University of Southern Queensland

Faculty of Engineering and Surveying

Co-Firing of Rice Husk for Electricity Generation in Malaysia

A dissertation submitted by

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Abstract

The threat of increased global warming has subjected the usage of fossil to be further researched for better alternatives. As a result, the utilisation of renewable and sustainable energy resources, such as biomass, for electricity production has become increasingly attractive. Co-firing biomass with low percentages in coal fired power plants will enable the use of sustainable fuels for power production without large investments. Co-firing can be seen as a method to mitigate the emissions of CO_2 as the amount of CO_2 released from combustion is equal to the amount consumed during plant growth.

This dissertation, looks into the utilisation of rice husk as a source of renewable and sustainable energy source for co-firing in coal power plants in Malaysia through the feasibility of the rice husk as a fuel, the combustion technology options for co-firing, and the fuel blend suitable for co-firing in local coal fired power plants.

In order to achieve the research area, modelling of the combustion of both coal and a blend of coal and rice husk was done. It was found that the rice husk and coal blend was able to produce the same temperature needed to produce the steam quality as specified by a coal power plant in Malaysia while reducing the amount of nitrogen and carbon dioxide concentration.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Acknowledgement

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Contents

CHAPTER 2 – THE POWER PLANT

CHAPTER 3 – CO-FIRING WITH PULVERISED COAL COMBUSTION METHOD

CHAPTER 4 – FUEL

List of Figures

List of Tables

Glossary of Terms

AFT	-	Adiabatic Flame Temperature
2D	-	Two dimensional
CDF	-	Computational Fluid Dynamics
CO_2	-	Carbon Dioxide
MW	-	Mega Watt
NO_x	-	Nitrogen Oxides
SO_x	-	Sulphur Oxides
TNB	-	Tenaga Nasional Berhad (Malaysian National Electricity Provider)
TNRD	-	Tenaga Nasional Research and Development

Chapter 1

Feasibility of Co-Firing in Malaysia

1.1 Introduction

With the awareness of humans towards the depletion of energy resources, it is time to move on to develop other methods of fulfilling our requirement of energy. Biomass is an effective alternative to alleviate this problem and is generally a valuable source in our lives.

Malaysia, well known for its agricultural sector, is one of the leading producers of paddy. Rice is a staple food in Malaysia, therefore coherent to that, large amounts of rice husks are being burdened by their producers to be dispelled. Moving towards a conscious of zero waste, rice husks is being increasingly seen as a potential source for biomass. Malaysia itself produces approximately 0.48 million tonnes of rice husks a year and due to vast technological developments in paddy growth, rice husks can be a valuable asset in reducing the cost and pollution in creating energy (Pusat Tenaga Negara, 2002)

Over the years, coal has been used as a fuel to generate useful electricity. Concurrently, many other fuels, mostly un-renewable fuels from crude oil are also used. The amount of these fuels is depleting rapidly, and one of the major impacts is pollution. Its high emission of sulphur and nitrate based gases is a threat to mankind (Bruce and William, 1986).

Because of that, alternative methods such as co-firing may be carried out. Negative impacts such as global warming, and acid rain may be avoided, and hence providing it with a bright future in becoming a popular alternative method in Malaysia and other parts of the world.

1.2 Objectives

This dissertation sets out to investigate the potential of rice husks to be a supplement medium in combustion to produce electricity in a coal fired power plant.

The aspects that this project will cover based on existing coal fired power plants includes,

a. Performance
b. Pollution
c. Cost

1.3 Dissertation Overview

This dissertation is divided into seven chapters. The current chapter, which is Chapter 1, introduces the reader with the idea of co-firing and the feasibility on the utilisation of co-firing in Malaysia. It will also cover the objectives and methodology of this project. Chapter 2 will be discussing on the power plant in general. It includes specifications of power plants, and various technologies on coal firing in coal fired power plants.

After that, Chapter 3 will introduce the reader to greater depth on the pulverised coal combustion system which will be used for modelling in this project. Chapter 4 will be discussing on the type of fuel and fuel blends, where comparisons were made between coal and rice husk blended fuels.

Next, Chapter 5 will be relating to a 2 dimensional model of the pulverised coal combustion of coal and rice husk blend using computational fluid dynamics package. Simulation of the model will prove the practicability of using rice husk as a supplement fuel for co-firing as will be discussed in Chapter 6 of Results and Discussions. Finally, Chapter 7 will conclude on all of the findings from this project together with some knowledge and experience learned from this project.

1.4 Project Methodology

The method utilised for this project is planned and executed according to several stages. As the project was approved, literature review on the electricity demand in Malaysia and the utilisation of coal fired power plants in Malaysia was found. Then further literature reviews were made on co-firing. This includes research on the types of biomass used in co-firing, the affects on pollution and methods used for co-firing.

The next step was to look in further into utilising rice husk with coal as a fuel. Again, literature review was done on both coal and rice husk. The objective for this was to check on the availability and properties of rice husk for calculation. Besides that, it was also to gather information on the main types of coal utilised in Malaysia as well as its ultimate analysis. For this, literature review on journals and research papers have been made besides undergoing a private discussion with a professor in the Tenaga Nasional Research and Development Centre.

After that, information on power plants in Malaysia was carried out through websites of coal fired power plants in Malaysia to obtain information on the method of firing utilised and also to gather data on the properties of steam of one of the coal fired power plants in Malaysia as a model for calculations.

With all the data obtained, a 2-dimensional model of the combustion process was to be created. Using a modelling software called GAMBIT and FLUENT 5.3 as a solver, the model was generated to determine the affects of co-firing rice husk in comparison of the conventional coal firing.

1.5 Electricity Demand

The peak demand for electricity in Malaysia grew at a rate of 5.8% per annum, reaching 11,462 megawatts (MW) in 2003. To meet the growth in peak demand, the electricity generation capacity was increased from 12,645MW in 2000 to 17,015MW in 2003 as can be seen in table 1.1 (Mid-Term Review of the 8th Malaysian Plan 2001-2005).

Table 1.1 Installed Capacity, Peak Demand and Reserve Margin, 2000-2005 for Tenaga Nasional Berhad, Malaysian National Electricity Provider (Mid-Term Review of the 8th Malaysian Plan 2001-2005)

Year	Accumulated installed capacity (MW)	Peak demand (MW)	Reserve Margin (%)
2000	12,645	9,712	30.2
2003	17,015	11,462	48.4
2005	18,465	13,172	40.2

The main sources of energy supply that are found in Malaysia are hydro, natural gas, crude oil, and coal.

Table 1.2 Fuel Mix in Electricity Generation (Mid-Term Review of the 8th Malaysian Plan 2001-2005)

Year	Oil (%)	Coal (%)	Gas (%)	Hydro (%)	Others (%)	Total (GWh)
2000	4.2	8.8	77	10	0	69,280
2003	2.6	16.5	73.2	7	0.7	81,488
2005	2.4	26.8	64.3	5.9	0.6	96,087

Figure 1.1 Fuel Mix in Electricity Generation for the Year 2000

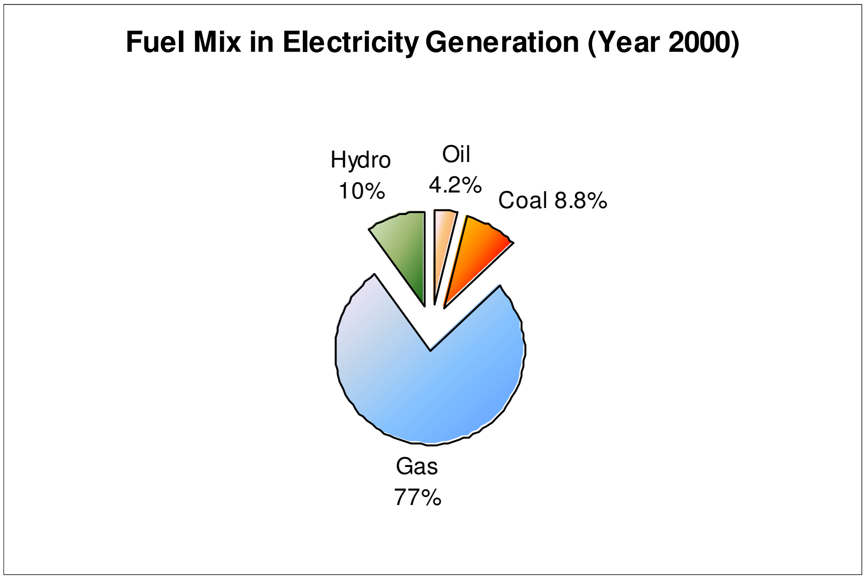


Figure 1.2 Fuel Mix in Electricity Generation for the Year 2003

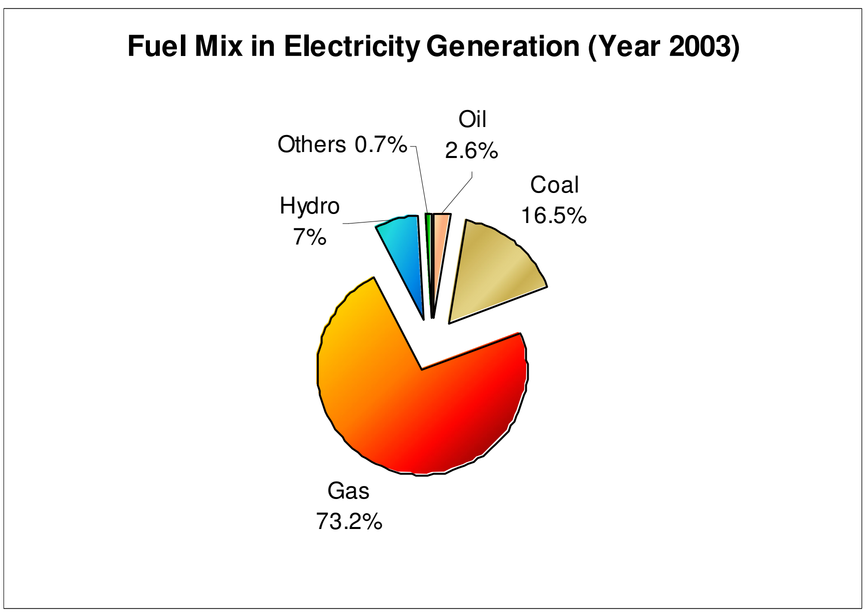
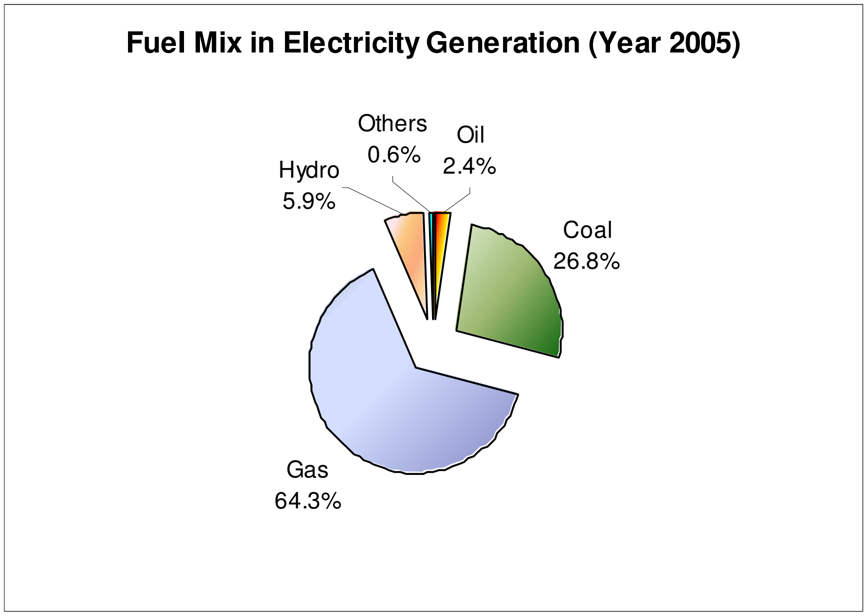


Figure 1.3 Projected Fuel Mix in Electricity Generation for the Year 2005



According to the review of the 8th Malaysian plan, the projected value for coal in the fuel mix in electricity generation is to be increased from 8.8 percent in 2003 to 26.8 percent in 2005. This means that the coal is to produce 25748.9GWh of electricity in 2005.

Based from the fuel mix table, the percentage of coal fired power plants in Malaysia is also to be increased year after year. This indicates that the utilisation of coal is still reliable and measures have to be taken to change the method.

1.6 Renewable Energy Sources

Renewable energy resources that are widely used in Malaysia are hydropower, biomass and solar energy. According to Pusat Tenaga Negara (Malaysian Energy Centre), Malaysia has an abundant biomass waste source which are mainly from its palm oil, wood and agricultural residues. It was reported that Malaysia produces an estimated amount of 20.8 million tonnes of biomass residue a year.

Table 1.3 List of Biomass Resources and Potential Power (Pusat Tenaga Negara)

Sector	Quantity kton/yr	Potential Annual Generation (GWh)	Potential Capacity (MW)
Rice Mills	474	263	30
Wood Industry	2,177	598	68
Palm Oil Mills	17,980	3,197	365
Baggase	300	218	25
Palm Oil Mills Effluents	31,500	1,587	177
Total	79,962	5,863	665

1.7 Pollution Aspects

Pollute, in the Oxford dictionary (1986), generally means a state where there occurs a certain disturbance in purity or contamination towards a matter. In the aspects of electricity generation, pollution or contamination occurs to several aspects which are air, water and land (El-Wakil, 1998).

Generally, the ideal combustion of fossil fuel produces carbon dioxide and water. However, in real cases, many other gasses are produced and most of them posses an effect to the well being of mankind.

According to El-Wakil (1998), the main contaminants from fossil power plants are:

a. Sulphur oxide – main cause of acid rain
b. Nitrogen oxides – causes respiratory illnesses
c. Carbon oxides – contributes to thermal pollution or global warming
d. Particulate matter – decreases visibility, increases soiling and corrosion and respiratory illnesses

In order for us to control pollutant emission, various measures can be taken. Thanks to researches made, certain steps have already been used to cope with pollution. Measures as listed below can be used to help reduce the amounts of pollutant produced.

a. Dry Flue Gas Desulphurisation
b. Single Alkali Scrubbing
c. Electrostatic Precipitators
d. Fabric Filters

However, like many other new technologies, cost plays an important aspect. Incorporating these new technologies to older methods of firing may impose large amounts of capital cost to be spent, thus cheaper alternative methods can be approached such as the utilisation of co-firing to reduce pollutant emission.

1.8 Regulations and National Plans

With the increased awareness of the community towards global warming and preserving the environment, many local and international regulations had been amended to control pollutant emissions to the surrounding. International Agreements such as the Kyoto protocol for example, legally binds industrialised nations to reduce their collective emissions of greenhouse gasses (Kyoto Protocol, 2004).

As a result of the high cost and regulatory amendments, electricity producers seek for better alternatives and as a result, they turn to the use of sustainable energy resources such as biomass. This is because the use of dedicated biomass feed stocks for electricity generation might be able to help in reducing the emission of greenhouse gasses. Biomass such as agricultural residues is able to provide fuel for electricity generation. Besides that, the increase usage of such fuel will also in turn reduce the cost and eliminate the burden of waste disposal.

