University of Southern Queensland

Faculty of Engineering and Surveying

Natural Gas Burner for Copper Smelter Converter

A dissertation submitted by

Clayton Harley Stansbie

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Project Abstract

The aim of this project was to investigate the best scenario for designing and installing a natural gas burner into the Peirce-Smith Converter. Initial data was reviewed on practices of different heating processes used in other converters and related devices. Development of heat balance models evaluated the heat losses during the various heating stages, which was achieved by using a 1D analytical analysis. The pattern of heat flow released inside the furnace for various burner positions was also analysed with the CFD software package Fluent. This information allowed for the optimisation and identification of the most economical and effective position for placement of the new burner.

An off the shelf burner was then decided on as it complied with Australian Gas Standard and was capable of handling the three different heating processes used in the running of the converters. Insertion and retraction of the burner system is outlined to achieve minimal downtime between roll outs as well, a maintenance schedule has been addressed in this project as working with combined spaces and explosive fuel can be a very dangerous combination.

With the placement of a natural gas burner the new converter furnace combustion system will assist in the improvement of the furnace temperature control, minimise the damage caused to the refractory which will inturn maximise the refractory life, minimise environmental effects and lower fuel expenses saving the company a considerable amount of money.

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ENG4111 & ENG4112 *Research Project*

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Clayton Harley Stansbie

Student Number: Q11205943

Signature

Date

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Glossary

RHF	Rotary Holding Furnace
LPG	Liquid Petroleum Gas
U.V	Ultra Violet
MIM	Mount Isa Mines Limited
WMCF	Western Mining Company Fertilizers Ltd
AQC	Air Quality Control
EPA	Environmental Protection Agency
AGL	Australian Gas Light Company
NG	Natural Gas
PS	Peirce-Smith
CFD	Computational Fluid Dynamics

Chapter 1:

Introduction

1.1 Project Background

In 1998 Mount Isa Mines constructed a natural gas pipe line giving the copper smelter access to natural gas as a cleaner and cheaper fuel source. The company's goal is to cease using diesel across the site and convert their heating processes to natural gas due to the cost savings to be gained and to minimise environmental effects. Introducing natural gas as a replacement to diesel should see a significant reduction in the damage to the environment and health risk to the public. Natural gas, in itself, maybe considered a very uninteresting gas - it is colourless, shapeless, and odourless in its pure form. Quite uninteresting - except that natural gas is combustible, and when burned it gives off a great deal of energy, approximately $40MJ/m^3$ where as diesel give of approximately 44MJ/kg. Natural gas is mostly made up of a gas called methane. Methane is a simple chemical compound that is made up of carbon and hydrogen atoms. Its chemical formula is CH_4.

Unlike other fossil fuels, however, natural gas is very clean burning in that it emits lower levels of potentially harmful by-products into the air. Composed primarily of methane, the main products of the combustion of natural gas are carbon dioxide and water vapour, the same compounds we exhale when we breathe.

1.1.1 Copper Smelter Process

The Copper Smelter process begins with the ore being fed into the Isasmelt furnace by large conveyor systems. The Isasmelt furnace is a submerged lance smelting process that smelts the ore into a molten liquid form called 'MATTE' which is made up of copper, Iron and sulphur. The matte is then tapped from the base of the Isasmelt furnace and transferred into a Rotary Holding Furnace (RHF), where it is held at a specific temperature until the converters are ready to be charged. Charging the converters is done by filling large charge buckets with matte from the RHF and transferring them by overhead cranes that run up and down the copper smelter aisle. The converting process turns the matte copper into blister copper by removing the iron and sulphur through an oxidisation process. The blister copper that is left is now approximately 99.7 % copper. Blister copper is then transferred from the converters to the anode furnace where the rest of the Oxygen and Sulphur is removed to form anode copper which is now approximately 99.92% copper and ready for casting into copper ingots. The anode furnace blows natural gas into the melt to burn off the oxygen. At first, a tall yellow flame billows from the top of the anode furnace, but after a few hours it becomes a beautiful blue-green when most of the oxygen in the copper has been burned away. The colour chance is due to a chemical process that is undertaken in the anode furnace.

Casting the copper into ingots is the last stage of the copper smelter process at the Mount Isa site, from there they are transported by rail to Xstrata's Townsville operations for more processing. (See figure 1.1 – Flow Diagram)

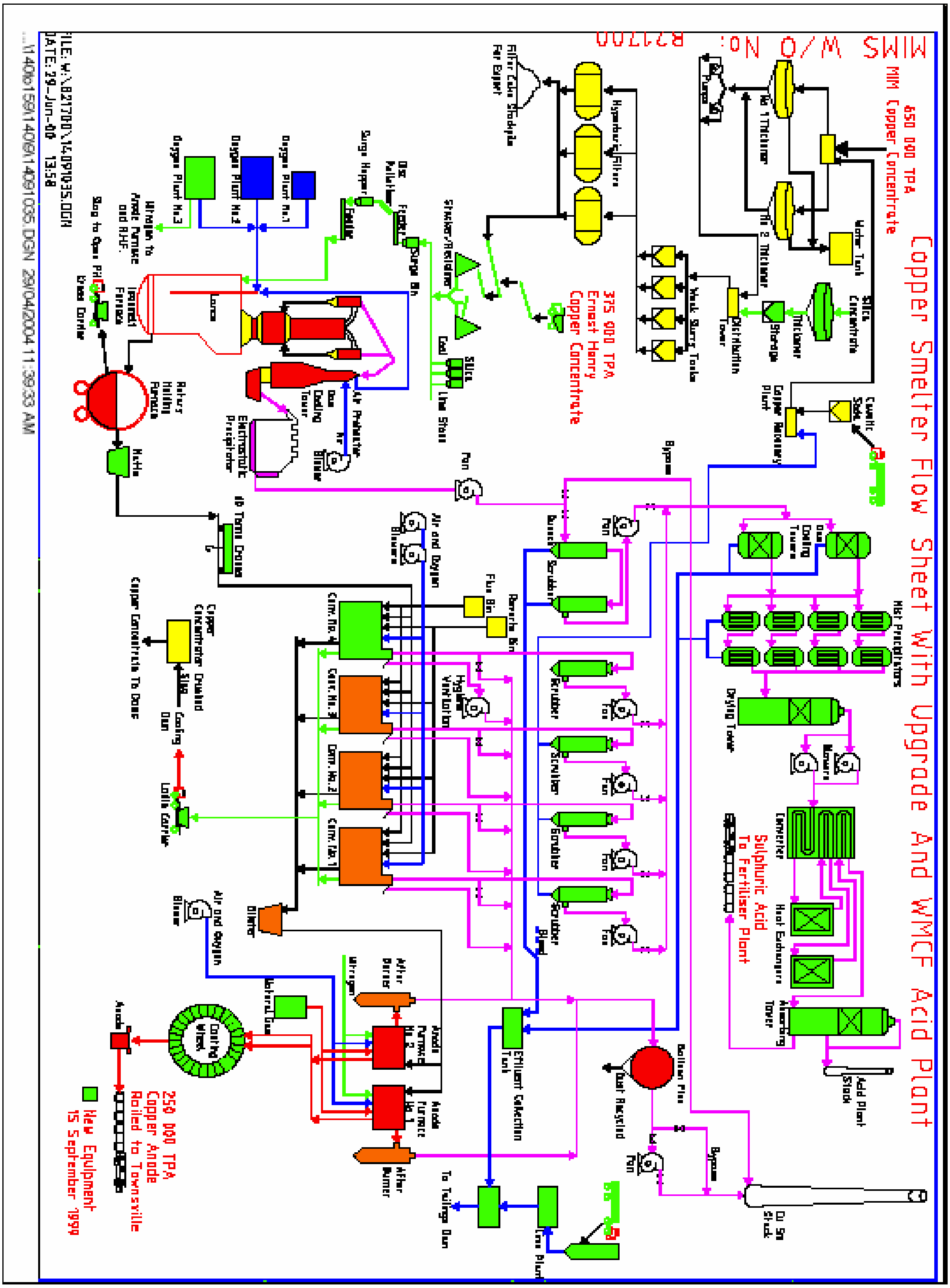

Figure 1.1: Flow Diagram of Copper Process

(Taken from Xstrata website www.xstrata.com.au, 2004)

Currently the anode furnaces have been changed to a natural gas heating system, but the converters are still using diesel as their main source of fuel. Heating in the converters is presently achieved by inserting a diesel spear in through the tuyeres and injecting distillate into the chamber. Tuyeres: A row of ball valves at the back of the converter used for blowing oxygen enriched air into the molten bath. (See figure 1.2). Temperature inside the vessel is usually high enough to maintain a flame.

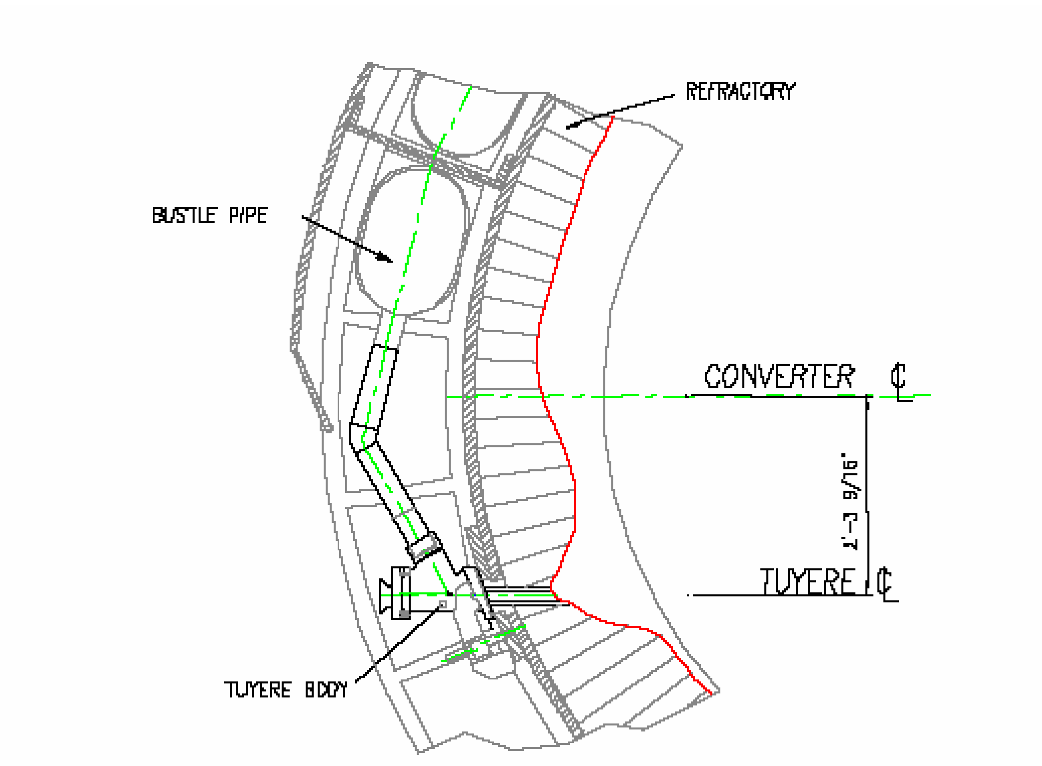

Figure 1.2: Tuyere design (Taken from Biswas, A. K. & Davenport, W.G, 1994)

1.1.2 Pierce-Smith Converter

The Converters referred to are Pierce-Smith type batch converters that have a capacity of approximately 290 tonnes. Pierce-Smith converters are supplanting reverberatory furnaces as the longest-serving mainstays of the copper smelting industry because of their efficiency in the converting process. However, technology advances seen elsewhere in smelting have not been made to the same extent in converting practices. The converter construction consists of a large barrel on rollers, approximately 10.5 metres long and 4 metres in diameter. The converters can be rotated about its axis and are fitted with 52 tuyeres arranged along one side of the vessel for injecting the oxygen enriched air into the bath just under the surface. The barrel is lined with refractory and operates at an average temperature of 1200 deg C. The top of the converter has a large mouth for charging molten matte and removing slag and product copper.
(See figure 1.3).

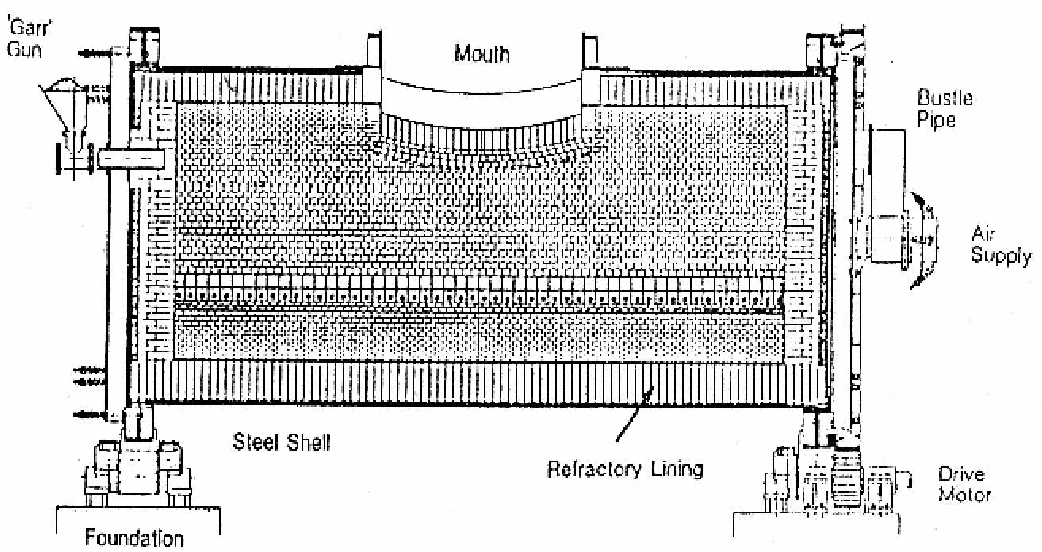

Figure 1.3: Pierce-Smith Converter
(Taken from Biswas, A. K. & Davenport, W.G, 1994)

In these vessels the matte copper (containing about 65% copper, 28% iron and the rest mostly sulphur) is converted to blister copper. This is accomplished by injecting oxygen enriched air, which bubbles violently through the bath, which gradually oxidises the matte during two stages. In the first stage which is called the slag-forming stage, iron sulphide is oxidised and fluxed with silica to form a fluid slag according to the following reaction.

$$2FeS(l) + 2SiO_2(s) + 3O_2(g) \rightarrow 2FeO \, . \, SiO_2(l) + 2SO_2(g)$$

The converter slag contains some copper (1 to 5% Cu). After all the iron has been removed, the remaining copper sulphide is further oxidised to blister copper by the following reaction:

$$Cu_2S(l) + O_2(g) \rightarrow 2Cu(l) + SO_2(g)$$

The reaction in the copper process is exothermic and normally does not require additional heat, but heat is required to maintain vessel temperature whenever the batch is being changed or when an interruption to production occurs. The blister copper from the converter is transferred by ladle to the anode furnace, where the residual sulphur and oxygen levels in the copper are reduced further.

1.1.3 Diesel Spear

Currently diesel spear burners are used to keep the converters at a controlled temperature. The diesel spear is inserted into a tuyere at each end of the converter and the diesel oil flow is adjusted to maintain the required temperature. A ratio of air/oil is automatically controlled to ensure the delivery of a clean hot flame.

The diesel spear is a simple design made up of a double tube arrangement, the oil travels through the inner tube and the combustion air travels through the annular area made by the outer tube. Diesel oil flows through a fine nozzle to disperse it prior to combustion. These burners are around 1 m long and 32 mm in diameter. (See figure 1.4)

Figure 1.4: Diesel Spear

1.1.4 Purpose of the Project

The purpose of this project is to optimise the design of a natural gas burner system for installation in the Peirce-Smith converters at Xstrata's Copper Smelter in Mount Isa. The natural gas burner system will be installed for the heating process in the converter and will be used during the three different heating stages needed to run the converters efficiently. These stages are: lid-off heating, lid-on heating and cold start-up heating.

1. Lid-off heating: This heating stage is required to keep the molten copper matte in the converter above 1100°C during short periods of time of up to approximately 1 hour, when the converter has been taken off line and the main heat process through the chemical reaction has ceased. During this period the lid is left off and most of the heat is lost through the mouth of the converter.

2. Lid-on heating: This heating stage is also used to keep the molten copper in the converter above 1100°C for longer periods of time. These periods range for longer than 1 hour when the converter has been taken of line and the main heat process has ceased. During this period the lid is placed over the mouth to limit the amount of heat lost.

3. Cold start-up heating: This stage of heating is used after a converter has been re-bricked and a new campaign is ready to be undertaken. Heat is added to the empty converter as the refractory material must be preheated to a required temperature before the addition of molten matte copper.

With changing to natural gas as the new fuel source, the new Converter Furnace Combustion System will be able to:

- Improve furnace temperature control
- Minimise refractory damage
- Maximise refractory life
- Minimise environmental effects
- Lower fuel expenses

This will be achieved by reviewing other heating processes and practices used around the world, calculating the heat losses through convection, radiation and conduction calculations and by analysis of the internal heat flow in the converter using CFD computer modelling software to simulate the different conditions. With all of this information, it will be possible to identify the most economical and effective option and decide on the best type of burner for this situation.

1.2 Changing to Natural Gas

The following report looks at the cost savings of changing from diesel to natural gas as a heating source.

1.2.1 'COPPER SMELTER CONVERSION TO NATURAL GAS'

The 'Copper Smelter Conversion to Natural Gas Report' was compiled in October 1997 by the Senior Project Metallurgist Peter Nevin and was issued to the Copper Smelter Manager. The purpose of this report was to evaluate the economic benefits for the conversion to natural gas and to recommend future direction and work required for this project.

Currently the Copper Smelter runs all of its burners on oil with the exception of the Anode Furnace where the casting launders and reduction cycle are run on LPG. Due to the installation of LPG the energy and operational savings have been calculated using naphtha. Naphtha is the complex mixture of volatile, liquid, inflammable hydrocarbons, occurring naturally, and usually called crude petroleum, mineral oil, or rock oil.

Table 1.1A outlines the current set-up of the Converters in terms of actual recorded usages and calculated energy rates.

Table 1.1B outlines the current and expected future costs of oil/naphtha in the Converters and expected future savings by converting to natural gas. The expected future savings for the conversion to natural gas is based on a 1:1 energy conversion of oil/naphtha to natural gas.

TABLE 1.1A: Current Oil and Naphtha usage – Basis 1995 – 1997

(Adapted from Nevin, P, 1997)

AREA	**No. Burner**	**No. Burners**	**1996/97 1995/96**	**Av/Max RATE Current**	**Oper Time Current**	**Av Energy-Current**
	Current	**Future**	**L/yr**	**L/yr**	**hrs/yr**	**MJ/hr**
Converters	2 Tuyere burners/ conv	2 Tuyere, 2 end wall, 1 mouth (alternative)	3059703 2618901	210/conv 420	3549/conv	8064 16128

TABLE 1.1B: Savings in the Conversion from Oil/Naphtha to Natural Gas.

