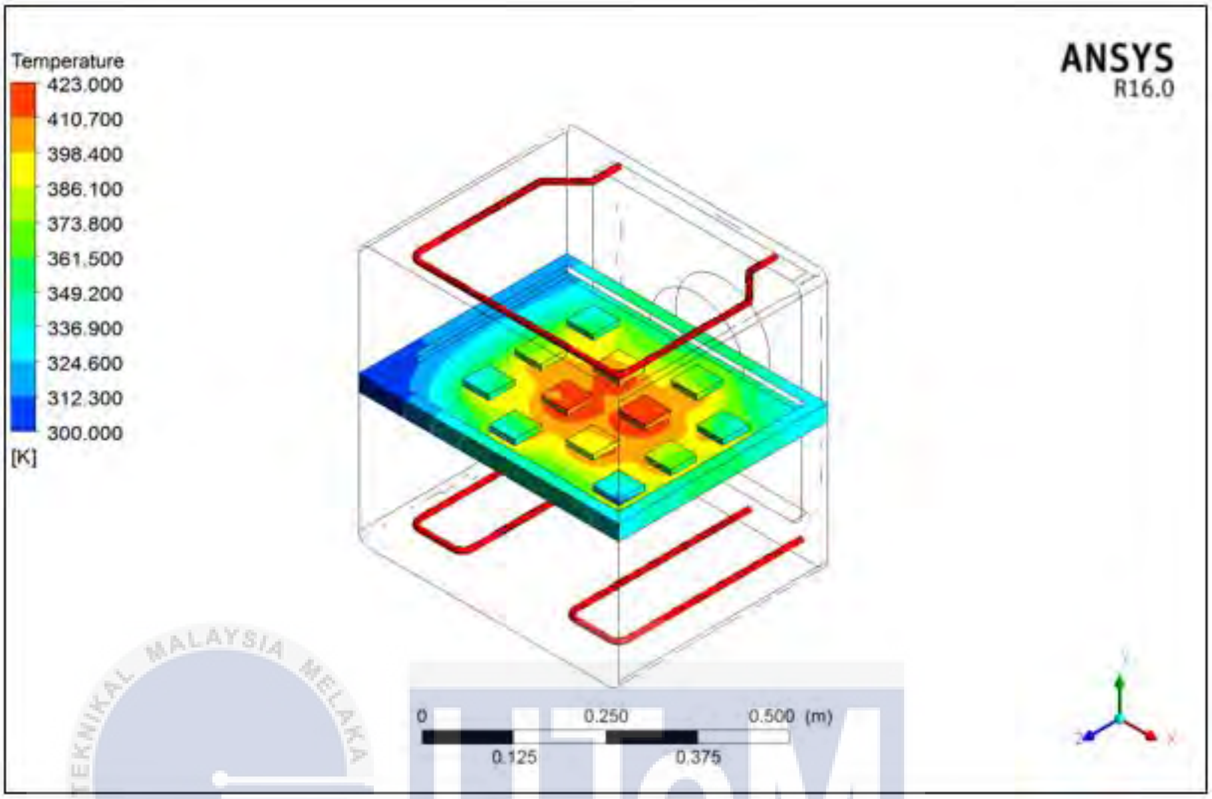

Figure 4.9 : Temperature at Critical Point

Table 4.2 : Temperature at Boundaries Condition

	Temperature After 1 Hour, °C	Maximum Temperature, °C
Upper Wall	316.99	418.15
Bottom Wall	319.73	418.15
Right Wall	319.34	418.15
Left Wall	319.28	418.15
Rear Wall	316.56	418.15
Front Wall	323.41	418.15
Tray	322.40	418.15
Cookies	324.67	396.46
Heating coil	422.08	423.00