Under the Eight Malaysian Plan, intensive encouragement to utilise renewable resources is to be done for electricity generation. In addition, renewable energy will be included in the fuel diversification policy. Under this policy, biomass based generating companies will be granted exemptions from the income tax on 70% statutory income for 5 years or a tax allowance of 60% capital expenditure incurred (Mid-Term Review of the 8th Malaysian Plan 2001-2005). Furthermore, companies will enjoy import duties and sales tax exemption on imported machinery and equipment.

1.9 Benefits and Limitations of Co-Firing

1.9.1 Benefits

Co-firing biomass with coal offers several environmental benefits. One of the benefits includes reducing the emission of CO_2. The emission of CO_2 for the combustion of biomass is equivalent to the amount of CO_2 absorbed during its growing cycle. Therefore, the net CO_2 released is approximately zero and by mass, this will show a reduction of CO_2 emissions when biomass is co-fired with coal (Lacrosse and Mathias, 2004).

Besides that, co-firing also possesses an effect to reduce the amount of NOx released. According to Planet Power (2004), the NO_X level will be reduced because of lower flame temperatures as a result of combustion with high moisture content biomass. However, the emissions are highly dependant on the boiler operating conditions and design.

In addition, renewable energy or biomass which was used results in reducing landfill material and alleviating the burden of waste disposal.

1.9.2 Limitations

Werther et al (2000) pointed that co-firing increases fouling and corrosion. This is due to the presence of low melting point compounds in the ash. To overcome fouling and corrosion, proper evaluation and mitigation should be carried out in the design of the combustion systems.

Chapter 2

The Power Plant

2.1 Introduction to Power Plants

According to the Webster's International Encyclopaedia (1996), an electric power plant creates mechanical energy that is converted via a generator into electricity. The production of electricity may be used for industrial, residential and rural use (Perry and Green, 1997). Besides that, Perry and Green, 1997) also states that these plant units, which are mainly stationary plants, convert energy from various methods which includes falling water, fossil fuel, solar, wind, and biomass.

Figure 2.1 Process conversion of heat to electrical energy

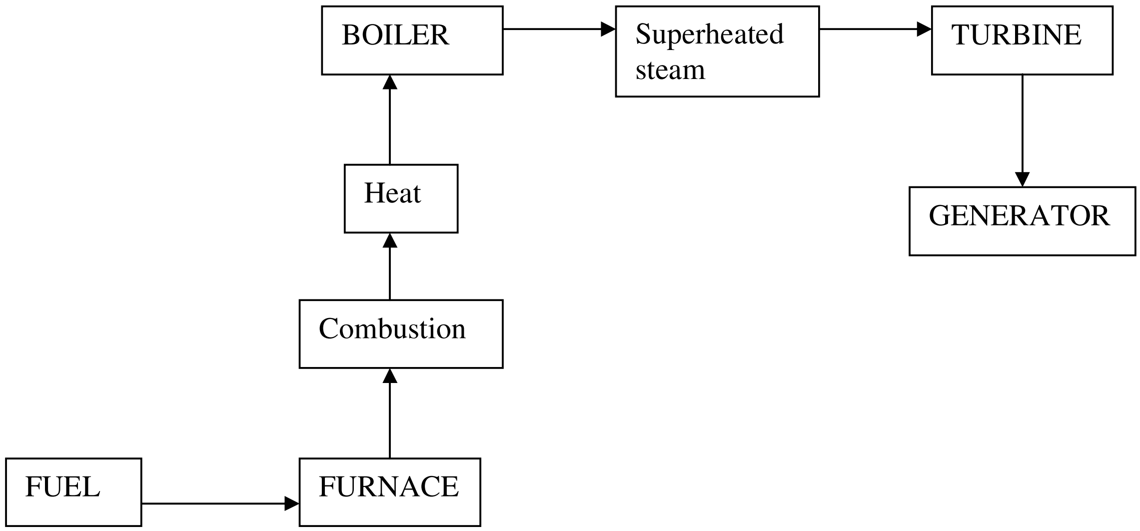
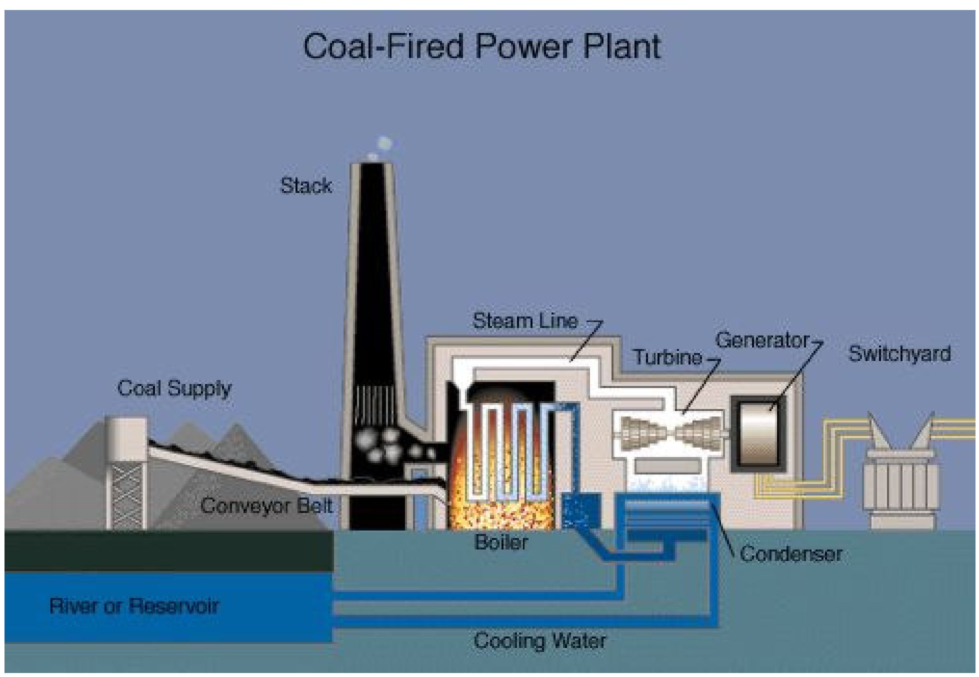


Figure 2.2 Example of the coal fired power plant. (Tennessee Valley Authority)



2.2 Coal Power Plants – Specification

The coal power plant utilises coal as fuel in producing electricity. A general description of coal power plant as stated by the Tennessee Valley Authority consist of,

a. Burner
    - Feeds coal to the combustion chamber for combustion

b. Boiler
    - Utilises the heat of coal combustion to convert feed water to high temperature and pressure steam

c. Steam lines
    - consists of properly sized pipes to feed the steam produced to the turbine

d. Turbine
    - converts steam pressure to rotational mechanical work

e. Generator
    - converts mechanical work to electricity

2.2.1 Generating Unit Size

There are a few factors, which can influence the size and capacity of a power plant. These factors include:

i. Type of unit
ii. Duty required

The types of units as stated by Parker (1993) are such as:

a. Base load – as large as 1200MW or more
b. Intermediate duty generators – 200 – 600 MW
c. Peak-load – 10 – 100 MW

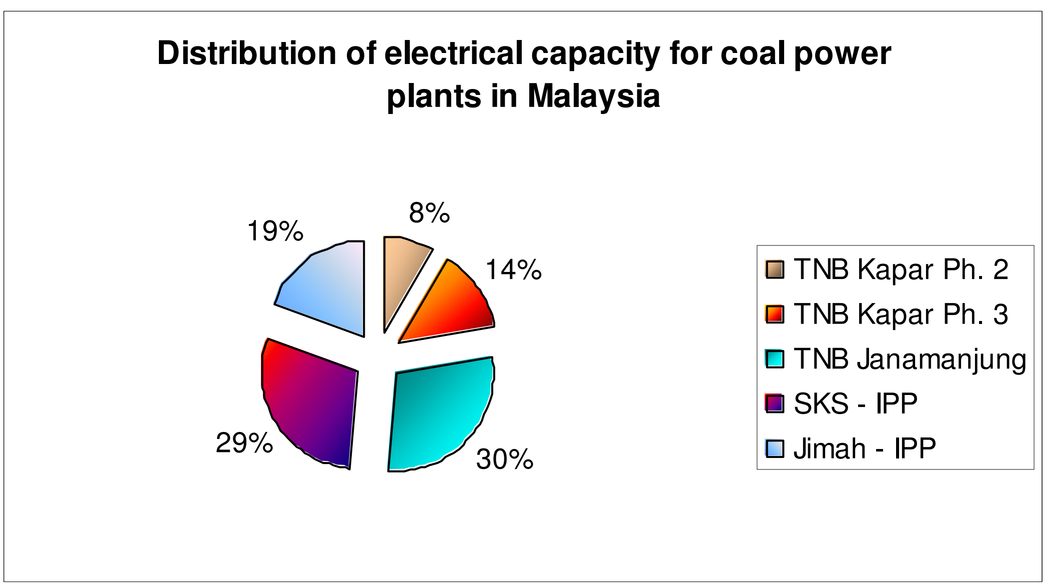
In Malaysia, the type of unit of a coal fired power plant ranges from intermediate duty generators to base load units as can be seen from the table 2.1.

Table 2.1 List of Coal Fired Power Plants in Malaysia (Existing and Planned Coal-Fired Power Plant, 2004)

Plant	Capacity	Coal Utilization
TNB Kapar Ph. 2	600 MW	1.5 mtpa
TNB Kapar Ph. 3	1000 MW	2.5 mtpa
TNB Janamanjung	2100 MW	6.0 mtpa
SKS - IPP	2100 MW	5.7 mtpa
Jimah - IPP	1400 MW	3.5 mtpa
Total	7200 MW	19.2 mtpa

The table above lists the coal fired power plants available in Malaysia. From there, it can be seen that the total amount of electrical energy supplied is 7200 MW with coal utilisation of 19.2 million tonnes of coal per year.

Figure 2.3 Distribution of Electrical Capacity for Coal Power Plants in Malaysia



2.3 Introduction to Various Technologies of Co-Firing

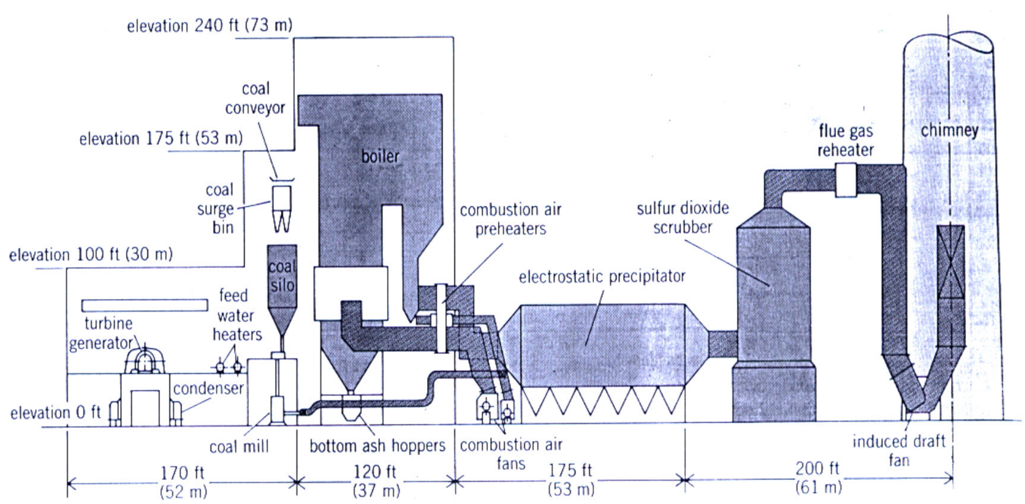
There are many coal combustion methods which are incorporated for over the years for electricity production. However, in this dissertation, the methods discussed will be technologies where co-firing had been tested and evaluated.

According to Bain and Amos (2003), these methods are:

- Pulverized Coal Boilers
- Stoker Boilers
- Fluidised Bed Boilers
- Cyclone Boilers.

2.3.1 Pulverised Coal Boiler

Figure 2.4 Pulverised Coal Combustion plant, (Perry and Green, 1997)

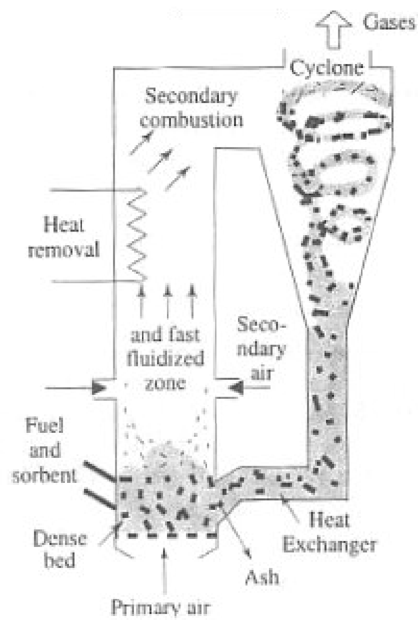


Pulverised fuel furnace basically burns pulverised fuel particles. The fuel, normally milled to obtain sizes from 5 to 400 microns in diameter is blown through nozzles into the furnace (Williams et al., 2001). These fine particles are injected with some proportion of air, known as the primary air and the combustion is ignited by oil or gas flames. The rest of the air is usually supplied around the burner in order to provide adequate oxygen for a complete combustion.

The advantages of pulverised fuel firing as stated by El-Wakil (1998) are the ability to use any size of coal, lower requirement of excess air resulting in lower fan power consumption, good variable load response, lower carbon loss, higher combustion temperature for improved thermal efficiency, low operation and maintenance cost and the possibility of design for multiple fuel combustion.

2.3.2 Fluidised Bed Combustion

Figure 2.5 Fluidised Bed Combustion, (P.K Nag, 2002)



In fluidised bed, combustion takes place in a hot granular material such as silica. The particles are suspended in a stream of upward turbulent moving air which enters the bottom of the furnace. The turbulence occurred distributes the fuel. The balance combustion air, or secondary air, enters a chamber above the furnace (Oregon Department of Energy, 2004).

The main advantage of fluidised bed combustion is that, the NOx gas emission can be reduced due to lower combustion temperature which is below 972 degree Celsius (Oregon Department of Energy, 2004).

Other advantages as stated by El-Wakil (1998) are:

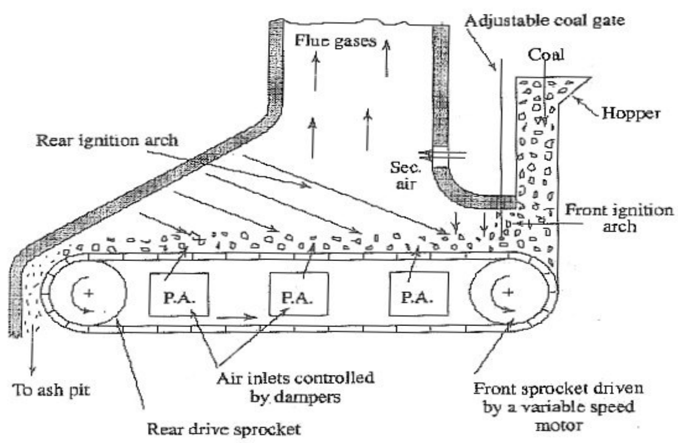
- The boiler does not require the coal to be grind to less than 70 microns which will be significant for maintenance expenses.
- It can accept a wide range of fuel.
- It does not require post combustion cleaning equipment as flue-gas desulphurization (FGD) and the selective catalytic reduction (SCR) systems to remove SO_2 and NO_X.