(Adapted from Nevin, P, 1997)

AREA	**Current Oil/Naph Cost**	**Future Usage**	**Total Cost Oil/Naphtha (future)**	**Cost NG Basis 1:1 Energy**	**Future Savings (energy)**
	$/yr		**$/yr**	**$/yr**	**$/yr**
Converters	424990	incr 3 conv on line: 2 conv op + 1 conv 50% op, 50 % hot	664138	331007	333130
TOTAL SAVINGS					**$333 130**

Table 1.2 outlines the data used in the reports evaluations.

TABLE 1.2: Property Data (Adapted from Nevin, P, 1997)

FUEL	**ENERGY**	**DENSITY**	**COST $/L**
OIL	45.7 MJ/kg	0.84kg/L	$0.26/L
NAPHTHA	44MJ/kg	0.67kg/L	$0.28/L
NATURAL GAS	40MJ/m^3	0.68kg/m^3	$3.25/GJ

It was found from this report that further work was needed. This entailed approaching different burner suppliers such as Prior Industries and AGL to investigate off-the-shelf burner units that would be satisfactory for the converters.

1.3 Burner Positions

The following report mainly looks at three different areas for the positioning of the burners: Mouth, Tuyere and End-wall positions.

1.3.1 'Copper Smelter Converter Natural Gas Conversion Report'

The 'Copper Smelter Converter Natural Gas Conversion Report' was compiled in May 2003 by George Wood of MIPAC Pty Ltd and was issued to the engineering section at Xstrata. The purpose of this report was to evaluate the best position and type of burner to use in the converters.

The goal was to find the optimum temperature control for the converters during lid off, lid on, and start up whilst minimising capital and operating costs. MIPAC looked at three different options.

1 End-wall burner
2 Mouth burner
3 Tuyere burner

In their report they found that the mouth burner would be exposed to severe temperatures particularly when the converter tuyeres were being punched. Punching of the tuyeres involves driving a round bar down the length of the tuyeres to dislodge any solidified matte copper that may restrict air flow. By keeping the tuyeres unblocked the operators at Mt Isa are able to increase the process time allowing the removal of sulphur and iron. The emission of exhaust gases is at a maximum when the tuyeres are punched causing very high temperatures due to the turbulent condition in the converter. This would prevent any electronic equipment to be installed on the burners.

Putting the burner through the tuyeres was also found to be unsuitable as the diameter of the port hole was too small. To allow the required amount of gas through the tuyeres port hole, a greater diameter hole would be needed to meet the required heating.

Using the end-wall burner would incur significant splash from the matte if left in position during the converter ‘blow’ operation. Blowing of the matte entails oxidising the Fe (iron) and S (sulphur) by blowing O_2 (oxygen) enriched air into the matte copper through submerged tuyeres. But to overcome this problem a retracting system is needed and the end-wall hole plugged.

It is MIPAC’s suggestion that the end-wall burner would be the only option suitable for optimum temperature control. Taking into consideration the money lost in down time while the end-wall holes are being plugged and drilled, the belief is that there may be other options such as a lid burner position that needs to be analysed before a final decision is made.

1.3.2 Phelps Dodge’s Steve Lopez report to MIM’s Dave Cavanagh

The email was compiled by Steve Lopez from Phelps Dodge on the 30th October 1997 and sent to Dave Cavanagh at Mt Isa Mines. The purpose of the email was to outline how Phelps Dodge utilised natural gas for their converters.

Natural gas burners are only in use in stand-by periods during the converter’s campaign. They used to have 2 or 3 natural gas lances (raw gas) put through the tuyeres for stand-by periods. The only control present was a manual valve and there were no safety or flame detectors on the lances. Of course the inside temperature of the vessel was high enough to ensure combustion, but with poor quality. All the combustion air was coming from the mouth of the converter.

They now use retractable burners in the mouth of the converter to assure a high steady temperature during stand-by periods. Three burners have a “Y” shape to ensure proper heat dispersion into the vessel. The combustion air provided by the burner pipe is premixed with natural gas before arriving at the burner’s nozzles. The flame detection is provided by an infra red scanner which transmits a signal to the control panel that gives permission to open the safety valves and have fire when the temperature inside the vessel is at least 815ºC (this temperature is required to meet Canadian Gas Association requirements). To do so, the burners must be positioned into the mouth and a limit switch condition has to be completed. The maximum output of this system is around 5000kW. Modulation is possible as the operator activates a motor that drives both natural gas and combustion air at the same time.

For the preheating of the converters Phelps Dodge are using a mobile combustion system. This equipment is complete with combustion air blower safety valves modulating air and natural gas valves, control panel removable burner with U.V scanner and spark ignition.

This equipment is installed beside one converter’s ends; the burner is put in place through a hole in the converter’s end and lit in place. A PC programmable controller provides the modulation of the burner’s output as the dry out is being made. The maximum energy output of the combustion system is 3500 kW.

1.4 Project Aims and Objectives

The overall aim of this project:

> *'This project aims to optimise the design of a natural gas burner system for installation in the Peirce-Smith converters at Xstrata's Copper Smelter in Mount Isa.'*

The aims of this project have been outlined below with a view to obtaining each goal:

1. **Conduct research into information on the practice of different heating processes used in other converters and other related devices worldwide.** This involves an extensive database search using all relevant engineering sites.

2. **Develop a heat balance model for heat input required under the various conditions including cold start up; lid off; lid on;** Using heat transfer calculation for conduction, convection and radiation the relevant heat energy's will be found.

3. **Estimate the pattern of heat release inside the furnace for various positions of the proposed gas burner.** This will be achieved through suitable extension of the heat balance model using the CFD software package Fluent.

4. **Identify the most economical and effective position to place the burner/s in the converter.** After all this information is found, it will be then possible to identify the most economical and effective option and decide on the best type of burner for this situation.

5. **Design an insertion and retraction system for the burner if required.** With the optimum position decide on an insertion and retraction system will be designed.

6. **Design a maintenance schedule for the burner system.** From manufacturer's information as well as research on other burners will be reviewed to design a appropriate schedule.

Further objectives may be added as new challenges and unforseen circumstances arise during the course of this project.

Satisfying all of the projects objectives will ultimately enable the project to reach the paramount goal of the design and installation of an efficient and effective natural gas burner.

1.5 Dissertation Overview

Relevant information and studies have been researched on the heat processes and practices and are presented in the Literature Review (Chapter 2). Chapter 3, project methodology outlines the course of action that will be undertaken by following a set of different procedures. Converter properties and operations are outlined in Chapter 4 & 5 to allow an overview of the conditions that the converters are subjected to. Estimation of the heat released during three different burner positions using different analytical tools such as heat balance models and CFD software are reviewed in Chapter 6. Chapter 7 looks at the results attained by the previous analysis and discusses the results. Burner design and maintenance schedule are outlined in Chapter 8. Concluding the project with a recommendation to implementing a natural gas burner, a brief summary of the project and an outline of some further work that can be looked at in the future are reviewed in Chapter 9.

Chapter 2:

Literature Review

2.1 Introduction

Many sources were reviewed during the search for information, even an extensive database search using all relevant engineering sites was used to find different heating and cost saving gains for the change to natural gas. Because of the lack of information on converters and other related heating, Mount Isa Mine documentation was consulted to ensure that the project work was relevant to the host company. This section lists literature sources that have been reviewed and found to be satisfactory in their content.

Fundamentals of Machine Component Design *(Juvinall & Marschek 2000)*

This text offers insight into broad considerations for any engineering project and is also a good reference for technical information relating to design. A quote in reference to safety is:

> *"The important first step in developing engineering competence in the safety area is cultivating an awareness of its importance."*

The Engineering Design Process *(Ertas & Jones 1996)*

This text provides information on the design process, cost analysis, optimisation, safety and communications. In reference to the design process:

> *"It is at the beginning of the design process, during the conceptualisation phase, that it is most important to consider alternative solutions."*

Research Methods for Postgraduates *(Greenfield 2002)*

This text provides information on research methods and on technical writing style and presentation.

Modification of the Mount Isa copper converters to feed a new sulphuric acid plant *(Hollis & Werny 1999)*

This paper offers insight into broad considerations for the upgrade of the Mount Isa copper smelter engineering project and explains how they have increased productivity. A quote from the abstract is:

> *"In 1998 Mount Isa copper smelter was expanded to accommodate a capacity of over 250000t/yr of anode copper which has increased from the previous rate of 200000t/yr. This new tonnage rate would be produced from a single stream consisting of an Isasmelt furnace and four Peirce-Smith converters."*

Refractory Performance in Peirce-Smith Converters at BHP *(Gonzalas, Rigby &Pasca 1999)*

This paper offers an insight into how BHP copper has improved there refractory life through uniform temperature in their operating conditions. A quote from their abstract is:

> *"The refractory performance of Peirce-Smith converters is considered to be mainly determined by effects of process control and refractory installation design. BHP Copper has shown that, over the last four years, considerable improvements in tuyere line life can be affected by maintaining a uniform temperature in the operating converter and by ensuring sufficient and specific placement of expansion allowance in the construction of refractory brick work."*

Refractory Performance in Peirce-Smith Converters at SPCC–ILO Smelter *(Suarez & Alvarado 1999)*

This paper offers an insight into how SPCC-ILO Smelter has improved their refractory over the past four years. A quote from their abstract is:

> *"The refractory performance in Peirce-Smith converters is determined by factors such as refractory quality, refractory installation design and operation process control. This paper describes the evolution of the PS converter campaign life throughout the past four years and discusses the process control and refractory installation design changes that have been made in order to extend the PS converter campaign."*

2.2 Literature Summary

The literature review was conducted to gather relevant information on different heating and cost saving gains for changing to a natural gas heating process. Although this review has discovered many different options, by optimising the heat flow using heat flow calculations and CFD diagrams for the Peirce-Smith converters at the Mount Isa site, identification of the most economical and effective burner for their heating processes will be found. The next chapter will outline the methods required to achieve a comprehensive result for a burner system in this project.

Chapter 3:

Project Methodology

3.1 Introduction

Project methodology investigates the methods that have been used to achieve the aims and objectives of this project. Each identified objective needs a clear plan that works towards fulfilling the project satisfactorily. Project planning and methodology is needed to allow for an efficient and effective analysis of any project. The plans for achieving these goals are detailed in the following sections.

3.2 Methodology Process

The methodology in place for this project entails many different areas. Knowledge and skills that have been gained during a four year Bachelor of Engineering degree have played a very important role in the undertaking of this project. By utilising this knowledge the project has be viewed in a professional engineering manner. During this project, CFD computer software Fluent had to be learnt to gain extra engineering skills that could be accessed as one of the tools needed to complete the analysis for an accurate result on the heat flows through the converters. A list of the steps is shown below:

1. The first stage entailed the review of literature, research and different methods of the heating processes and practices that are currently in use or have been a topic of research at some stage. To complete this task the involvement of different search engines and tools was undertaken. The internet and library were the main tools of choice, but other tools were accessed to extract the relevant information. The main goal at this stage was to gain a good knowledge of the project which will enable a solid base to start.

2. Development of a heat balance model is undertaken to estimate the heat input required in the converter under the 3 heating conditions. The conditions include the period when the converter is heated from ambient temperature to a satisfactory running temperature and also with the heating of the matte copper during periods when the lid is on or the lid is off the converter mouth. Heat transfer calculations allowed for the identification of the energy that will be lost from the matte and to confirm the amount of energy that is needed to restore the required temperatures.

3. Optimising the 3 different heating scenarios with the CFD software program Fluent. The temperature graphs that are produced, allowed an evaluation for the best position of the burner system. Once the CFD program had found the required information, it was analysed in conjunction with the heat balance models to evaluate the required heat energy needed for each heat process.

4. A position of the burner was chosen from the heat balance and CFD information, and an evaluation of whether it was to be manually or mechanically positioned was considered. For a mechanical positioning system of the burner, an insertion and retraction mechanism was to be designed to allow quick turnover periods for the heating process. Knowledge for this design would be drawn from many different courses that have been completed in a four year Bachelor of Engineering degree.

5. Australian Standards for natural gas burners was reviewed and followed to ensure safe practices in the design and operation of the system. The required gas standard allows a specific level of work to be completed in the knowledge that the designs will coincide with Australian regulations.

6. If time permits a maintenance schedule will be designed for the burner system. This will help with the upkeep and running of burners, which will enhance the life and cut the risk of any unforseen hazards taking place.

3.3 Communication Network

The communication network must provide an effective means of communication between the following parties:

- The project supervisors
- Refractory suppliers
- Gas inspector
- Commercial burner companies

Where such communication involves decision-making or other important data, it must be easily recorded.

To address these communication needs the following methods will be utilised:

1. **Supervisor Meetings.** Meetings were held weekly between the project supervisor and myself.

2. **Email**. Email is the preferred medium for all other significant communication. It proved to be easily monitored and very quick when relaying information, especially between my supervisor in Mt Isa and myself, due to the great land distance between us.

3. **Phone lines.** Phone lines were also used for communication between parties. This process was mainly used for clarification on different ideas and allows for a one on one discussion between two parties.

3.4 Goal Formulation

Goals are an important part of any project as they give focus and direction to each task. It is easy to lose perspective on a problem when looking only at the details. Goals are a standard to which decisions can be compared. Each decision made should bring the project closer to attaining its goal.

The most significant goal was to optimise a position for the natural gas burner that will enhance the time between re-bricks in the converter. Other goals that had been identified for the natural gas burner are:

- Improve furnace temperature control
- Minimise refractory damage
- Maximise refractory life
- Minimise environmental effects
- Lower fuel expenses

Further goals may be developed over the course of the project. After project completion these goals will provide a standard for which to evaluate the heat up processes in the future.

3.5 Methodology Conclusion

A good methodology map was essential to establish the correct course of action needed to complete this project. Many different methodology steps could have been used to approach a project such as this, but the steps that were undertaken were aimed at creating a good knowledge base that allowed the correct analysis to achieve a sound result in the end. The methodology map shows a well documented path as well as the communication process used in this project. Having good documentation and communication practises assisted an effective process in working towards the light at the end of the tunnel. Benefits from a good methodology include identification of gaps in current knowledge, the identification of possible solutions to particular problems and to clarify the precise areas in which existing ideas apply.

Chapter 4:

Design Parameters

4.1 Introduction

Converter properties and conditions must be taken into account to give an accurate analysis for the calculations that are needed to show the heat transfer through the vessels. Particular attention is drawn to the extreme high temperatures frequently experienced in the region and must be taken into account. As well as site condition parameters, the properties for the matte copper, refractory and the steel outer shell will be reviewed and taken into account. Some of the parameters outlined in the chapter are the climate conditions, process conditions, natural gas properties and natural gas supply to the copper smelter. The data obtained from the following charts will be useful for the development and understanding of the conditions surrounding the design of a natural gas burner system.

4.2 Site Conditions

Ambient conditions in the project area are arduous. The frequency of the extreme high temperatures of mid to high 40ºC in Mount Isa needs to be taken into account.

4.2.1 Climate

The tables below look mainly at the climate conditions in Mt Isa with a main consideration on the pressure, rainfall and humidity that are achieved through a normal year. Also the wind conditions and main airborne properties that are released by the smelter have been reviewed. (See table 4.1)

Ambient Temperatures (shade temp)	**Max**	**Min**	**Ref**
Annual averages	31.4°C	17.8°C	MIM
Extremes	45°C	1.7°C	MIM
Design ambient	45°C	1.7°C	MIM
♦ Equipment operating outdoors in direct sunlight shall be designed for a 'black body' temperature of 78°C			
Ambient Pressure	**Ave**	**Min**	**Ref**
Ambient variation (abs)	97kPa	95kPa	MIM
Rainfall	**Max**		**Ref**
Average yearly rainfall	369		MIM
Average number of wet days per year	54		MIM
Relative Humidity	**9:00 AM**	**3:00 PM**	**Ref**
Overall average	38%	21%	MIM
Highest mean	53%	23%	MIM
Lowest mean	29%	12%	MIM
Wind			**Ref**
Terrain Category	2.5		MIM
Return Period	50 years		MIM
Basic Design Wind Velocity	41 m/s		MIM
Main Airborne Impurities	**Max**		**Ref**
SO_2	6000μg/m^3		MIM
CO	40μg/m^3		MIM
Hydrocarbons	160μg/m^3		MIM
NO_x	160μg/m^3		MIM
Airborne dust average (<10 μm)	900μg/m^3		MIM

TABLE 4.1: Site climate conditions at Mt Isa mine site.

(Adapted from Wood, G, 2003)

4.2.2 Process Conditions

The converting process at Mt Isa consists of 4 converters. Converters 1, 2 & 3 are the original vessels that were installed when the copper smelter first went on line, but converter 4 is a newer vessel and is slightly larger than the original vessels. Below are the details of the quantity of matte used in the converters and the duration of the converting process. (See Table 4.2)

Converter	Typical	Des. Max	Ref
Isasmelt matte to converter 4	200 t/charge	225 t/charge	MIM
Isasmelt matte to converter 1,2 & 3	175 t/charge	200 t/charge	MIM
Cu content	62% w/w		MIM
Approximation of ladles per charge	8		MIM
Duration of Charge	7-9 hrs		MIM

TABLE 4.2: Process conditions at Mount Isa mine site.
(Adapted from Wood, G, 2003)

4.2.3 Natural Gas Supply

Natural gas is supplied to the copper smelter through a pipe line that was constructed in 1998. This has allowed the copper smelter to access natural gas as the primary heat source. Below are some important properties that are required for the design of new natural gas systems. (See Table 4.3 & 4.4)

Natural Gas Properties	Typical	Ref
Temperature	25℃	MIM
Gross heating value	36.8 MJ/stm^3	MIM
	50.2 MJ/kg	MIM
Specific Gravity (air = 1)	0.628	MIM
Stoichiometric air : gas	9.91 Vol/Vol	AGL

TABLE 4.3: Natural Gas properties (Adapted from Wood, G, 2003)

Natural Gas Supply	Typical	Des. Min	Des. Max	Ref
Supply pressure to MIM			2700 kPag	MIM
Total supply to Cu smelter			6.7kg/s	MIM
	31188stm^3/hr		31393stm^3/hr	MIM
Furnace operating temperature	1200℃	1150℃		MIM
Natural Gas flow to converter	420stm^3/hr	50stm^3/hr	600stm^3/hr	MIM
Air : Gas ratio's	9.5:1 m^3:m^3	9:1 m^3:m^3	10:1 m^3:m^3	MIM

TABLE 4.4: Natural Gas supply to Mount Isa mine site.
(Adapted from Wood, G, 2003)

4.3 Converter Properties

The properties of the different materials used in the converters must be taken into account to allow for accurate heat transfer calculation to be achieved. The converters are made up of two different materials, the outer shell which is made from 0.5% carbon steel and the refractory which is used as insulation between the steel and the matte copper. Properties of the matte copper at approximately 1200°C are to be taken into account in our calculations also.

Refractory

Current refractory being used in the Pierce-Smith converters at Mount Isa Mines is RADEX DB605B. This refractory is a Magnesia-chrome brick, high fired, direct bonded with 55% fused grain content, low porosity, very good temperature shock resistant and also slag resistant. Its main applications are used in the cement and lime industry and non ferrous metal furnaces. Properties for the refractory have been taken at 1200°C as this is the average temperature found in the vessels. (Table 7 shows the relevant refractory information; see Appendix C for RADEX DB605B)

Steel Outer Shell

The outer shell of the converter is made from a 36mm steel plate that has a carbon content of approximately 0.25 - 0.45%. It must be of good quality to sustain the harsh environment that it must endure during the converter processes.