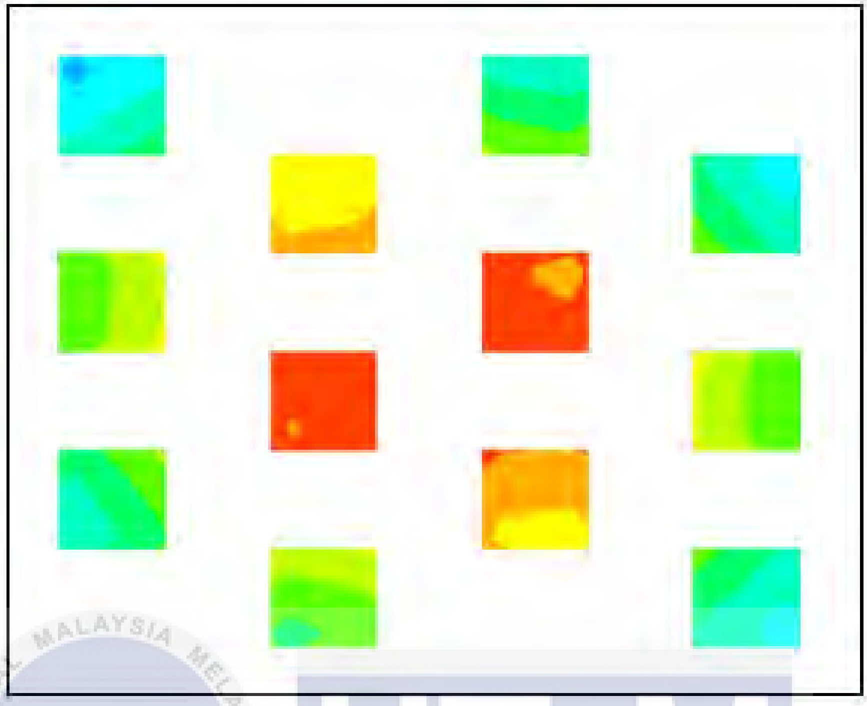

Figure 4.10 : Temperature Distribution at Cookies

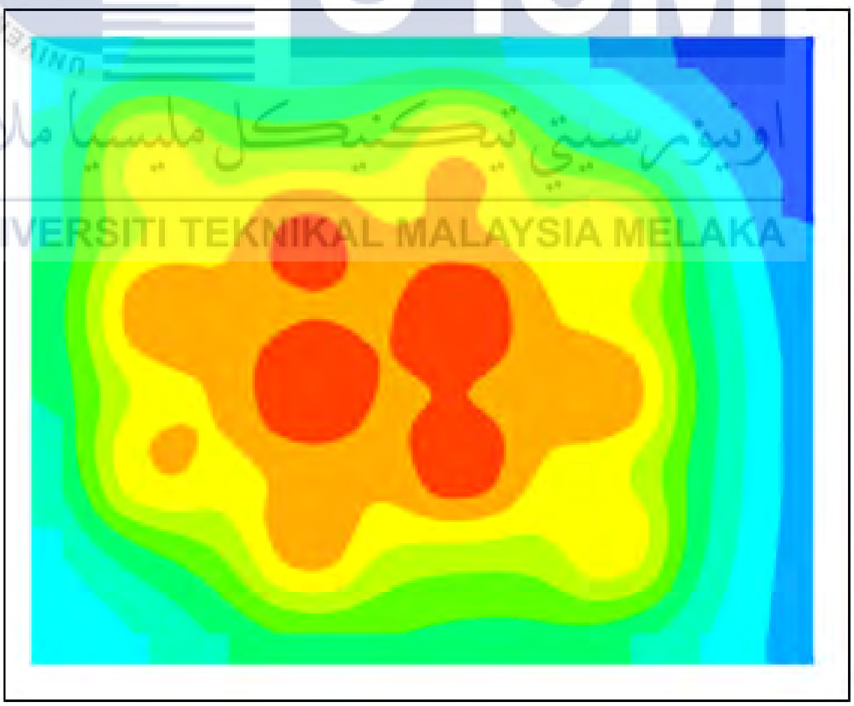

Figure 4.11 : Temperature Distribution at Tray

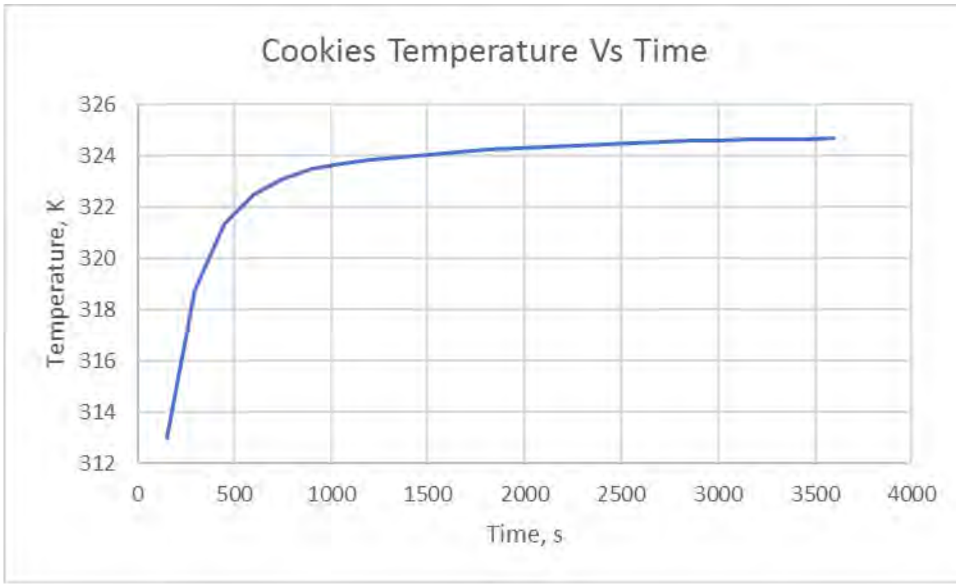

Figure 4.12 : Graph Cookies Temperature Vs Time

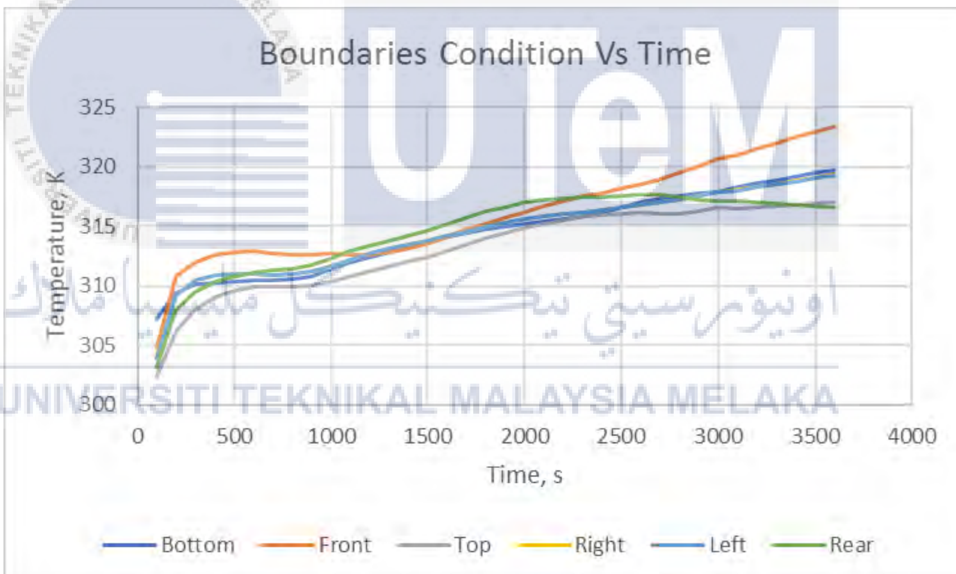

Figure 4.13 : Graph Boundaries Temperature Vs Time

4.2.2.1 Analysis and Discussion of Temperature Distribution

The simulation result of the transient temperature distribution of the forced convection oven shows in figure 4.8. The initial temperature for forced convection was the same with natural convection.

After simulation completed, the high temperature region was spotted near to the rear wall. The rear wall temperature profile has the majority temperature range between 300 K until 316 K. The average temperature recorded for rear wall was the lowest value. The reason because, the air flow was forced to moved inside the oven cavity. Therefore, the rear wall itself seems to have the lowest temperature, but the boundaries condition around the wall have different temperature field.

In forced convection simulation, the critical boundaries condition almost has uniform temperature distribution. With the help of fan that placed the rear wall, the temperature rise was 95% faster than natural convection. However, as the position approaching the front wall, the temperature was lower but the maximum temperature recorded at the front wall was the highest since the material set was glass and the absorption coefficient is different from the aluminium.