However, there exist some disadvantages towards this method of combustion, such as:

- Feeding system of coal and limestone
- Control of carbon carryover with flue gas
- Regeneration or disposal of calcium sulphate
- Variable load operation

2.3.3 Stoker Boilers

Figure 2.6 Stoker Boilers (El-Wakil, 1998)



There are four major groups of mechanical stokers, depending on the method of introducing the coal into the furnace.

For example, the travelling grate stokers have grates, with joints in an endless belt driven by a motorised sprocket. The fuel is fed continuously from a hopper to the moving grate through a gate.

The fuel bed continues to burn and creates small amounts of ash depending on the chemical properties of the fuel where it is then discharged to the ash pit (Oregon Department of Energy, 2004).

The advantages of stokers as stated by Werther et.al. (2001) are:

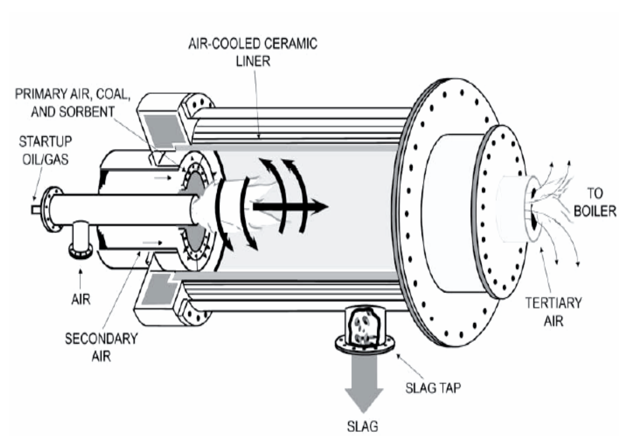
- Good burnout of fly ash particles with low dust load in the flue gas.
- Less sensitive to slagging than fluidised bed combustors.
- The investment and operating cost for plants with capacity less than 10MW are comparatively low.

On the other hand, the limitations found are:

- The least efficient of all types of firing with low burning rates, requiring a large furnace width for a given steam output.
- Combustions are not homogeneous.

2.3.4 Cyclone Combustion

Figure 2.7 Cyclone Combustion (Advanced cyclone combustor with internal sulphur nitrogen and ash control, 2004)



The cyclone combustor is basically a horizontal cylinder located outside the main boiler furnace, where crushed coal is fed and fired with high rate of heat. Therefore, the combustion of coal takes place before the resulting hot gasses enters the boiler furnace.

Combustion takes place in a cyclonic motion due to air, which is injected tangentially into the cylinder (Clean Coal, 2004).

Cyclone furnace firing was the most significant step in coal firing since the introduction in pulverised coal firing in the 1920s. Today, it is widely used to combust lower grades of coal which contains high ash content (6% - 25%) and high volatility matter (> 15%) which is unsuitable for pulverised fuel burners (Borman, 1998).

Chapter 3

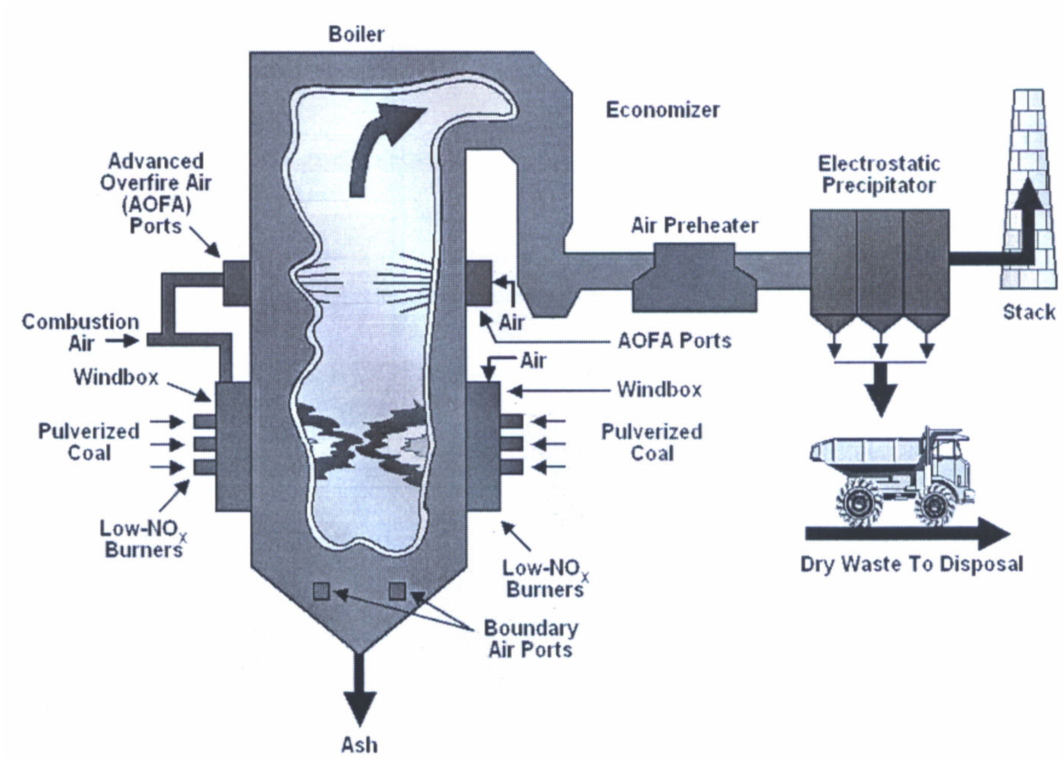
Co-Firing with Pulverised Fuel Combustion Technique

3.1 Introduction

Based on literature review, it was found that the majority of base load power plants such as the Kapar, Janamanjung and Jimah power plants are using the pulverised coal firing system. Therefore, this chapter will be entirely focusing on the utilisation of the pulverised fuel firing method for further research.

According to El-Wakil (1998), it was because of the efforts of John Anderson and his associates that made pulverised coal combustion a success in electric generating power plants. The general concept of coal pulverisation was made with the belief that coal could burn as easily and efficiently as gas provided it was made fine enough.

Figure 3.1 Pulverised coal combustion system (Singer, 1981)



Before the fuel can be fired in the combustor or furnace, the fuel has to be prepared for it to be suitable for combustion. There are several steps in producing pulverised fuel for firing such as:

3.1.1 Coal Crushing Methods

Coal has to be crushed to meet the required size of the pulverisers. It is normally done in a coal handling house located at a suitable location.

There are several methods to prepare coal for pulverisation, which includes:

a. Ring Crusher

b. Granulator

c. The Hammer Mill

According to El-Wakil (1998), in pulverised coal power plants, the hammer mill is the most preferred coal crushers. Coal is fed at the top and is crushed by swinging hammers attached to a rotor. There are also adjustable screen bars which are used to determine the maximum particle size of the coal to be discharged.

Figure 3.2 The Hammermill (El-Wakil, 1998)

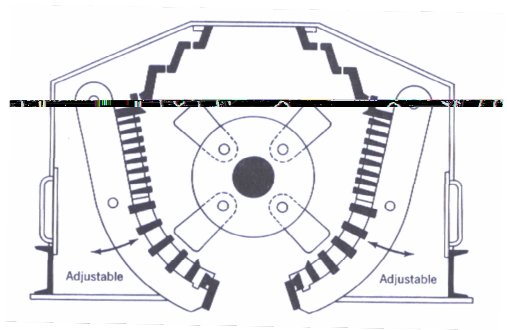
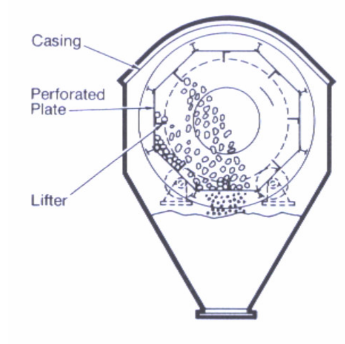


Figure 3.3 A Bradford Beaker (El-Wakil, 1998)



All these methods are used to crush coal to smaller particles to enable it to be pulverised and used as fuel in the firing process.

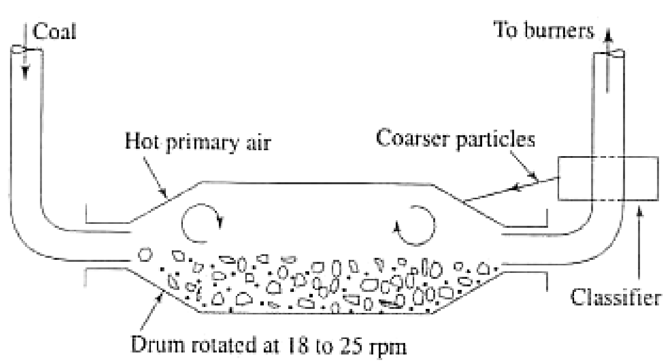
3.1.2 Coal Pulverisation

After being crushed, the coals are stored in a silo or bunker where it is then fed to the pulveriser. The pulveriser is composed of several stages mainly:

a. Feeding – control the rate of which coals are fed to the boiler
b. Drying – to prepare pulverised coal to be dry and dusty with suitable moisture content for firing.
c. Pulveriser – attained by impact, attritions, crushing or a combination of these

There are fairly many types of pulverisers being used concurrently. However, the medium speed ball and race, and roll and race pulverisers are preferred.

Figure 3.4 Ball Mill (P.K Nag., 2002)



Primary air which is preheated to about 340 degree Celsius causes the coal feed to circulate between the grinding elements. When the particles are made fine enough, it gets suspended in the air and is carried for firing.

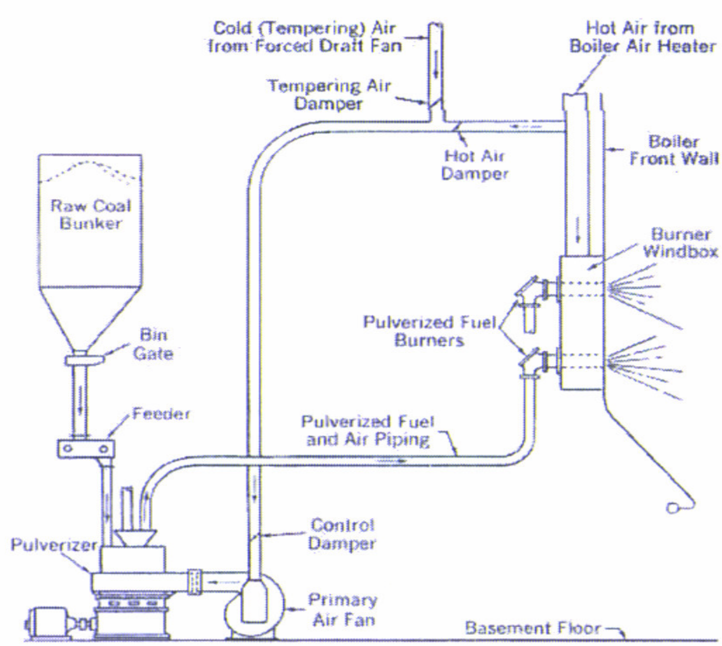
3.1.3 Coal Firing

The firing process consists of burning or combusting the fuel in the chamber to produce heat in producing steam to run the turbines. There are generally two types of systems being utilised for this purpose which are:

a) The bin or storage system
   - This is the system where the pulverised coal is prepared away from the furnace and needs to be separately transported for firing.

b) The direct firing system
   - It is a continuous process where coals from the feeder, pulveriser and primary air fan are fed to the furnace burners. Fuel flow is modulated by control of the feeder and primary air fan. This system has greater simplicity, safety and lower space requirements.

Figure 3.5 Pulverised-coal direct-firing system (El-Wakil, 1998)



According to Singer (1981), fuel burning systems introduce fuel and air for combustion, mix the reactants, ignite the mixture and distribute the flame envelope and product of combustion. The rate and degree of complete combustion is greatly dependant on the temperature, concentration, preparation and distribution of the reactants by catalysts and mechanical turbulence.

There are two methods of producing flow pattern in the combustion chamber to provide mixing through turbulence and they are:

a) Horizontally fired system

   Distribute fuel and air to many streams thus creating multiple flame envelopes.

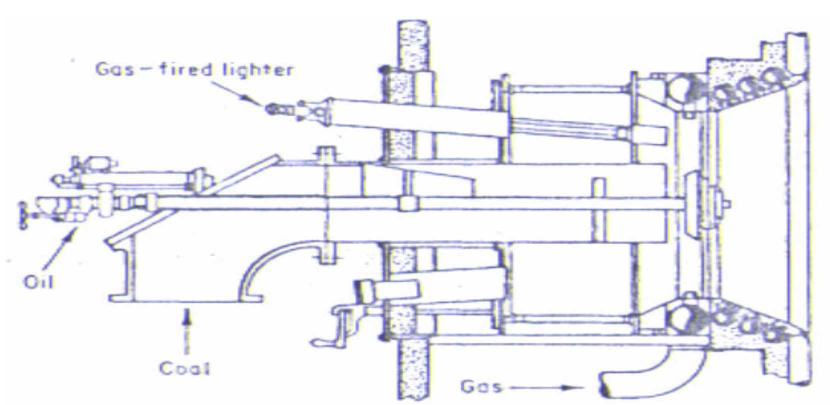
b) Tangentially fired systems

   Based on the concept of a single flame envelope where both fuel and air are projected from the corners of the furnace creating a vortex, which in turn creates intense mixing.

- **Ignition System for Firing**

According to Perry and Green (1997), initial temperature has to be at least 600 degree Celsius before coal can be introduced to the system. Propane gas, of liquefied petroleum gas is used as lighter fluid.

Figure 3.6 Burner with gas fired lighter to initiate combustion (Parker, 1993)



There are two main types of burners which are the circular and the slot burner. The circular burner feeds the fuel and air primary air mixture through a cylindrical tube with the secondary air enters through another separate tube whereas the slot type differs only by the shape of its cross section (P.K Nag, 2002).