Matte Copper

The matte copper is the product taken from the Isasmelt furnace which is the first stage of the smelting process. It is made up of 65% copper, 28% iron and the rest mostly sulphur. (Table 4.5 shows the relevant matte copper properties at 1200ºC)

Material	Cp	k	ρ	ε	β	α	Outside Diameter	Inside Diameter
Refractory @ 1200ºC	1204 J/kg.K	2.6 W/m.K	3270 kg/m^2	0.8			3.968 m	3.028 m
Steel @ 160ºC	519 J/kg.K	53.2 W/m.K	7872 kg/m^2	0.8			4.04 m	3.968 m
Matte Copper @ 1200ºC	460 J/kg.K	163 W/m.K	7850 kg/m^2	0.85	24.8×10^{-6} 1/K	4.5×10^{-5} m^2/s	4.04 m	3.968 m

TABLE 4.5: Properties of the converter materials

4.4 Design Parameters Summary

The design parameters were reviewed to gather information on the different properties and conditions that the converters are subjected to during normal running. These conditions can play a crucial role in the design of a natural gas burner system as it can change the amount of heat energy needed to run the converter process efficiently. The next chapter reviews the operations of the converter and looks at the periods that the converter can be 'held' for.

Chapter 5:

Converter Operations

5.1 Introduction

In the Xstrata copper smelter when converter operation is ‘held’ a burner is used to maintain furnace temperatures of approximately 1200°C. This chapter discusses the process operation and control of a single air/natural gas converter burner system. This description will be equally applicable to all converter burner systems at the Mt Isa copper smelter.

5.2 Natural Gas Burner System

When using natural gas burner systems there are a number of statutory obligations which must be met. These standards are stipulated by the Australian Gas Association. Each converter will possess a natural gas burner system to be used during the heat stage of the converting process.

The primary functions of the converter burners are:

1. At the end of a ‘campaign’ the furnace is cooled to ambient temperatures and the refractory lining is replaced. On completion of the refractory repair the burner is used to heat-up the refractory from ambient to operating temperatures above 1100°C the furnace so that it can continue operating. For an empty furnace, rates of heat-up (from ambient) between 2.5°C/hour and 30°C/hour must be achievable.

2. When the furnace is in operation the burner runs for approximately 6 hours per day. To maintain or increase bath temperature the furnace operating temperature must be keep above 1100°C. For a furnace containing up to 200T of molten copper matte, the burner must also be capable of operating within a range of 2.5°C/hour and 30°C/hour.

The burner will operate at sub-stoichiometric air to natural gas ratios of approximately 9.5:1, as allowed by statutory requirements.

Converter heat-up from ambient temperatures may be undertaken jointly by a wood fire and by the use of the natural gas burner. This is done to minimise the risk of brick damage through thermal shock in the event of a flame failure occurring. As well the new refractory will need to be heated at a range of set temperatures for set periods of time to remove moisture in preparation for the new campaign; this heat-up curve will be discussed in Chapter 6.

5.3 Flow Control

The ‘firing rate’ for the combustion system will be set by the operator of the converter. The setpoint will be a percentage of an arbitrary design maximum for natural gas flow, to be determined during commissioning. Once the firing rate has been set the combustion air flow rate is regulated by the flow control valve.

Combustion air flow rate = “firing rate” setpoint x max NG flow stm^3/hour x “air:gas” ratio.

The “air : gas” ratio is the combustion air to natural gas mixture required to ensure combustion. This is nominally set to 9.5:1. The air to gas ratio has three (3) operator activated setpoints:

- Lean flame, ratio = 10:1 (high air)
- Normal flame, ratio = 9.5:1
- Rich flame, ratio = 9:1 (low air)

If desired, a max natural gas flow setpoint can be inserted to limit the maximum firing rate. This setpoint is not operator accessible.

5.4 Fuel Consumption

The converters are normally fired by two diesel spears that are inserted into the tuyeres. ‘Fuel consumption is approximately 90 L/hour each at the higher rate (with lid off – short term condition of insufficient matte). In a longer term interruption the lid will be placed over the converter mouth and the usage will drop to 60 L/hour. Converter gas usage will therefore be about 300 Nm^3/hour (2.5MW) at the highest and 200 Nm^3/hour (1.7 MW) at the lower rate.’ (Borthwick 2004).

At present the converters are running about 25% of the time with four (4) converters in service. During AQC three converters are rolled out and may all require the full 300Nm^3/hour depending on the stages that the converters are at. The holding time of the converters is approximately 3 days per month. Below is a table that looks at teh fuel consumption data for 4 different areas in the copper smelting process. The relevant information for this project applies to the converters only. (See Table 7)

LOCATION	Fuel Usage l/yr	Cost, c/l	Heat Value TJ	Present Cost, $	Gas Cost @4000/TJ	Gas Cost @8000/TJ	Savings (lowest) $	Savings (highest) $	Est Cost to convert $
Rotary Holding Furnace	1,299,258	36	24.26	$467,733	$97,040	$194,080	$273,653	$370,693	$1,000,000
Converters	524,468	74	20.13	$388,106	$80,520	$161,040	$227,066	$307,586	$400,000
CIP Standby burner	182,500	36	7.01	$135,079	$28,025	$56,049	$79,030	$107,054	$80,000
CIP Heat-up Burner	19,200	36	0.74	$14,211	$2,948	$5,897	$8,314	$11,263	$50,000
TOTALS	2,025,426			$1,005,129	$208,533	$417,066	$588,063	$796,596	$1,530,000

TABLE 5.1: Fuel Consumption Data
(Adapted from Borthwick, I, 2004)

Using the three (3) days per month and 50% of this time is at the full firing rate, gas usage per converter is estimated to be 300 Nm^3/hour x 73 hours x 0.5 plus 200 Nm^3/hour x 72 hours x 0.5 which works out to be 18 000 Nm^3. At 23.3 MJ/std m^3 this is equivalent to 5.03 TJ per year per converter, or 20.13 TJ per year for all four converters. Present fuel cost of the converter is approximately $388,106. Changing to natural gas will have a potential saving for the converters of between $80,520 and $160,040 per year.

5.5 Converter Operation Review

The converter operation chapter has outlined some of the financial benefits for changing to natural gas as well it has reviewed the time periods that the converters may be 'held' or rolled out for during normal running. Estimates of the heat losses are reviewed in the next chapter using heat balance models and CFD software along with an overview of the most effective positions for the placement of the burner system in the converter.

Chapter 6:

Heat-Flow Analysis

6.1 Introduction

A position and heat-flow analysis for the natural gas burner system in the converter is out-lined in this chapter to identify the heat flow and losses during roll out periods. 1D analysis and a 2D analysis using the CFD software Fluent was used to evaluate the different heat balances. This information will reveal where most of the heat energy is being lost in the system as well as to see how the heat is distributed through the converter for various positions of the burner, so a decision about the most suitable burner position can be made.

6.2 Position Analysis

There are three recommended positions for the burner. Looking individually at each position there seems to be some pros and cons to consider and by reviewing them, an optimum position would be unveiled. The three position recommended are the tuyere, side wall and mouth. Other areas were not reviewed as the placement of a burner in another area, other than the three stated would require the removal of refractory which would then decrease the performance of the converter.

6.2.1 Tuyere

Currently the converters are being heated through the tuyeres for the various heating processes as stated in the Chapter 1. To maximise the performance of the heating conditions it was found that the tuyere positioning was restricted in some areas. With only an inlet diameter of 0.030m and a length of approximately 1.2m, it makes it very difficult to increase and decrease the excess air rates that are needed to vary the temperatures especially for cold start-up heating. This restriction on the other hand works well with the heating of the matte copper during roll out periods. Another problem exists with insertion and retraction of a tuyere burner. The tuyere is used also as an access for unblocking the O_2 pipe. A process called punching is used to achieve this. It requires a long rod which is forced down the length of the pipe and removes any obstacles. This means that the burner would have to be inserted and retracted manually, so that it is not in the road of the punching device. Positioning of a natural gas burner through the tuyeres would be good as a back-up heating device but does not prove to be the optimum choice for maximum performance. (See figure 6.1)

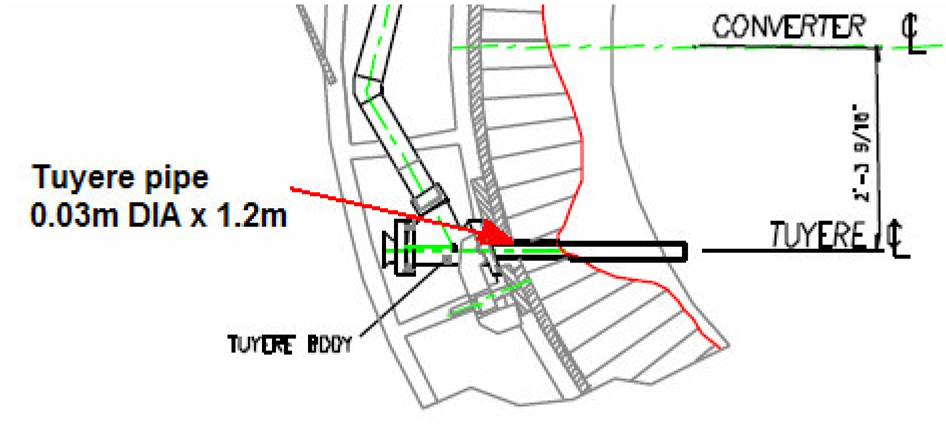

Figure 6.1: Tuyere pipe (Taken from Biswas, A. K. & Davenport, W.G, 1994)

6.2.2 Side Wall

Positioning the burner in the side wall would also pose some problems. During normal running of the converter the exothermic heating process causes the matte and exhaust gases to become very turbulent in the chamber. To place a burner in the side wall would require an insertion and retraction system to keep the burner out of the chamber when not in use. The hole, in which the burner is inserted, will have to be plugged up with refractory when not in use to stop the matte copper and exhaust gas escaping. Then to reinsert the burner, the refractory would have to be redrilled to allow access. This process can be used efficiently in maintaining the temperatures but for the time taken to insert and retract the burner would make it uneconomical to the company. (See figure 6.2)

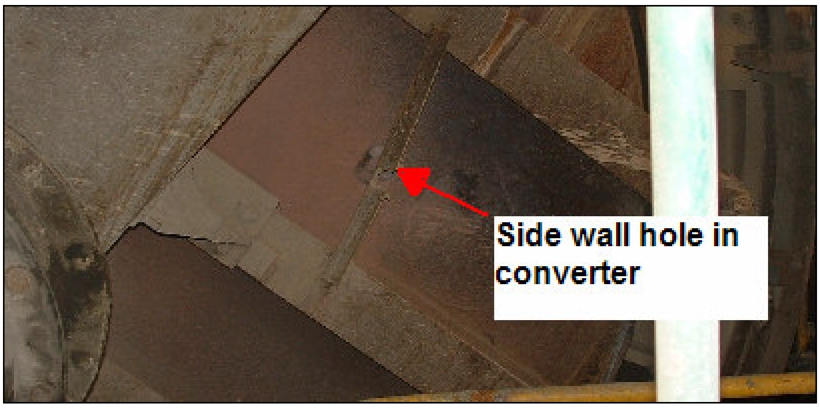

Figure 6.2: End wall position for a Peirce-Smith Converter

6.2.3 Converter Lid

By placing the lid over the mouth, it is assumed that the heat energy lost would be reduced from having the mouth open to the atmosphere. By positioning the burner in the lid and using it for all three of the heating processes lid-off, lid-on and cold start-up, the energy lost would be at the minimal amount, this would save on the energy required to be put back into the system. This position would also make it easier for the mounting of a burner which can work at different excess air rates. As most of these burners are approximately 100mm in diameter and require a bit more of an area than the tuyere and end wall can offer, the lid mounting is the position that will gain best performance. Figure 6.3 shows the best position available for placement in the lid. (See figure 6.3)

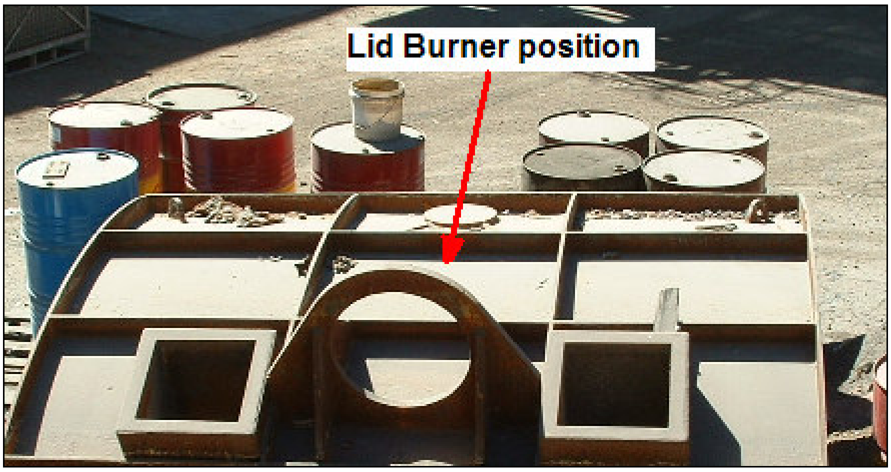

Figure 6.3: Peirce-Smith Converter lid

6.2.4 Position Analysis Review

The optimum position based on the previous discussion seems to be in the converter lid as this area would provide the most economical and efficient position for the burner to be used during all stages of heating. Mounting the burner in the lid will also open up the option of placing it at different angles if required and if more than one burner is needed, there is still plenty of room to place another one or two.

6.3 Different Heat Settings

Heat models for lid-off, lid-on and cold start up are reviewed to analyse the different amounts of heat loss during these conditions. Comparing the heat balance models to each other will show how the heat energy can be decreased, allowing the system to stay hotter through the heating processes.

6.3.1 Lid-off heat balance

Conducting a heat balance using 1D analytical analysis for the case when the lid is off, has revealed many different areas from where the heat energy is being lost. Natural convection from the matte to the chamber air shows that there is only a small amount of approximately 2.8 kW of energy lost, as there is little temperature difference from the surface of the matte to the air at the top of the chamber. Conduction, convection and radiation through and from the shell also show various amounts of energy being lost. Convection for the outer shell has a loss of 55.8kW. (Heat Transfer Calculations, Appendix B) The highest amount of energy leaving the vessel is in the form of radiation from the mouth at 1683kW, the next highest is also from radiation from the outer shell at 178.5kW. To put it in perspective the outer shell has a surface area of 160.18m^2 and the mouth has a surface area of 7.06m^2, meaning that the biggest heat loss comes from the mouth of the vessel as there is approximately 1683kW of heat energy leaving the mouth. (See figure 6.4)

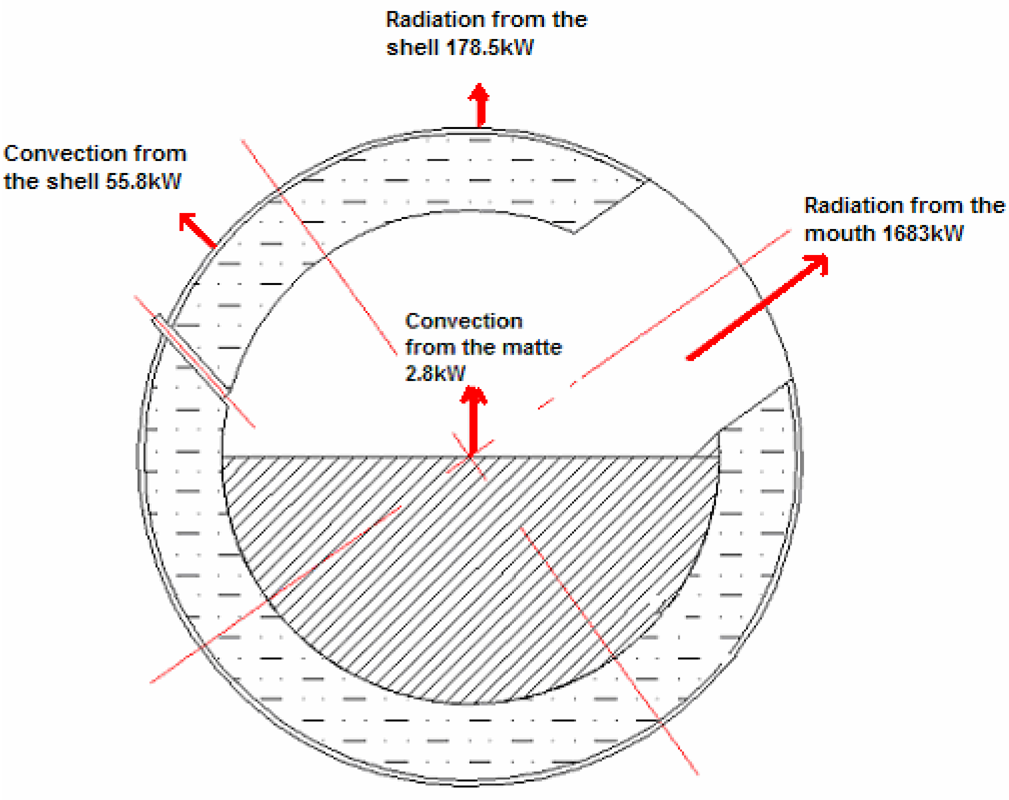

Figure 6.4: Lid-off heat balance

6.3.2 Lid-on heat balance

The heat balance diagram of the lid-on scenario below shows the same heat losses as for the lid-off scenario with one major exception. With the placement of the lid over the mouth of the converter the energy losses through the mouth are reduced drastically from 1683kW to 383.6kW. (Heat Transfer Calculations, Appendix B) This inturn is keeping the heat inside the vessel and minimizing the energy needed to achieve the required temperature during the heating process. (See figure 6.5)

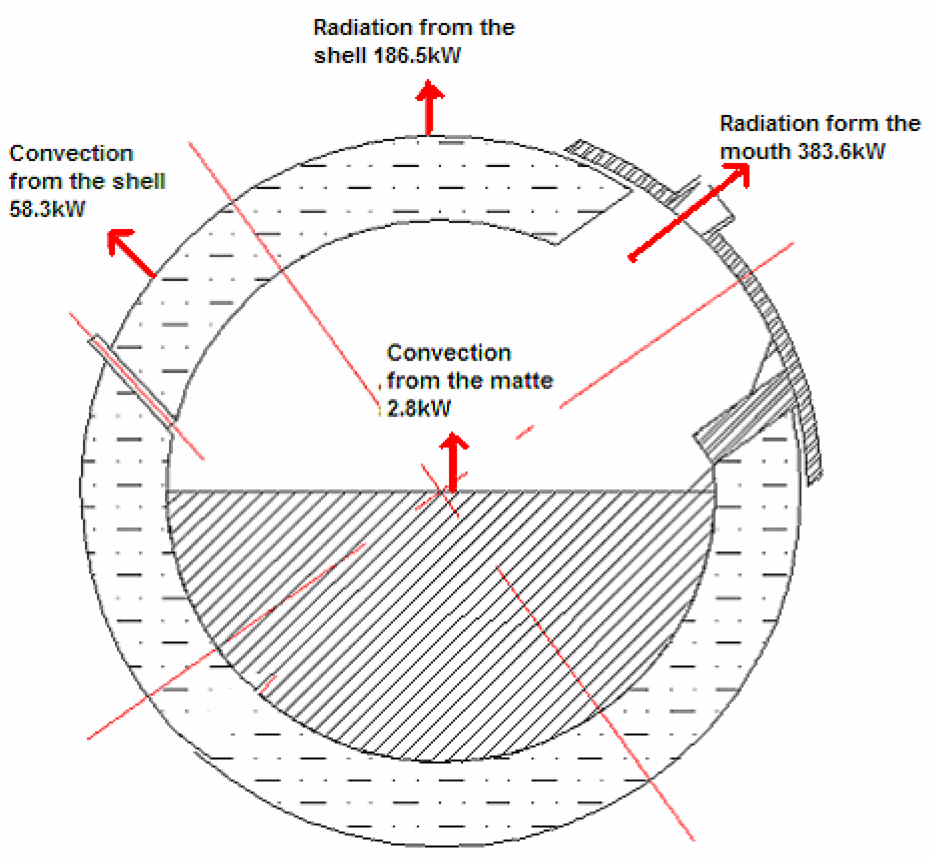

Figure 6.5: Lid-on heat balance

6.3.3 Cold start-up

At the beginning of a new campaign the refractory that has just been replaced needs to be cured for a required period of time. This is done to remove the moisture from the bricks and mortar and to prepare the new refractory lining for the molten matte copper. The refractory walls in the furnace interior have a much greater surface area than that of the matte copper. They also have a very high heat capacity therefore, initially, a significant portion of furnace heat-up time, approximately 12 hours is needed to cure the refractory.

