University of Southern Queensland
Faculty of Engineering and Surveying

Numerical Investigation of the Temperature Distribution in an Industrial Oven

A dissertation submitted by

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towards the degree of

Bachelor of Engineering (Mechanical)

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Abstract

A numerical investigation was performed on an industrial oven using a Computational Fluid Dynamics technique. The objective of this project was to investigate the temperature distribution and fluid flow inside an industrial oven.

Results obtained from the numerical investigation proved that the industrial oven at Orford Refrigeration was predominantly uniform in temperature. From the results collected, the problem areas inside the industrial oven have be identified as cold spots, air flow through the perforations and circulation zones.

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Date

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Glossary of Terms

2-D	Two dimensions
3-D	Three dimensions
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
Conduction	Heat transfer through a solid material due to a temperature difference
Convection	Heat transfer through liquids and gases caused by the motion of fluid. The fluid moves from a dense region into a less dense region
Radiation	The transfer of heat in the form of electromagnetic waves from one separate surface to another

1 Introduction

This dissertation examines the current oven design being used in the plastic coating process at Orford Refrigeration and discusses the results of a numerical investigation into the temperature distribution and fluid flow within the oven.

1.1 Background

Orford Refrigeration is a main supplier of refrigerators and cabinets to some of Australia's major companies and they also export their products overseas. For this reason Orford Refrigeration insist on maintaining a high product quality. This standard is also held for the shelves used in the refrigerators.

The motivation behind this project into the numerical analysis of the oven has been largely due to recent problems with discolouration of the refrigerator shelves after being coated. Instead of being bright white in colour the shelves were affected by discolouration in certain areas. This problem could be due to an uneven temperature distribution within the oven causing the plastic coating on the shelves to become discoloured in regions of high temperatures. Other benefits from performing a numerical analysis of the oven would be an insight into the flow of air inside the oven, concentrating mainly on circulation areas of the air.

1.2 Objectives

In accordance with the requirements of the course ENG4111/4112 Engineering Research Project conducted by the University of Southern Queensland, the main objectives of the project are:

- Learn how to use computational fluid dynamics (CFD) software Fluent, and experiment with this software.
- Apply the CFD software knowledge to a 2-D model of the industrial oven, to analyse and investigate the temperature distribution and air flow in the current situation.
- Analyse the results and comment on areas which will improve the temperature distribution.

If time permits:

- Perform a 3-D analysis of the oven using the CFD software Fluent.

1.3 Organisation of Study

Chapters 2 and 3 discuss the background information of the plastic coating process and the fundamentals of ovens and how the modes of heat transfer affect the oven. Chapter 4 describes the theories of modelling ovens and the flow inside them. Chapters 5 and 6 present the results and a discussion of the pros and cons of the temperature distribution, and chapter 7 contains the conclusions based on the information found and provide recommendations for further work.

1.4 Scope and Limitations

The research carried out in this project is mostly from a numerical perspective. The only experimental testing was to collect measurements and data to enable correct modelling of the oven and to verify the numerical models. The temperature distribution in the industrial oven at Orford refrigeration was based solely on two-dimensional analysis.

1.5 Research Methodology

In order to fulfil the requirements of the objectives previously stated. In undertaking this project, background information was required on how the industrial oven was actually used. Also information needed to be calculated on the plastic coating process at Orford Refrigeration, and industrial ovens and furnaces.

Once this information was gathered the second step was to perform literature reviews in related areas. The reason for this review was to look at what previous research has been done in the field of numerical oven analysis. However, literature into the numerical analysis of baking ovens was found, also flow inside of ducts which can be applied to this project.

The numerical investigation of the industrial oven used at Orford Refrigeration can now be started. This analysis will be carried out using CFD software in order to evaluate the temperature distribution inside the oven.

2 Background

This chapter presents the background information of the plastic coating process used at Orford Refrigeration, also the fundamentals of industrial ovens including the history, heat generation and fuels used in combustion. The methods of controlling temperature and how heat is transferred inside the oven are also discussed.

2.1 Plastic Coating Process

Plastic coating is becoming widely accepted as the most efficient means of coating wire products, tubular frames and other open design metal products. Plastic coating provides a cost effective method for protecting metals and other materials that are subjected to harsh environments. Not only does plastic coating provide protection from the environment, it also covers slight defects in the products like weld blemishes and sharp edges, thus reducing the cost to manufacture the components, as extra processes such as grinding or linishing are eliminated. Plastic coating provides a thick and continuous covering over the component with pleasing aesthetics, and can be a range of thermoplastic materials can be used.

This method has been applied to the refrigerator shelves at Orford Refrigeration because they need to be aesthetically pleasing, and protected due to their continuous use. All of the shelves at Orford's are subjected to this method of coating by the following process:

1. The shelves are made on site by spot welding different size diameter wires together in specially made jigs. The shelves are made using the

batch production method since the need for shelves will always exist as long as the company is producing refrigerators.

2. The shelves are hung up ten at a time using tie wire on a movable rack which is capable of moving throughout the whole coating process.
3. The shelves are then placed in the industrial oven and pre-heated to a temperature between 340 and 350 degrees Celsius. The company desires a temperature of 347 degrees Celsius.
4. Once the shelves have been heated the fluidized bed is operated and the shelves are dipped straight into the fine plastic powder which is aerated. Since the temperature of the shelves is above the melting point of the plastic, the shelves liquefy surrounding plastic powder which then clings to the shelf and solidifies, forming a continuous plastic coating.
5. To cure the plastic powder, the shelves are once again placed in the oven, for the short time that it takes to fully lift the rack into the oven and then straight back out again. This is to complete the curing reactions of the thermosetting powder.
6. The shelves are then left to cool and finally packed ready to be fitted to the refrigerators.

Figure 2.1 Plastic Coating Plant at Orford Refrigeration

2.1.1 Fluidized Bed

The fluidized bed powder coating method is used to apply heavy coats to products. There are two methods involved with the fluidized bed coating process, the conventional or electrostatic method.

The conventional process is shown in figure 2.2. This is the process used at Orford Refrigeration for the plastic coating of refrigerator shelves. The fluidized bed is a movable tank which has a porous bottom plate. This porous plate enables a low pressure supply of air to be evenly distributed across the plate and forces rising air to surround and suspend the fine plastic powder particles, so the powder-air mixture has a light and fluffy texture. The shelves are preheated to above the melting point of the plastic powder and are dipped into the fluidized bed where the powder melts onto the shelves leaving an even, continuous coating.

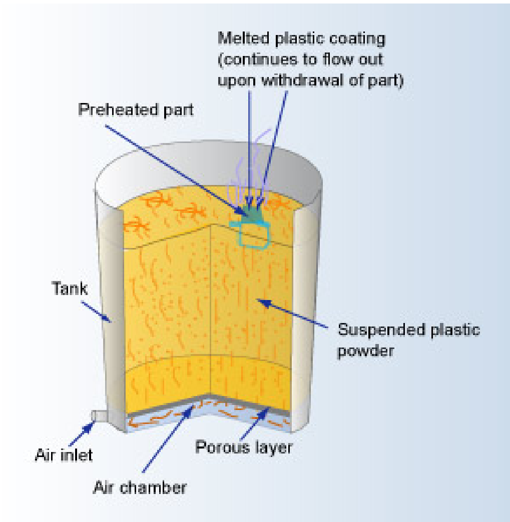

Figure 2.2 Conventional Fluidized Bed Process.

(Source: Specialchem4coatings)

In the electrostatic bed shown in figure 2.3 the powder is fluidized the same way as the conventional method by suppling air at a low pressure to create the air-powder mixture. When using this method the shelves can be placed into the fluidized bed at room temperature. In order for the plastic powder to stick to the shelves the air-powder mixture is subjected to a positive charge from a high power supply and the shelves are earthed (negative charge). The opposite charges on the different items cause them to be attracted to each other and then cured in the oven.

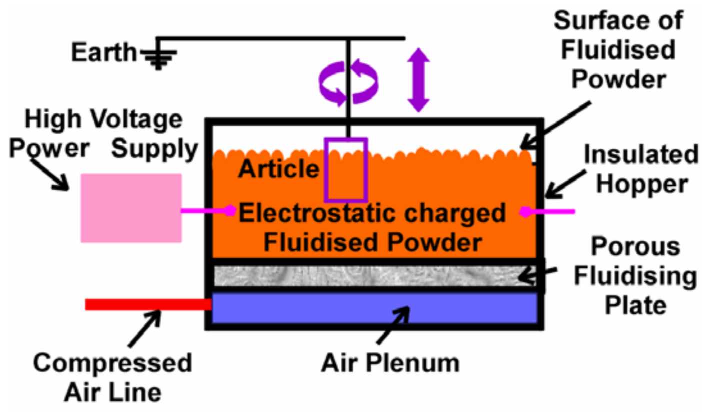

Figure 2.3 Electrostatic Fluidized Bed Process

(Source: Coatings + Fabrication)

This method of charging the powder can also be applied using a special electrostatic spray gun. Before the powder reaches the gun it is fluidized to give the light air-powder mixture, this improves the electrostatic charge that can be given to the powder. In order for this method to work properly the shelves still have to be earthed so the opposite ions attract and stick together.

2.2 Oven Fundamentals

The function of an industrial oven is to generate and apply heat according to certain specifications of the product being heated, with the lowest cost of heating per unit of finished product.

2.2.1 History

Industrial ovens and furnaces have been in operation since the fourteenth century, when the first blast furnace was developed by the Germans, Belgians and French for the making of castings. The line between an oven and a furnace is very broad. Heating devices that are operated at temperatures below 538 degrees Celsius are commonly called ovens.

The dawn of the twentieth century saw great advances in the building of engines, cars and railroads, ships and structural steel works. These innovations were due to the discovery of new alloys and advanced methods in the heat treating of metals. In order to keep up with this new technology ovens and furnaces were required to have greater temperature control and internal atmosphere.

2.2.2 Heat Generation

Heat is generated in industrial ovens by combustion of fuel or by the conversion of electrical energy. Another method of heat generation is that of nuclear energy (atomic energy or fission energy), but this source of heat has not been utilized in industrial ovens.

Combustion

Depending on the fuel used in the generation of heat, the methods of combustion will vary. The different combustion methods are:

- Solid Fuels are burnt due to a series of chemical reactions with the fuel and the air which takes place on a fuel bed. When the solid fuels are in a pulverised form the fuel is burnt by suspending it in an air stream where it is injected into the oven or furnace. This method is similar to the combustion process of a gas.
- Oil can be burned in two ways. The first method involves the oil being vaporised before ignition so that it burns like a gas. The second method is for the oil to be broken down into fine droplets which are injected into hot air so they evaporate while burning.
- Gaseous fuels can also be burned in two ways:
  1. The gas and air are mixed together cold and are burnt at the end of the mixing chamber. A Bunsen burner is a simple example of

this kind of method. In general, only part of the air is used in the mixing stage. The rest of the air is acquired from the air in the oven this combustion is known as a premixed flame.

2. The gas and air flow into the oven separately and mix together as combustion proceeds this type of combustion is referred to as diffusion flames.

Electrical

Electricity is not a fuel but is a substitute for fuel and is readily available in all industrial areas today and is therefore a convenient way of transmitting energy.

Heat is easily obtained from electricity and can be monitored and controlled without difficulty. For the conversion of electrical energy to heat energy there are four main types of electrical furnaces/ovens:

1. Resistance.
2. Arc.
3. Induction.
4. Capacitance.

The use of electricity to run ovens is not the most efficient method of generating heat because there is a lot of wasted energy. Firstly it has to be created by burning a fuel, then created into electricity, and then into heat energy.

2.2.3 Combustion Fuels

There are many different types of fuels that can be used in the combustion process of ovens and furnaces. Some of these including solid fuel beds, pulverised fuels or powdered fuel. Oil and gaseous fuels can be used with successful heating results.

Solid Fuels

There are many solid fuels that can be used in the heat generation in ovens and furnaces. Some of these solid fuels include coal, coke, petroleum coke, wood and charcoal. Wood and charcoal are very rarely used in the application of industrial ovens. Solid fuels have their disadvantages for use due to difficulties in transporting the fuel to the ovens/furnaces and because the burning of solid fuels leaves ash which has to be removed from time to time. This problem can be overcome with the use of the solid fuels in powdered or pulverized form. The combustion of solid fuel is hard to control, compared to that of liquid or gaseous fuels.

Coal is the most important solid fuel that is used in industry. From coal stems a large source of other fuels such as coke, tar, coke-oven gas and blast-furnace gas. Coal is a term used for a variety of fuels with different properties and different heating values.

Liquid Fuels

Liquid fuels that are commonly used in generating heat in industrial ovens and furnaces are fuel oil and tar. Fuels like kerosene and alcohol and petroleum are too expensive to be applied to industrial ovens and furnaces.

Liquid fuels can be stored in out of the way places, for example underground, or in tanks. The fuels are easily transported from these tanks to the combustion device, and generally burn without any ash or smoke except if incomplete combustion occurs then the products of combustion may appear as soot due to the high carbon content. Liquid fuels are burnt in a similar fashion to that of gaseous fuels.

Gaseous Fuels

Out of the three types of fuels available for the combustion process in industrial ovens, gases are the most advantageous. Gases are easily transported to the ovens and most of them can be burned without smoke and soot. Gases can be mixed with air in the correct proportions to obtain perfect combustion, or rich and lean mixtures where necessary. Due to this, the temperature and atmosphere of the ovens can be easily controlled. Thereby flow can be accurately measured.

There are many gases available for use in ovens and furnaces such as natural gas, coke-oven gas, water gas, L.P.G, refinery gas, producer gases and blast-furnace gas to list a few.

Natural gas is one of the most desirable gases used in industrial ovens today because of its attractive properties. The reason natural gas is so popular is because it is clean, safe and when it is burned, gives off a great deal of energy. The oven at Orford Refrigeration uses natural gas as its combustible fuel to generate the heat required. Natural gas is available in most industrial areas by a gas line so access is very easy. The gas is made up of a mixture of combustible hydrocarbon gases. Although natural gas is primarily made up of methane it also contains ethane, propane, butane and pentane.