3.2 Combustion Parameters

There exist many conditions where combustion may occur. In practice, each condition for different method of firing differs. According to Borman (1998), pulverised fuel firing requires that:

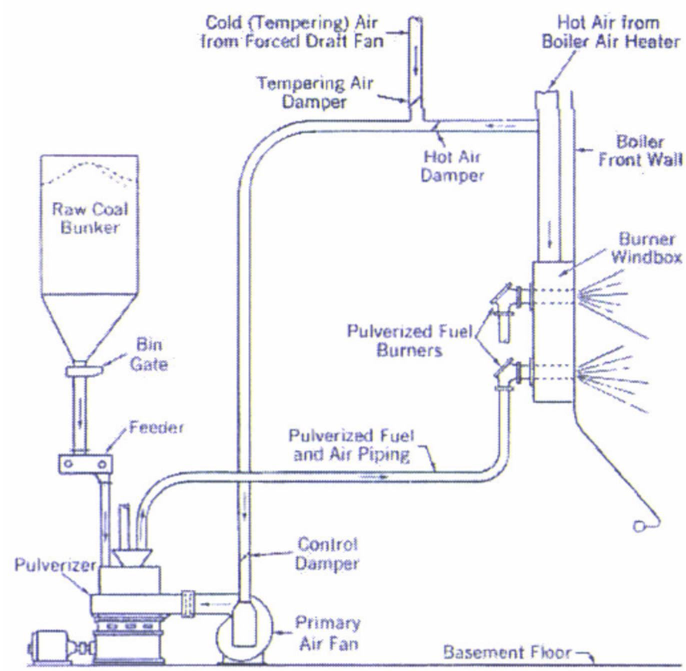
- Primary air being heated to 340 degree Celsius before blown to pulverised fuel to dry and being conveyed to the burner.
- Secondary air supply heated to approximately 300 degree Celsius
- Pulverised fuel that enters combustion chamber to be between 50 – 100 degree Celsius
- Conveying line should have velocities greater than 15m/s to avoid setting of pulverised fuel
- Pulverised fuel particles should be less than 300 micrometers
- Primary air should be of excess 20%
- Pulverised fuel should contain a volatility content of about 20% to maintain flame stability.
- Peak temperature at nozzle should reach 1650 degree Celsius.

3.3 Adopted System for Coal Firing

For this project, the system that will be utilised for modelling was adopted from one of the current coal fired power plants in Malaysia which is the Kapar power plant located in Selangor.

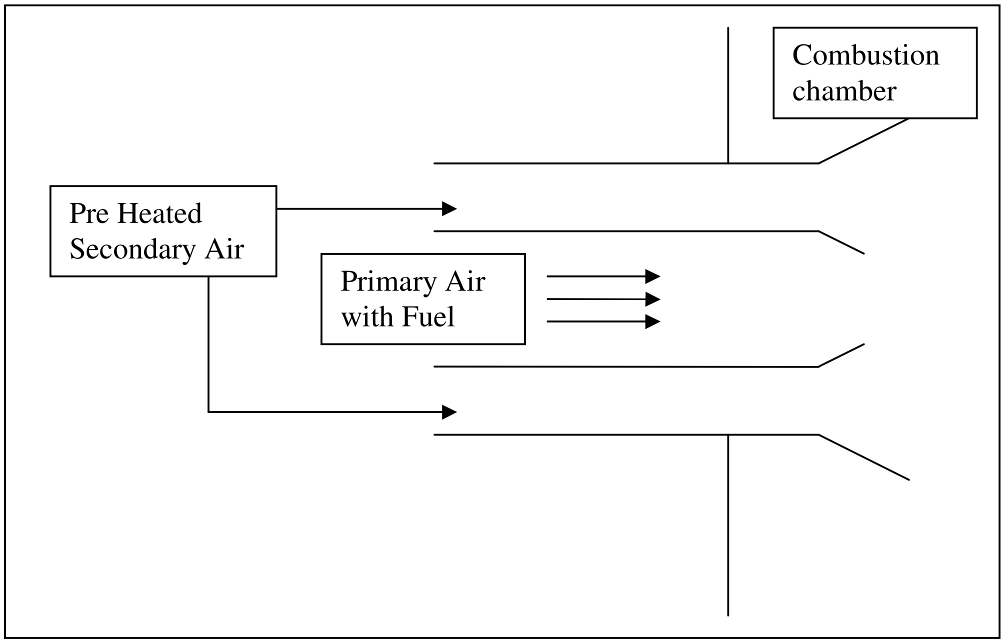
The method in which this power plant operates is utilising the direct firing system as shown in the figure below.

Figure 3.7 Pulverised-coal direct-firing system (El-Wakil, 1998)



Coal stored in the silo or bunker is fed into the crusher via a screw feeder or hopper at a certain rate. From there, the coal is made to a powderised form where it is then carried to the burner by a preheated air stream created by a forced draught fan passing through the flue gas which is released. Secondary air, which is also pre-heated, is passed through the secondary air inlet of the burner (www.tenaga.com.my, n.d.).

Figure 3.8 Figure of Primary air and Secondary air inlets



The boiler being used for this configuration of the Kapar power plant will be the water tube boiler. According to El-Wakil (1998), the benefits that surround the usage of water tube boilers are:

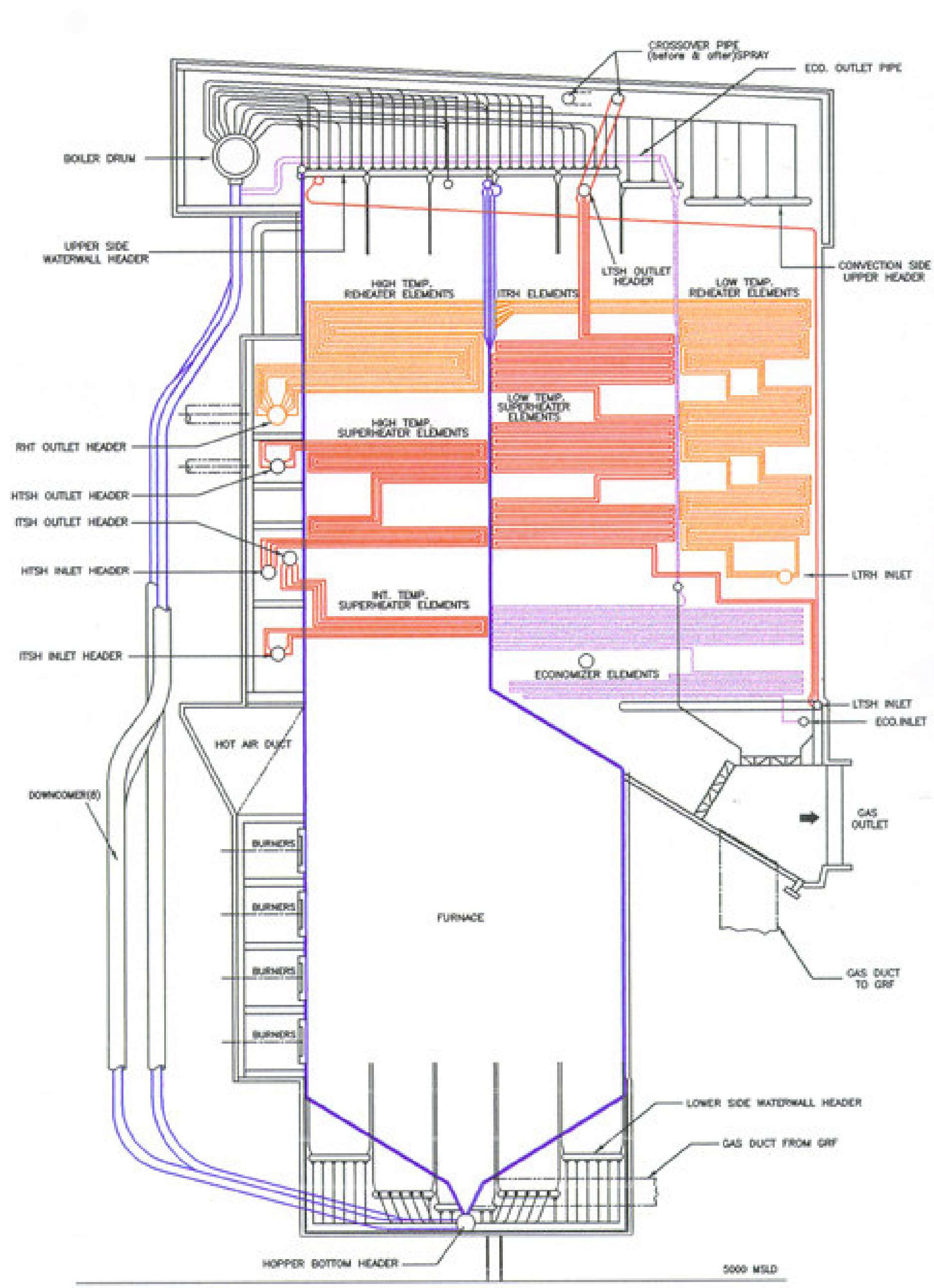
a. It is able to withstand high flow and steam pressures.
b. Reduces scale deposits in the tubes as compared to fire tube boilers.
c. Eliminates boiler explosions due to high pressure load.

The overall system of the boiler used in the Kapar power plant is that, water from the steam drum located well above the boiler flows to the downcomer pipes located outside of the furnace. From there, the downcomer pipes are connected to the water tubes through a header which acts like risers. It uses natural circulation, as the difference in density between water in the downcomer and in the tubes is large enough (www.tenaga.com.my, n.d.).

Steam, which is created, is separated from the heated bubbling water in the drum. From there, it flows to the superheater where the superheated steam produced should be at approximately 166 bars of pressure and 538 degrees Celsius of temperature. It is designed to produce approximately 720,000 kg of steam per hour (www.tenaga.com.my, n.d.).

Steam of those properties is then passed to the high pressure section of the turbine. The exhaust steam from the high pressure turbine is then passed on to the low pressure turbine. The condensate of the steam is used primarily for feedwater heating which in turn increases plant efficiency.

Figure 3.9 Boiler system of the 300MW coal fired power plant.
(www.tenaga.com.my, n.d.)



Chapter 4

Fuel

4.1 Fuel Consideration

In the context of co-firing, two general approaches may be used to co-fire rice husk in pulverised fuel boilers, which are:

a. Rice husk and coal can be blended in the coal yard and then transported to the bunkers and firing system.
b. Rice husk is transferred and injected separately into the combustion chamber.

However, through literature review, blending coal with rice husk or biomass in the yard results in lesser percentage of substance. Even though separate injection is more applicable being able to co-fire higher percentage of biomass, this project utilizes the blending approach to save cost. The fuel is assumed to have been sufficiently milled for combustion.

4.2 Fuel Utilisation

In order to utilise rice husk in co-firing, many aspects have to be considered. This is due to the different properties of rice husk which differs greatly from the properties of coal. Because of that, impacts that may occur have to be carefully assessed.

In order to understand the types of fuel being used, we have to study the chemical and physical properties of the fuel being used.

From the literature review, there are many different types of coal used in coal fired power plants, with each having slightly different properties and also cost. In Malaysia, the type of coal being utilised can be categorised to two different groups which are the local and imported coals.

The type of coal being utilized in coal fired power plants that can be found in Malaysia is of the Abok Coal from Merit Pilla coal mines of Sarawak, Malaysia and also the Ulan coal which is imported form Australia. In this section comparisons are made between those two types of coals.

The ultimate analysis of these coals is stated in the table below.

Table 4.1 Ultimate Analysis of the Ulan Coal according to Dr. Hamdan (personal communication, 12 August 2004)

Species	Percentage of content
Carbon	70.20%
Hydrogen	4.60%
Oxygen	22.40%
Nitrogen	2.80%

Table 4.2 Ultimate Analysis of the Abok Coal according to Dr. Hamdan (personal communication, 12 August 2004)

Species	Percentage of content
Carbon	76.40%
Hydrogen	4.80%
Oxygen	14.90%
Nitrogen	3.90%

The analyses of these coals were made based on a dry basis. From the tables, it can be seen that both these fuels differ greatly in the percentage of Carbon, and Oxygen. The amount of carbon in the fuel contributes to the amount of CO_2 produced; where as the amount of oxygen may lead to the increase of NO_x and SO_x emissions.

4.3 Air to Fuel Ratio

The effectiveness of combustion depends greatly on the air to fuel ratio. Insufficient presence of oxygen will cause incomplete combustion which will result in unburned hydrocarbon products and carbon monoxide in the combustion products. This will result in heat transfer surface fouling, pollution, lower combustion efficiency, flame instability and a potential for explosions (Werther et al, 2000).

On the other hand, if more than the amount of the required air is present, the temperature of the reaction will be reduced. In order to maximize combustion efficiency, the air to fuel ratio must be maintained as close as possible to the stoichometric ratio to reduce the amount of unburned hydrocarbon in the combustion products.

4.3.1 Calculation for Air to Fuel ratio of Abok and Ulan Coal

- **Air to fuel ratio of Ulan Coal**

Table 4.3 Analysis and Mole Fractions of Elements in Ulan Coal

Species	% content	M(kg/Kmol)	N (Kmol)
Carbon	70.2	12	5.85
Hydrogen	4.6	2	2.3
Oxygen	22.4	32	0.7
Nitrogen	2.8	28	0.1

$$5.85C + 2.3H_2 + 0.7O_2 + 0.1N_2 + A(O_2 + 3.76N_2) \rightarrow 5.85CO_2 + 2.3H_2O + A(3.76)N_2 + 0.1N_2$$

solving A from oxygen balance:

$$(0.7\times 2) + 2A = (5.85\times 2) + 2.3$$

$$2A = 12.6$$

$$A = 6.3$$

$$\therefore \left(\frac{A}{F}\right) = \left(\frac{6.3\times(1+3.76)\times 29}{100}\right)$$

$$= 8.69$$

- **Air to fuel ration of Abok Coal**

Table 4.4 Analysis and Mole Fractions of Elements in Abok Coal

Species	% content	M(kg/Kmol)	N (Kmol)
Carbon	76.4	12	6.37
Hydrogen	4.8	2	4.8
Oxygen	14.9	32	14.9
Nitrogen	3.9	28	0.14

$$6.37C + 2.4H_2 + 0.46O_2 + 0.14N_2 + A(O_2 + 3.76N_2) \rightarrow 6.37CO_2 + 2.4H_2O + A(3.76)N_2 + 0.14N_2$$

solving A from oxygen balance:

$$(0.46 \times 2) + 2A = (6.37 \times 2) + 2.4$$

$$2A = 14.22$$

$$A = 7.11$$

$$\therefore \left(\frac{A}{F}\right) = \left(\frac{7.11 \times (1 + 3.76) \times 29}{100}\right)$$

$$= 9.81$$

From the calculations of the Air to Fuel Ratio, it was found that the Abok coal has an AFT of 9.81 which is higher than the AFT for the Ulan coal which is 8.69. This shows that the Abok coal requires to produce a stoichometric combustion or ideal combustion.

4.4 Adiabatic Flame Temperature

It is a very important aspect to consider the adiabatic flame temperature (AFT) in the combustion process. The AFT can be defined as the maximum temperature attained assuming the heat loss is negligible (Cengel and Boles, 1998). Based on the AFT, temperatures should be always kept lower from the tolerated temperatures of components. The adiabatic flame temperature is used as an estimate to the actual temperature of combustion. It attains its maximum value when complete combustion takes place with the presence of theoretical air (Cengel and Boles, 1998).