RHI refractory is a company in England that have done a great deal of research into the preparation and life of their refractory. The diagram below shows a heat-up curve for the anode furnace's at the Mt Isa copper smelter. This process is followed so that thermal expansion of the refractory is undertaken to eliminate the initial shock from a sudden change in temperature. Because the anode furnace is a larger vessel than the converter, the heat-up period runs for 72 hours, the converter heat-up process will only run for short period's of time, approximately 12 hours as there is less surface area to heat up. Due to the on going work that RHI refractory is doing on the converters it was not possible to access the heat-up curve. The converter process is done along the same lines as the anode heat-up curve and can be viewed in the same way. By reviewing the data below we can see that the burner system will have to be able to produce a range of different temperatures which will be held for different periods of time. (See figure 6.6)

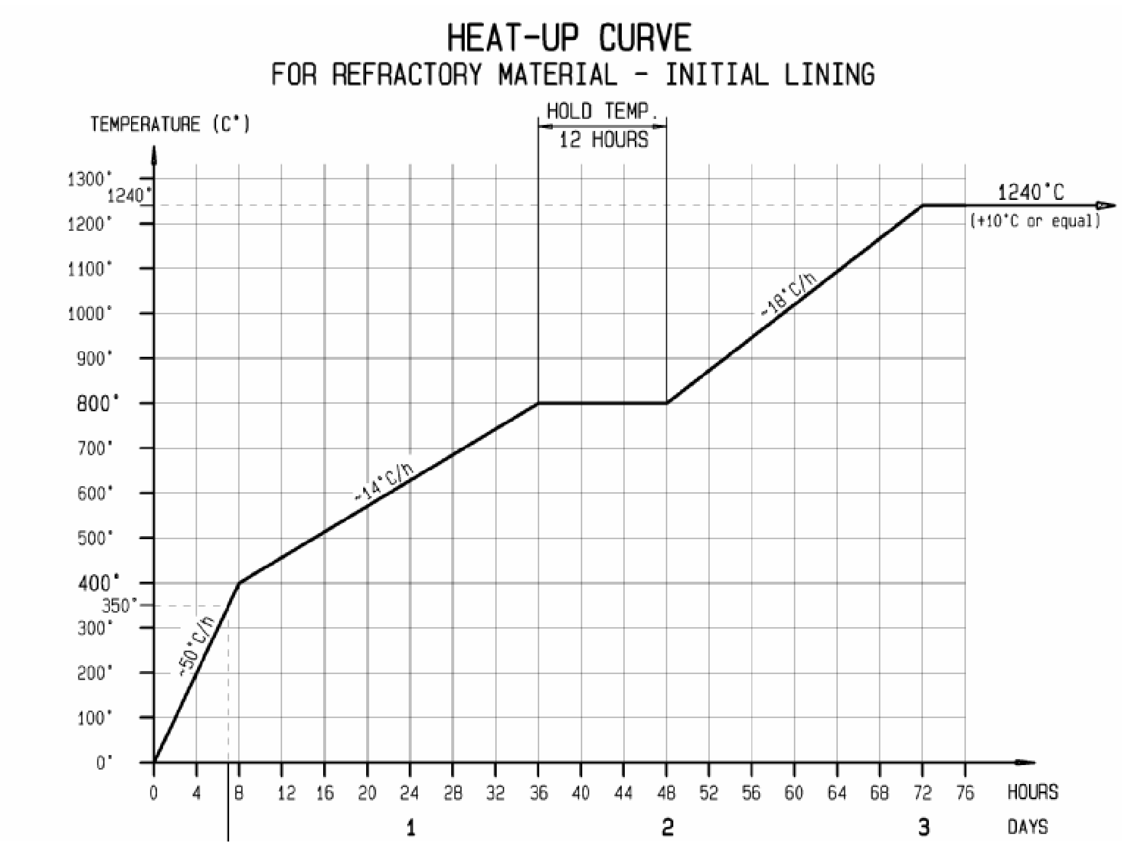

Figure 6.6: Anode furnace heat-up curve.

6.4 Transient Heat Conduction

During the transient heat conduction a time period must elapse after the heat transfer process is initiated before a steady-state condition can be achieved. Results for transient calculations in this case were taken over a time period of 1 hour as this is the period used for lid-off conditions on the converter. After checking the Biot number it was revealed that the lump capacity method could be used, as Bi<0.1. Reviewing the lump capacity method found that the heat energy lost from the system was calculated at 80592.433 kW, while the temperature dropped from 1200ºC to 40ºC. To check these results the transient calculations were then calculated using the charts from Kreith, F. & Bohn, M. (2001), these results show a different outcome as the heat losses were only 3604.187 kW, this is a lot less compared to the lump capacity method. Also the temperature only dropped from 1200ºC to 1176ºC, this also proved that there was a lot less heat leaving the matte, which is outline by the two different transient calculations. Because of the different results found, it was assumed that theses calculations were not suitable for larger components such as the converter. The feeling for the temperature drop over 1 hour before the calculations were reviewed is that the outer area of the matte will loss some heat but the centre of the matte could stay 1200ºC for days this is why the calculations assumed above were inaccurate. (Transient calculations, Appendix B)

6.5 Heat Balance

To analyse the different heat transfer conditions from the matte copper, steel outer shell and refractory lining the following equations are used.

The heat transfer due to conduction through the vessel wall is estimated as follows:

$$q_k = \frac{\Delta T}{R_{TOTAL}} \tag{6.1}$$

where:

q_k is the rate of heat flow by conduction [W];

ΔT is the difference in temperature between the internal air and ambient air [K];

R_{TOTAL} is the sum of thermal resistances of the refractory and outer shell [K/W];

The heat transfer due to natural convection from the matte and shell is estimated as follows:

$$q_c = \bar{h}_c A(\Delta T) \tag{6.2}$$

where:

q_c is the rate of heat flow by convection [W];

$\bar{h}_c$ is the heat transfer coefficient [W/m^{2}K];

A is the surface area [m^2];

ΔT is the difference in temperature between the matte and chamber air [K];

The heat transfer due to radiation from the shell and mouth is estimated as follows:

$$q_R = \sigma A \varepsilon (T_1^4 - T_2^4) \tag{6.3}$$

where:

q_R is the rate of heat flow by radiation [W];
A is the surface area [m^2];
σ is Stefan-Boltzmann constant [W/m^2K^4];
ε is emissivity of the surface
T_1 is the temperature of the chamber [K];
T_2 is the temperature of the ambient air [K];

Transient heat transfer of the matte copper is estimated as follows:

$$q = \frac{(T_{Initial} - T_{new}) \times Mass \times c_p}{t} \tag{6.4}$$

where:

q is the rate of heat flow [W];
t is the rate of time [s];
$Mass$ is total mass of the matte [kg];
$T_{Initial}$ is the initial temperature of the matte [K];
T_{new} is the new temperature of the matte after 1 hour [K];
c_p is the specific heat of the matte [J/kg K];

6.6 Fluent

For nearly twenty years the name Fluent has been synonymous with the world's leading commercial software for solving fluid flow problems. Today's engineers throughout the world use Fluent to simulate applications ranging from air flow over footballs to combustion in high temperature furnaces. Fluent is a CFD software package that allows the study of the dynamics of fluids. Based on a numerical technique called computational fluid dynamics, Fluent has a stock pile of state-of-the-art models that allows it to tackle a vast array of problem physics. The use of fluent requires the building of a geometrical model that represents the system that you want to analyse. The heat transfer physics are applied to the modelled system and the software outputs a prediction of the heat transfer. This can then be used to analyse the system and evaluate the optimum performance.

Using fluent for this project entailed creating a geometrical model of different views of the converter. Pre-processing is the first step in building and analysing a flow model. It includes building the model (or importing from a CAD package), applying a mesh, and entering the data.

To analyse the burner system in the Peirce-Smith converter a side view and front view of the vessel was modelled. This was obtained using the software package Gambit as it has a single interface for geometry creation. Meshing of the model after it has been drawn is the next part of the gambit process as it brings together all of Fluent's pre-processing technologies in one environment.

After pre-processing, the CFD solver does the calculations and produces the results. Post processing is the final step in CFD analysis, and involves organization and graphical presentation of the data and images.

6.8.1 Benefits of fluent

- Insight:
  Fluent gives a means of visualizing and enhancing the understanding of the designed system by showing parts of the system or phenomena happening that may otherwise not be visible through other means.

- Foresight:
  Fluent is a tool for predicting what will happen under a given set of circumstances, it can answer many 'what if?' questions very quickly. Many different variables can be given to the software which inturn gives back an outcome in a very short amount of time. This information allows the testing of many different variations to help in the design of the optimal solution.

- Efficiency:
  Better and faster analysis leads to shorter design cycles, saving time and money and getting the design to market faster.

6.9 Heat-Flow Analysis Summary

Using heat balance scenarios and the CFD software package fluent, will allow for an accurate analysis to be under taken to resolve the best position for the burner system and to evaluate the amount of energy required for the optimum performance. This takes into account the heat flow of each burner position during lid-on and lid-off. Results and discussions of the heat analysis are provided in Chapter 7 to evaluate the optimum position.

Chapter 7:

Results and Discussion

7.1 Introduction

The highest rate of heat losses occurs when the lid is off the mouth of the converter. This is of course the most interesting region in the heat transfer analysis as more heat energy is required to keep the matte copper above 1100ºC. Outlined in this chapter are the results for the three burner positions that have been stated in previous chapters. The results will be reviewed against each other, compared with the 1D analytical analysis and discussed to arrive at the optimum position.

7.2 Fuel Cost Analysis

Evaluating the cost of natural gas compared to diesel will show evidence that the change to the new heating fuel will be economical for the burner system. Even though the heat energy losses that were found, using the transient heat conduction calculations were inaccurate for larger components such as the converter. It is assumed that for the replacement of heat energy in a system, a proportion of fuel is to be burnt to achieve the energy required to be put back. To analyse this system 80592.433kW was used as it was calculated as the larger amount of energy from the transient conduction analysis. The running time period of 1 hour was taken in to account as it is currently the time used when the system is 'held' with the lid –off.

The heating cost for running natural gas as a fuel source for 1 hour with the lid-off is $1500.13 where as to run the same system with diesel the cost would be $3401.63. Just by using natural gas there would be a saving of $1901.50 per hour. In the long term it would work out to be a considerable saving for the company. (See appendix B for full cost saving calculations) As mentioned in the introduction in Chapter 1, a natural gas line was constructed in 1998, this construction along with the cost analysis above will add to the total saving for the change to natural gas. Currently diesel is stored on site in 3 large tanks, this means the monitoring and maintaining of the tanks must coincide with government regulations. This currently costs large amounts of money to the company as external inspectors have to be brought in to analyse the storage environment. Changing to natural gas from the newly build pipe line would not only be more environmentally friendly but from this cost analysis would also prove to be very economical for the company.

7.3 CFD Analysis

With the aid of the computer software Fluent, an analysis of the three different burner positions has been looked at. This was used to see how much heat energy would be lost from different areas of the model and to review the heat flow in the converter chamber. Each scenario has been analysed with the lid-on and with the lid-off the mouth of the converter. Temperature of the matte must be held above 1100°C to stop the slag from crystallising. Once crystallising has occurred the slag will be unable to be remelted to a molten form, leaving the converter unusable until the content is removed. (Fluent results, Appendix D)

7.3.1 Tuyere Burner Position

Placing the burner through the tuyeres was the first position analysed, as outlined earlier this is the position currently being used by the diesel spears. Comparing the heat losses during lid-off and lid-on, it was found that a larger amount of heat was required to maintain the correct temperature for the matte when the lid is off. The tables below shows that during the lid off condition, the flame temperature is to be maintained at 1300ºC, where as after reviewing different temperatures for when the lid is on, it was found that the flame temperature can be lowered to 1200ºC. The outlet for the lid on scenario reduces the heat energy by 190.7kW but shows higher losses through the outer shell and refractory. This is due to the temperature in the chamber staying higher and allowing more heat energy to be released through the walls. With the high temperatures in the chamber it is also obvious that when the lid is on the matte stays hotter as the heat energy lost is less than when the lid is off. (See table 7.1)

Tuyere Burner Lid off @ 1300 ºC	Heat energy lost
Outlet	914.195 kW
Steel shell	44.5 kW
Matte	19.137 kW
Refractory	21.37 kW
Steel wall	3.9 kW

Tuyere Burner Lid on @ 1200 ºC	Heat energy lost
Outlet	723.5 kW
Steel shell	71.43 kW
Matte	18.69 kW
Refractory	24.8 kW
Steel wall	27.7 kW

Table 7.1: Heat loss results from Fluent for tuyere burner position.

Temperature distribution through the chamber shows that while the lid is off the mouth of the converter, a buoyancy effect is drawing in colder air in at the bottom of the mouth and releasing the hotter air at the top. This is not allowing a constant flow of heat through the chamber and a higher flame temperature is needed to maintain the matte copper temperature (see figure 7.1). With the lid on the mouth the temperature distribution is uniform throughout the chamber, creating an ideal environment to allow the flame temperature to be lower than when the lid is off.(See figure 7.2)

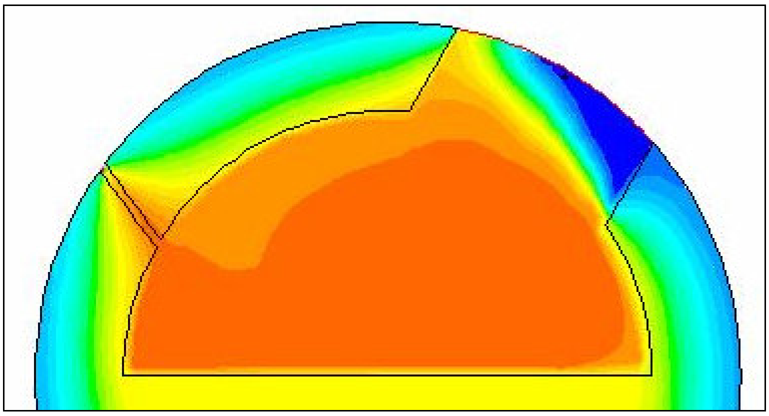

Figure 7.1: Temperature distribution for tuyere position lid-off

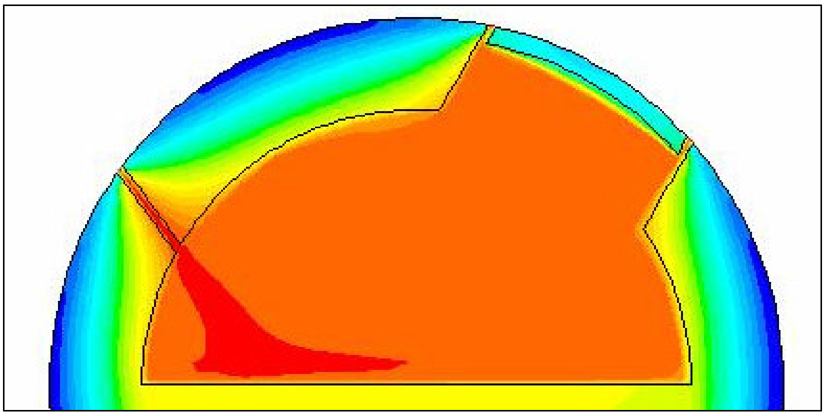

Figure 7.2: Temperature distribution for tuyere position lid-on

Looking at the analysis for the tuyere position, we see that the burner will need to produce temperatures of 1300ºC for short periods of heating while the lid is off and temperature of 1200ºC for the longer periods while the lid is on. Comparing the temperature graphs it can be seen that for both analyses we find that the matte is being kept above 1100ºC. This has been analysed by plotting the point from a vertical line that starts at the top of the mouth and ends at the top of the refractory at the bottom. The graph shows negative and positive values, the negative distances being the matte copper temperatures and the positive values the chamber air temperatures. (See figure 7.3)

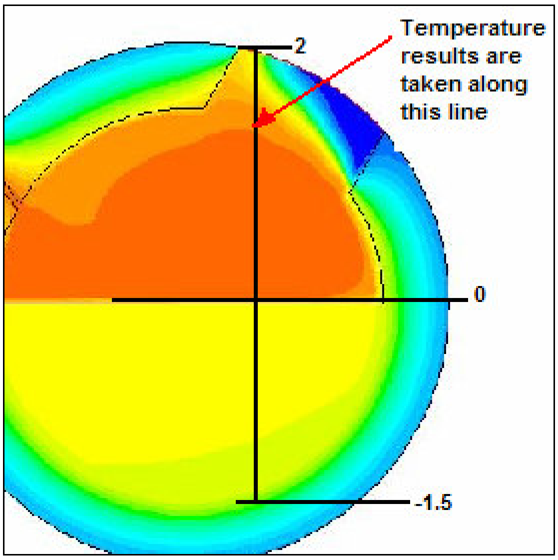

Figure 7.3: Vertical line for temperature distribution points

The graph of temperature distribution for a tuyere burner position with the lid-off is shown here in figure 7.4. A flame temperature of 1300ºC is capable of maintaining the matte copper above 1100ºC.