2.3 Temperature Control

The heating process in the oven aims to bring the outer surface of the shelves up to a given temperature approximately 347 degrees Celsius and to keep this temperature constant until the desired temperature uniformity has been obtained. It is desired to keep the temperature uniform throughout the shelves, regarding to their location in the oven. The reason for reaching this temperature and not exceeding it is quite simple. For the plastic coating process to be successful, there has to be a minimum temperature. If the temperature is lower than this minimum the plastic powder will not adhere to the shelves and if the temperature is much greater, not only is it a waste of heat but it may also produce undesirable results like the discolouration of the refrigerator shelves.

2.3.1 Maintaining Constant Temperature

In order to maintain a constant temperature, the concept of temperature needs to be looked at. Temperature is a balance between the heat flowing into a body and the heat flowing out of it. If there is more heat flowing into a body than there is heat flowing out the temperature of the body will rise. If the opposite occurs, and there is more heat flow out of a body than in it the temperature of the body will fall.

Current methods applied to maintain a constant temperature in the industrial oven, by rapid circulation of the air in the oven, and by placing the flame in a muffle.

Rapid Circulation

Rapid circulation is otherwise known as the recirculation of the oven gases. This enables the heat from a small flame to be distributed through a large volume of oven gases. The recirculation of air inside the oven helps to stop local overheating, as the hot air from combustion is mixed with cooler air in the oven constantly. Since the temperatures dealt with in this oven are relatively low, the magnitude of radiation inside the oven is weak, compared to furnaces that operate at high temperatures. So to overcome this problem, the amount of heat transfer due to the convection component needs to be increased, which will be discussed in depth in a later section. It is known that the rate of heat transferred by convection increases when density and velocity of the flowing gas are increased. So to increase the velocity and the circulation inside the oven the designer has installed a recirculation fan which is situated opposite the burner (see figure 3.1).

Placing the products of Combustion in a Muffle

The main purpose of a muffle in an oven is to protect the items being heated in the oven from the product of combustion. Placing the flame behind a wall or a muffle as seen in figure 2.4 happens in order that the flame cannot radiate heat directly into the heating chamber and onto the shelves themselves. By having this muffle in place, the radiation projected into the heating chamber is halved, and produces a more even temperature distribution within the oven.

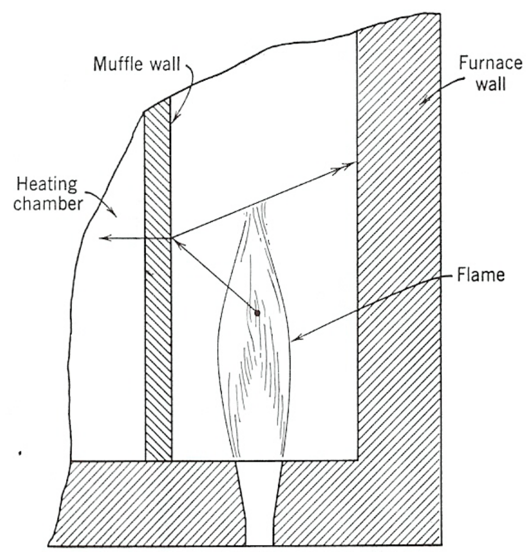

Figure 2.4 Temperature-equalizing effect of a muffle wall

(Source: Trinks (1955))

2.4 Insulation

The main objective of insulation is to reduce the amount of heat escaping the oven to the atmosphere. In order for an insulation material to work effectively, it must have a low thermal conductivity. This is achieved by trapping air or gas inside small voids in the solids. There are generally three types of insulation fibrous, cellular, and granular.

The insulation installed in the oven at Orford Refrigeration is a product called Fibertex 450 which is produced by Bradford Insulation apart of the CSR group. Fibertex 450 is a fibrous insulation produced from a molten mixture of natural rock and recycled blast furnace waste products, bonded with a thermosetting resin. This insulation has a maximum operating temperature of 450 degrees Celsius and the thermal conductivity can be obtained from figure 2.5 depending on the temperature in this case it is approximately 0.11 W/mK.

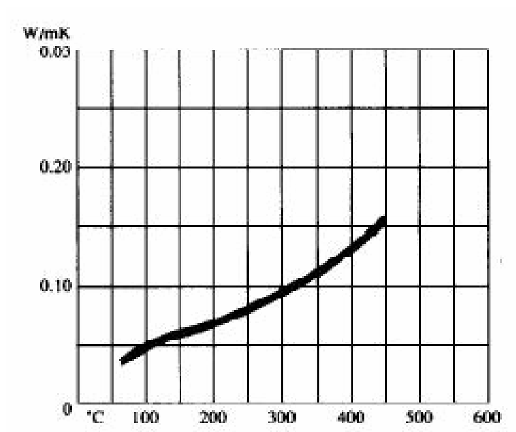

Figure 2.5 Thermal Conductivity vs Temperature

3 Thermal Efficiency

The achievement of high thermal efficiency is very important and desirable in this oven. This means the energy released from the combustion of fuel needs to be directed to the shelves as much as possible with the least amount of energy escaping to the surroundings. If there are large losses to the surrounding the economic efficiency also is reduced and money is lost rather than being saved

The temperature drops through the outside walls of the oven are quite dramatic when operated in steady-state. Methods of reducing the amount of heat escaping to the surroundings, is with the use of insulation around these outside walls of the oven. This section on insulation has been covered in the previous section on it purpose and the material chosen for the oven being analysed.

3.1 Heat Energy

The release of heat energy is only the first stage in the heating process. For this heat energy to be transmitted from one region to another, there needs to exist a temperature difference between them. Heat is transferred by three mechanisms conduction, convection and radiation. During oven use, the heat is transferred by a combination of all three means, usually with one of the methods predominating.

3.1.1 Conduction

Conduction is the transfer of heat energy by mutual interactions between vibrating atoms. Atoms with greater kinetic energy (temperature) pass their excess energy onto atoms with less energy by collisions. In other words heat will be transferred from an area of high temperature to an area with low temperature. Conduction occurs mainly in solid mediums where the mobility of the atoms is minimal. Heat transfer by conduction alone in ovens is rare but can occur in special furnaces like salt baths.

Conduction does occur in the oven that is being analysed but is considered negligible once steady-state is reached. As soon as steady-state is reached the temperature of the air and the steel will be the same temperature, therefore as there is no temperature difference conduction will not occur. The only time conduction occurs in the oven is when the oven is being heated up or cooled down. Heat transfers due to conduction takes place at the steel walls and the perforated sheets which are made of 3mm thick steel and are located around the heating chamber and the intake to the fan as seen in figure 3.1.

In conduction the rate at which heat is transferred is given by the basic equation:

$$q_k = kA\frac{dT}{dx} \tag{3.1}$$

where q_k is the amount of heat transferred by conduction

k is the thermal conductivity of the medium

A is the area through which the heat is transferred

$\frac{dT}{dx}$ is the temperature gradient normal to the area

3.1.2 Convection

Convection is the transfer of heat due to the motion of molecules carrying heat from one place to the other. This mode of heat transfer takes place in liquids and gases. There are two types of convection: natural, which is caused by a density gradient, and forced convection, which is due to a pressure gradient. The general equation for convection is given by:

$$q_c = \overline{h_c} A \Delta T \tag{3.2}$$

where q_c is the amount of heat transferred by convection

$\overline{h_c}$ is the average convection heat transfer coefficient

A is heat transfer area

ΔT is the difference between the surface temperature T_s and the ambient temperature of the fluid T_∞ far from the surface

3.1.3 Natural Convection

Natural convection occurs when a fluid flows over a body of different temperature to that of the fluid. The temperature difference causes heat to flow between the solid and the fluid, and causes a difference in density. This density difference causes the lighter fluid or hotter one to flow upwards and the heavier or cool fluid to take its place. This movement of the fluids is known as the convection current.

This type of heat transfer involves many variables. Such as the coefficient of thermal expansion, acceleration due to gravity, the specific heat, and the viscosity of the fluid. With so many variables affecting the transfer, the theory of dimensionless group is applied to calculate the heat transfer coefficient and finally the amount of heat transferred by natural convection using Equation 3.2.

The Grashof (Gr) number involves all of the quantities which determine the velocity of the fluid over the surface in the case of the oven vertical surfaces. For Gr between 10^3 and 10^9 the flow is laminar, above 10^9 the flow is turbulent.

$$Gr = \frac{g\beta\left(T - T_\infty\right)L^3}{\nu^2} \quad \textbf{(3.3)}$$

where g is acceleration due to gravity

β is the coefficient of expansion

$\left(T - T_\infty\right)$ is the temperature difference

L is the characteristic length

ν is the kinematic viscosity

The Nusselt Number (Nu) is given by:

$$\overline{Nu}_L = \frac{\bar{h}_c L}{k} \quad \textbf{(3.4)}$$

where k is the thermal conductivity.

The Prandtl (Pr) Number can be found in most heat and mass transfer texts for air Pr = 0.71.

$$\Pr = \frac{\nu}{\alpha} = \frac{C_p \mu}{k} \quad \textbf{(3.5)}$$

For laminar natural convection over a vertical flat plate

$$\overline{Nu}_L = 0.508 \Pr^{1/2} \frac{Gr^{1/4}}{\left(0.952 + \Pr\right)^{1/4}} \quad \textbf{(3.6)}$$

and for turbulent natural convection over a vertical flat plate

$$\overline{Nu}_L = 0.13\left(Gr \Pr\right)^{1/3} \quad \textbf{(3.7)}$$

3.1.4 Forced Convection

Forced convection applies to the case where the flow of the fluid is caused not by a density gradient, but by a pressure gradient. This pressure gradient is achieved in this case, by air flow inside and oven due to the recirculation fan. This is the primary method of heat transfer in this oven. In regions where the velocity is low, natural convection will be combined with forced convection. With forced convection, the most important variable is the velocity, V. The relevant dimensionless groups are the Nusselt and Prandtl Numbers and the Reynolds number (Re). In using the Nusselt number equation 3.4 to calculate the heat transfer coefficient $\overline{h_c}$ the characteristic length L is replaced by the hydraulic diameter D_H equation 3.9. If Re > 2000 the flow is turbulent.

$$\mathrm{Re} = \frac{VD_H}{\nu} \qquad \textbf{(3.8)}$$

$$D_H = 4\,\frac{\text{flow cross-section area}}{\text{wetted perimeter}} \qquad \textbf{(3.9)}$$

3.1.5 Radiation

The amount of heat transferred by radiation in low temperature ovens is minimal. For ovens with high temperatures most of heat transfer occurs largely due to radiation between the walls and items inside the heating chamber. Since the oven analysed is a low temperature oven radiation is not of great concern. The amount of heat dissipated from radiation can be found by the following equation

$$q_r = A.F_{12}\sigma(T_1^{\,4} - T_2^{\,4}) \qquad \textbf{(3.10)}$$

where q_r is the heat transferred by radiation;

A is the surface area;

F_{12} is the shape factor, which is affected due to geometry and emittance of the bodies;

σ is the Stefan-Boltzmann constant which equals $5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

The amount of heat is not dependant on the surrounding conditions. However, the transfer does require a temperature difference, for example the radiation from the oven walls to the shelves.

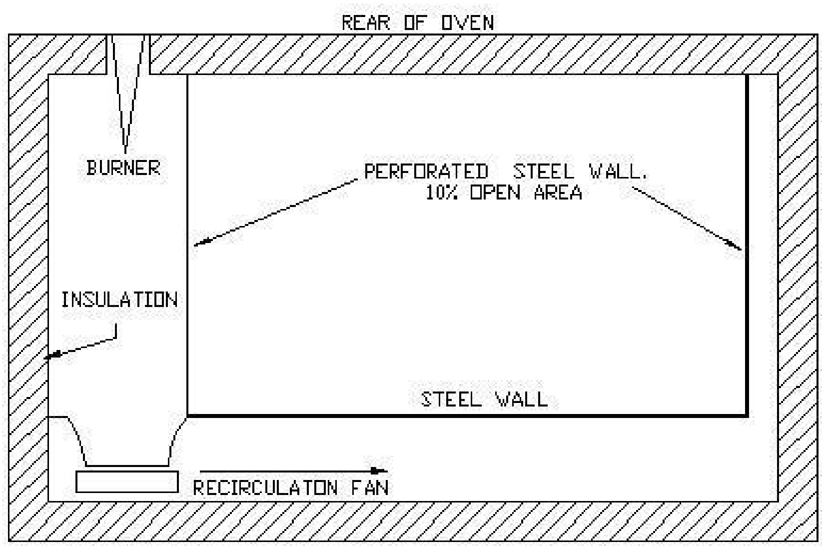

Figure 3.1 Illustration of the horizontal cross-section layout

4 Literature Review

Textbooks, fellow engineers, journal articles and the World Wide were employed to carry out a literature review on the current methods of oven modelling and flow inside ovens.

4.1 Numerical modelling of Ovens

Previous research methods into the numerical modelling, of industrial ovens has been limited. After speaking to a designer of industrial ovens it was realised that, researchers in this field do not publish a good deal of information on the work done in analysing industrial ovens.

Previous research work found in the area of numerical modelling of ovens and the temperature distribution, has been of minimal help in the duration of the project.

Verboven et al., 1999 presents the validation of air flow inside a forced convection, electrical oven. This paper discusses a 3-D model using the fan model and turbulence model.

The most helpful paper in this area was written by Therdthai, N 2003, discusses a two-dimensional CFD model that was used to simulate the temperature profile and airflow in an industrial bread baking oven. This paper helped as a guide for numerical modelling and simulation of the industrial oven used at Orford’s.

4.2 Flow in Ducts

It was seen as an advantage, to research other professionals work into the flow in ducts, in particular those of rectangular geometry.

Rokni 2003 discusses fully developed turbulent flow in ducts, over a large range of Reynolds numbers. This process combines the viscosity model with the "two-equation" model, the model is also valid over a wide range of Prandtl numbers and different fluids. To obtain an algebraic flux model with variable diffusivity.

Jones 1993, presents a relevant topic on the convection flow in vertical parallel walls. The paper provides a numerical solution for the situation and provides results for the velocity profile inside the walls, local Nusselt numbers, average temperatures, friction factors and areas of circulation that occur.