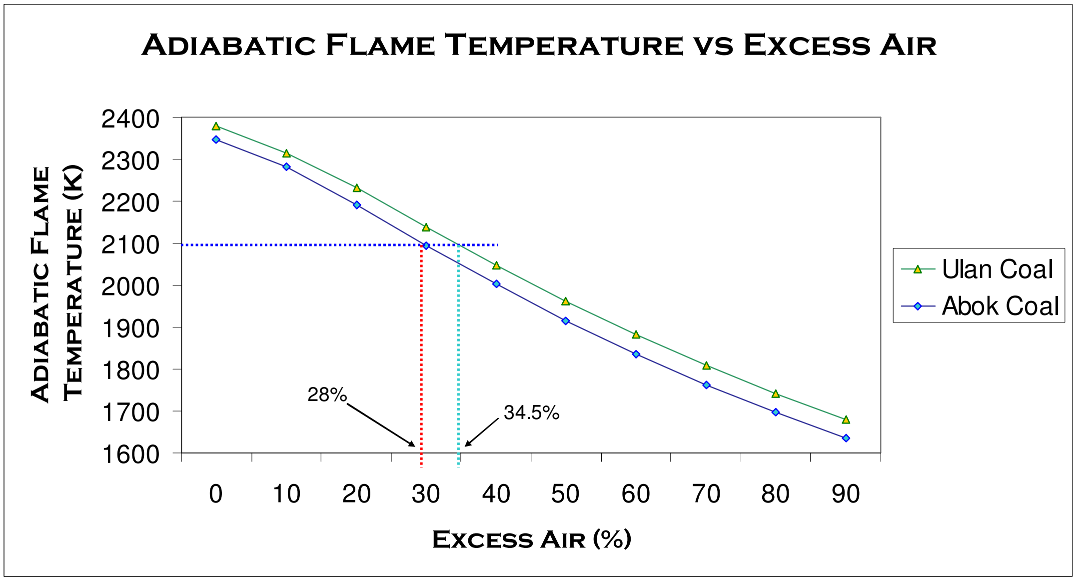
Using the HPflame software produced by Turns (2000), the adiabatic flame temperature for the two types of coal with respect to the amount of excess air was calculated and found to be as follows:

Table 4.5 Results of AFT from Turns 2000 Software

	Ulan Coal	Abok Coal
Excess Air (%)	Flame Temp (K)	Flame Temp (K)
0	2378.64	2347.28
10	2316.12	2281.17
20	2231.23	2190.62
30	2139.52	2095.00
40	2047.88	2001.62
50	1962.33	1915.78
60	1881.53	1835.48
70	1807.59	1762.45
80	1741.74	1697.79
90	1678.64	1635.75

The results of Adiabatic Flame Temperature were plotted with the amount of excess air for both fuels, and the results are:

Figure 4.1 Adiabatic Flame Temperature vs Excess Air for Ulan and Abok Coal



As can be seen from the graph above, it can be concluded that the adiabatic flame temperatures of the Abok coal is apparently lower than the Ulan coal. According to P.K Nag (2002), the maximum temperature in the combustion chamber or furnace should be about 2000K to 2100K. Therefore, temperatures higher than this in the stoichometric combustion have to be provided with excess air in order to reduce the flame temperature. This results in higher amounts of electric capacity for the forced draught fan to produce higher flow rate of air and generally increases cost.

From the graph above and assuming the flame temperature in the combustion chamber to be 2100K, it can be seen that, for the Ulan coal, an excess air of 34.5% is needed rather than the Abok coal which requires about 28%. This shows that, between the combustion of both coals, lesser consumption of electricity is needed for the Abok coal due to the reduction of fan capacity to produce higher flow rates of excess air to achieve the optimal temperature.

Therefore, based on the previous results, this project will be narrowed down to the utilisation of the Abok coal in blending with rice husk instead of the Ulan coal.

Besides that, with a volatile matter of more than 20% and gross calorific value of 30.911MJ, the composition analysis of Abok coals fits the parameters pointed by Borman (1998) to be used in co-firing.

4.5 Rice Husks as Fuel

Many types of rice husk exist in Malaysia which in turn, produces many different compositions of rice husk. The Malaysian Agricultural Research Development Institute (MARDI) states that Malaysian paddy is scientifically known as *Oryzasativa L.* There are several types of cultivate for Malaysian paddy such as MR84, MR157, 167, 185, 219 (www.mardi.my, n.d.).

In general, biomass which includes rice husk has high moisture content which will result in a reduction of boiler efficiency due to additional heat needed for drying. However, the high volatility of biomass will also result in the reduction to ignition temperature. According to Sami, Annamalai and Wooldridge (2001), the adiabatic flame temperature decreases as moisture and ash content increases.

Based on the high volatile content, low densities and high concentrations of unburned pollutants, a cyclone separator can be used to control the unburned pollutant released to the atmosphere from the flue gas.

The ultimate and proximate analysis of the Malaysian rice husk can be seen tabulated in Table 4.6 and 4.7 shown below.

Table 4.6 Ultimate Analysis of Rice Husks

Species	% content	M(kg/Kmol)	N (Kmol)
Carbon	34.2	12	2.85
Hydrogen	4.7	2	2.35
Oxygen	60.5	32	1.89
Nitrogen	0.6	28	0.02

Table 4.7 Proximate Analysis of Rice Husk (Wt%)

Proximate Analysis (Wt %)	Rice Husk
Moisture	6.5
Volatile matter	61.7
Fixed carbon	14.1
Ash	17.7
Total	100

4.6 Fuel Blend Considerations

From the previous analysis of coal, the Abok coal was chosen to be the suitable type of coal in the context of reductions in the percentage of excess air needed. Coherent to that, in the fuel blend analysis, the Abok coal will be used for blending with rice husks.

As stated by Bain and Amos (2003), tests done from co-firing of pulverised combustion shows that the amount of biomass to be co-fired is only about 5 – 10% by mass when using blended compound. Based on that, calculations were made based on a 1 to 10 percent margin ratio by mass in order to further study the combustion properties.

4.6.1 Calculation for Fuel Blend Composition based on Mass

The fuel blend composition was calculated using the mass fraction of the fuel blend.

Composition of $X = (M_{coal} \times X_{coal}) + (M_{ricehusk} \times X_{ricehusk})$

Where,

X = Number of moles for type of species in fuel blend

M_{coal} = Percentage of Coal in fuel blend

X_{coal} = Number of Moles for type of species in coal

$M_{rice\ husk}$ = Percentage of rice husk in fuel blend

$X_{rice\ husk}$ = Number of Moles for type of species in rice husk

Based on the percentage of coal and rice husk in the fuel blend, other information of the fuels can also be obtained by the same method with minor error coefficients.

From a research undergone by Dr. Hamdan (personal communication,12 August 2004), a professor in the Tenaga Nasional Research and Development Center (TNRD), the amount of moisture, fixed carbon, volatility and calorific values has been obtained through lab experimentation. A comparison has been done between the data obtained from TNRD with calculations based on the blend ratio. The comparisons obtained are shown as:

Figure 4.2 Comparisons of Calorific Values of Blend

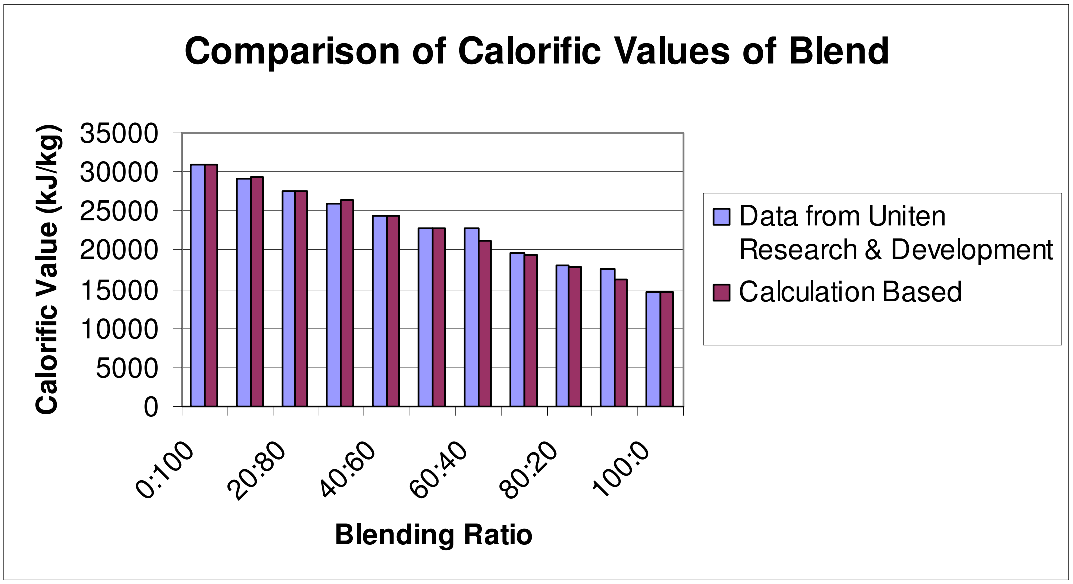


Figure 4.3 Comparisons of Fixed Carbon Content

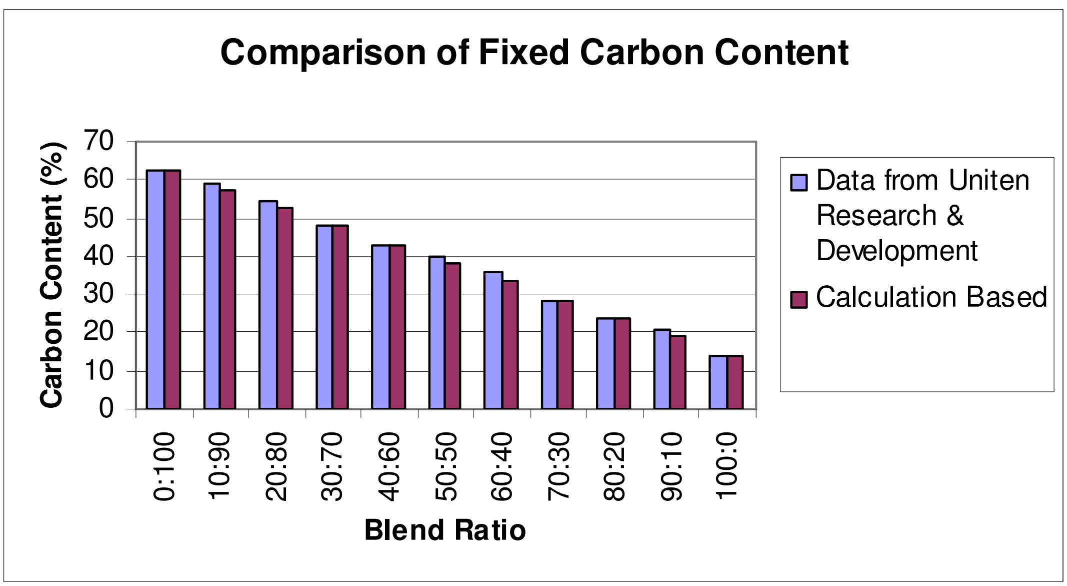


Figure 4.4 Comparisons of Moisture

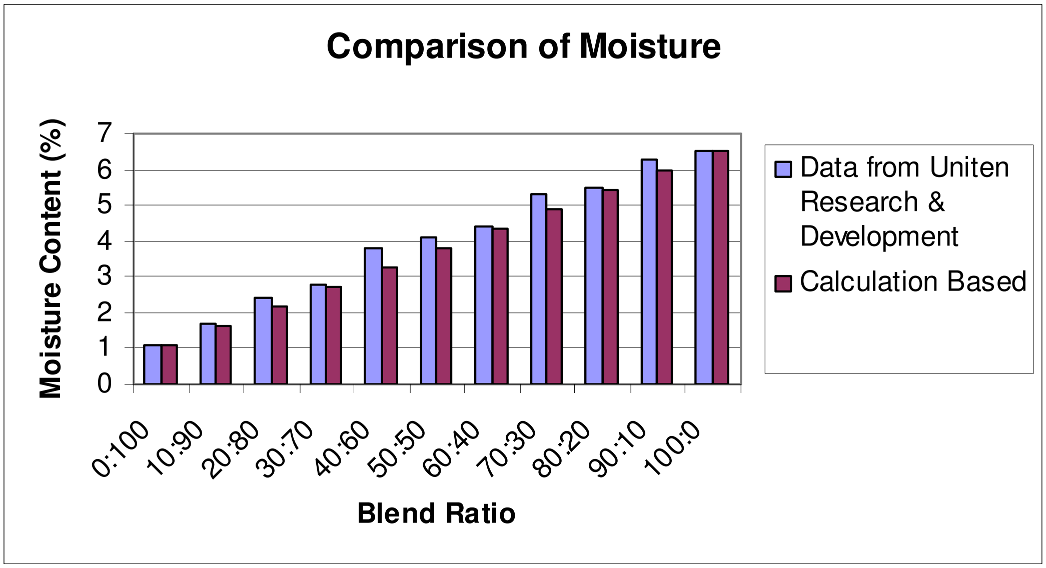
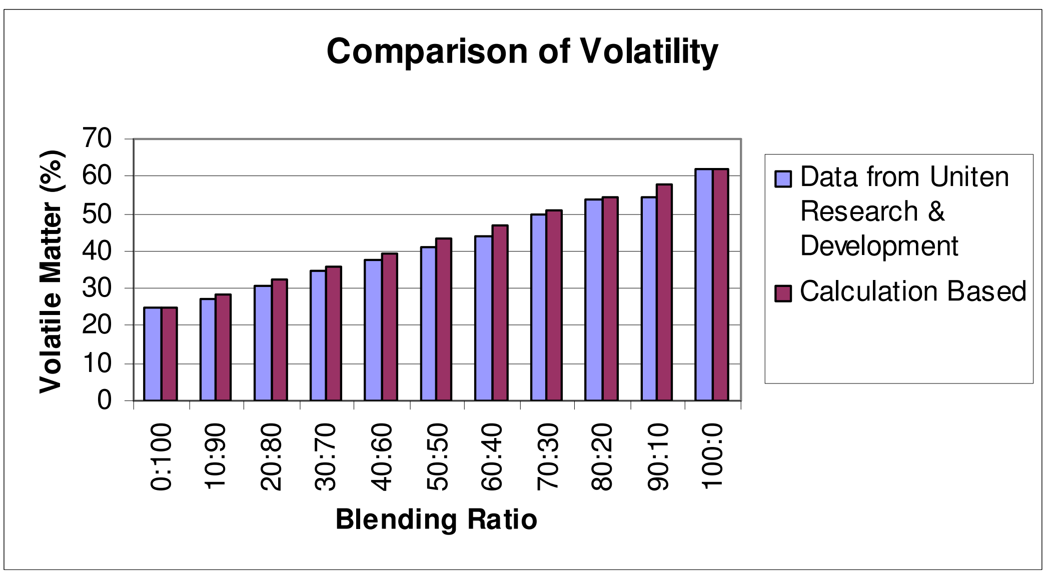


Figure 4.5 Comparisons of Volatility



From these graphs, it can be seen that the difference between the actual and theoretical values are almost similar. This indicates that the error factor between theoretical calculations and real experimentations are small. Due to that, upcoming calculations for the fuel blend ratio covered in this project will be based on the blend ratio.