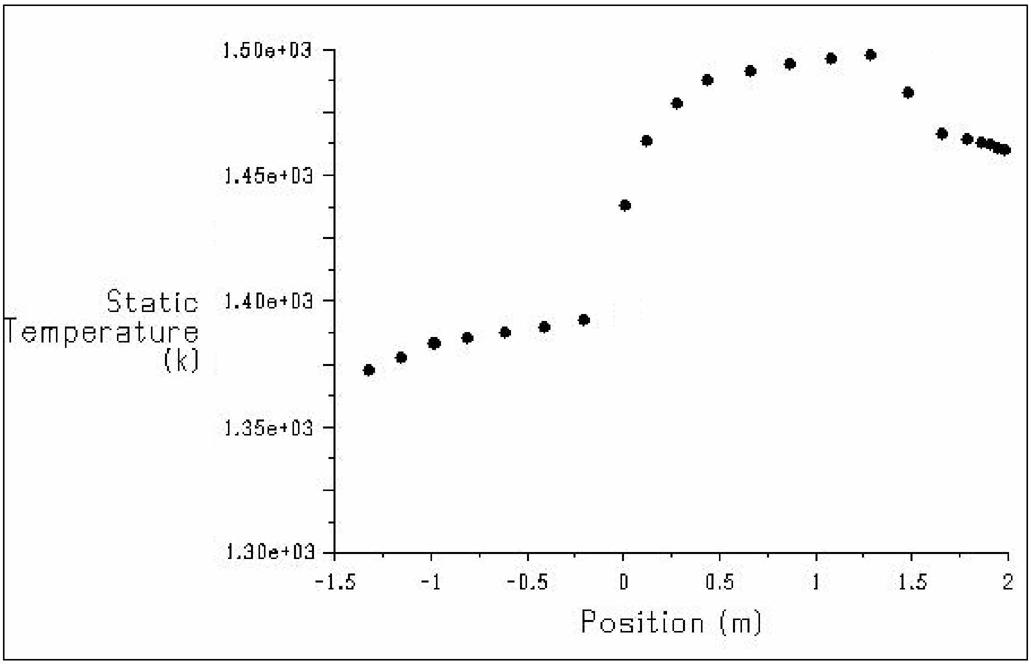

Figure 7.4: Tuyere position lid-off

The graph of temperature distribution for a tuyere burner position with the lid-on is shown here in figure 7.5. A flame temperature of 1200ºC is capable of maintaining the matte copper above 1100ºC.

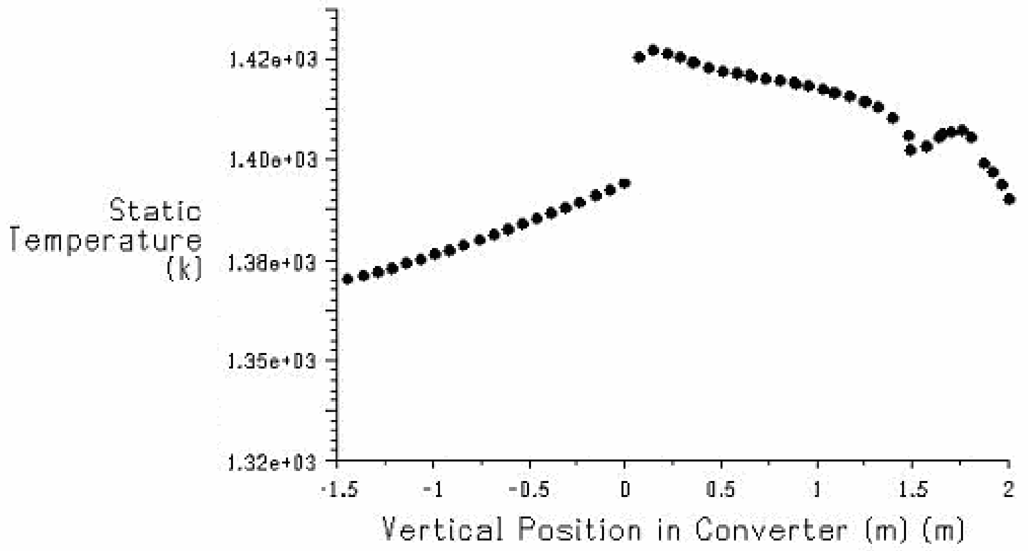

Figure 7.5: Tuyere position lid-on

7.3.2 Side Wall Burner Position

Analysing the side wall position was looked at next and showed that for heating in both cases of lid-on and lid off, the matte copper temperature could not be maintained. This was mainly due to the position of the burner being in the centre of the top half of the chamber, as this is the only viable position that could be used in the end wall. When the converter is rolled out the burner would be submerged in the matte copper if it was placed any lower than the centre.

The same analysis for heat losses and temperature distribution as the tuyere position was looked at. The table below shows that there is still a saving of heat energy when the lid is on compared to when the lid is off (see table 7.2) but the temperature distribution graphs show that the temperature of the matte are both below 1100ºC, meaning that the slag would crystallise, spoiling the matte copper in the vessel. This position is inefficient and ineffective for this new natural gas burner system. (See figures 7.5 & 7.6)

Side Wall Burner Lid off @ 1300 deg C	Heat energy lost
Outlet	810.14 kW
Steel shell	81.273 kW
Matte	34.125 kW
Refractory	43.8 kW
Steel wall	3.304 kW

Side Wall Burner Lid on @ 1200 deg C	Heat energy lost
Outlet	557.38 kW
Steel shell	105.61 kW
Matte	32.84 kW
Refractory	56 kW
Steel wall	8.89 kW

Table 7.2: Heat loss results from Fluent for side wall burner position

The graph of temperature distribution for a side wall burner position with the lid-off is shown here in figure 7.6. A flame temperature of 1300ºC is unable to maintain the matte copper at 1100ºC.

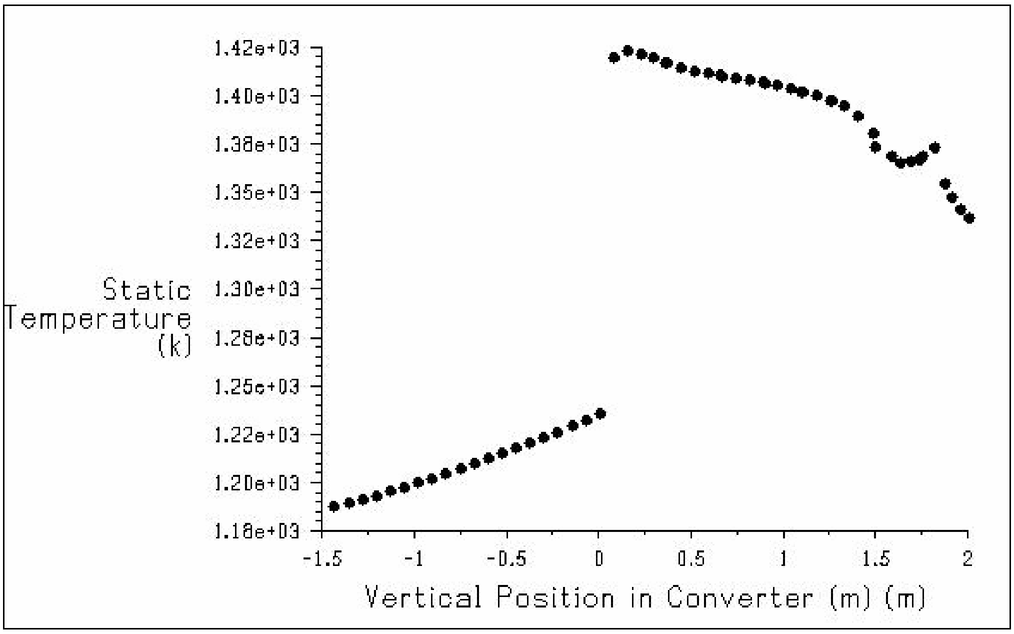

Figure 7.6: Side wall position lid-off

The graph of temperature distribution for a side wall burner position with the lid-on is shown here in figure 7.7. A flame temperature of 1300ºC is also unable to maintain the matte copper at 1100ºC.

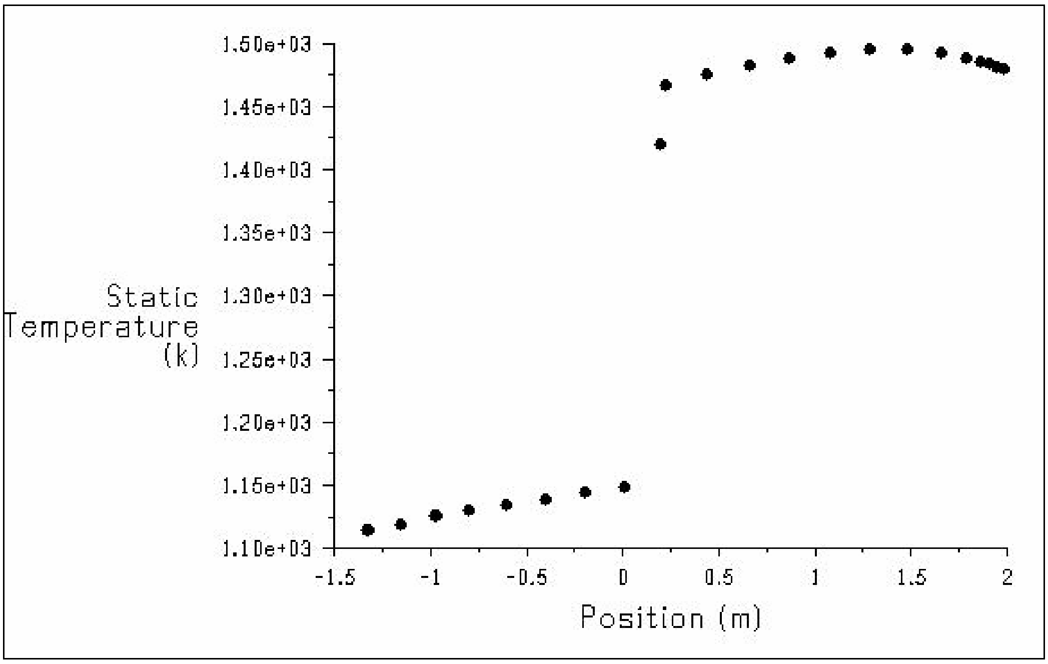

Figure 7.7: Side wall burner position lid-on

7.3.3 Mouth burner position

The last position to be analysed using Fluent was the mouth position. Previously the two positions (tuyere & side wall) were analysed during lid-off and lid-on conditions, where as the mouth can only be analysed under lid-on, as placing a burner in the mouth would require the lid to be covering the mouth. Reviewing the results in table 7.3 and the temperature distribution in figure 7.8, it is obvious that a mouth burner, is capable of producing a flame temperature of 1200ºC will satisfy the required conditions. Heat losses outlined in table 7.3 shows that heat energy is being lost throughout the converter, but the heat energy is once again largely decreased by having a lid over the mouth.

Heating Burner Lid on @ 1200 ºC Front View	Heat energy lost
Outlet	785.8 kW
Steel shell	112.63 kW
Matte	49.45 kW
Refractory	42.05 kW
Steel wall	4.87 kW

Table 7.3: Heat loss results from Fluent for mouth burner position

The graph of temperature distribution for a mouth burner is shown here in figure 7.8. A flame temperature of 1200ºC is capable of maintaining the matte copper above 1100ºC.

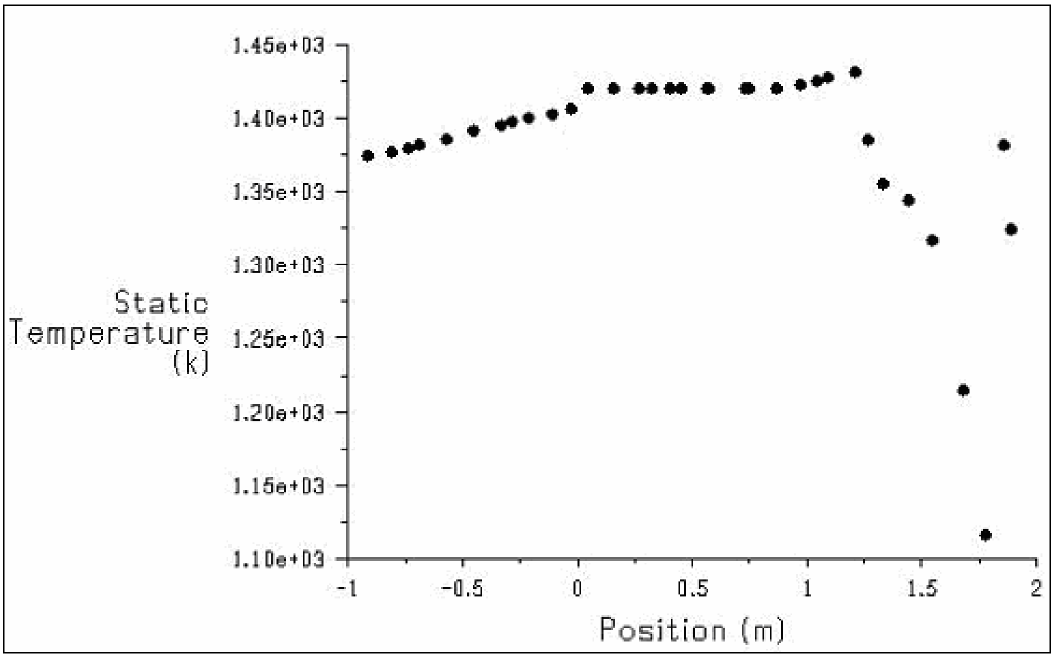

Figure 7.8: Mouth burner for heating the matte copper

The mouth position was also analysed for the cold start-up heating condition, as the burner needed to control a large range of temperatures to satisfy the manufacturer's heat-up curve, as well a larger area for installation was required. Tuyere and side wall positioning could not offer this option as the area accessible for the burner was too small. A side view and front view of the mouth position was analysed to review the temperature distribution inside the vessel. Table 7.4 shows that during the heating process, heat energy is also being lost throughout the converter. In particular the refractory shows energy losses of approximately 50kW. This reveals that heat is getting into the refractory, which means that the curing process will work well for cold start-up under these conditions.

Start-up Burner Lid on @ 1300 ºC	
Side View	Heat energy lost
Outlet	821.4 kW
Steel shell	378.2 kW
Refractory	50.4 kW
Steel wall	96.6 kW

Start-up Burner Lid on @ 1300 ºC	
Front View	Heat energy lost
Outlet	709.86 kW
Steel shell	443.56 kW
Refractory	44.98 kW
Steel wall	19.14 kW

Table 7.4: Heat loss results from Fluent for mouth burner position for cold start-up

Figure 7.9 shows that there is a constant and uniform flow of heat, that is reaching all section of the refractory surface in the vessel.

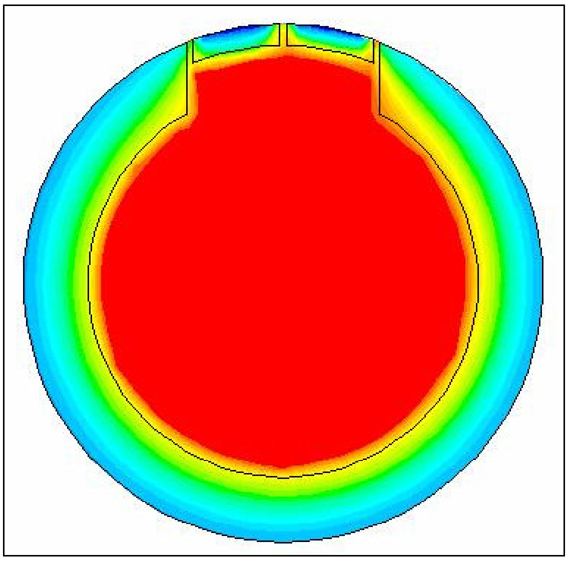

Figure 7.9: Heat distribution throughout the vessel during cold start-up

The graph of temperature distribution for a mouth burner during cold start-up is shown here in figure 7.10. A range of flame temperatures can be used to satisfy the heat-up curve for the Peirce-Smith Converter.

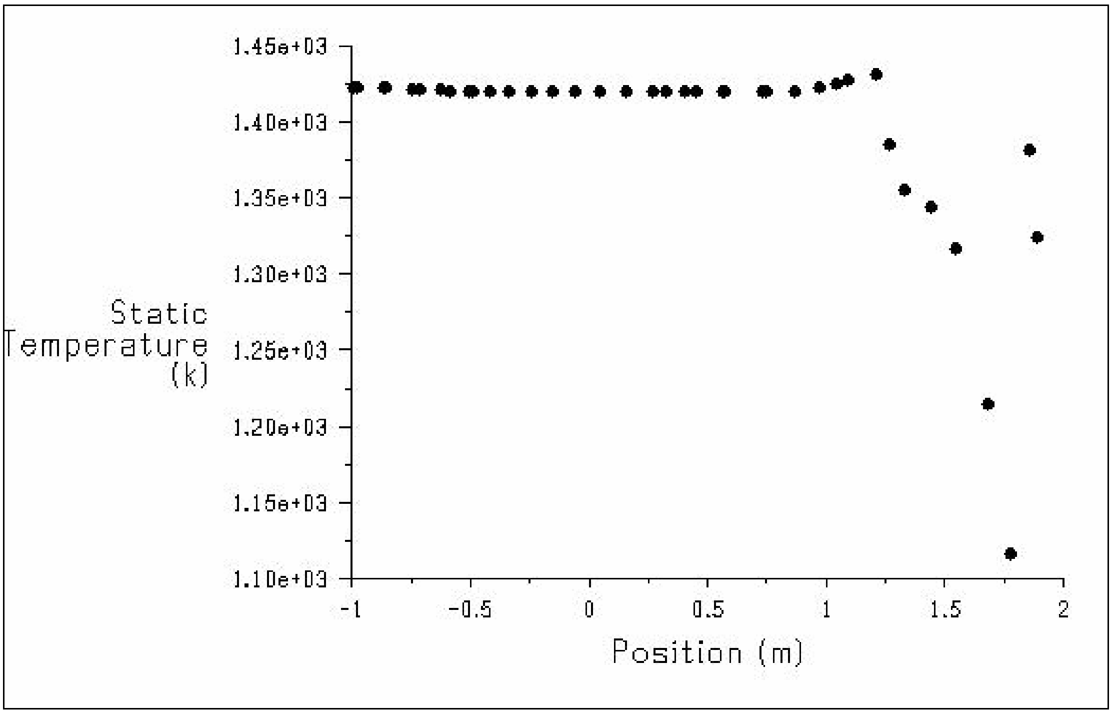

Figure 7.10: Mouth burner for cold start-up

7.4 Summary of Results

Through the 1D analytical and Fluent analysis it has been successfully demonstrated that two of the three positions for the natural gas burner system would be capable of achieving the required results set out for this project. Reviewing the results gathered from Fluent and the limitations that were outlined in Chapter 6 about the mounting of the burner, an optimum position was obtained. It was found that the most effective, efficient and economical position for the new natural gas burner system would be to install the burner in the lid of the converter. Placing the burner in the lid would resolve one of the main issues for most of the heat energy being lost through the mouth, as the lid would be in place during all heating conditions. This would then inturn cut down the amount of energy needed to be put back into the system, which would save money on fuel consumption. The lid position also allows for a greater area to work with when it comes to installing the new burner. A larger area means a larger burner can be used and will allow the system to work at different excessive flow rates of air. Different flow rates of air are used for various temperatures that are required for the different heating processes, especially cold start-up when temperature has to be varied and held for different periods of time. With this optimum position found the next stage is to decide on a burner to meet all heating conditions. Chapter 8 discusses the appropriate type of burner that can be used in conjunction with mounting it in the lid.

Chapter 8:

Burner Design

8.1 Introduction

An important component of this project was to decide on a burner design that would be capable of producing the required heat for the various different heating procedures. After reviewing the results from Chapter 7 an optimum position was decided on that would allow the system to achieve the best performance. Using this information a burner design can be decided upon that will create a high performing system for the use in all heating processes for the Peirce-Smith converters at Mt Isa.

8.2 Burner Design

A burner is a device which combines fuel and air in proper proportions for combustion and which enables the fuel-air mixture to burn stably, to give a specified flame size, shape and temperature.