The temperature contour shows the maximum value placed at the lowest and upper part of the wall. Since the position is near to the heating coil. The initial velocity of the fan was 1.2 m/s^2, the velocity of the air flow in dropped since the circulation area was large. Therefore, the temperature of the cookies that placed in the front, is low and the baking condition is poor. While the temperature distribution in the middle of the oven have shown the maximum value of temperature.

Figure 4.12 and 4.13 show the temperature arising along with time. The boundaries condition shows temperature increasing proportional with time with different rate. While cookies temperature rate of increasing is 24% faster than the total average temperature of the walls. Since cookies have different material properties and different material with the walls, the cookies tend to cook faster with the help of air circulate around itself.

4.3 Velocity Distribution

Velocity distribution will show the contour of how the hot air circulated inside the oven. For forced convection, the additional boundary condition was fan that operated at 1.2 m/s^2. The result will be compared between the two models.

4.3.1 Natural Convention

Figure 4.14 : Velocity Distribution Inside the oven

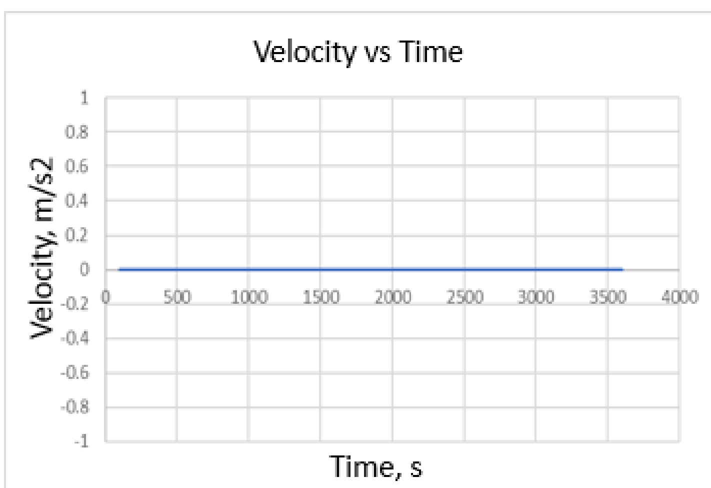

Figure 4.15 : Graph Velocity Vs Time

4.3.1.1 Analysis and Discussion of Velocity Distribution

Figure 4.4 shows velocity distribution at a plane that positioned between rear wall and left wall. The velocity value inside the oven after an hour did not shows any different after an hour. Since there is no device that help to create the hot air to move the air velocity was observed to have zero value.