4.6.2 Fuel Blend

For co-firing, the proper amount of biomass to co-fire is an important aspect that has to be considered. This is because the temperature of the combustion is greatly dependant on the percentage of blend. From previous literature review, it was noted that co-firing with pulverised fuel combustion methods only allows approximately 5-10% of biomass matter. This is to avoid a great loss in efficiency as well as the increase in fuel capacity which increases the electricity consumption of the system.

Calculations were made to obtain the species composition in the fuel blends which is tabulated in table 4.8.

Table 4.8 Composition of species for different fuel blends

Species	99:1	98:2	97:3	96:4	95:5	94:6	93:7	92:8	91:9	90:10
Carbon	6.335	6.2996	6.2635	6.2292	6.1925	6.1588	6.1235	6.0844	6.0525	6.018
Hydrogen	2.3995	2.399	2.3985	2.398	2.398	2.397	2.3965	2.396	2.3955	2.395
Oxygen	0.4743	0.4886	0.5029	0.5172	0.5315	0.5454	0.5601	0.5744	0.5877	0.603
Nitrogen	0.1388	0.1376	0.1364	0.1352	0.134	0.1328	0.1316	0.1304	0.1292	0.128

As can be seen, the differences of the fuel composition between the blend ratios are very small. Therefore, taking the maximum and average values between the margins, the blend chosen to be considered is the 95:5 and the 90:10

4.6.3 Adiabatic Flame Temperature of Blends

In order to obtain the adiabatic flame temperatures of both the blends, calculations were made to obtain the mole fractions of the composition of species in the fuel. Calculations were made using the mass fraction equation as shown previously and the data obtained can be seen in table 4.9 below:

Table 4.9 Mole fractions for 95:5 and 90:10 fuel blend

Species	95:5	90:10
	N (Kmol)	N (Kmol)
Carbon	6.19	6.02
Hydrogen	2.39	2.39
Oxygen	0.53	0.6
Nitrogen	0.13	0.13

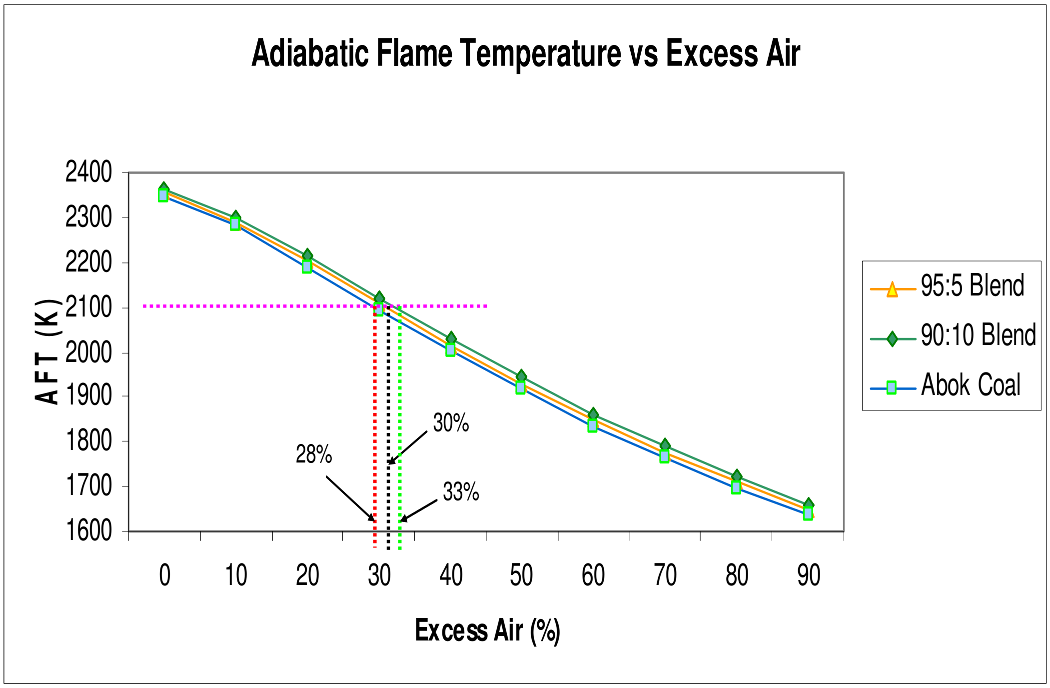
Utilising the two different fuel composition of blend ratio, calculations for adiabatic flame temperatures for the fuels have been made using the Turns (2000) software. The output of the AFT was tabulated and shown as:

Table 4.10 Adiabatic Flame Temperatures of Fuel Blend

Excess Air (%)	Abok Coal Adiabatic Flame Temp (K)	
	95:5:	90:10
0	2356.14	2365.41
10	2291.09	2301.45
20	2202.16	2214.2
30	2107.6	2120.82
40	2014.66	2028.43
50	1928.88	1942.76
60	1848.44	1862.2
70	1775.17	1788.69
80	1710.19	1723.35
90	1647.84	1660.72

The plots for the results are as shown in figure 4.6

Figure 4.6 Plot of AFT versus Percentage of Excess air for Fuel Blends



The graph above shows an analysis of the Adiabatic Flame Temperature (AFT) of three different blends of fuel in combustion. The analysis shows the AFT of the Abok Coal, the 95% Abok Coal and 5% rice husk blend and the 90% Abok coal and the 10% rice husk blend.

From the graph of the AFT versus the percentage of excess air, it can be seen that the 95:5 blend ratio of fuel requires slightly higher amount of excess air rather than the 90:10 blend ratio. This shows that the 95:5 fuel blend ratio is able to perform or produce the required amount of temperature in spite of using less amount of excess air than the 90:10 fuel blend ratio. Therefore, in this dissertation, the 95:5 fuel blend ratio will be further analysed to achieve the objectives of this project.

4.7 Suitability of Fuel

Dr. Hamdan states that in Malaysia, the type of coal being used in the power plant has to have properties according to a specific range of values (personal communication, 12 August, 2004). This is to maintain efficiency of the plant and to avoid complications or adjustments to the whole system. For that, parameters such as fixed carbon, moisture and volatility content are considered. The accepted specification of the fuel was obtained from the Tenaga Nasional Berhad Research and Development Centre.

From the proximate analysis, the values of the parameters considered are:

Table 4.11 Proximate Analysis of Abok Coal and 95:5 Blend.

Wt%	Fixed Carbon	Ash	Volatile Matter	Moisture
Abok Coal	62.3	11.8	24.8	1.1
95:5 Blend	59.89	12.1	26.645	1.37

For this project, comparisons of such parameters have been made between the Abok Coal and the 95:5 fuel blends as shown in upcoming figures.

Figure 4.7 Comparison of Fixed Carbon Content in Fuel with Specification by Tenaga Nasional Berhad.

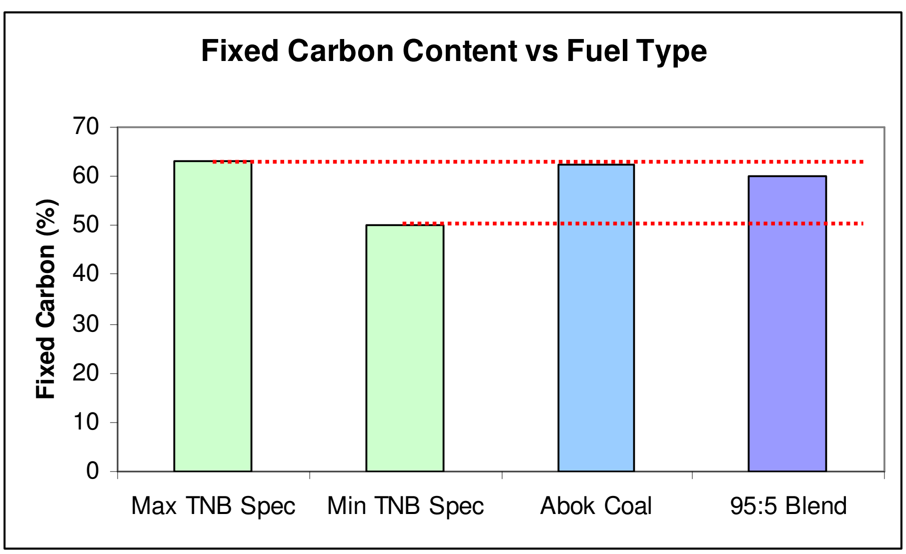


Figure 4.8 Comparison of Ash Content in Fuel with Specification by Tenaga Nasional Berhad.

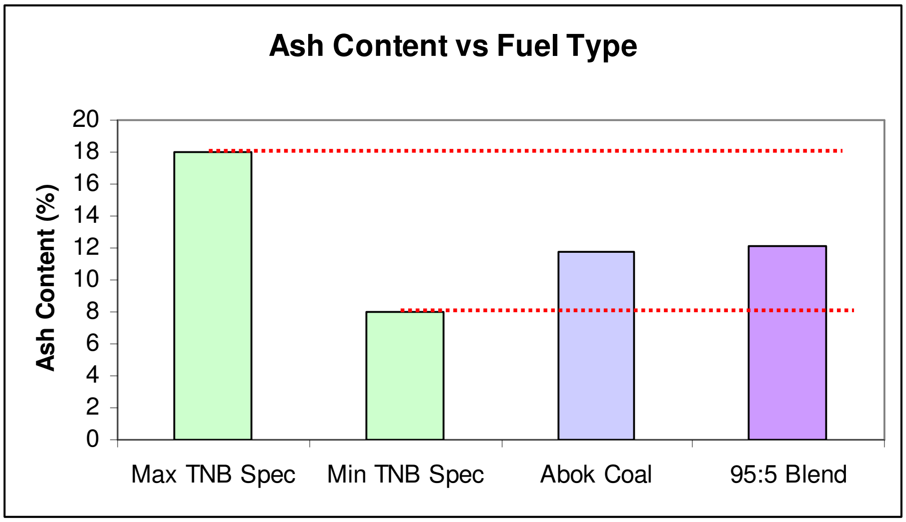


Figure 4.9 Comparison of Volatile Matter in Fuel with Specification by Tenaga Nasional Berhad.

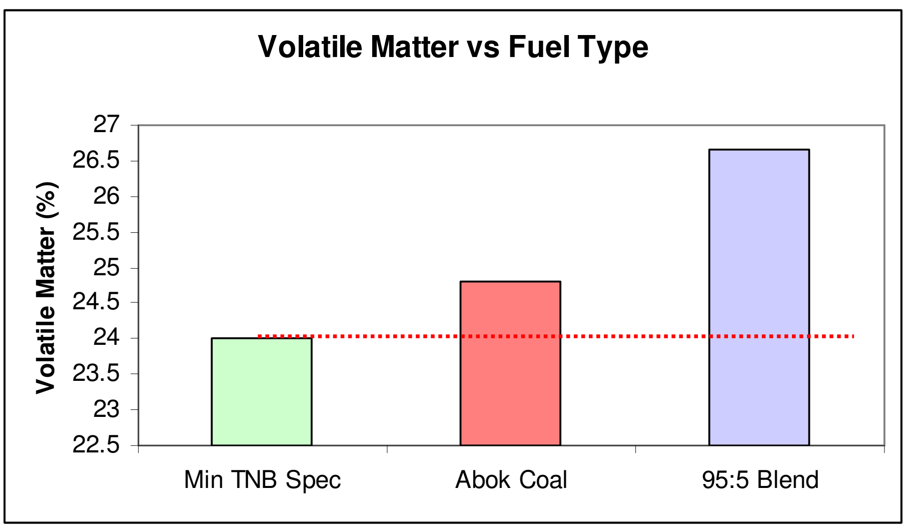
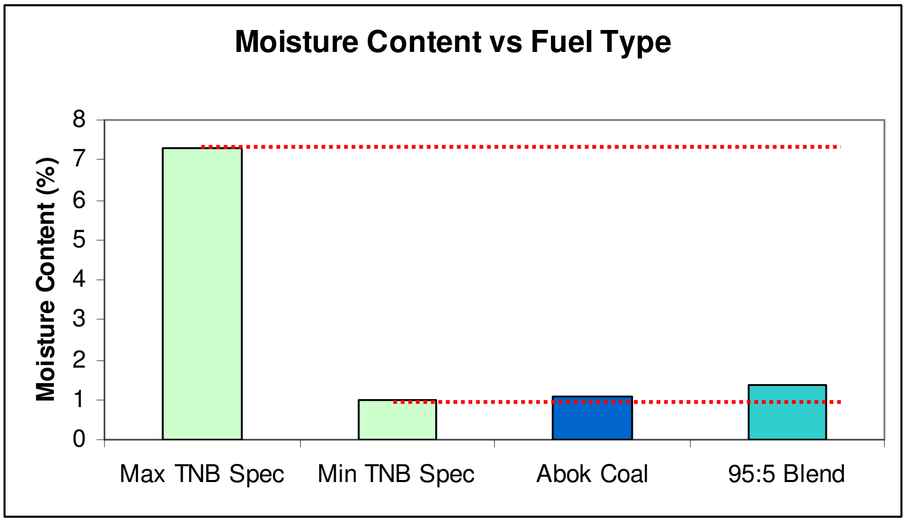


Figure 4.10 Comparison of Moisture Content in Fuel with Specification by Tenaga Nasional Berhad.



4.7.1 Results

From the graphs shown above, it can be noticed that the value of considered parameter are in the range of the specification provided. Therefore, a conclusion has been made that these fuels are suitable for utilisation in the Tenaga Nasional boilers available in Malaysia.

Chapter 5

Modelling of the Characteristics of Flame Produced by Abok Coal and 95:5 Fuel Blend using FLUENT

5.1 Introduction to FLUENT

FLUENT is a multi-purpose interactive computational fluid dynamics software. It is able to simulate complicated chemical reactions, fluid flow and heat transfer through a range of models it has. FLUENT is regarded as the world's largest provider of commercial computational fluid dynamics software and also its services. Its clients are from various backgrounds of industries such as automotive, aerospace, power generation, biomedical, electronics and even chemical and materials processing (www.fluent.com, n.d.).

5.2 General Concept of CFD Modelling using FLUENT

Pre- Processing

It is the first step in building or analysing a specific design. It includes the model building process which is to be analysed, applying meshes and input data for the model. The pre-processor provided in the FLUENT package are GAMBIT, G/Turbo and Tgrid.

Solving

The solver, namely FLUENT, does calculations based on the mesh and produces the results required in the analysis.

Post-Processing

It is the final step in the analysis which involves the interpretation and organisation of data and images.

5.3 Utilisation of the FLUENT Package in Project Analysis

Concurrently, technologies such as computational fluid dynamics software are ideally beneficial towards engineers. It occurs to be an attractive method which sets aside conventional methods of testing and modifying prototypes which consumes more time and cost. Using the aid of CFD software, namely FLUENT, engineers are able to simulate a number of conditions using various parameters for testing, which in turn produces the optimum result before working on the real prototype.