4.3 Flow through Perforated Sheets

Papers involving the flow of fluids through perforated sheets, was believed to give a good in sight into how these problem effect the current design.

Sparrow 1981, presents an experimental investigation into the heat transfer coefficients up stream of a perforated sheet. This paper was able to show the flow of the fluid adjacent to the surface of the sheet.

5 Numerical Analysis

This chapter illustrates the governing equations, CFD software and an overview of the software used. The chapter also discusses the geometry of the oven, the modelling assumptions and boundary conditions and the numerical investigation procedure.

5.1 CFD Modelling

CFD is a powerful numerical simulation technique that allows the end user a greater insight into the flow behaviour of fluids which would be impossible to visualise with experimental techniques. CFD not only predicts fluid flow behaviour, it is also capable of analysing heat transfer, mass, phase change and chemical reactions. When analysing incompressible viscous flow, the Navier-Stokes equation and the continuity equation are used. When heat transfer is included, another equation is required the conservation of energy.

The CFD method converts the governing partial differential equations of fluid flow (Navier-Stokes Equations) into a set of algebraic equations. This involves the discretization of the fluid domain into cells, which make up the finite-difference mesh. This mesh area contains the whole fluid and its connected boundaries. These boundaries can be inlets, outlets and walls and are known as the boundary conditions and enforces how the fluid is affected at the boundaries of the domain. When the simulation is being calculated the correct solution of the non-linear equations will occur when the iterations converge.

5.1.1 CFD Software Selection

In the analysis of the oven the use of a CFD package will be required to provide detailed and complete information on the following variables velocity, pressure, temperature and turbulence intensity throughout the domain of interest. The CFD software will also need to be capable of solving the Navier-Stokes equations using an iterative method. Due to the recirculation fan, there will be a large degree of turbulence within the oven; turbulence would be another requirement that the software will have to be capable of computing.

Most CFD packages that are available on the market can be used to analyse heat transfer situations with turbulence and are able to solve the Navier-Stokes equations. The main objective when selecting a CFD package was that it was easily accessible, one such CFD software that the author had easy access to was Fluent 6.1.

5.1.2 Access

When carrying out a CFD analysis the CFD software programs require very fast computers in order to deal with the huge number of computations. A mainframe or supercomputer is required because of their ability to cope with large scheduled processes. The University of Southern Queensland (USQ), Toowoomba has an education/research license for Fluent, and a mainframe which is owned by an association called the Queensland Parallel Supercomputing Foundation.

A separate login and password were required in order to have access to the mainframe at USQ. To gain access to Fluent 6.1, a connection had to be setup between the catlabs and the mainframe. This connection was called hpc0. This connection allowed the author to use the supercomputer to carry out the large number of computations involved with using Fluent.

5.1.3 Fluent Overview

Fluent is one of the world's leading CFD programs for modelling fluid flow and heat transfer in complex geometries. The Fluent solver provides comprehensive modelling capabilities such as:

- 2-D and 3-D geometries;
- flow through porous mediums;
- transient or steady-state analysis;
- convection, conduction and radiation;
- sliding meshes;
- chemical species mixing and reactions;
- turbulent and laminar models and;
- incompressible and compressible.

5.2 Flow Equations

To model the air flow inside the oven correctly, the correct model needs to be chosen. Since there is a recirculation of the gases inside the oven due to the fan, turbulent flow is predicted. Fluent can model turbulence by two methods- either the "two-equation" turbulence models, or the Reynolds stress model. In the "two-equation" models the viscosity is evaluated by the turbulent kinetic energy (k) and its rate of dissipation (ε).

The standard k-ε model has been chosen to carry out the analysis on the oven as it is reasonably accurate over a wide range of turbulent flows and is commonly used in industrial flow and heat transfer. This turbulence model is based on the Reynolds averages of the governing equations. For the reason that in a turbulent flow the values are constantly fluctuating. This averaging allows the equations to have the same form as the instantaneous Navier-Stokes equations.

5.2.1 Mass Conservation

The conservation of mass or continuity equation is given by:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \tag{5.1}$$

5.2.2 Momentum Conservation

The conservation of momentum otherwise known as the Navier-Stokes equation which is given by:

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial \rho u_i u_j}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i \tag{5.2}$$

where p is the static pressure, τ_{ij} is the stress tensor described by equation (5.3). ρg_i are the gravitational body forces and F_i are the external body forces. The stress tensor τ_{ij}, is given by

$$\tau_{ij}=\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]-\frac{2}{3}\mu\frac{\partial u_l}{\partial x_l}\delta_{ij} \tag{5.3}$$

where μ is the molecular viscosity and δ_{ij} is the effect of volume dilation.

5.2.3 Conservation of Energy

The energy conservation equation is needed to solve for the temperature and the heat transfer which is given by

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x_i}(\rho u_i h)=\frac{\partial}{\partial x_i}\left[\left(k+\frac{\mu_t}{\Pr_t}\right)\frac{\partial T}{\partial x_i}\right]+\frac{Dp}{Dt}+(\tau_{ik})_{eff}\frac{\partial u_i}{\partial x_k}+S_h \qquad \textbf{(5.4)}$$

where h is the sensible enthalpy, k is the molecular conductivity, τ_{ik} is the deviatoric stress tensor, μ_t is the turbulent viscosity and $\Pr_t$ is the turbulent Prandtl number for temperature or enthalpy.

5.3 Oven Geometry

The dimensions of the industrial oven are a length of 2.595 m, a width of 1.625 m and a height of 1.425 m. There are 10 shelves of various sizes (depending on the shelves being coated at the time) that are placed perpendicular to the flow.

There is one burner which is situated in the rear left corner of the oven see figure 5.1 which has been designed to generate hot air from the combustion of natural gas. The hot air is then circulated through the supply duct by the recirculation fan and into the heating chamber. After the hot air has passed through the heating chamber, it then returns to the burner to be reheated, and finally back into the supply duct via a recirculation fan located opposite the burner in the front right corner see figure 5.1.

The whole oven is surrounded by insulation made of Fibretex 450 a type of rockwool, which is 0.125m thick. This is to stop the heat escaping to the atmosphere and make the oven more efficient.

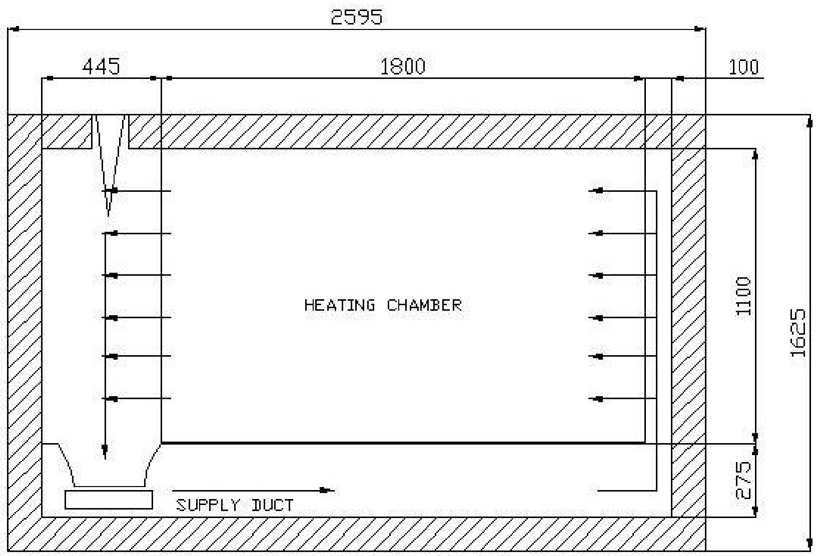

Figure 5.1 Horizontal Cross-Section of the oven

5.4 Modelling Assumptions

A two-dimensional horizontal cross-section of the oven was taken as the calculation domain to reduce the computational time taken to achieve convergence. Also there would be difficulties for the author to model this oven in the third dimension due to inexperience with the Computer Aided Drafting (CAD) package Gambit which was used to create the geometry.

As the oven has a recirculation fan installed, the flow inside the ducts would not be of laminar flow. The flow into the heating chamber would reduce the amount of turbulence due to the perforated sheet see figure 5.4. This fan will cause the air in the oven to be influenced by forced convection. Since in the 2-D plane chosen gravity is not considered therefore natural convection is no included, if a vertical section or a 3-D model was analysed natural convection would play a role, as gravity would be included.

Creating the recirculation fan in a 2-D geometry was difficult to model because Fluent would not recognise that the flow could circulate so some modifications to the geometry were made. In order to overcome this problem its was assumed that the air would exit the system where it was drawn into the fan and enter through the supply duct see figure 5.2 and 5.3. The fan was removed and replaced with a pressure out let and a pressure inlet. This was done to generate the velocity created by the fan due to a pressure difference between the outlet and the inlet.

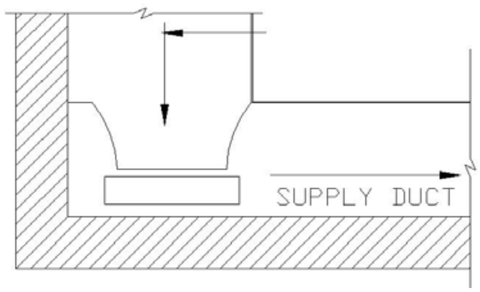

Figure 5.2 Original Geometry

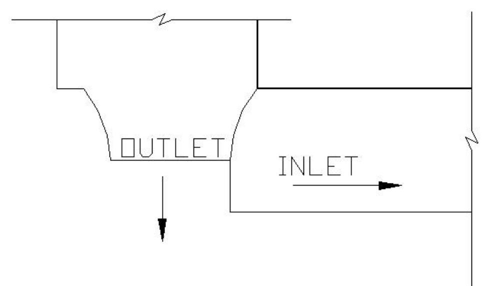

Figure 5.3 Modified Geometry

5.5 Collected Oven Data

Since the fan has been emitted due to the difficulties mentioned above some specific details were needed in order to model the oven correctly in Fluent. The upstream pressure and downstream pressure of the fan, where required in order to model the pressure inlet and outlet in Fluent. Since the supply duct is separated from the heating chamber by a steel wall, the pressure measurement was not easy to obtain. To get this pressure a very small hole had to be drilled close to the fan on the upstream side. This enabled the author to use a manometer supplied by Orford Refrigeration to take the stagnation pressures. The measured pressure for the upstream flow was 194 Pa and the pressure downstream from the fan was measured at -170 Pa. this pressure difference between the upstream and downstream stagnation pressures will cause the air in the oven to circulate with the same velocity as the fan would create.

The mass flow rate was needed to verify that the model had the correct flow rate occurring within the oven according to the experimental data collected. To calculate the mass flow rate of the hot air, the velocities of the air had to be measured. This was done at three separate points on both of the perforated sheets, as this was the only area where the velocity could be measured easily.

The velocities were measured using an anemometer at three points along the horizontal cross-section shown in figure 5.4. The velocities through the first perforated sheet (the entrance of air to the heating chamber) were taken at the three points looking from the inside of the heating chamber. The velocities of air at the second perforated sheet (the exit of air from the heating chamber) were measured using the same approach at the first sheet. The velocities at the three points can be seen below in table 1. The stagnation pressure at points 1 and 3 in the first perforated sheet (entrance) was 190 Pa and 146 Pa respectively.
The velocities at the exit were dramatically slower than the entrance velocities, the stagnation temperature did not differ much at the three points and had an average value of -173 Pa.

Perforated Sheet	**Position**		
	1	**2**	**3**
1 (Entrance)	8.21 m/s	9.34 m/s	7.24 m/s
2 (Exit)	1.1 m/s	2.17 m/s	2.76 m/s

Table 1 Velocities at different point in the perforated sheets

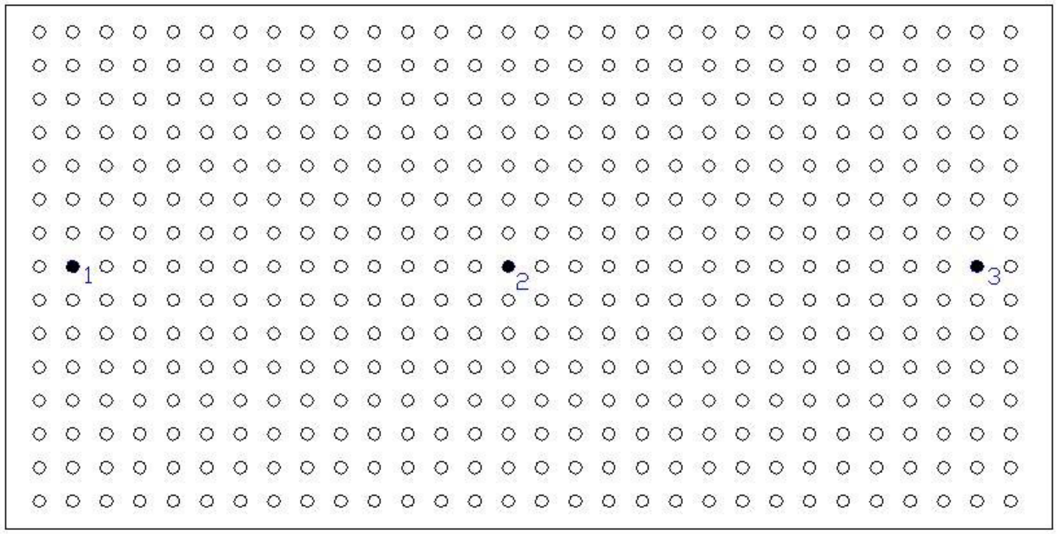

Figure 5.4 Illustration of the Perforated Sheet

To calculate the mass flow rate, the values from the first perforated sheet were used, as the values from the second sheet had greater errors due to disturbances in the flow. In order to calculate the mass flow rate, the following variables are needed, area, density and the velocity. In this case, the average velocity across sheet 1 will be used.