It is critical when choosing a burner that it performs effectively and efficiently as a heating system, as well it must comply with Australian Gas Standards and meet all government regulations. There are no hard and fast rules to govern the choice of burner, but design of the furnace and the burner must be matched carefully to achieve a good overall performance.

The burner used for a given system must provide three basic design functions.

1. A burner must provide for controlling mixing of the reactant, fuel, and the oxidizing agent, in most cases air.

2. The burner must provide a stable and self-renewing ignition source.

3. The burner should provide for a controlled region of reaction or controllable flame shape.

The burner for the converter would have to be designed to operate at various rates of excess air. When undertaking heat transfer calculations using products of combustion, the excess air is usually broken up and included in the nitrogen and water vapour of the stoichiometric products of combustion.

Temperatures of the flame can only be changed by changing the excess air rate. A small flame at a certain excess air rate has the same temperature as a large flame at the same excess air rate. The small flame only appears to have a lower temperature due to the influence of the surrounding environment. With a small flame the thermal energy is dissipated into the surrounding environment before it effects in process temperature.

The burner system has to be able to work under different excess air rates to allow the burner to have the temperature adjusted to suit each heating process.

8.3 Burner Choice

There are many suitable burners that if chosen would achieve a high performance during the heating processes for the converter. Due to the type of furnace, positioning of the burner and flues, the TH-HBT 100 burner has been chosen as it can produce a range of temperatures up to 1300°C by adjusting the excess air. Being an off the shelf burner that has been designed and sold by Combust Technologies, it has all ready been assessed and complies with all Australian Gas Standards. This burner is classed as a furnace burner that uses small amounts of high pressure air to pick up incoming gas at a modified mixer. The gas pressure is elevated and the resulting mixture of air/gas is delivered to the orifice in the inspirator where large quantities of air required for combustion are induced. Greater mixture pressures and capacities are therefore possible.

Heating of the matte copper during roll out periods up to and above 1 hour can now be achieved with the TH-HBT 100 burner as the flame temperature can be maintained at temperatures up to 1300°C. With the right control system it can also be used in cold start-up conditions by varying the excess air which will then vary the temperature of the flame to match the specific heat-up curve nominated by the manufacturer. As well as having one of these burners mounted on the converter lid there can be a group of up to three if a required area inside the furnace may require excess heating. (Burner information, Appendix E)

This burner has the potential of performing the three heating processes with great efficiency and economical benefits. Because it is positioned in the lid of the converter most of the heat is held inside the vessel, meaning that less heat energy is required in maintaining the temperature above 1100°C, saving the company more money in the long run. (See figure 8.1)

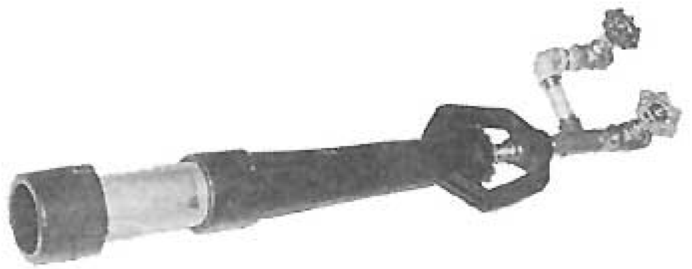

Figure 8.1: TB-HBT100 Burner
(Taken from Combust website www.combust.com.au, 2004)

8.4 Insertion and Retraction System

The removal of the converter lid is currently being done by the over head crane and takes approximately 1 minute to be positioned in place and removed. The reason that the lid can be removed and placed over the mouth so quickly is because the lid is stored only metres away from the converter when not in use. (See figure 8.2) The biggest concern for the converter operator is the time taken once they have been told by Air Quality Control (AQC) that the sulphur levels have reached the maximum, as they must roll the converter out and turn the burners on to keep the matte surface molten. The quickest and most efficient way to insert and retract them new system would be to use the same system as currently being used for lid placement. This would only take a 2-way radio call from the operator to the crane driver, telling him that the converter has to be rolled out and will require the lid being placed over the mouth. Once the lid is in position the operator can flick the switch to fire up the burners saving a lot more time than if he was to do it manually. Using this process will cut down the time that the converter has to lose heat energy from the mouth, saving on the heat energy required to be put back into the system.

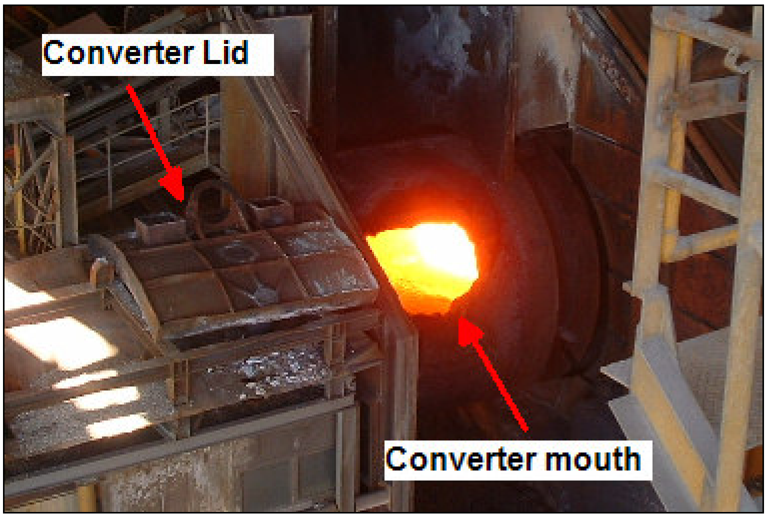

Figure 8.2: Peirce-Smith Converter at Mt Isa Copper Smelter

8.5 Burner Maintenance

Burner performances typically deteriorate with operating time due to fouling, plugging and wear on the burner components. The fouling, plugging and wear reduce the effectiveness of the fuel and air mixing and can affect the flame and heat flux patterns. Maintenance is required on burner parts to avoid serious performance loss and safety issues. These burner parts include the fuel gas tip, the fuel gas orifice and mixer, flame stabilizer cone and burner tile. Checking and cleaning of these parts should be done on a daily basis by the converter operator and maintenance fitter.

Burner maintenance for monthly planned shutdowns should entail checking of internal and external components and to allow for a total clean and check of the system. Replacement parts should be held in stock at the copper smelter store to cover any problem that may be encountered during running of the converters. Parts should be ordered from the original manufacturer so as to maintain the appropriate quality and durability. Copied parts normally do not have the same tolerances as the original parts and can often cause inferior operations.

8.5.1 Training

The training material will be available from the manufacturer of the burner and will comprise both operator and maintenance trouble shooting courses.

Training that is to be carried out is intended to achieve a standard such that the remaining copper smelter converters natural gas conversion and associated equipment can be operated and diagnosed in a similar matter.

The scope of work shall include:

1. Supply and design of course training notes
2. Setup of plant simulation for hands on practise
3. Safety procedures and equipment

8.6 Burner Conclusion

The choice of burner is critical to achieve the best performance in this type of furnace. Because of the different heating processes required the TH-HBT 100 burner is an ideal choice, as it can be varied to work for different heating conditions. This means that the new burner system will be capable of performing the three different heating conditions effectively and efficiently. With the right control system the new burner will also save Xstrata not only in fuel consumption but in maximising the refractory life, and offer a more efficient process.

Chapter 9:

Conclusions and Recommendations

9.1 Summary

This project has proceeded through a number of different steps to ultimately achieve the best optimum design for the problem of installing a new natural gas burner system. The main aims of this project that were set out in Chapter 1 have all been meet, along with a fuel analysis review, that has verified the cost benefits in changing to natural gas and a decrease in time saved between heating processes, by utilising the over head crane for the inserting and retracing process of the burner.

Recommendations for the position and type of burner are set out in this chapter along with some further work that is required before installation of the new system can be achieved. This project also covered the required objectives in regards to the specific project and is outlined in the chapter.
(Project specifications, Appendix A)

9.2 Recommendations

To satisfy the aims of this project a burner position and burner was decided on. After a considerable amount of heat transfer analysis it was found that the recommended position for a new burner system would be to position it in the mouth of the converter. Placing the burner in the lid would allow the new heating system to handle the three heating conditions: Lid-off, Lid-on and cold start-up. Also the insertion and retraction system used for placing the burner over the mouth can now be done using mechanical means (overhead crane) which will decrease the heat loss times and save money for the company.

The recommended burner chosen to coincide with the mouth position is a TH-HBT 100 burner sold by Combust Technologies. This burner has the capability of producing a range of different flame types and temperatures through a change in excessive air rates. This is especially important for the cold start-up process, which requires different temperatures for different periods in time. For the heating process of the matte copper, the TH-HBT 100 burner is also capable of keeping a high range of temperatures for long periods. This makes this burner ideal to produce the best performance of the new system.

9.3 Achievement of Objectives

In regards to the specific project objectives. (Project specifications, Appendix A)

1. The review of literature in the areas of heating processes was conducted, although after an extensive search, little information was found. Therefore Mt Isa Mine documents were consulted to ensure that the project work was relevant to the host company.

2. The development of heat balance models was formed for the various heating procedures to see where the heat energy was being lost in the system.

3. Using CFD software fluent the pattern of heat released inside the vessel was found and used to determine the optimum burner position from the three preselected areas. (Mouth, Side Wall and Tuyere)

4. The most economical and effective position of the burner was decided on and was used for the new burner system.

5. An insertion and retraction system for the new burner position was achieved, utilising previous methods used currently for the placement of the converter lid.

6. A maintenance schedule was designed for the new burner system.

9.4 Further Work

Design of a control system to work in conjunction with the TH-HBT 100 burner would be the next step to follow on with this project. The control system currently being used in the converters is an outdated Yokogawa U-XL system. Changeover to a natural gas burner system for the heating processes would require a new burner management system that would involve an upgrade of the controls to coincide with the Australian Gas Standards. The new control system will have to allow the burner to achieve the required results that have been outlined throughout the project report.

3D Fluent analysis of the heat flow throughout the chamber may be reviewed further to reveal if there are any cold spots forming on the refractory surface. This analysis can be analysed to see how the new heating processes will affect the refractory life in the converter.

A HAZOP study should be reviewed before implementing any new system in the mining industry. The hazard and operability study is a structured discovery technique for hazard identification. HAZOP systematically examines a process to discover how deviation from design intention can occur and can cause hazard and/or operability problems. If required, the hazards that are discovered can be analysed in detail to determine frequency and consequence of occurrence (A Hazard Analysis (HAZAN) study).

In a HAZOP study, the process under investigation is sub-divided into smaller sub-sections, and each is considered with the aim of identifying possible deviations from design behaviour. Each sub-section is chosen so that the HAZOP assessor can conveniently handle the content. For example, on a piping and instrument diagram, normally a line between two major items of plant (vessels, pumps) is considered.

The process designer then gives a brief description of the purpose of the particular part of the process and guidewords are applied. The purpose of guide words is to generate discussion regarding possible deviations from design behaviour. For each guide word, the following questions are asked:

- Can it happen?
- If so, how?
- What are the consequences?
- Are the consequences hazardous?
- Do the consequences prevent efficient operation?
- Is action needed, or are the consequences tolerable?
- What action is to be taken?

A record of identified problems, recommended actions and the person responsible for the action is made. The HAZOP assessor uses a drawing, and the number of each action item is the marked on drawing for future reference. Guide words are applied to all operations and variables; include start-up, shutdown and abnormal operations.

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Appendix A:

Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR: Clayton Harley Stansbie

TOPIC: Natural Gas Burner for Copper Smelter Converter

SUPERVISORS: Dr David Buttsworth, Dr Ruth Mossad
Mr Ian Borthwick, Mt Isa Mines, XSTRATA

SPONSORSHIP: Copper Smelter, XSTRATA

PROJECT AIM: The project aims to investigate the best scenario for designing and installing a natural gas burner into a Peirce-Smith Converter.

PROGRAMME: Issue B, 30th September 2004

7. Search for and review information on the practice of different heating processes used in other converters and other related devices worldwide.

8. Develop a heat balance model for heat input required under the various conditions including cold start up; lid off; lid on; etc.

9. Estimate the pattern of heat release inside the furnace for various positions of the proposed gas burner (such as at the end of vessel, in through charging mouth, tuyere, diesel spear hole etc). This may be achieved through suitable extension of the heat balance model or may require some basic CFD modelling.

10. Identify the most economical and effective position to place the burner/s in the converter.

11. Design an insertion and retraction system for the burner if required.

As time permits

6. Design a maintenance schedule for the burner system.

AGREED:____________ (Student)___________(Supervisor) (Dated) __/ __/ 2004

Appendix B:

Heat Transfer Calculations

Properties of Pierce-Smith Converter:

Refractory – RADEX DB605B

c_p = 1204 J/kg.K
k = 2.6 W/m.K
ρ = 3270 kg/m^3
ε = 0.8

Inner Temperature 1200°C

OD = 3.968m
ID = 3.028m

Steel outer shell -0.05% carbon

c_p = 519 J/kg.K
k = 53.2 W/m.K
ρ = 7872 kg/m^3

Outer temp 140°C - 180°C

OD = 4.04m
ID = 3.968m

Matte Copper

c_p = 460 J/kg.K
k = 163 W/m.K
ρ = 7850 kg/m^3
β = 24.8 x 10^{-6} 1/K

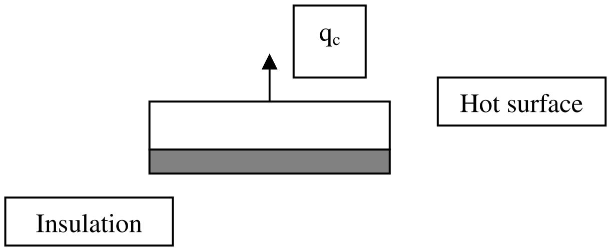
Inner Temperature 1200°C

ε = 0.85 to 0.95

$$\alpha = \frac{k}{\rho \times c_p} = \frac{163}{7850 \times 460} = 4.514 \times 10^{-5}\ m^2/s$$

Properties and formulas for the following calculations are taken from Kreith, F. & Bohn, M. (2001), *Principles of Heat Transfer*

Natural Convection calculated: matte copper to the air in the chamber.



Air properties @ 1150°C (Extrapolation from table 27)

$\rho = 0.2158$ kg/m^2 Pr = 0.759
$\beta = 0.64 \times 10^{-3}$ 1/K $\alpha = 278.04 \times 10^{-6}$ m^2/s
$\mu = 52.2403 \times 10^{-6}$ $c_p = 1157.9$ J/kg.K
$\nu = 211 \times 10^{-6}$ k = 0.08286 W/m.K

$$Gr = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2} \qquad L = \frac{SurfaceArea}{Perimeter}$$

Area = 3.028 x 9.6 = 29.0688 m^2
Perimeter = (3.028 + 9.6) x 2 = 25.256 m

L = 29.0688 / 25.256 = 1.151

$$Gr = \frac{9.81 \times 0.64 \times 10^{-3}(1200 - 1150)1.151^3}{(211 \times 10^{-6})^2}$$

= 0.47867964 / 4.4521 x 10^{-8}

= 10751771.99

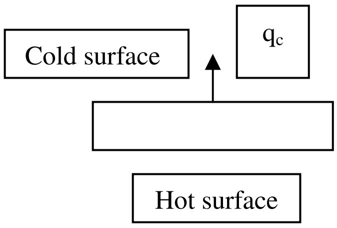
Ra = Gr x Pr = 10751771.99 x 0.759
Ra = 8.160594943 x 10^{-6}

$Nu_L = 0.5Ra_L^{0.25}$ (equation 5.15)
= 0.5 x (8.16 x 10^{-6})$^{0.25}$
= 26.72393826

$$\bar{h}_c = \frac{Nu_L \times k}{L} = \frac{26.7239 \times 0.08286}{1.151} = 1.924$$

$q_c = \bar{h}_c\ A(T_s - T_\infty)$
1.924 x 29.0688(1200 – 1150)
q_c = 2796.42 watts

Natural Convection calculated: mouth of the converter to ambient air .



Air properties @ 40°C

$\rho = 1.092$ kg/m^2 | Pr = 0.71
$\beta = 3.19 \times 10^{-3}$ 1/K | $\alpha = 24.8 \times 10^{-6}$ m^2/s
$\mu = 19.123 \times 10^{-6}$ | $c_p = 1014$ J/kg.K
$\nu = 17.6 \times 10^{-6}$ | k = 0.0265 W/m.K

$$Gr = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2} \qquad L = \frac{SurfaceArea}{Perimeter}$$

Mouth area = 7.06 m^2
Mouth perimeter = 9.425 m

L = 7.06 / 9.425 = 0.75

$$Gr = \frac{9.81 \times 3.19 \times 10^{-3}(1150 - 40)0.75^3}{(17.6 \times 10^{-6})^2}$$

$= 14.65435 / 3.0976 \times 10^{-10}$

$= 4.7308722 \times 10^{10}$

Ra = Gr x Pr = $4.7308 \times 10^{10} \times 0.71$
Ra = 3.35892×10^{10}

$Nu_L = 0.27 Ra_L^{0.25}$ (equation 5.17)
$= 0.27 \times (3.359 \times 10^{10})^{0.25}$
$= 115.588$

$$\bar{h}_c = \frac{Nu_L \times k}{L} = \frac{115.588 \times 0.0265}{0.75} = 4.084$$

$q_c = \bar{h}_c A(T_s - T_\infty)$
$4.084 \times 7.06(1150 - 40)$
$\underline{q_c = 32005.59 \text{ watts}}$

Heat-up with lid-off

Natural Convection calculated: Converter outer shell to ambient air.

Air properties @ 40°C

Shell Area = $2\left(\frac{\pi 4.04^2}{4}\right) + \pi 4.04 \times 10.668 = 161.0365\ m^2$

Mouth Area = 7.06 m^2

= 161.04 – 7.06 = 153.98 m^2

$\rho = 1.092\ kg/m^2$

$\beta = 3.19 \times 10^{-3}\ 1/K$

$\mu = 19.123 \times 10^{-6}$

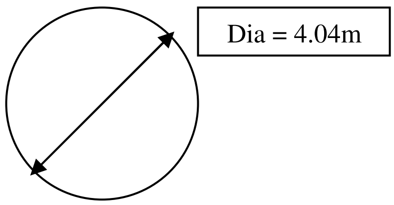
$\nu = 17.6 \times 10^{-6}$

$Pr = 0.71$

$\alpha = 24.8 \times 10^{-6}\ m^2/s$

$c_p = 1014\ J/kg.K$

$k = 0.0265\ W/m.K$



$$Gr = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2} = \frac{9.81 \times 3.19 \times 10^{-3}(160-40)4.04^3}{(17.6 \times 10^{-6})^2}$$

$$Gr = 7.99391813 \times 10^{11}$$

$$Ra = Gr \times Pr = 7.99391813 \times 10^{11} \times 0.71$$
$$Ra = 5.675681872 \times 10^{11}$$

$$Nu_D = 0.53(Gr_D Pr)^{1/4} \quad \text{(Equation 5.20)}$$
$$= 0.53 \times (5.675681872 \times 10^{11})^{1/4}$$
$$= 460.0238844$$

$$\bar{h}_c = \frac{Nu_L \times k}{D} = \frac{460.0238844 \times 0.0265}{4.04} = 3.0175$$

$$q_c = \bar{h}_c\ A(T_s - T_\infty)$$

$$= 3.0175 \times 153.98(160 - 40)$$

<u>q_c = 55756.16 watts or 55.8 kW</u>

Radiation from the mouth and Vessel

Vessel surface area = 161.18 – 7.06 = 153.98 m^2

Mouth area = 7.06 m^2

Shell

$$q_r = \sigma A \varepsilon (\Delta T^4)$$

$$q_r = 5.67 \times 10^{-8} \times 153.98 \times 0.8(433^4 - 313^4)$$

$$q_r = 178484.15W$$

Mouth

$$q_r = \sigma A \varepsilon (\Delta T^4)$$

$$q_r = 5.67 \times 10^{-8} \times 7.06 \times 0.8(1473^4 - 313^4)$$

$$q_r = 1504535.4W$$

Total loss of radiation from the converter during lid-off.