4.3.2 Forced Convention

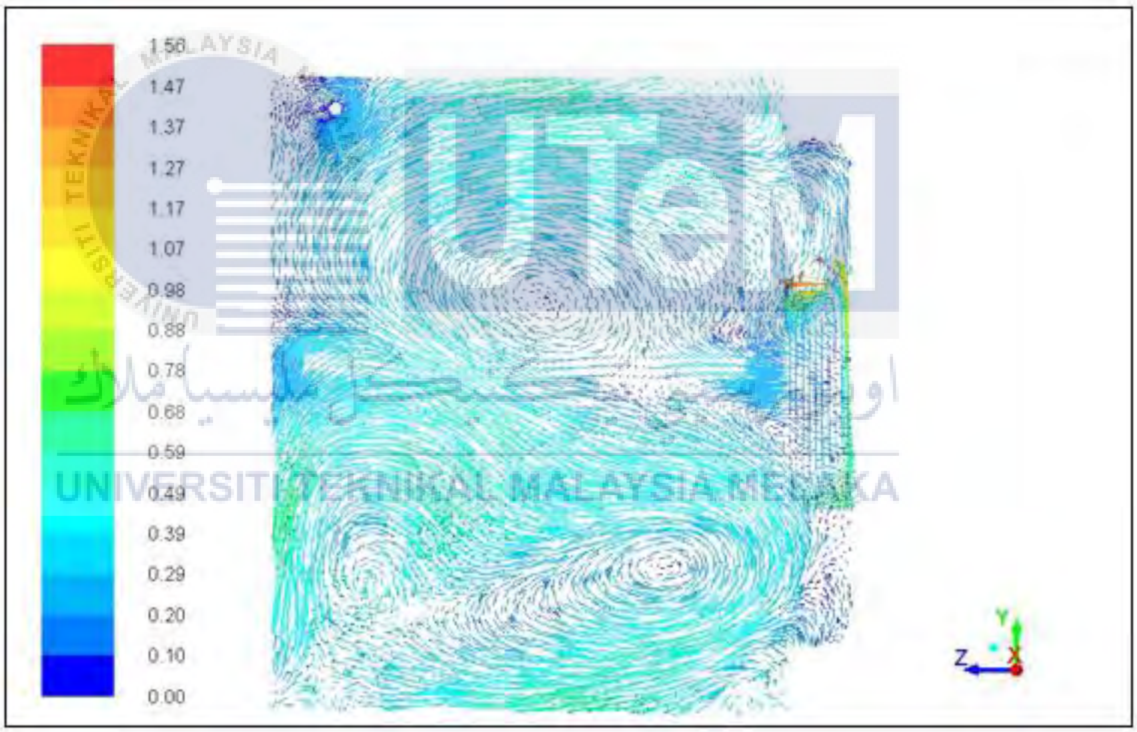

Figure 4.16 : Velocity Vector at Middle Plane in the oven

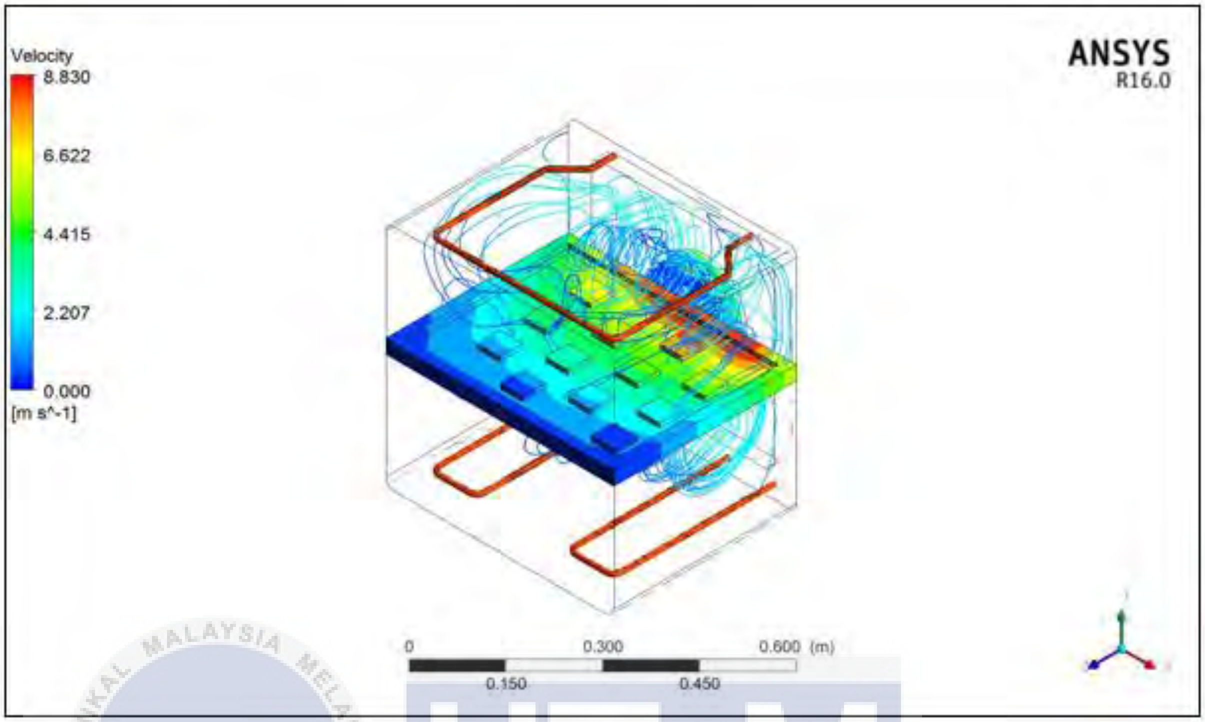

Figure 4.17 : Velocity streamline Inside the Oven

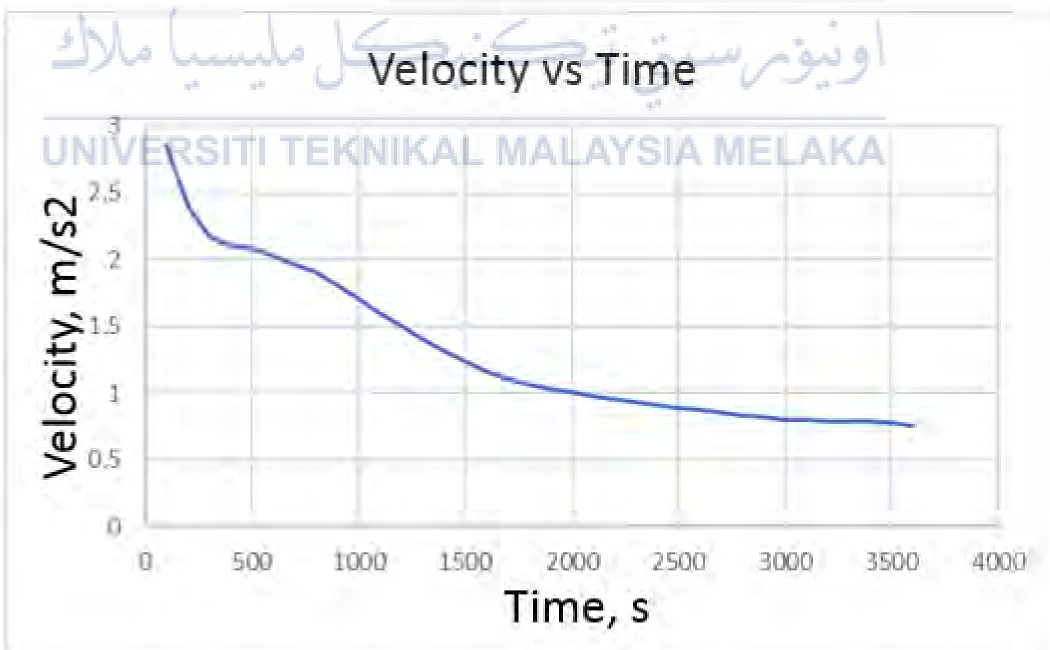

Figure 4.18 : Graph Velocity Vs Time

4.3.2.1 Analysis and Discussion of Velocity Distribution

For forced convection oven, the fan act as a device that help the air circulate around the oven cavity. Figure 4.16 shows velocity distribution of a plane placed in between right and left wall. The initial air velocity was 1.2 m/s^2. However, after an hour the velocity decrease proportionally with time since the air was circulated around the oven. Therefore, the temperature of all boundaries condition increasing proportionally with time and it show in figure 4.12 and 4.13.

However, as the time increase the velocity is predicted value predicted to be constant as the time increase since the air circulated flow will be constant.

CHAPTER 5

CONCLUSION

6.1 General Conclusion

6.1.1 Natural Convection

The simulation of natural convection oven has been setup convection and radiation model with Discrete Ordinate model. The result shown for condition after an hour what had happen to the model in real situation. The cookies did not reach the desire temperature for the cookies to fully cooked. The temperature increment is only 7.31%. The baking condition is acceptable. There are no velocity changes inside the oven since there is no mass flow in and flow out from the oven. The temperature changes for all other boundaries condition also show slight changes. However, the bottom and upper wall shows larger amount of value changes since the position of the wall itself is nearest to the heating coil. The air velocity was observed to be zero since there is no air movement inside the oven cavity.

6.1.2 Forced Convection

Forced convection simulation shows different result from the natural convection, the increasing of temperature in all boundaries condition gave better cooking result for the cookies. The cookies cooking condition have meet the desired temperature with temperature increase was % from the initial temperature, however the cookies placed at the front did not satisfy the cooking result since the air velocity circulated at the area is low.

6.2 Recommendation

The development of design an oven will help the baking industry. Future recommendation to study about energy efficiency of the oven since most oven use more energy to heat up the heating coil. The carbon foot produced by the oven should be taken as a subject for future study. To produce a better cooking condition, the heating coil material and design also can be a key factor to have the uniformity of the temperature distribution. Numerical study to compare about the effect of different velocity and the position of the fan placed also can be conducted.

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