The area of the perforated sheet that the air flows through is 10% of the sheet, the sheets dimensions are 1m x 0.5m and the holes in the sheet are 12mm in diameter and spaced by 20mm in both directions. The mass flow rate is calculated as follows from the data collected in oven.

$$A = \frac{(1*0.5)*10}{100}$$
$$= 0.05m^2$$
$$\bar{V} = \frac{(7.24+9.34+8.21)}{3}$$
$$= 8.26m/s$$

$\rho = 0.552 kg / m^3$

$$\dot{m} = \rho \bar{V} A$$
$$= 0.552 * 8.26 * 0.05$$
$$= 0.228 kg / s$$

5.6 Boundary Conditions

Boundary conditions are a very important aspect of modelling in Fluent, they specify the flow and thermal variables at the boundaries of the model. To obtain an accurate simulation of the physical model, the boundary conditions have to be specified as close as possible to the real environment affecting the flow. There are four types of boundary conditions affecting the oven; they are pressure inlet, pressure outlet, velocity inlet and wall. The boundary conditions for the oven can be seen in figure 5.5 which illustrates the position of these boundaries.

To represent the flame from the combustion of the gas and air, an inlet condition with a specified temperature that corresponds to the flame velocity was chosen. By choosing this type of condition it enabled the heat to affect the cooler air exiting the heating chamber. As the fan was removed from the oven geometry the pressure difference created by the fan was modelled using the pressure inlet and outlet which specifies how much pressure difference was generated by the fan. The values for these boundary conditions can be seen in the following table (table 2).

Boundary Name	Boundary Type	Temp (°C)	Pressure (Pa)	Velocity (m/s)	Turbulence type	Turbulence
BURNER	Velocity inlet	1000	-	0.5	k-ε	0.2
EXIT	Pressure outlet	300 (Backflow)	-170	-	k-ε	0.1
INLET	Pressure inlet	348	194	-	Intensity + D_H	30 %

Table 2 Boundary Conditions for Inlets and Outlets

Since the conditions during operation are not known for the steel wall and the perforated sheet, they were modelled as solid faces with the material property steel. Fluent automatically creates a shadow boundary that separates the two zones. These zones can have different thermal properties but for this oven geometry the two zones were selected to be coupled. By coupling the two zones no further thermal parameters are required as the solver will calculate the amount of heat transferred directly between the adjacent zones. For the insulation and INT L FAN see figure 5.5 some further variables were needed as these two boundaries were not coupled. As these boundaries were not faces, just edges, the wall thickness, free stream temperature which is the temperature outside of wall and the heat transfer coefficient has to be defined. The type of material also required to be added in order to model the condition correctly. The boundary INT L FAN was made of steel and the insulation was made of the same material as the boundary name see table 4 for the properties of these materials.

Boundary Name	**Boundary Type**	**Thermal Condition**	**Free Stream Temperature**	**Wall thickness**	**Heat transfer coefficient**
INISULATION	Wall	Convection	28 °C	0.125 m	5 W/m²K
INT L FAN	Wall	Convection	300 °C	0.003 m	15 W/m²K
BOTTOM WALL INSIDE	Wall	Coupled	-	-	-
BOTTOM WALL OUT	Wall	Coupled	-	-	-
INSIDE CURVE	Wall	Coupled	-	-	-
PERFORATED	Wall	Coupled	-	-	-
LEFTCRNOUT	Wall	Coupled	-	-	-

Table 3 Boundary Conditions for Walls

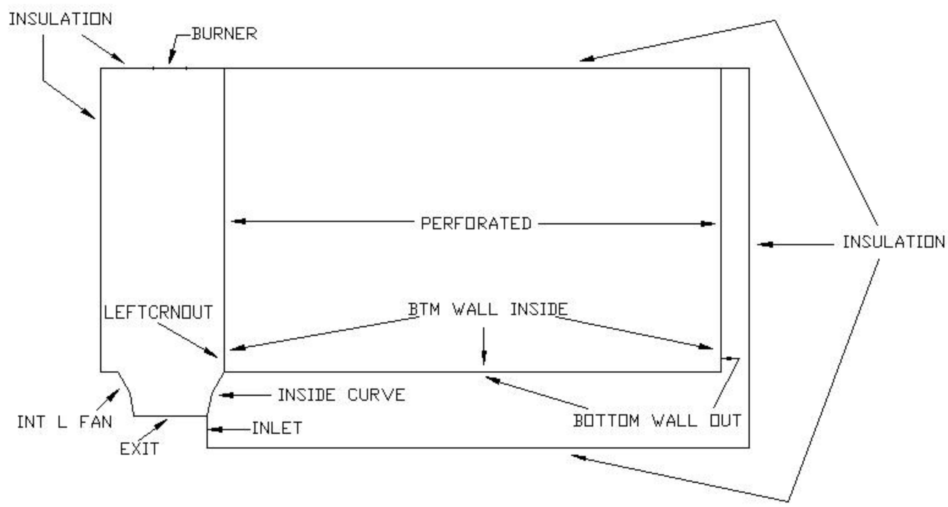

Figure 5.5 Layout of Boundary Conditions

5.7 Material Properties

There are three types of materials that data is required in order to model the oven using Fluent. They are the heated air, the insulation, and the steel inside the oven. The following table displays the material properties.

Material	Density (kg/m^3)	C_p (J/kg.K)	Thermal Conductivity (W/m.K)	Viscosity (kg/m.s)
Air	0.552	1053	0.04395	56.9 e-6
Insulation	80	1200	0.11	-
Steel	7801	473	43	-

Table 4 Material properties used in the oven calculations.

5.8 Numerical Procedure

5.8.1 Generation of Mesh

Geometry has to be created to sufficiently represent the boundaries and fluid domain for analysis. This geometry is created using a computer aided design (CAD) package. These packages must be compatible with the CFD software. In this case the CAD program used was Gambit v 2.0.4, as it was easily accessible and is bundled with Fluent.

As this analysis is to be carried out in 2-D, the geometry can be created in the x, y plane. Vertices are placed according to specific points in the oven geometry, so the edges and faces can be produced. For instance the placement of the pressure inlet and outlets by coordinates then joining the vertices with edges. Once all the critical points were in place, they were joined together by lines to create the edges of the oven geometry (insulation, perforations, inlets and outlets, curves). From these edges, a face can be created which represents the fluid domain, in this case the air inside the oven. Several faces were created in this model to show how the heat is transferred through the air and the effect that the air has on the steel faces.

The next step in the creation of the geometry was to mesh the edges and faces. Gambit offers the user many choices with regards to the number of nodes on the edges either by the number of nodes or the spacing between the nodes. The method that is used in this model was by interval count or the number of nodes per edge. Gambit allows the user to create a very fine mesh of areas of interest or where the flow needs to be analysed in some detail. Once this is complete, the faces can be meshed with regards to the edge meshing. As the variation of edge lengths and spaces the geometry could not be meshed with the desired mapped mode, instead a quad pave mesh was chosen and successfully meshed the fluid regions.

Once all the edges and faces are meshed the mesh can be check for areas that may cause problems in Fluent. The desired solver is chosen fluent 5/6 in this instance. If the mesh is suitable then the boundary conditions can be set and the 2-D mesh exported to Fluent.

5.8.2 Geometry Mesh

As briefly discussed in the previous chapter the generation of mesh was a complicated procedure due to the difficult geometry. The fluid or air in this case had to be directed through the small gaps from the perforated sheet and treat the wall as an obstruction to the flow shown in figure 5.6. To overcome this problem all of the little walls from the perforation and the internal bottom wall described earlier where taken away from the entire fluid domain. This left the fluid region around and in between the mentioned walls.

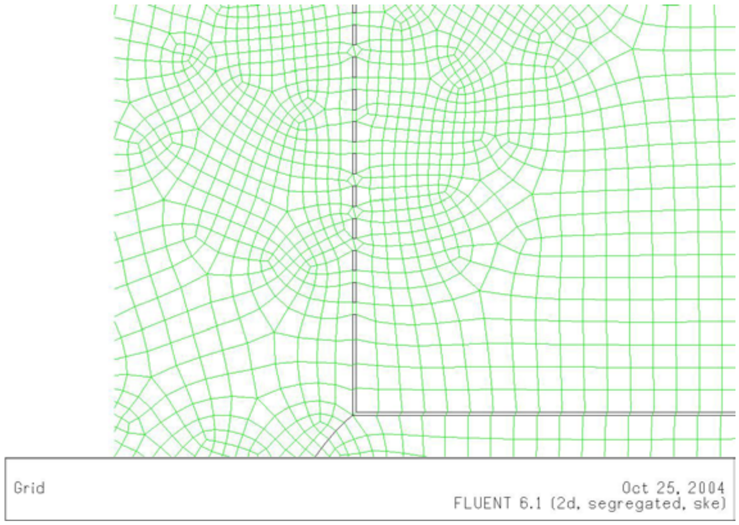

Figure 5.6 Fluid flow through the perforations

The other difficulty that had to be overcome while meshing was that the internal curve had to be treated as a wall so the air could not flow through this region. As this was not created as a surface a face had to be created, this face inclosed the supply duct. This face was then like before taken away from the total fluid area but the face was retained. The reason the face was kept is because it was to be included as a part of the air this can be seen in figure 5.7.

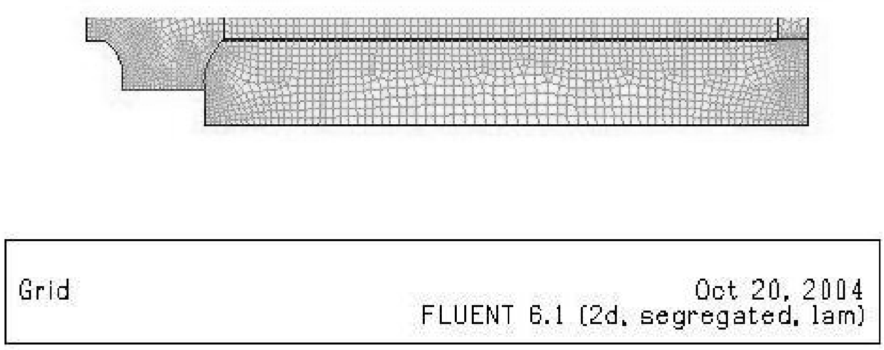

Figure 5.7 Mesh geometry for the industrial oven

5.8.3 Fluent Solver

In Fluent the grid or mesh of the geometry has to be check to make sure it is suitable to be analysed. If there are any problems with the mesh than the Gambit model has to be modified so it is accepted by Fluent.

Fluent uses a segregated solution method to solve the conservation equations using the control volume technique. The solver uses a loop to solve the equations as shown in the following figure 5.8.

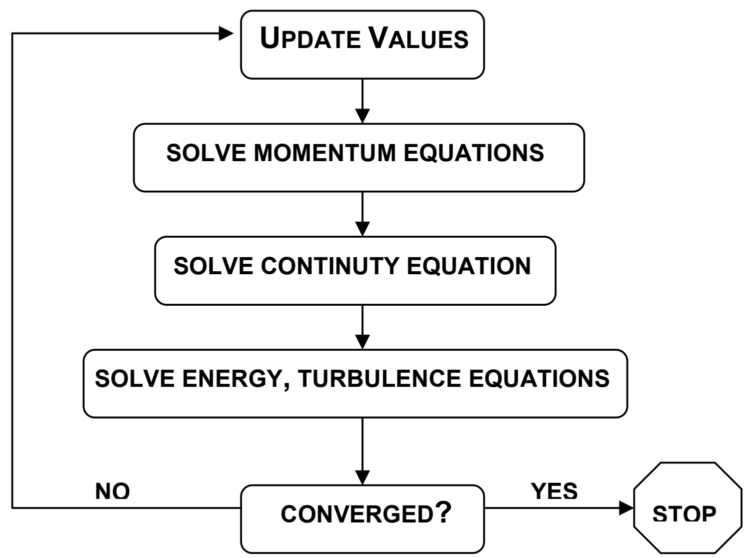

Figure 5.8 Segregated Solution Method

Since the governing equations are non-linear several iteration of the loop are required before the converged solution is calculated. Convergence occurs when the scaled residuals of the equations are less than 10^{-5}.

The time for this analysis was conducted using the steady-state time which provides the details of the oven after the system has reached steady-state. This steady-state approach of time was chosen over a transient method. Due to the temperature distribution inside the oven not being important in the heating and cooling of the oven, just the operating conditions which occurs after steady-state is reached.

6 Results

6.1 Outline of Project Results

The results from the numerical analysis of the industrial oven have been grouped into three sections:

- *Temperature* which looks into the temperature distribution in the oven and profiles of how the air is cooled around and through the heating chamber.
- *Velocity* which looks at the contours of velocity, the flow of air in the oven and the stream function.
- *Pressure* covers the static pressure inside the oven.

6.2 Temperature

The overall steady-state temperature profile of the oven is shown in figure 6.1. It appears that, the majority of the oven is within the range of between 314 to 348 degrees Celsius. Figure 6.1 shows that the oven appears to be of uniform temperature. It is difficult to distinguish the actual temperature of the heating chamber, as the difference in temperature for the current plot is over 600 degrees Celsius. From this profile the high temperature of the flame appears to be reheating the cooler air leaving the heating chamber which is the intension of the designer. The inlet temperature seems to cool gradually as it moves along the supply duct.

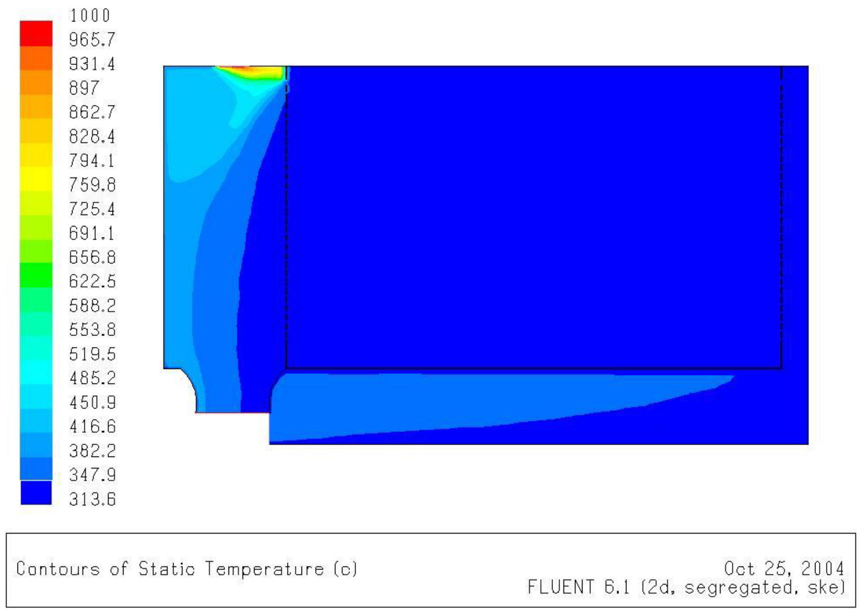

Figure 6.1 The Overall Temperature Distribution

To display more accurately how the temperature is distributed within the oven smaller temperature ranges need to be assessed. In figure 6.2 a temperature range has been selected of between 313 and 500 degrees Celsius. This range is still to large to determine the temperature distribution inside the oven and more specific the heating chamber. From this profile the heating chamber and supply duct are in the same contour range of between 341 and 351 degrees Celsius. This profile illustrates how the flame is affecting the temperature of the cooler air. The air is gradually being heated as is moves out of the heating chamber to the oven wall, with a temperature of approximately 416 degrees Celsius.