Mouth + shell = Total radiation loss

178484.15 + 1504535.4 = 1683019.54 kW

Total losses = 1683.02 kW

Heat-up with lid-on

Natural Convection calculated: Converter outer shell to ambient air.

Air properties @ 40°C

Shell Area = $2\left(\frac{\pi 4.04^2}{4}\right) + \pi 4.04 \times 10.668 = 161.0365$ m^2

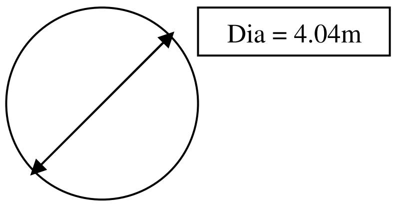
= 161.04 – 0.18 = 160.86 m^2

ρ = 1.092 kg/m^2 Pr = 0.71

β = 3.19 x 10^{-3} 1/K α = 24.8 x 10^{-6} m^2/s

μ = 19.123 x 10^{-6} c_p = 1014 J/kg.K

ν = 17.6 x 10^{-6} k = 0.0265 W/m.K



$$Gr = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2} = \frac{9.81 \times 3.19 \times 10^{-3}(160-40)4.04^3}{(17.6 \times 10^{-6})^2}$$

Gr = 7.99391813 x 10^{11}

Ra = Gr x Pr = 7.99391813 x 10^{11} x 0.71

Ra = 5.675681872 x 10^{11}

$Nu_D = 0.53(Gr_D Pr)^{1/4}$ (Equation 5.20)

= 0.53 x (5.675681872 x 10^{11})$^{1/4}$

= 460.0238844

$$\bar{h}_c = \frac{Nu_L \times k}{D} = \frac{460.0238844 \times 0.0265}{4.04} = 3.0175$$

$$q_c = \bar{h}_c\, A(T_s - T_\infty)$$

= 3.0175 x 160.86(160 – 40)

<u>q_c = 58247.406 watts or 58.25 kW</u>

Radiation from the mouth and Vessel while lid is on

Vessel surface area = 160.18 m^2

Area of the flues = 2(0.3 x 0.3) = 0.18 m^2

Shell

$$q_r = \sigma A \varepsilon (\Delta T^4)$$

$$q_r = 5.67 \times 10^{-8} \times 160.86 \times 0.8(433^4 - 313^4)$$

$$q_r = 186549.02W$$

Mouth

$$q_r = \sigma A \varepsilon (\Delta T^4)$$

$$q_r = 5.67 \times 10^{-8} \times 0.18 \times 0.8(1473^4 - 313^4)$$

$$q_r = 38359.26W$$

Total loss of radiation from the converter during lid-on.

Mouth + shell = Total radiation loss

186459.02 + 38359.26 = 224818.28kW

Total radiation lost = 224.82kW

Transient Heat of matte copper

Air properties @ 40°C   Area = πDL = π x 4.04 x 10.6 = 134.54 m^2

$$\text{Volume} = 2\left(\frac{\pi 4.04^2}{4}\right) + \pi \times 4.04 \times 10.6 = 135.88 m^3$$

ρ = 1.092 kg/m^2 Pr = 0.71

β = 3.19 x 10^{-3} 1/K   α = 24.8 x 10^{-6} m^2/s

μ = 19.123 x 10^{-6} c_p = 1014 J/kg.K

ν = 17.6 x 10^{-6} k = 0.0265 W/m.K

Using Table on Page 307

$$\log_{10}\left(\frac{c_p \rho^2 g\beta\Delta T D^3}{\mu k}\right) = \log_{10}\left(\frac{1014 \times 1.092^2 \times 9.81 \times 3.19 \times 10^{-3}(1200-40)4.04^3}{19.123 \times 10^{-6} \times 0.0265}\right)$$

$$\log_{10}\left(\frac{2894309.744}{5.067595 \times 10^{-7}}\right) = \log_{10}(5.711406977 \times 10^{12})$$

12.7567

This value is unable to be read of the table

$$Gr = \frac{g\beta\Delta T D^3}{\nu^2} = \left(\frac{9.81 \times 3.19 \times 10^{-3}(1200-40)4.04^3}{(17.6 \times 10^{-6})^2}\right)$$

Gr = 7.72745 x 10^{12}

Ra_D = Gr x Pr

7.72745 x 10^{12} x 0.71

Ra_D = 5.48649199 x 10^{12}

Using equation _________ 5.20

Nu_D = 0.53(Gr.Pr)$^{0.25}$ =0.53(5.486492 x 10^{12})$^{0.25}$

Nu_D = 811.146

$$hc = \frac{Nu_D k}{D} = \frac{811.146 \times 0.0265}{4.04} = 5.32$$

Total resistance = $R_{total} = R_{refrac} + R_{matte}$

$$R_{refrac} = \frac{L_{refrac}}{A_{refrac} \times K_{refrac}} = \frac{0.47}{117.68 \times 2.6} = 0.00154 K/W$$

$$R_{matte} = \frac{1}{h_c \times A_c} = \frac{1}{5.32 \times 134.54} = 0.001397 K/W$$

$$R_{total} = 0.00154 + 0.001397 = 0.002937\ K/W$$

$$\text{New } h_c = \frac{1}{134.54 \times 0.002937} = 2.5307$$

Cylinder of Matte @ 1200ºC

Check the Biot number $Bi = \frac{h_c \times r_c}{k} = \frac{2.5307 \times 2.02}{163} = 0.03136$

Bi < 0.1 Try the lump sum method

Using $\tau = 3600 \sec$

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{-(h_c A_s / V c_p)\tau} = \frac{T - 40}{1200 - 40} = e^{-(2.5307 \times 134.54 / 135.85 \times 440)3600}$$

$$T = 40°C$$

Δ Temperature X Total mass of matte copper X Specific heat

$$(1200 - 40) \times 135.88 \times 7850 \times 460 = 5.691687088 \times 10^{11} J$$

Heat energy lost for a full cylinder of matte = $\frac{5.691687 \times 10^{11}}{3600} = 158102419.1W$

Heat energy lost for a ½ cylinder of matte = $\frac{158102419.1}{2}$ = $79051209.56W$

$$q_{matte} = 79051.21kW$$

Cylinder of matte @ 1200ºC using the charts

Fourier number = $\frac{\alpha \times \tau}{r_0^2} = \frac{4.514 \times 10^{-5} \times 3600}{2.02^2} = 0.0398$

$$\frac{1}{Bi} = \frac{1}{0.03136} = 31.887$$

Chart (a) value for temperature at the centre of a cylinder comes to 0.98

$$\therefore 0.98 = \frac{T(0,t) - T_\infty}{T_0 - T_\infty} = \frac{T(0,t) - 40}{1200 - 40}$$

T(0,t) = 1176.8ºC

Chart (b) value for temperature at the outside of a cylinder comes to 0.96

$$\therefore 0.96 = \frac{T(r,t) - T_\infty}{T(0,t) - T_\infty} = \frac{T(r,t) - 40}{1176.8 - 40}$$

T(r,t) = 1169.728ºC

(Chart values are taken from Kreith, F. & Bohn, M.S. (2001) p137)

Δ Temperature X Total mass of matte copper X Specific heat

$$(1200 - 1169.728) \times 135.88 \times 0.2148 \times 1014 = 1.485334065 \times 10^{10} J$$

Heat energy lost from full cylinder of matte = $\frac{1.485334065 \times 10^{10}}{3600} = 4125927.958W$

Heat energy lost from ½ cylinder of matte = $\frac{4125927.958}{2} = 2062963.98W$

$$q_{matte} = 2062963.98W$$

Cylinder of air @ 1200ºC

Check the Biot number $Bi = \frac{h_c \times r_c}{k} = \frac{2.5307 \times 2.02}{0.08508} = 60.0848$

Bi > 0.1 Use the charts

Fourier number = $\frac{\alpha \times \tau}{r_0^2} = \frac{290.72 \times 10^{-6} \times 3600}{2.02^2} = 0.2565$

$$\frac{1}{Bi} = \frac{1}{60.0848} = 0.01664$$

Chart (a) value for temperature at the centre of a cylinder comes to 0.6

$$\therefore 0.6 = \frac{T(0,t) - T_\infty}{T_0 - T_\infty} = \frac{T(0,t) - 40}{1200 - 40}$$

T(0,t) = 736ºC

Chart (b) value for temperature at the outside of a cylinder comes to 0.03

$$\therefore 0.03 = \frac{T(r,t) - T_\infty}{T(0,t) - T_\infty} = \frac{T(r,t) - 40}{736 - 40}$$

T(r,t) = 60.88ºC

(Chart values are taken from Kreith, F. & Bohn, M.S. (2001) p137)

Δ Temperature X Total mass of matte copper X Specific heat

$$(1200 - 60.88) \times 135.88 \times 0.2148 \times 1014 = 33712988.1J$$

Heat energy lost from full cylinder of air = $\frac{33712988.1}{3600} = 9364.719W$

Heat energy lost from ½ cylinder of air = $\frac{9364.719}{2} = 4682.3594W$

$$q_{air} = 4682.3594W$$

Heat energy lost through radiation from the mouth, $q_r = \sigma A \varepsilon (\Delta T^4)$

$$q_r = 5.67 \times 10^{-8} \times 7.06 \times 0.8(1473^4 - 313^4)$$

$$q_r = 1504535.39W \text{ or } 1504.535\ kW$$

Heat energy lost through convection from the mouth, $q_c = \bar{h}_c\ A(T_s - T_\infty)$

4.084 x 7.06(1150 – 40)

q_c = 32005.59 W or 32 kW

Total heat energy lost during lid-off using lump sum capacity for matte = q_{total}

$q_{total} = q_{matte} + q_{air} + q_r + q_c$ = 79051209.56 + 4682.3594 + 1504535.39 + 32005.59

= 80592432.9W

<u>q_{total} = 80592.433 kW</u>

Total heat energy lost during lid-off using charts for matte = q_{total}

$q_{total} = q_{matte} + q_{air} + q_r + q_c$ = 2062963.98 + 4682.3594 + 1504535.39 + 32005.59

= 3604187.319W

$$\underline{q_{total} = 3604.187\ kW}$$

Cost comparison between Natural Gas and Diesel:

Stoichiometric Air to Natural Gas ratio.

NATURAL GAS

Substance	% vol	Equation	O2	CO2	H2O	N2
Methane	94.8	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	189.6	94.8	189.6	
Ethane	2.9	$C_2H_6 + 3.5O_2 \rightarrow 2CO_2 + 3H_2O$	10.15	5.8	8.7	
Propane	0.8	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	4	2.4	3.2	
Butane	0.2	$C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O$	1.3	0.8	1	
Carbon Dioxide	0.1	$CO_2 \rightarrow CO_2$		0.1		
Nitrogen	1.2	$N_2 \rightarrow N_2$				1.2
	100		205.05	103.9	202.5	1.2

$$\text{Dry Air required} = \frac{O_2 required}{\% \cdot O_2 inair} = \frac{205.05}{0.21} = 976.57 m^3 air / m^3 gas$$

$$9.766\ m^3\ air / m^3\ gas$$

$$\therefore 9.766 : 1$$

Fuel data table

FUEL	ENERGY	DENSITY	COST $/L
Diesel	44 MJ/kg	0.84kg/L	$0.26/L
Natural Gas	40MJ/m^3	0.68kg/m^3	$3.25/GJ

Property Data (Adapted from Wood, G. 2003)

Cost of Natural Gas to heat the converter for 1 hour

Assume $\phi = 1$ (Stoichiometric F/A ratio)

Q (Heat Energy) = Vol flow rate x Hv_{gas} (Calorific value) x δ_{gas}(Combustion Eff)

Known values:

Q = 80592432.9 W

$Hv_{gas} = 40 \times 10^6\ J/m^3$

δ_{gas} = 60% (Taken from Ferguson, C. R. & Kirkpatrick, A. T. (2001) Table 5.6)

$$\text{Flow rate} = \frac{Q}{Hv \times \delta_{gas}} = \frac{80592433}{40 \times 10^6 \times 0.6} = 3.358018 m^3 / \sec$$

For 1 hour the gas required is 3.358018 x 3600s = 12088.865 m^3

Natural gas = 38.3 MJ/m^3 (Taken from www.angvc.org)

Volume of natural gas used: 12088.865 x 38.3 x 10^6 = 4.63 x 10^{11} J

Using the value from the table the cost will be

$$\frac{\$3.24}{1 \times 10^9} \times 4.63 \times 10^{11} = \$1500.13$$

To replace the heat energy, during 1 hour while the lid is off the mouth of the converter it will cost $1500.13 in natural gas.

Cost of Diesel to heat the converter for 1 hour

Q (Heat Energy) = Vol flow rate x Hv_{diesel} (Calorific value) x δ_{diesel}(Combustion Eff)

Known values:

Q = 80592432.9 W

Hv_{gas} = 44 x 10^6 MJ/m^3

δ_{gas} = 60% (Taken from Ferguson, C. R. & Kirkpatrick, A. T. 2001)

ρ = 0.84 kg/L (From fuel data table)

$$\text{Flow rate} = \frac{Q}{Hv \times \delta_{gas}} = \frac{80592432.9}{44 \times 10^6 \times 0.6} = 3.0527 kg / \sec$$

For 1 hour the gas required is 3.0527 x 3600s = 10989.878 kg

To convert to litres we divide mass by ρ

$$\frac{10989.878}{0.84} = 13093.187 litres$$

Amount of diesel used: $13093.187 \times 0.26 = \$3401.63$

To replace the heat energy, during 1 hour while the lid is off the mouth of the converter it will cost $3401.63 in diesel

Appendix C:

Radex refractory Properties

RADEX DB605B

Description

Magnesia-chrome brick, high fired, direct bonded with 55 % fused grain
content, low porosity, very
good temperature shock resistance, slag resistant

Main application

Cement and lime industry, non ferrous metal furnaces

Chemical analysis

MgO Dif.	57,0	%
Cr_2O_3	21,0	%
Fe_2O_3	13,0	%
Al_2O_3	6,7	%
CaO	0,8	%
SiO_2	0,6	%

Physical data

Bulk density	3,27	g/cm³	EN 993-1
Apparent porosity	16,0	vol%	EN 993-1
Cold crushing strength	50,0	N/mm²	EN 993-5

Refractoriness under load T0,5	> 1700 °C	EN 993-8
Thermal conductivity (500°C)	2,70 W/mK	DR. KLASSE
Thermal conductivity (750°C)	2,60 W/mK	DR. KLASSE
Thermal conductivity (1000°C)	2,60W/mK	DR. KLASSE
Thermal conductivity (1200°C)	2,60W/mK	DR. KLASSE
lin. thermal expansion (500°C)	0,41%	-
lin. thermal expansion (750°C)	0,65%	-
lin. thermal expansion(1000°C)	0,94%	-
lin. thermal expansion(1200°C)	1,20%	-
lin. thermal expansion(1400°C)	1,47%	-
lin. thermal expansion(1600°C)	1,70%	-

The indicated values are standard values, i.e. values taken over a longer representative period of time according to either valid test standards or internal test methods. They may not be regarded as committed specifications and therefore not as guaranteed properties. We reserve the right to further technical developments and new editions of technical product information.

RADEX CMS

Description

Magnesia-chrome brick, ceramic bond, made from simultan sinter, direct
bonded and low SiO_2-content,
high hot strength, resistant to mechanical wear, high fired

Main application

OH-furnace, EAF, non ferrous metals industry, degassing ladle

Chemical analysis

MgO Dif.	57,0	%
Cr_2O_3	21,0	%
Fe_2O_3	12,5	%
Al_2O_3	6,0	%
CaO	1,0	%
SiO_2	1,6	%

Physical data

Bulk density	3,21	g/cm³	EN 993-1
Apparent porosity	17,0	vol%	EN 993-1
Cold crushing strength	75,0	N/mm²	EN 993-5

Refractoriness under load ta	1700 °C	DIN 51064
Refractoriness under load tb	> 1750 °C	DIN 51064
Refractoriness under load T0,5	> 1750 °C	EN 993-8

Thermal conductivity (500°C)	3,10 W/mK	DR. KLASSE
Thermal conductivity (750°C)	2,90 W/mK	DR. KLASSE
Thermal conductivity (1000°C)	2,80W/mK	DR. KLASSE
Thermal conductivity (1200°C)	2,80W/mK	DR. KLASSE
lin. thermal expansion (500°C)	0,41%	-
lin. thermal expansion (750°C)	0,65%	-
lin. thermal expansion(1000°C)	0,90%	-
lin. thermal expansion(1200°C)	1,20%	-
lin. thermal expansion(1400°C)	1,47%	-
lin. thermal expansion(1600°C)	1,70%	-

The indicated values are standard values, i.e. values taken over a longer representative period of time according to either valid test standards or internal test methods. They may not be regarded as committed specifications and therefore not as guaranteed properties. We reserve the right to further technical developments and new editions of technical product information.