Previously, estimations of the flame temperature was described in Chapter 4 clearly shows its importance to this project. The utilisation of the FLUENT package towards this project is mainly to model the flame occurring from the combusted 95:5 fuel blend mixture based on a non-adiabatic parameter where heat losses occur rather than an adiabatic calculation as made before. Thus, using CFD, a more accurate model of the combustion such as in a real case scenario was to be achieved.

For that, the properties and parameters used in the model should attain a value close to the working conditions in real cases.

The concept of using FLUENT in modelling pulverised coal combustion was aided by a tutorial guide obtained from FLUENT INC. (www.shef.ac.uk, n.d.). However modifications had to be made to suit the properties of the fuel and combustion parameters used for this project.

5.3.1 Pre-PDF file Definition

Because of the limitation to the chemical database for solid fuels in FLUENT, a modified definition of the fuel blend had to be made in order for the solver to produce calculations. The definition of fuel was made first by creating a pre-PDF file. The file consists of the concentration of species in the fuel being fed at the burner.

For this project, two pre-PDF files have been made for the Abok coal and the 95:5 blend mixtures respectively. The file produced sets the species or properties identified in the fuel stream, oxidiser stream and secondary stream with respect to its temperatures.

However, before creating the pre-PDF file, the fuel composition of both fuels has to be determined. Using the ultimate analysis of both the fuels, the mole fraction which was needed for input was calculated.

Table 5.1 Ultimate Analysis of Abok Coal

Species	% content	M(kg/Kmol)	N (Kmol)
Carbon	76.4	12	6.37
Hydrogen	4.8	2	4.8
Oxygen	14.9	32	14.9
Nitrogen	3.9	28	0.14

Table 5.2 Estimated Ultimate analysis of 95:5 Fuel Blend

Species	95:5
	N (Kmol)
Carbon	6.19
Hydrogen	4.68
Oxygen	14.25
Nitrogen	0.13

The mole fraction needed for input in the pre-PDF file was calculated by,

$$M_{species} = \frac{N_{species}}{N_{total}}$$

Using the previous equation, the mole fractions for the species in each fuel was calculated and tabulated as can be seen below:

Table 5.3 Mole Fraction for Abok Coal and 95:5 fuel blend

Type of Fuel	Abok Coal	95:5 Fuel Blend
Species	Molar Fraction	Molar Fraction
Carbon	0.243	0.245
Hydrogen	0.183	0.185
Oxygen	0.568	0.564
Nitrogen	0.0053	0.0051

The values obtained was provided as an input for the pre-PDF file at the secondary stream which represents the fuel to be combusted with the oxidiser stream which consist of primarily oxygen and nitrogen gases in the atmosphere.

Conditions applied to the pre PDF files such as temperatures used were according to the parameter suggested by Borman (1998). The temperatures which were defined were the temperatures of the fuel at 373K, oxidiser at 613K and the secondary air to be preheated to 500K.

From there, the data was computed using a non-adiabatic pre-PDF system. Calculations of the instantaneous flame temperature were made to overlook at the overall maximum flame temperature about to be modelled. The results found are:

Figure 5.1 Instantaneous Flame Temperature for Abok Coal

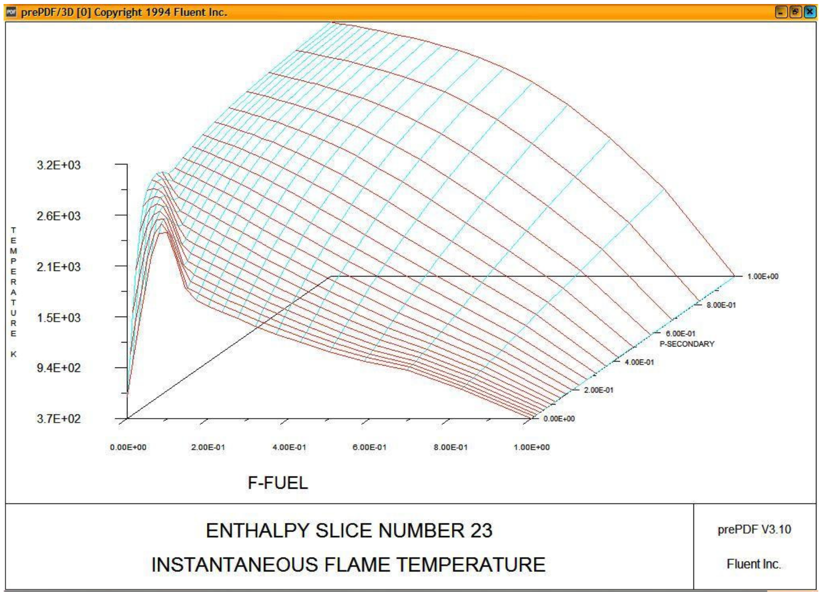
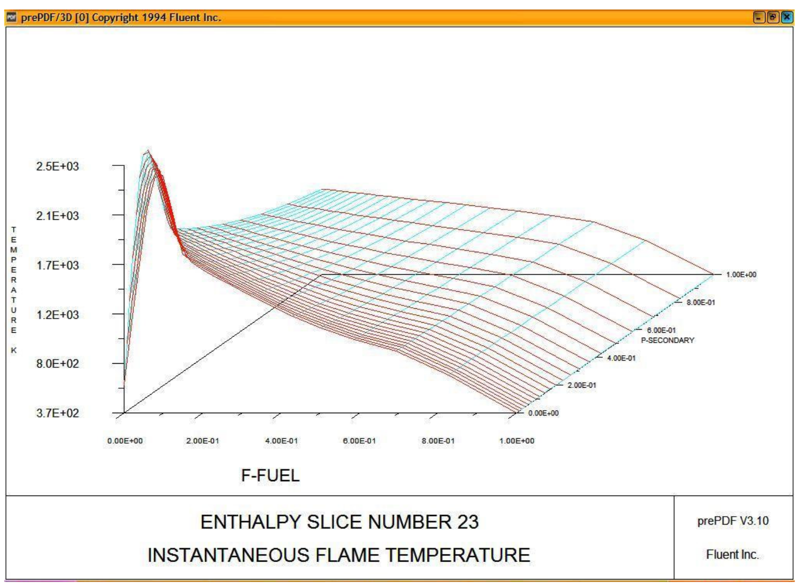


Figure 5.2 Instantaneous Flame Temperature for blend of 95% Abok Coal and 5% Rice Husk



Both figures 5.1 and 5.2 shows the instantaneous flame temperature of the fuel specified in the pre-PDF file created. The 3 axis graph shows the relationship between the flame temperature, air concentration and fuel concentration at which peak flame temperatures for both fuel occur. This may be due to the difference in properties such as volatility and mainly the moisture content.

5.3.2 2 Dimensional Modelling of the furnace

In order to model the flame occurring, the furnace was modelled. For this project, only a single burner was modelled. As mentioned previously, a software called GAMBIT 1.2 was used to model the furnace which was drawn 2 dimensionally to scale. The model created was adapted from a real coal power plant located in Selangor, Malaysia. The real dimensions of the furnace were approximately given by:

- height = 11m
- width = 7m
- length = 9m

From that, the model of the furnace was created using a control volume of 7m by 1.45m.

Since the size of the burner was unknown, a burner sizing calculator by the F. L. Smidth and Fuller Company (Swirlax burner, 2004) was used in determining the size of the primary and secondary inlets. The sizing provided was based on the flow rate of the fuel to be fed through the burner.

Therefore, in order to size the burner, the flow rate of coal used in the combustion was to be calculated. The flow rate of coal to be utilised is dependant on both the boiler efficiency, flow rate of steam and the enthalpies of feed water and steam produced. The flow rate of coal can be calculated by:

Data:

Boiler Efficiency, $\eta_B = 35\%$

h_1 = enthalpy of steam at 538 degree Celcius = 3396.47 KJ/kg

h_2 = enthalpy of feedwater at 120 degree Celcius = 2207.53 KJ/kg

Flow rate of steam, $\dot{m}_S$ = 720,000kg/hr

Flow rate of steam, $\dot{m}_f$

Where,

For Abok Coal

HHV = 30911KJ/kg

$$\eta_B = \frac{\dot{m}_S \times (h_1 - h_4)}{\dot{m}_f \times HHV}$$

$$0.35 = \frac{720{,}000 \times (3396.47 - 2207.53)}{\dot{m}_f \times 30911}$$

$$\dot{m}_f = 79124.565 kg/hr$$

$$\dot{m}_f = 21.98 kg/s$$

and for each burner

$$\dot{m}_f = \frac{21.98}{16} = 1.374 kg/s$$

similarly,

For 95:5 Coal-Rice husk fuel blend

HHV = 30110KJ/kg

$$\eta_B = \frac{\dot{m}_S \times (h_1 - h_4)}{\dot{m}_f \times HHV}$$

$$0.35 = \frac{720{,}000 \times (3396.47 - 2207.53)}{\dot{m}_f \times 30110}$$

$$\dot{m}_f = 81229.47 kg/hr$$

$$\dot{m}_f = 22.56 kg/s$$

and for each burner

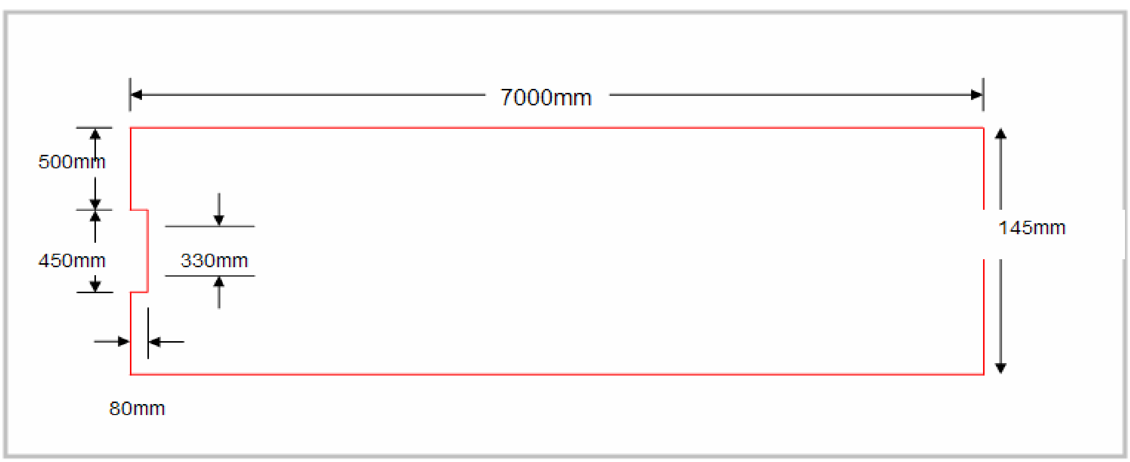
$$\dot{m}_f = \frac{22.56}{16} = 1.41 kg/s$$

Therefore, based on the calculations, the flow rate input to model the combustion properties of Abok coal is found to be 1.37kg/s and for the 95:5 blend to be 1.41kg/s.

Using the flow rates obtained through calculations and data from the sizing calculator, the primary air inlet was set to be 33cm in diameter and the secondary inlet with a hydraulic diameter of 12cm.

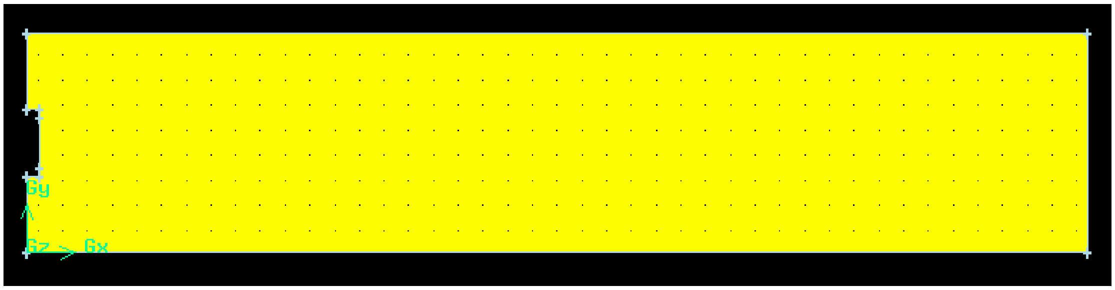
With the gathered data, the burner was modelled with dimensions as can be seen below.

Figure 5.3 Dimensions of the control volume adapted for modelling



The model which was created is meshed to smaller quadrilaterals cells to enable the solver to compute data at these areas. After meshing 101140 faces, the mesh produced was as shown in figure 5.4.

Figure 5.4 Model of the Meshed Burner and Combustion Chamber in GAMBIT 1.2



5.3.3 Modelling with FLUENT 5.3

The analysis of the computational fluid dynamics software was made using FLUENT 5.3 where combusting parameters are available. The meshed file from GAMBIT was exported to the FLUENT software for modelling.

Using FLUENT, a segregated solver was chose with an implicit formulation and steady time frame. From that the mixture of fuel and air is assumed to be fully turbulent, and the effects of molecular viscosity are negligible. For that, the k-epsilon equation was utilised.

The mixture of the fuel with air which was created in the pre-PDF file was imported by FLUENT in order for the entry of fuel properties. The fuel inlet was set by the definition of injection where the discrete phase model was used to enable predictions towards the trajectories of each coal particles with the considerations of heat, mass and momentum.

Since the properties of the fuel used is unavailable in the definition of injections, medium volatility coal was assumed with its thermodynamic properties altered to suit the Abok Coal or 95:5 Fuel Blend data. For this, the assumptions for Abok Coal and the 95:5 fuel blends are taken to be the same except for the volatile composition and the combustible fractions. The assumptions made were tabulated and can be seen 5.4.

Table 5.4 Constants used in Modelling

Abok Coal	Data
Thermal Conductivity	0.0454
Density	1300kg/m³
Specific Heat	1000
Volatile Component	24.8
Binary Diffusivity	5 X 10^-4
Particle Emissivity	0.9
Scattering Factor	0.6
Swelling Coefficient	2
Burnout Ratio	2.67
Combustible Fraction	62.3

95:5 Fuel Blend	Data
Thermal Conductivity	0.0454
Density	1300kg/m³
Specific Heat	1000
Volatile Component	26.645
Binary Diffusivity	5 X 10^-4
Particle Emissivity	0.9
Scattering Factor	0.6
Swelling Coefficient	2
Burnout Ratio	2.67
Combustible Fraction	59.89

However, in the mixture of fuel and air, the pre-PDF data is used for the fuel mix present at the exit of the burner.

Assignation was also done to the areas where primary and secondary inlets, wall and the pressure outlet. This is to set the boundary conditions for the combustion to operate and to enable modelling. According to the Borman (1998), the primary air should be of 20 percent excess, therefore, the velocities chosen for the fuel and air steam was set to be 30m/s and 15m/s. Both the temperatures of the primary and secondary fuel streams were set to be at 500K as stated by Borman (1998) in Chapter 3.