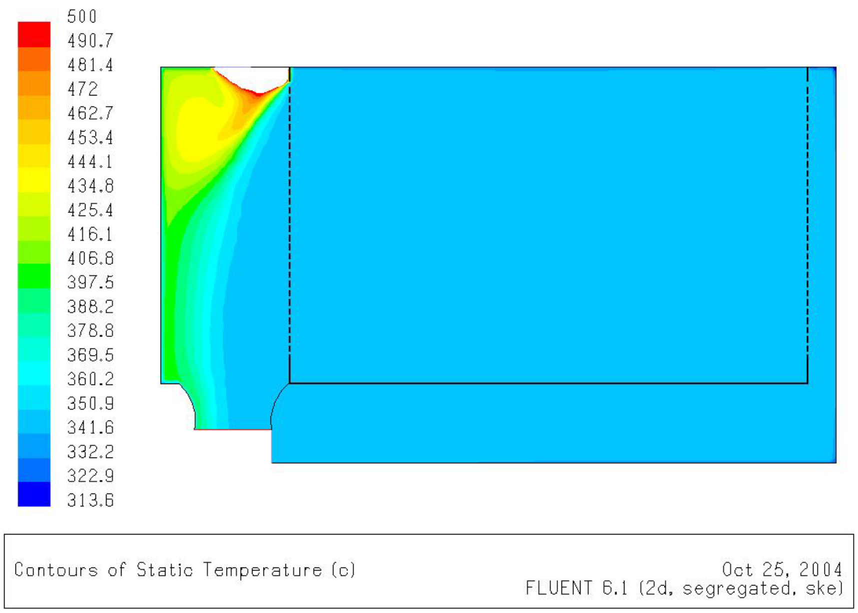

Figure 6.2 Temperature profile between 313°C and 500°C

Since the main temperature of interest for the oven is 347 degrees Celsius. The temperature range of 343 to 348 degrees Celsius was chosen to examine exactly what is happening in the heating chamber with regard to the temperature. The following figure (figure 6.3), best displays the temperatures of interest.

The orange contour in the centre of the heating chamber occupies the majority of the space and is at a average temperature of 347.4 degrees Celsius. This temperature is very close to that required by Orford Refrigeration. There does seem to be a section of air coming out of the perforated sheet that is slightly hotter than the rest of the heating chamber. As the air inside the oven moves towards the outside wall, the temperature decreases. This is clearly apparent in the bottom right corner of the supply duct and in the top left corner of the heating chamber.

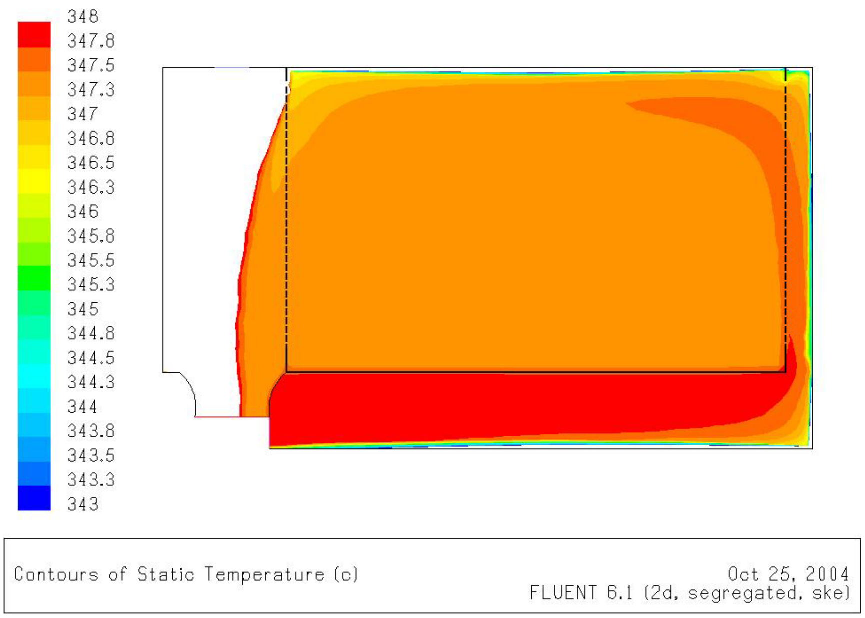

Figure 6.3 Temperature Profile between 343°C and 348°C

6.3 Velocity

The vector contours of the velocity magnitude are shown in figure 6.4. This velocity profile indicates areas of circulation and the general flow direction of air around the oven. The air is flowing in an anti-clockwise direction inside the oven. From the difference in pressure between the exit and inlet a velocity for the fan was simulated as being approximately 20 m/s. The region where the air changes direction in the supply duct has a very high velocity of 27 m/s. The reason for this sudden increase in velocity is due to the volume flow rate, given by equation 6.1, from this equation it is determined that, as the area decreases in size the velocity will increases in magnitude.

$$Q = VA \tag{6.1}$$

where
$$Q = Volume\ Flow\ Rate$$
$$V = Velocity$$
$$A = Area$$

As the air flows into the heating chamber the velocities gradually increase the further along the perforated sheet the air moves. At the exit of the heating chamber not all the air escapes through the perforated sheet, the air that does not get through is recirculated inside the heating chamber in an anti-clockwise direction. The air at the centre of the heating chamber has a very small and almost stagnate velocity. There are two areas of circulation that occur in the oven. One at the inlet this is because of the curvature that guides the air into the fan or exit in the model. The second is left of the flame, here the hot air is circulating in the corner not affecting any of the cool air.

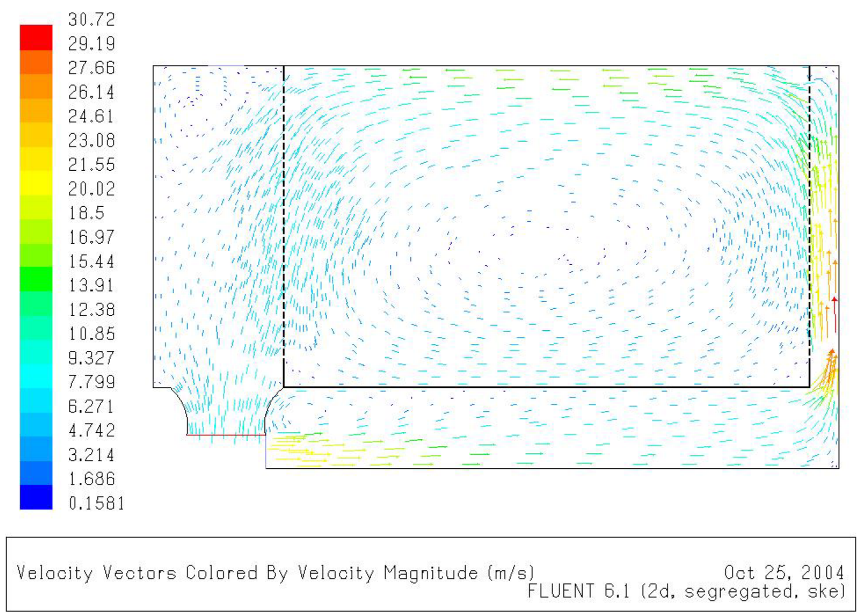

Figure 6.4 Illustrates the Velocity using vectors

The stream function displays the amount of mass flow rate in the model. This is shown in figure 6.5. The mass flow rate was calculated earlier in the numerical analysis from experimental data collected from the oven. The obtained flow rate from the experimental values was a great deal smaller than that of the mass flow rate calculated in Fluent. At first the author thought there was an error in the measurement of the experimental values, but the values obtained were within an acceptable range of the values calculated in Fluent.

It was then realised that when using Fluent to calculate the mass flow rate in 2-D geometry, the area was calculated by taking an appropriate section length from the geometry and multiplying it by one metre. For the area where the experimental mass flow rate was calculated, this is incorrect. Fluent assumes that the holes in the perforated sheet to be slits, one metre in depth when in actual fact the holes are evenly spaced by 20 mm of steel sheet and the holes in the perforated sheet are only 0.5 m in depth not one metre. The reason such a small mass flow rate was achieved compared to that in Fluent. This was because not all of the air is able to pass through the perforated sheet and is dispersed back around the supply duct, hence the small mass flow rate at the perforations.

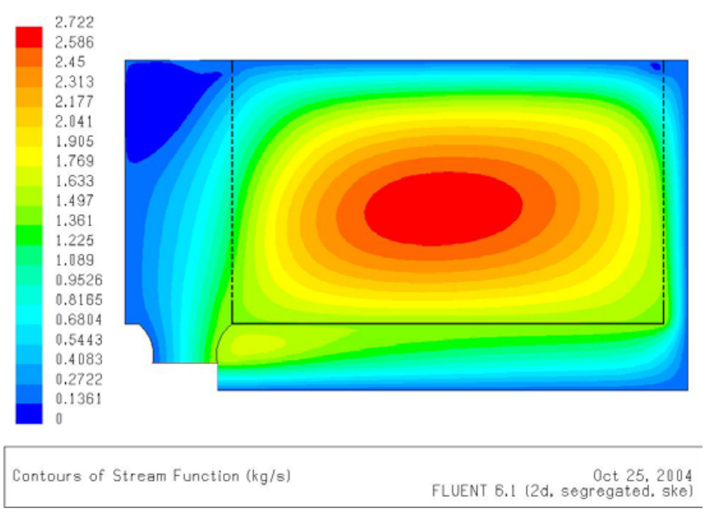

Figure 6.5 Stream Function

7 Discussion

7.1 Areas of Concern

7.1.1 Circulation areas

The simulation of the model revealed some areas which may need re-designing. The air is being guided by curved walls, is causing some problems with circulation. This current shape or design is causing a circulation zone just after the inlet entry (figure7.1). This could mainly be due to the fact that this investigation is only 2-D and cannot get a greater view of this area to see whether it is localised or just due to the actual 2-D modelling applied. Another circulation zone that occurred in the simulation was near the flame see figure 7.1. The circulation in this area is due to the speed of the flame which causes and eddy effect in the corner of the oven.

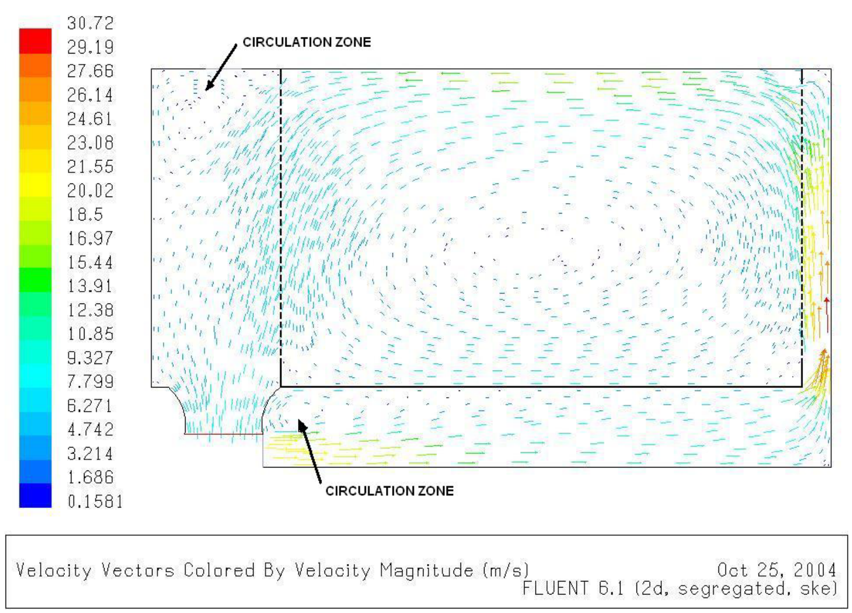

Figure 7.1 Circulation zones inside the oven

Possible solution methods to overcome these circulation zones would be redesign of the fan area possibly changing the section or creating a new wall that does both requirements. In other words the wall would guide the air into the fan and also reduce the amount of circulation when the air is recirculated back into the oven. With regards to the circulation zone near the flame there does not appear to be a great deal that can be done with this area in order to solve the problem.

7.1.2 Areas of Low Temperature

Areas of low temperature were occurring around the outside boundary of the oven geometry. An area of particular concern was the top right corner of the oven refer to figure7.2, in this area it registered the lowest temperature in the oven, of 313 degrees Celsius. Reasons for this low temperature are not clear to the author, there may have been some errors in defining the boundary conditions in this area but were the same as the rest of the insulated walls. It could also be to do with how fluent has interpreted something in this region a finer mesh needs to be implemented in this area to get a better understanding of what is happening.