Appendix D:

Fluent heat distribution graphs

Tables below show the Fluent results for heat losses for different areas during the three burner positions

Tuyere Burner Lid off @ 1300 ºC	Heat energy lost
Outlet	914.195 kW
Steel shell	44.5 kW
Matte	19.137 kW
Refractory	21.37 kW
Steel wall	3.9 kW

Side Wall Burner Lid off @ 1300 ºC	Heat energy lost
Outlet	810.14 kW
Steel shell	81.273 kW
Matte	34.125 kW
Refractory	43.8 kW
Steel wall	3.304 kW

Tuyere Burner Lid on @ 1300 ºC	Heat energy lost
Outlet	730.97 kW
Steel shell	76.58 kW
Matte	20.118 kW
Refractory	26.921 kW
Steel wall	29.604 kW

Side Wall Burner Lid on @ 1300 ºC	Heat energy lost
Outlet	576.97 kW
Steel shell	142.08 kW
Matte	29.85 kW
Refractory	60.95 kW
Steel wall	9.45 kW

Tuyere Burner Lid on @ 1250 ºC	Heat energy lost
Outlet	727.5 kW
Steel shell	73.89 kW
Matte	19.41 kW
Refractory	25.84 kW
Steel wall	28.676 kW

Side Wall Burner Lid on @ 1250 ºC	Heat energy lost
Outlet	568.56 kW
Steel shell	102.64 kW
Matte	32.53 kW
Refractory	58.54 kW
Steel wall	9.17 kW

Tuyere Burner Lid on @ 1200 ºC	Heat energy lost
Outlet	723.5 kW
Steel shell	71.43 kW
Matte	18.69 kW
Refractory	24.8 kW
Steel wall	27.7 kW

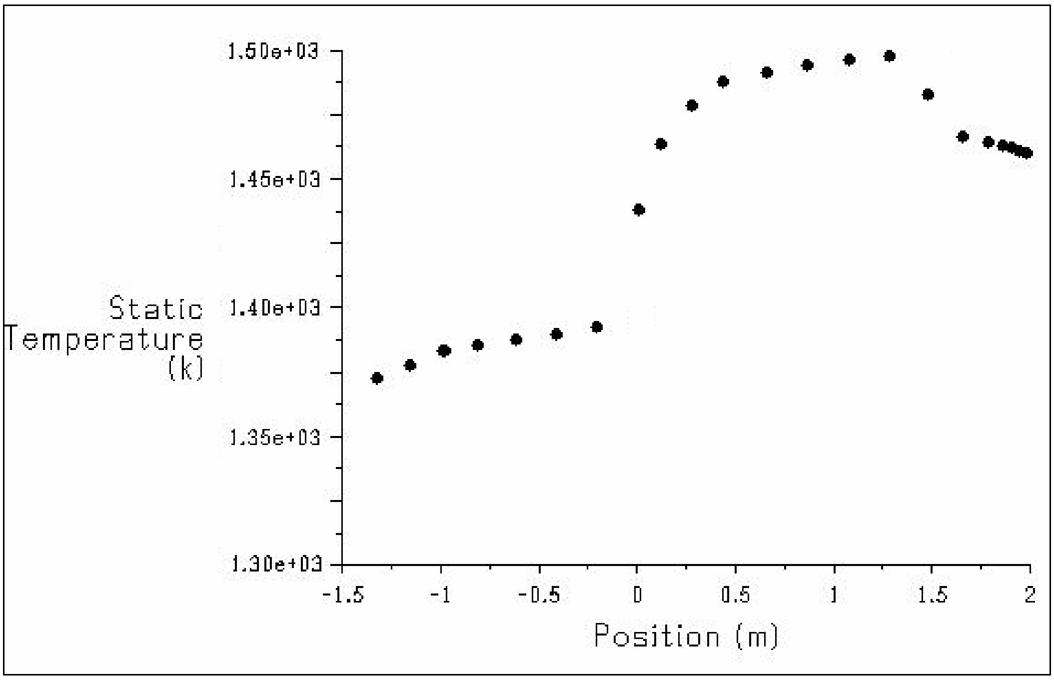
Side Wall Burner Lid on @ 1200ºC	Heat energy lost
Outlet	557.38 kW
Steel shell	105.61 kW
Matte	32.84 kW
Refractory	56 kW
Steel wall	8.89 kW

Start-up Burner Lid on @ 1300 ºC Side View	Heat energy lost
Outlet	821.4 kW
Steel shell	378.2 kW
Refractory	50.4 kW
Steel wall	1.58 kW

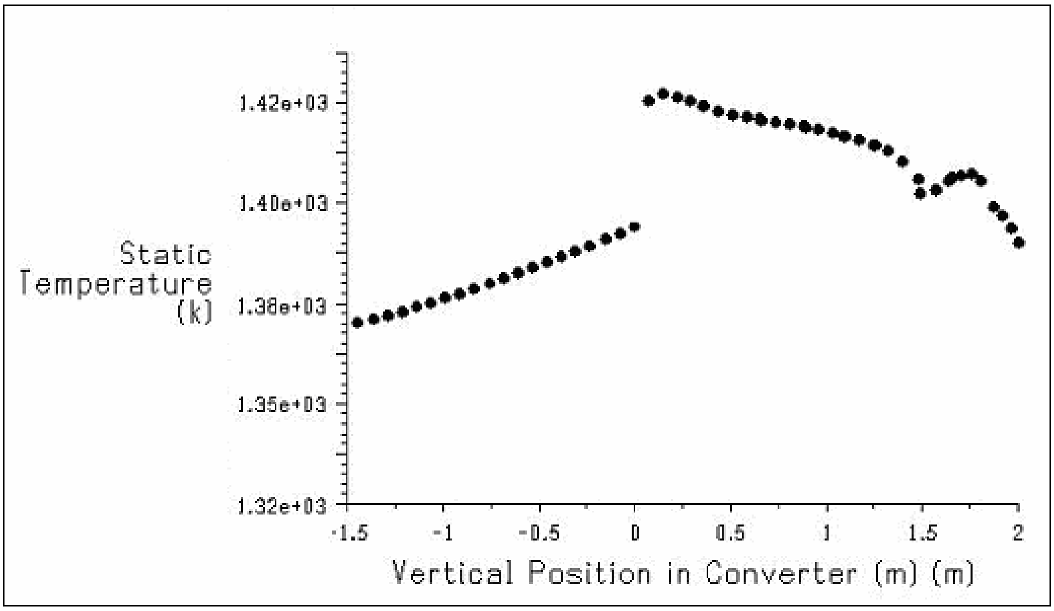
Start-up Burner Lid on @ 1300 ºC Front View	Heat energy lost
Outlet	709.86 kW
Steel shell	443.56 kW
Refractory	44.98 kW
Steel wall	19.14 kW

Heating Burner Lid on @ 1200 ºC Front View	Heat energy lost
Outlet	785.8 kW
Steel shell	112.63 kW
Matte	49.45kW
Refractory	42.05 kW
Steel wall	4.87 kW

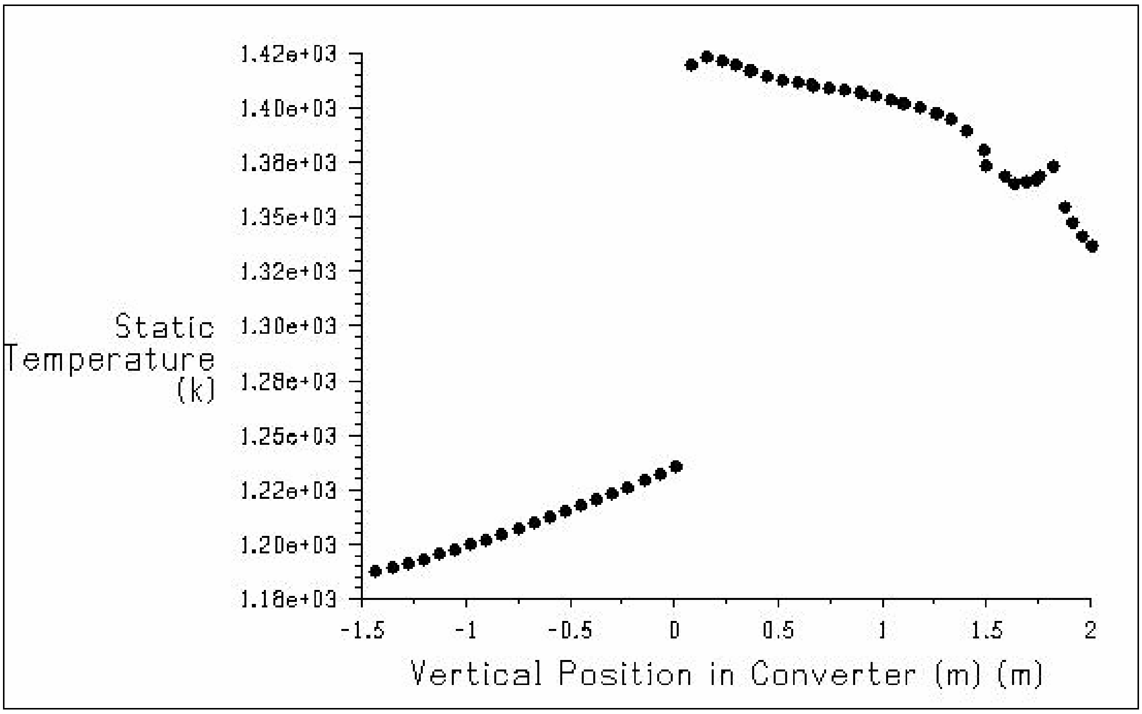
Temperature Distribution Graph for Tuyere Burner, Lid-off. 1300ºC heating results from Fluent



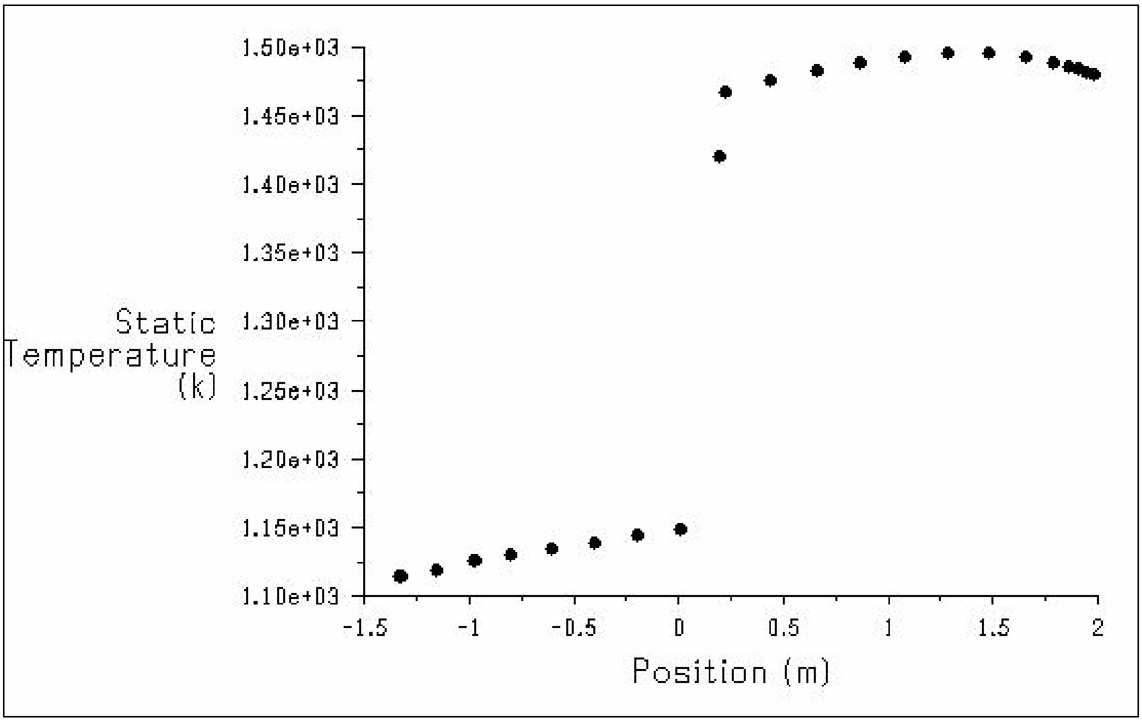
Temperature Distribution Graph for Tuyere Burner, Lid-on. 1200ºC heating results from Fluent



Temperature Distribution Graph for Side Wall Burner, Lid-on 1200ºC heating results from Fluent

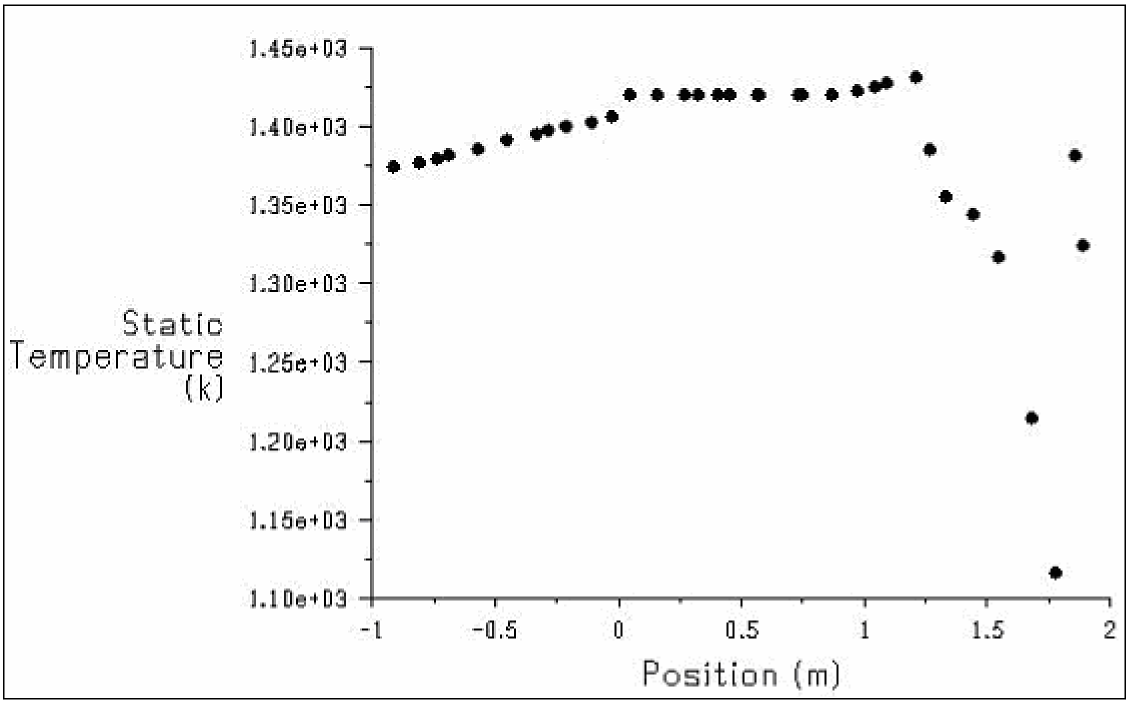


Temperature Distribution Graph for Side Wall Burner, Lid-off. 1300ºC heating results from Fluent



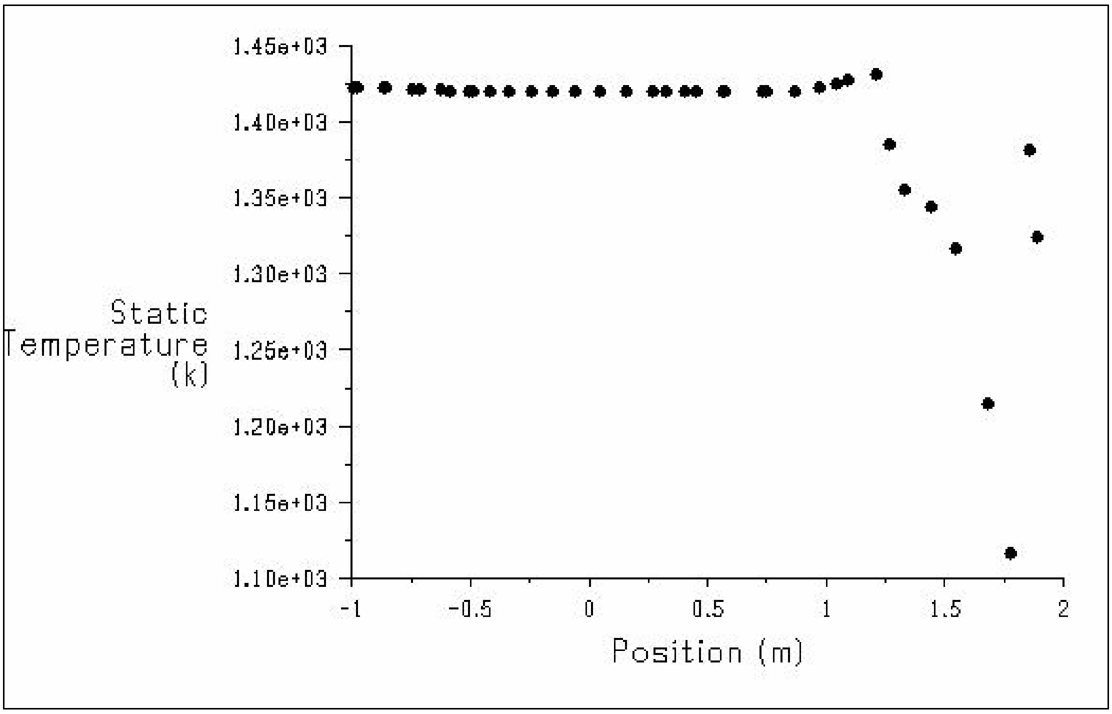
Temperature Distribution Graph for Mouth Burner.

1200ºC heating results from Fluent



Temperature Distribution for Mouth Burner cold start-up condition

results from Fluent



Appendix E:

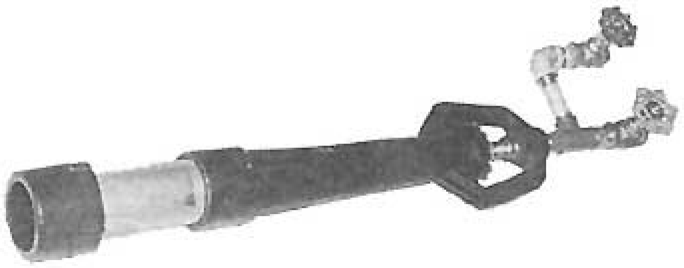
Burner Properties

HBT HI-BLAST TORCHES

The high blast torches are compact heating burners that deliver higher capacities than normal heating torches. They are a complete assembly with modified FR burner tip, mixers and valves.

APPLICATIONS

- Mould drying
- Ladle heating
- Crucible heating
- Metal melting
- General heating applications
- Furnace heating



OPERATION

Hi-blast torches use small amounts of high pressure air (100-700 kPa) to pick up incoming gas at a modified mixer. The gas pressure is elevated and the resulting mixture of air/gas is delivered to the orifice in the inspirator where large quantities of air required for combustion are induced. Greater mixture pressures and capacities are therefore possible.

The assembly can be purchased complete with the modified flame retaining burner nozzle, air valve and gas valve or separately. Approximate capacity should be stated as well as gas type and pressure when ordering.

MODEL NUMBER	SIZE (BSP)	FLAME LENGTH	OVERALL LENGTH	CAPACITY MJ/HOUR	WEIGHT KG
TH-HBT25	25mm	300	685	90	2.5
TH-HBT32	32mm	380	880	205	4.8
TH-HBT40	40mm	450	970	320	6.4
TH-HBT50	50mm	600	1000	560	8.2
TH-HBT65	65mm	800	1200	870	11.7
TH-HBT80	80mm	1000	1360	1060	14.8
TH-HBT100	100mm	1300	1720	1700	26.8

FR torches operate on high pressure L.P.G or Natural Gas from 30-300kPa and are supplied with a gas control valve. The FR torches induce between 65% and 100% of the total air from the inspirator. Maximum input per appliance combustion space is 60-100 MJ/Hour/28 litres (60-100 MJ per ft3).

MODEL NUMBER	SIZE (BSP)	FLAME LENGTH (mm)	OVER ALL LENGTH (mm)	CAPACITY RANGE MJ/HOUR	WEIGHT KG
TH-FR1	15mm	150	340	0 - 20	.45
TH-FR2	20mm	220	415	20 - 50	.70
TH-FR3	25mm	300	545	30 - 90	2.0
TH-FR4	32mm	380	710	80 - 200	3.6
TH-FR5	40mm	450	800	140 - 300	5.2
TH-FR6	50mm	550	830	250 - 500	7.0
TH-FR7	65mm	620	930	300 - 800	9.9
TH-FR8	80mm	800	1090	400 - 1000	13.0
TH-FR9	100mm	1000	1450	700 - 1800	25.0

The capacity values are approx. only and are at 100 kPa. Greater capacities are possible at higher pressures

(Taken from Combust website www.combust.com.au, 2004)