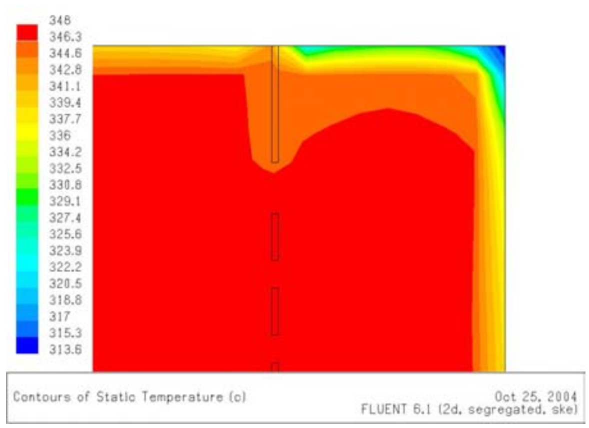

Figure 7.2 Temperature of top right corner of oven

7.1.3 Temperature vs Velocity

It was found, that once the temperature range was reduced the distribution of the temperature was much clearer, and when the velocities where analysed the direction and magnitude seemed to be closely related to the rate at which the temperature was being cooled. In order to make a direct comparison, an overlay of the temperature and velocity vectors where analysed see figure 7.3. In this figure the temperature contours are between 343 and 348 degrees Celsius with the contours filled and the velocity vectors placed on top of the temperature plot the values for the velocity magnitude are on the scale left of the figure.

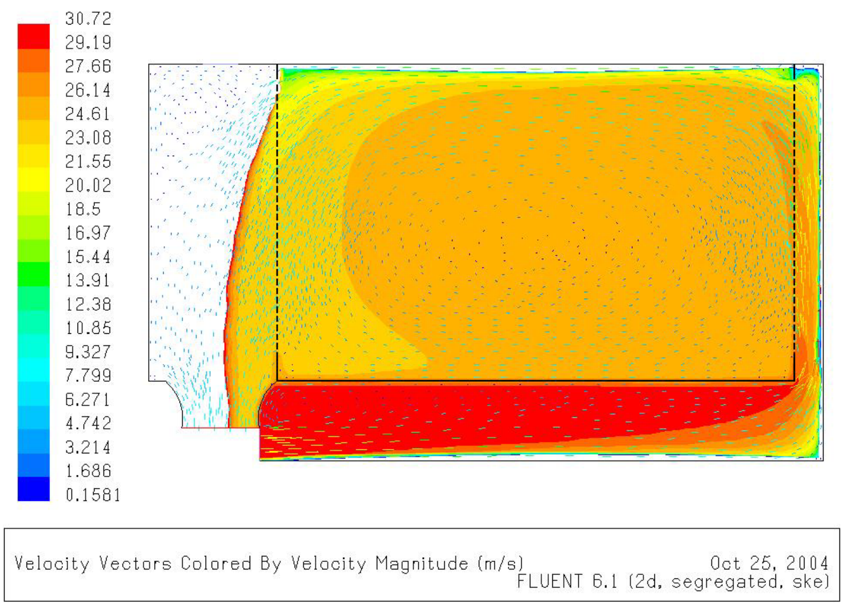

Figure 7.3 Velocity vectors overlayed on temperature profile

7.2 Issues to be addressed

Perforated Sheets

The rate at which the air is flowing through the perforated sheet does not seem to be uniform. The air is entering the heating chamber almost parallel with the sheet. This flow direction is causing the temperature to change in this direction. Some possible control methods that need to be looked at to create an even inlet velocity across the sheet could be a gradual size decrease in the hole diameters, as the air becomes faster, mainly towards the far end of the sheet

Heat Flux Losses

If the flame temperature is not high enough to reheat the air leaving the heating chamber then there are some losses in energy that need to be assessed. For the model analysed, the energy or heat flux at the exit, inlet and burner were assessed and given in table 5. The exit heat flux has a minus sign due to the direction of energy flow, out of the system.

Boundary Name	Heat Transfer Rates (W/m^{2}K)
Burner	20380.45
Exit	-467813.84
Inlet	449222.84

Table 5 Heat Transfer Rates

8 Conclusions

8.1 Project Findings

The general objectives set in the revised project specification were successfully completed, in this investigation into the temperature distribution of an industrial oven. From this investigation it was found that the temperature distribution within the oven was relatively even. The temperature distribution inside the oven was found to be related to the velocity. The variation in temperature seemed to follow the velocity contours.

8.2 Recommendations for future work

There are quite a number of areas that could be researched further on this topic which include:

- A numerical analysis of the vertical cross-section of the oven to observe the effects of the temperature distribution.
- Verify the numerical results by conducting an experimental analysis
- A numerical study of the oven in 3-D, this analysis would be very advantageous for the following reasons:
  - Observe full temperature distribution and flow conditions with in the oven.
  - Identify problem areas
  - Inclusion of the fan
  - Inclusion of the shelves into the analysis
  - The oven doors, open and closed
- An investigation into the combustion device and process used for the oven.

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Appendix A

Project Specification

University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	**ANDREW LEE**
TOPIC:	NUMERICAL INVESTIGATION OF THE TEMPERATURE DISTIBUTION IN AN INDUSTRIAL OVEN
SUPERVISORS:	Dr. Ruth Mossad
ENROLMENT:	ENG 4111 – S1, D, 2004; ENG 4112 – S2, D, 2004
PROJECT AIM:	This project aims to investigate the temperature distribution in an industrial oven used in the plastic coating process of refrigerator shelves.
SPONSORSHIP:	University of Southern Queensland Faculty of Engineering, Orford Refrigeration

PROGRAMME: **Issue B, 28th September 2004**

1. Build the background knowledge on industrial ovens and the plastic coating process.
2. Perform literature review on numerical modelling of industrial ovens, flow in rectangular ducts and flow through perforated sheets.
3. Learn how to use Computational fluid dynamics (CFD) software and experiment with the chosen software model.
4. Apply the CFD software to investigate the temperature distribution within the industrial oven.
5. Analyse the results obtained from the analysis and comment on areas which will improve the temperature profile.

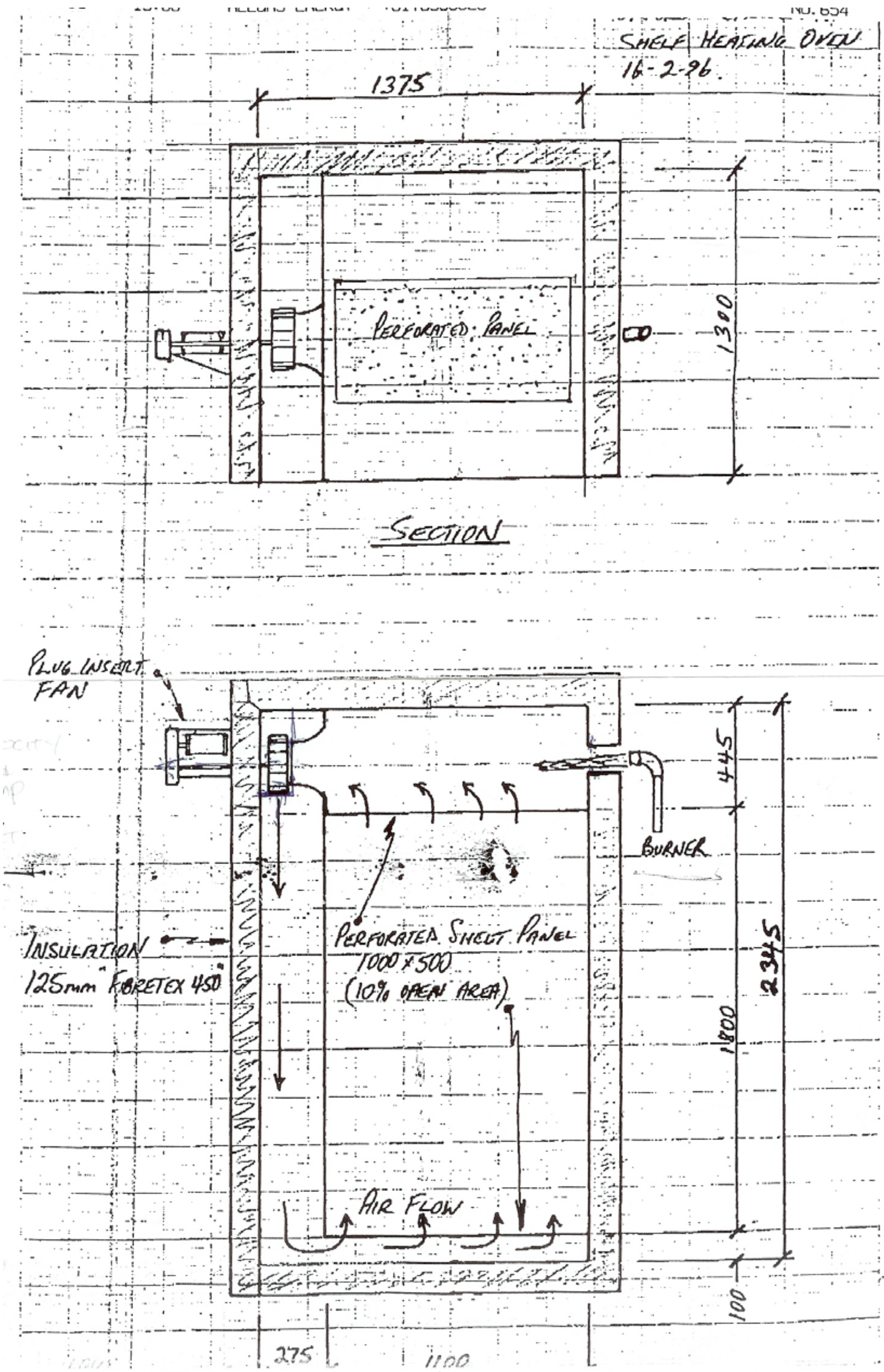
As time permits:

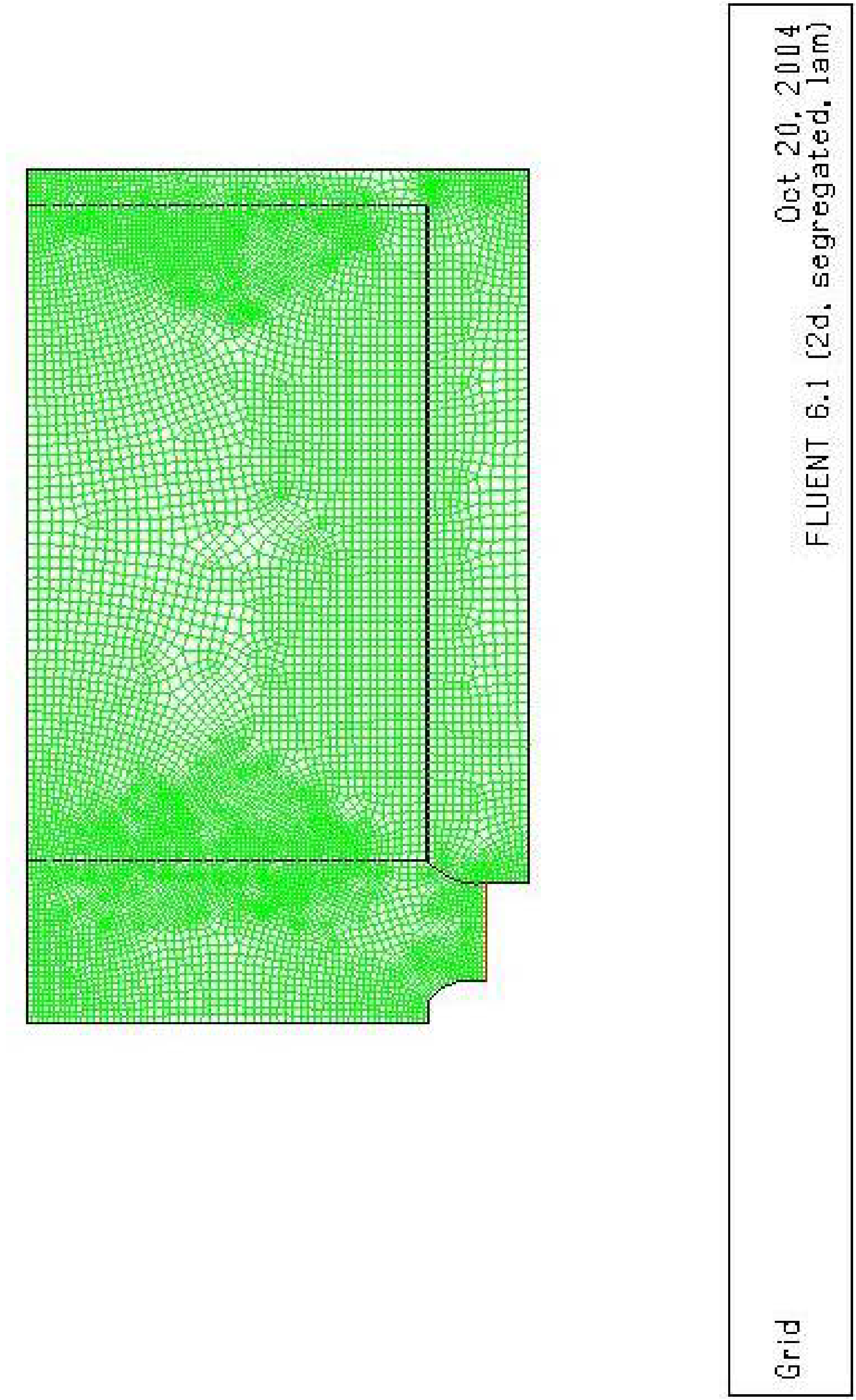
6. Perform a 3-D analysis of the industrial oven using CFD software.

AGREED: __________________ (student) __________________(supervisors)
(dated) ___ /___ /____

Appendix B

Layout of Industrial Oven

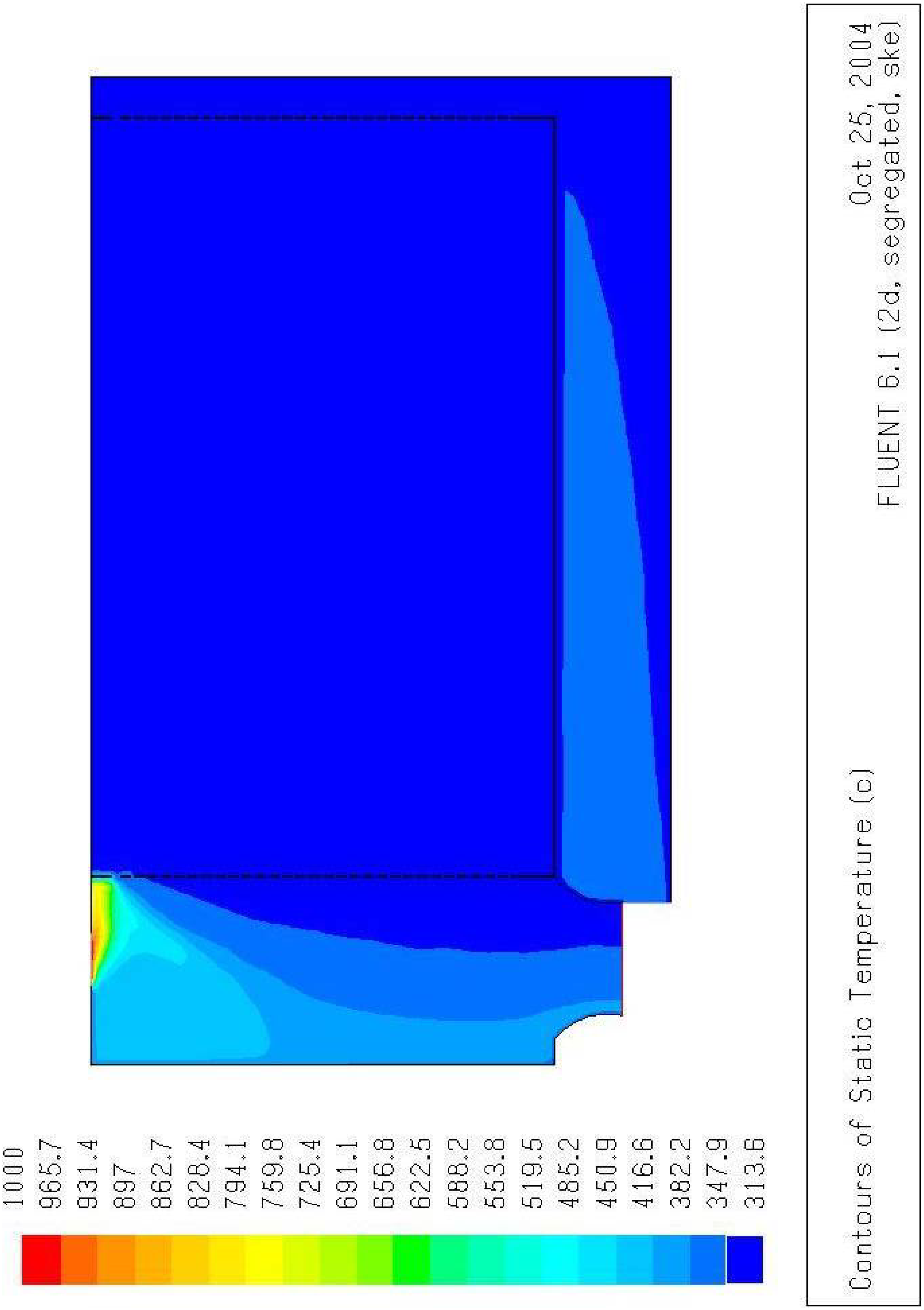

SHELF HEATING OVEN
16-2-96
1375
PERFORATED PANEL
1300
SECTION
PLUG INSERT FAN
445
BURNER
PERFORATED SHEET PANEL
1000 x 500
(10% OPEN AREA)
INSULATION
125mm "FIBRETEX 450"
2345
1800
AIR FLOW
100
275
1100

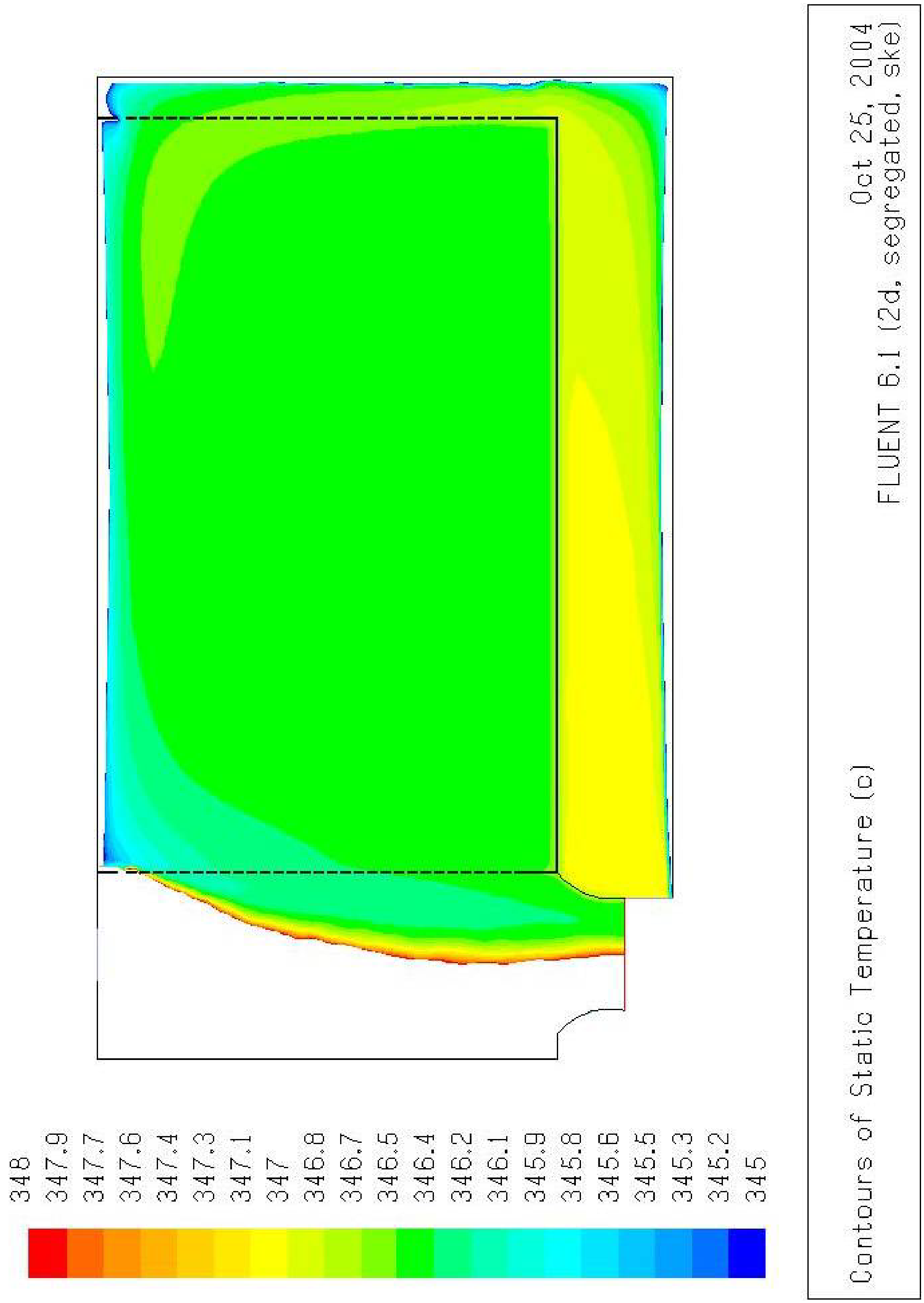

Grid
Oct 20, 2004
FLUENT 6.1 (2d, segregated, lam)

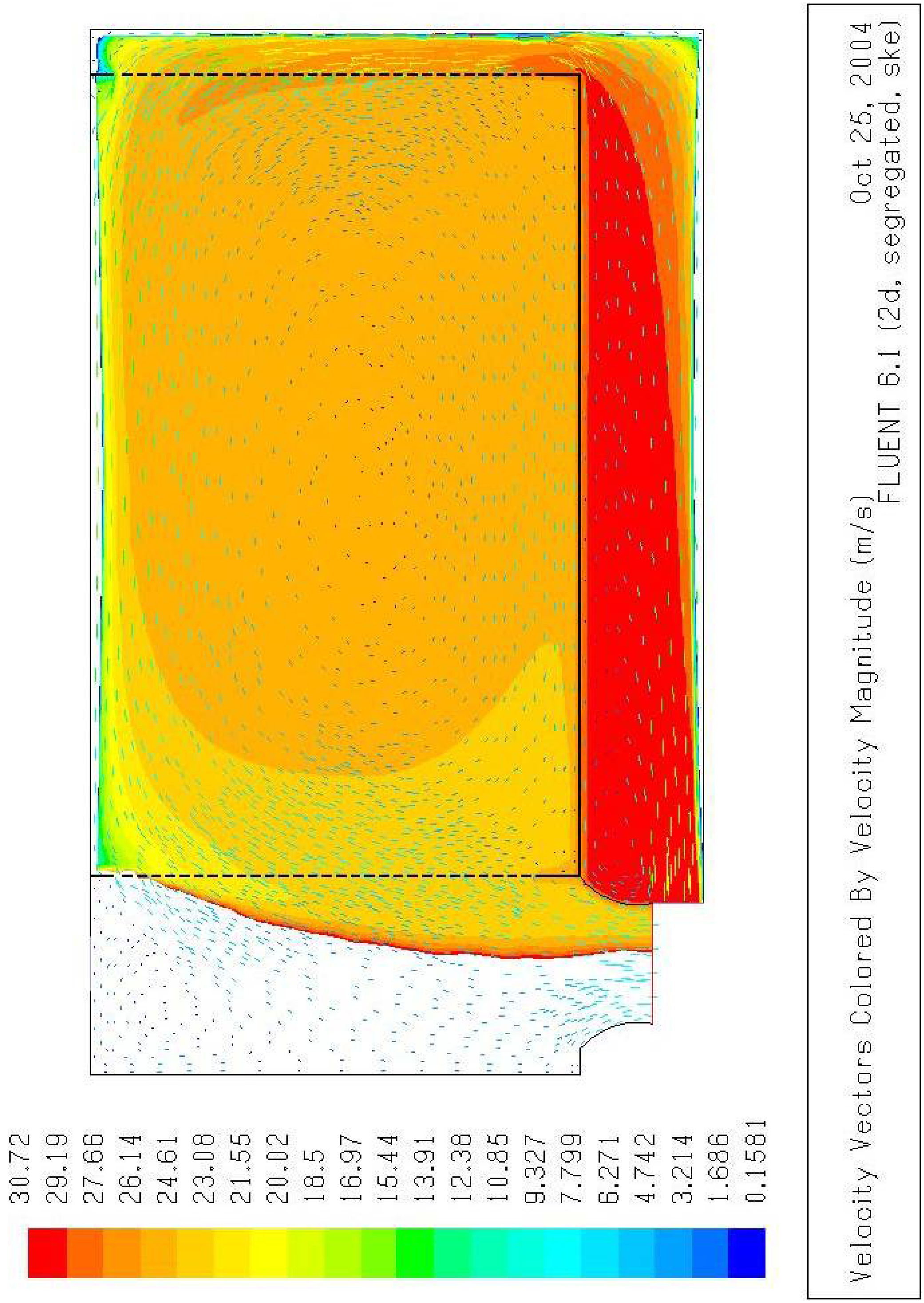
Appendix C

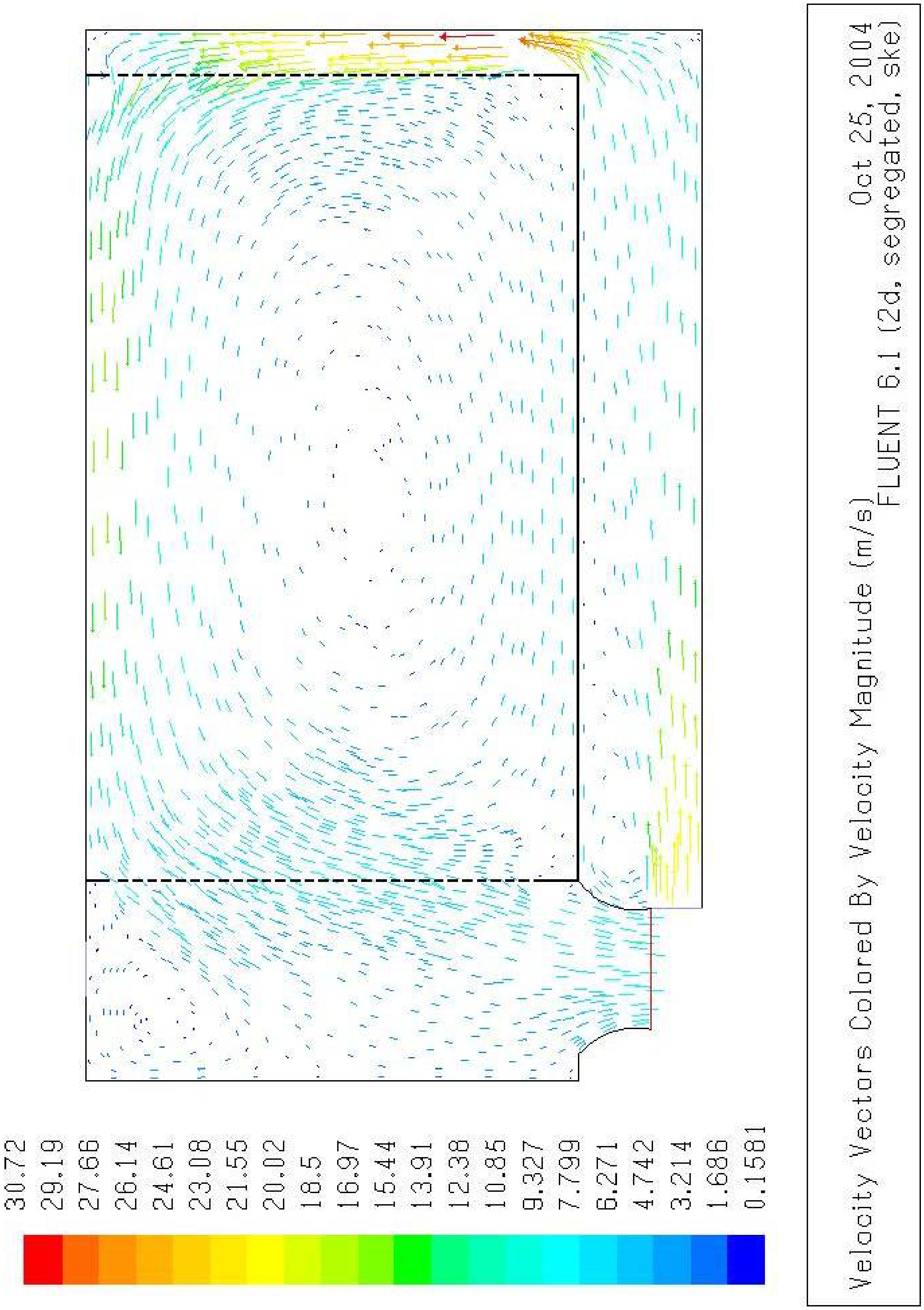
Numerical Modelling Results

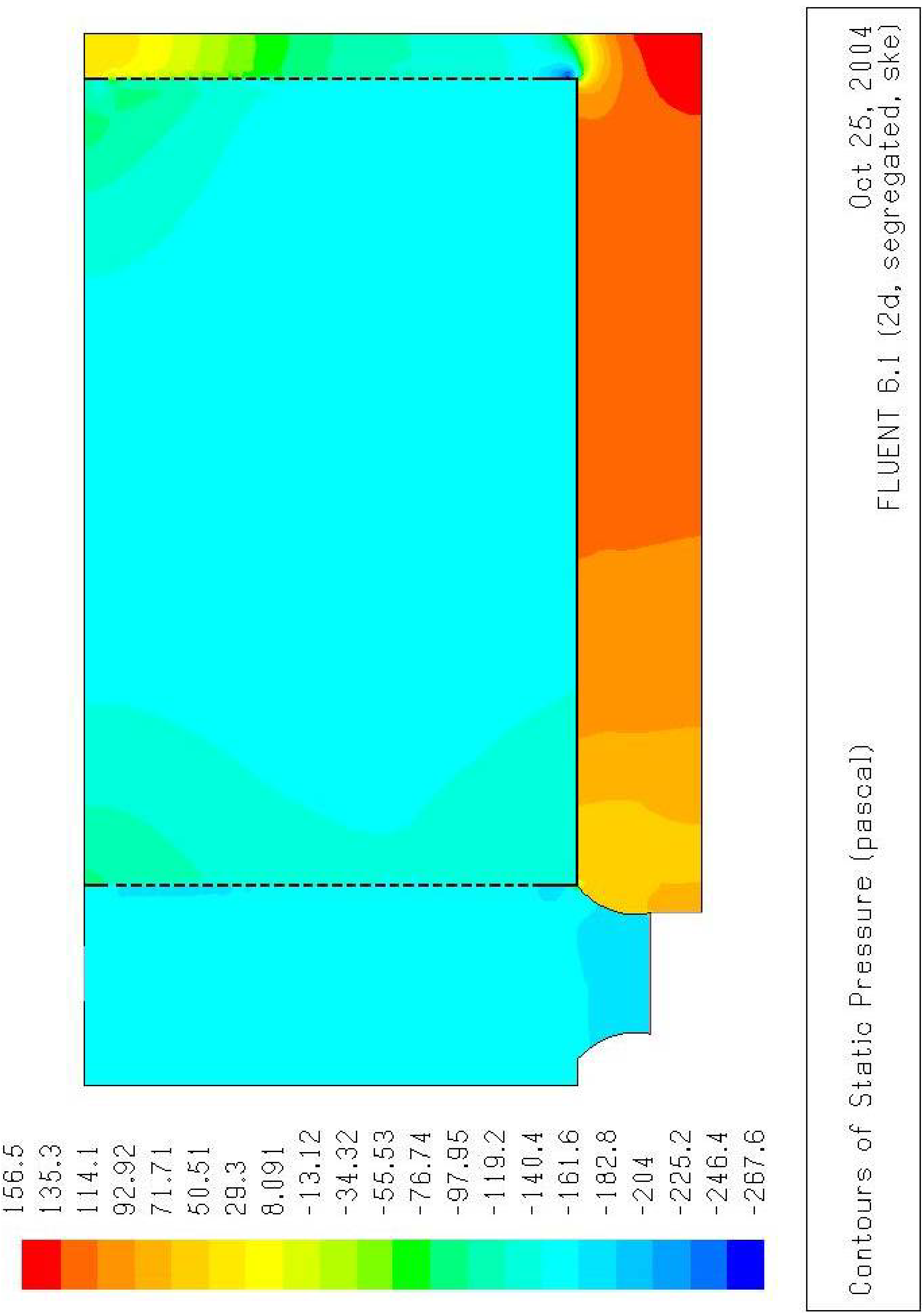
Industrial Oven – Fluent Case Data	
Model	
Solver	Segregated
Formulation	Implicit
Time	Steady
Models	Energy
	Viscous
Velocity Formulation	Absolute
Element Type	Mapped Pave
Space	2-D
Boundary Conditions	
Burner	Velocity Inlet
Exit	Pressure Outlet
Inlet	Pressure Inlet
Insulation	Coupled
Bottom Wall	Coupled
Perforated	Coupled
Operating Conditions	
Operating Pressure	101 325 Pa
Reference Location	(-0.06,-0.275)


1000
965.7
931.4
897
862.7
828.4
794.1
759.8
725.4
691.1
656.8
622.5
588.2
553.8
519.5
485.2
450.9
416.6
382.2
347.9
313.6
Contours of Static Temperature (c)
Oct 25, 2004
FLUENT 6.1 (2d, segregated, ske)


348
347.9
347.7
347.6
347.4
347.3
347.1
347
346.8
346.7
346.5
346.4
346.2
346.1
345.9
345.8
345.6
345.5
345.3
345.2
345
Contours of Static Temperature (c)
Oct 25, 2004
FLUENT 6.1 (2d, segregated, ske)


30.72
29.19
27.66
26.14
24.61
23.08
21.55
20.02
18.5
16.97
15.44
13.91
12.38
10.85
9.327
7.799
6.271
4.742
3.214
1.686
0.1581
Velocity Vectors Colored By Velocity Magnitude (m/s)
Oct 25, 2004
FLUENT 6.1 (2d, segregated, ske)


30.72
29.19
27.66
26.14
24.61
23.08
21.55
20.02
18.5
16.97
15.44
13.91
12.38
10.85
9.327
7.799
6.271
4.742
3.214
1.686
0.1581
Velocity Vectors Colored By Velocity Magnitude (m/s)
Oct 25, 2004
FLUENT 6.1 (2d, segregated, ske)


156.5
135.3
114.1
92.92
71.71
50.51
29.3
8.091
-13.12
-34.32
-55.53
-76.74
-97.95
-119.2
-140.4
-161.6
-182.8
-204
-225.2
-246.4
-267.6
Contours of Static Pressure (pascal)
Oct 25, 2004
FLUENT 6.1 (2d, segregated, ske)

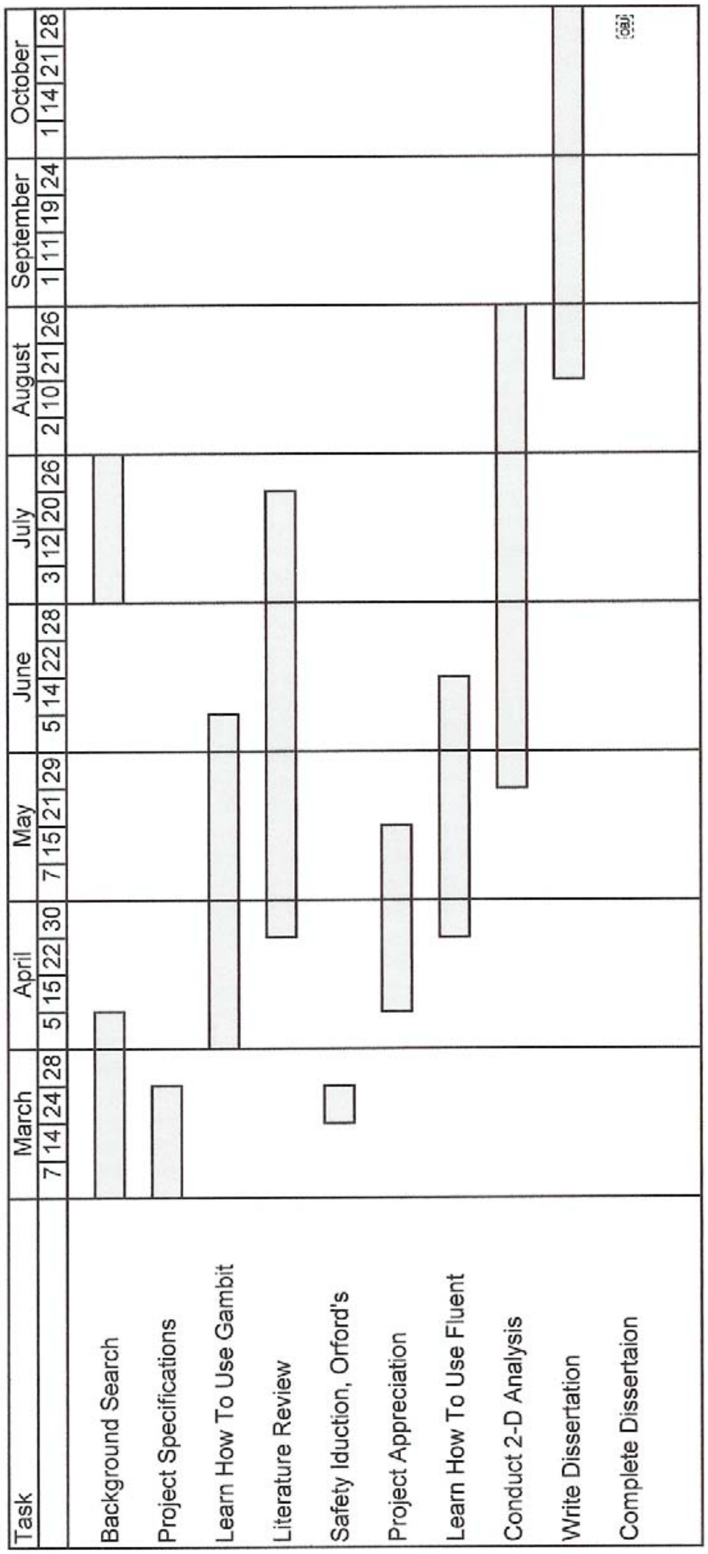
Appendix D

Project Resources

Resource	***Location***	***Purpose***	***Date Reqd***	***Cost***	***Action Required***
UQ Engineering Library	St Lucia, Brisbane.	Searching of books and journals	Done	$450	None
Inter Library Loans	USQ, Toowoomba	Request journal articles from other sources	August	$30	Get resource information and signatures
Fluent 5/6 Software	Catlabs USQ, Toowoomba	Numerical modelling and analysis	-	Nil	None
Gambit Software	Catlabs USQ, Toowoomba	Geometry and meshing	Done	Nil	None
Access to factory	Orford Refrigeration Toowoomba	Background information and measurements	Done	Nil	Safety induction
Word Processing software	Own Computer	Writing of Dissertation	Oct 28	Electricity	None
Internet Access	USQ, Toowoomba	Searching of databases and world wide web	Done	Nil	None

Appendix E

Project Timeline


Task
March
7 14 24 28
April
5 15 22 30
May
7 15 21 29
June
5 14 22 28
July
3 12 20 26
August
2 10 21 26
September
1 11 19 24
October
1 14 21 28
Background Search
Project Specifications
Learn How To Use Gambit
Literature Review
Safety Iduction, Orford's
Project Appreciation
Learn How To Use Fluent
Conduct 2-D Analysis
Write Dissertation
Complete Dissertaion

Appendix F

Risk Assessment

There are two main areas that possible risks associated with the project could occur. The first of these is at while conducting the numerical analysis and the writing of the dissertation, and the second could occur when site visits to Orford Refrigeration were needed. For effective management of these risks this assessment seeks to identify the problems and find ways to minimise the potential for an incident to arise from these associated risks.

Computer Workstation

Risk Situation: Over use, strains, electrical hazards.

Hazard Incident: Strains, repetitive injuries, eye strain. Limited range of adjustments.

Consequence: Substantial

Likelihood: Possible

Risk Assessment: Moderate

Recommended Risk Control Measures: Provide adjustable workstations to suit operator. Training users to set up correct operating positions to minimise strain. Electrical testing and tagging of all computer equipment.

Orford Refrigeration

Before it was possible to enter the factory at Orford's it was compulsory that a safety induction course be completed. This course un by the companies OH&S officers, the course explained a number of major hazards around the workplace and the procedures on how these risks could be reduced, these risks include excess noise, eye damage, heavy objects, forklifts and fire.

Risk Management Plan

1. Excess Noise

Risk Situation: Exposure to large amount of noise for long periods of time, Hearing loss or damage.

Consequence: Substantial

Likelihood: Possible

Risk Assessment: Moderate

Control Measures: Ear plugs are provided for workers and visitors if required.

2. Potential Eye Damage

Risk Situation: Foreign matter coming in contact with the eyes.

Consequence: Substantial - Serious

Likelihood: Likely

Risk Assessment: Moderate to High

Control Measures: All employees and visitors must wear safety eye glasses at all times while on site. There are also eye wash facilities situated around the workshop if some foreign matter gets into the eye.

3. Foot Protection

Risk Situation: Heavy objects falling on to the feet.

Consequence: Serious

Likelihood: Remotely possible

Risk Assessment: Moderate

Control Measures: All employees and visitors to the factory site are required to wear steel cap safety shoes at all times.

4. Forklifts

Risk Situation: Being hit or run over by a forklift and its contents.

Consequence: Serious

Likelihood: Remotely possible

Risk Assessment: Moderate

Control Measures: The forklifts are fitted with flashing amber lights. Education for employees about working around forklifts also signage around factory to let workers and visitors know of the risk.

5. Fire

Risk Situation: Breakout of fire within the factory or office.

Consequence: Very Serious

Likelihood: Remotely possible

Risk Assessment: Moderate

Control Measures: The use of security cards for workers to swipe on and off when entering and leaving the factory, this data registers to a computer which can then account for how many workers were on the site at the time of fire. Evacuation procedures are in place and safe areas displayed around the factory.