5.4 Results from FLUENT

The contour plots obtained are:

Static Temperature:

Figure 5.5 Contour Plots of Static Temperature (Abok Coal)

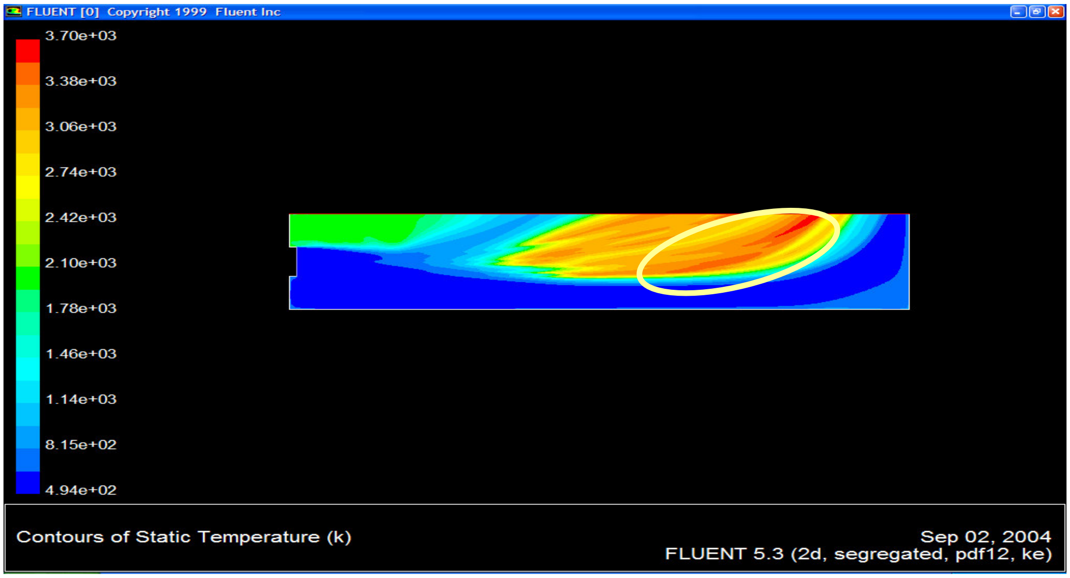
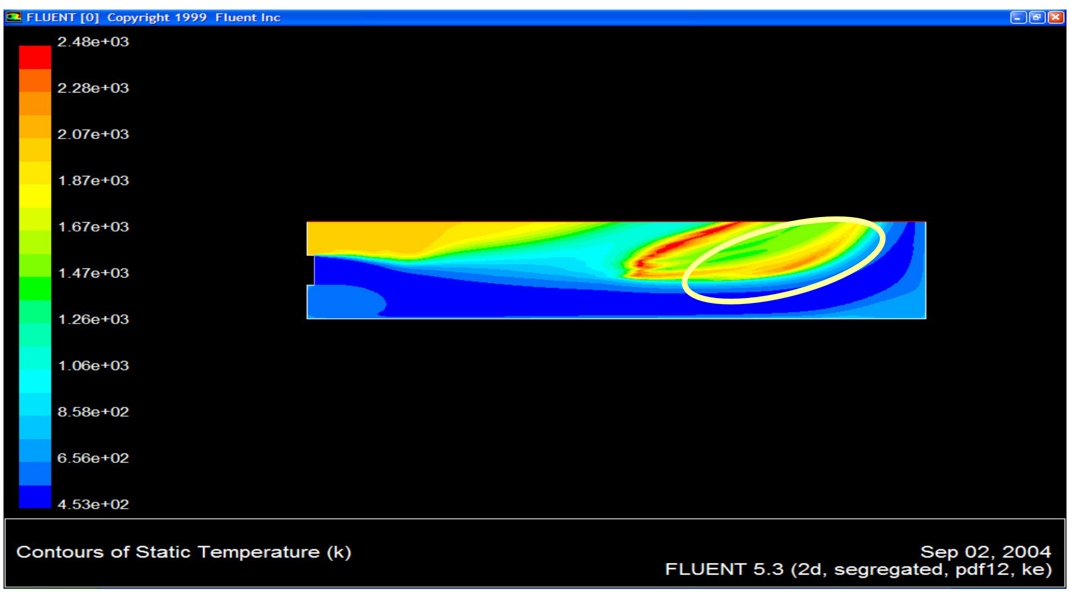


Figure 5.6 Contour Plots of Static Temperature (95:5 Fuel blend)



The results from the contour plots above relates to the static temperature which was found to be in connection to this project. Through this result, we are able to see that both fuels are able to produce temperatures greater than the optimum temperature of about 2000-2100K as stated by P.K Nag (2002) and therefore, provided with amounts of excess air, the temperature of these fuels can be lowered to suit the boiler requirements.

In figure 5.6, the fuel rich zone which is located at the centre of the peak flame temperatures are lower for the 95:5 fuel blend as highlighted. This is caused by the high moisture and volatility of rice husk which in turn reduces the flame temperature of fuel rich zone and similarly decreases the amount of thermal NO_X produced due to oxidation of atmospheric nitrogen atoms at high temperatures.

Nitrogen Concentration:

Figure 5.7 Contours of Concentration of Nitrogen (Abok Coal)

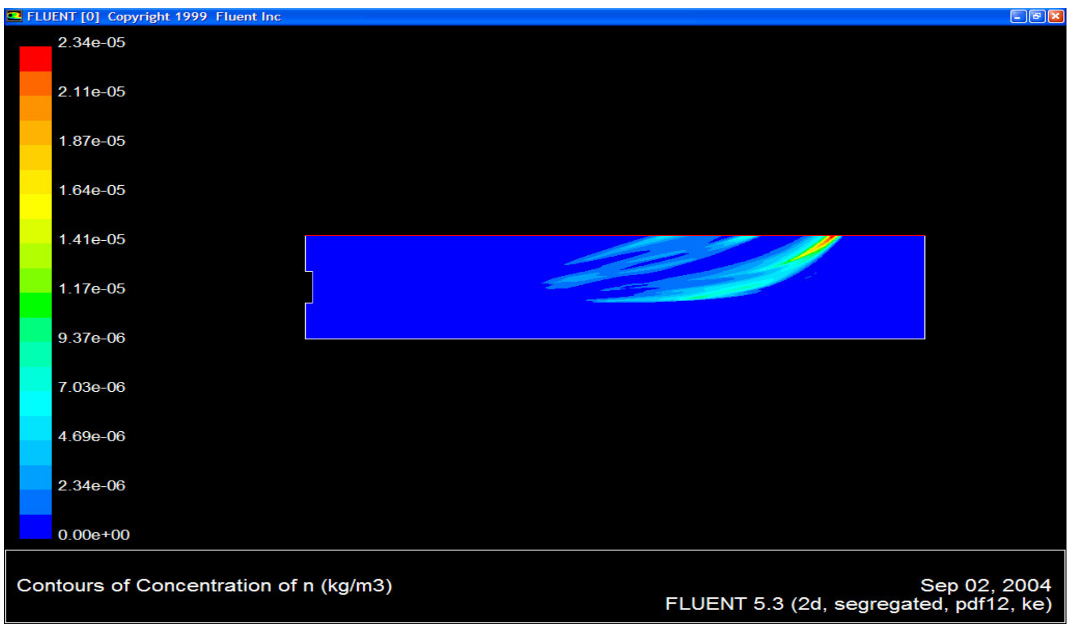
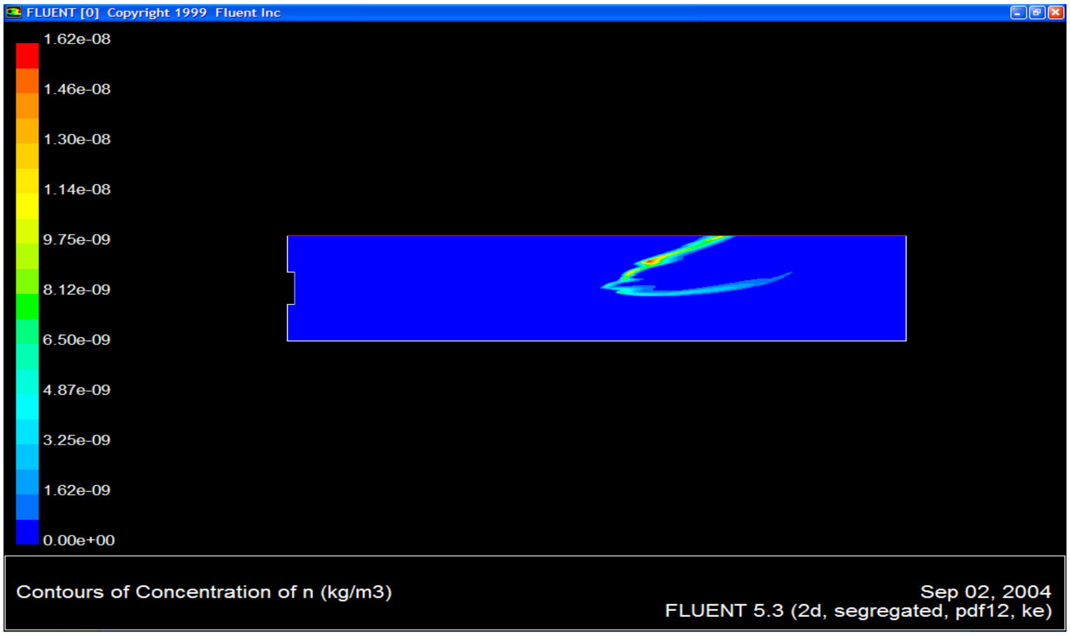


Figure 5.8 Contours of Concentration of Nitrogen (95:5 fuel blend)



Following on with pollution reduction, the results obtained for the concentration of NO_x proves that the NO_x emission can be reduced. As can be seen from the contour plots of nitrogen concentration, there exist a reduction on the amount of nitrogen atoms produced in the 95:5 fuel blend. The reduction in the concentration of nitrogen generally reduces the amount of nitrogen oxides produces. This is due to lessen amounts of nitrogen atoms which is able to react with oxygen molecules to form NO_X in spite of forming due to high combustion temperatures.

Carbon Dioxide Concentration

Figure 5.9 Concentration of Carbon Dioxide (Abok Coal)

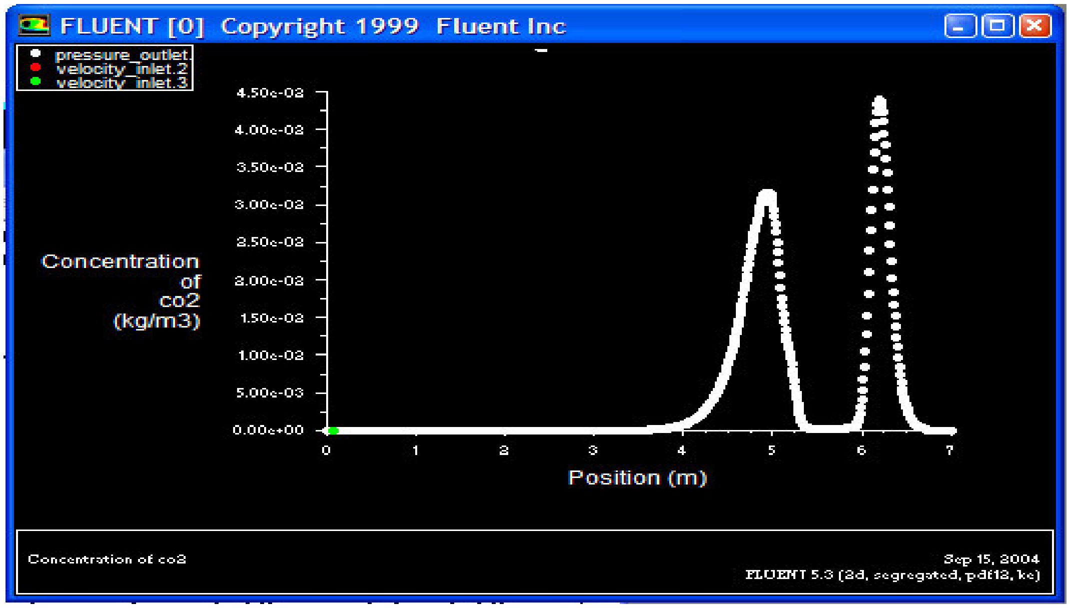
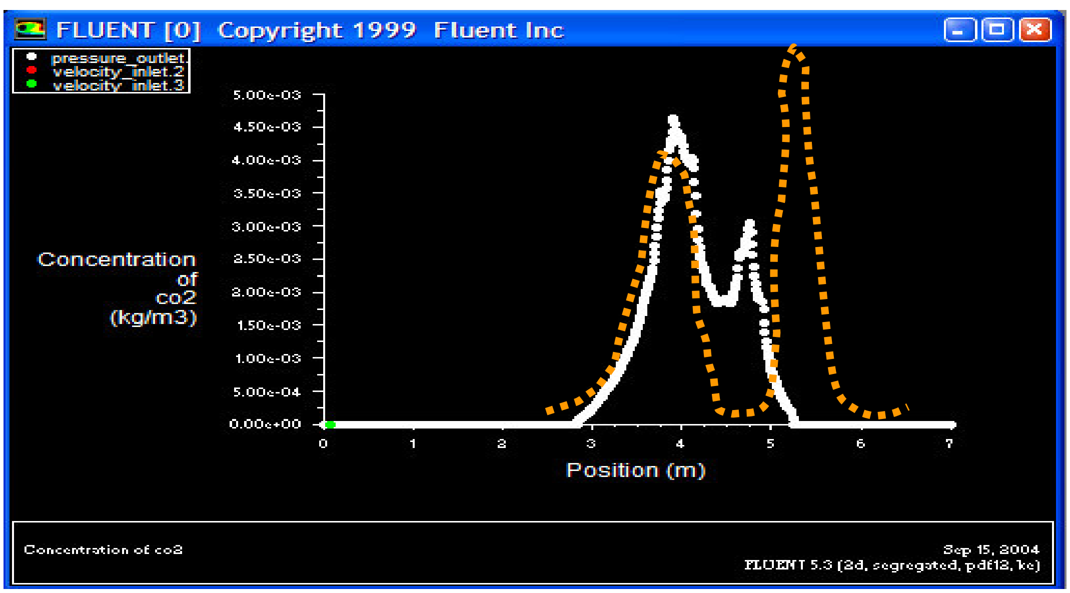


Figure 5.10 Concentration of Carbon Dioxide (95:5 Fuel Blend)



From the figures 5.9 and 5.10 shown previously, there exist little differences on the concentration of carbon dioxide (CO_2) produced even when both the graphs are superimposed with each other.

However, the actual concentration of CO_2 produced by the 95:5 fuel blend has also reduced. As stated by Lacrosse and Mathias, (2004) the amount of CO_2 produced through the combustion of the biomass (rice husk) is generally returned to the carbon dioxide cycle of the atmosphere as it is of equal amount to the CO_2 used in its plant cycle. Therefore, the amount of CO_2 produced from the 95:5 fuel blend is generally 5 percent lower than the Abok coal combustion.

Chapter 6

Results and Discussion

6.1 Combustion Technology

Combustion technologies that can be employed for co-firing of coal and biomass (rice husks) are Pulverised fuel, cyclone, stoker and fluidised bed boilers. However, for electricity generation in Malaysia, the pulverised fuel method is seen to be more popular rather than the other specified. This will in turn reduce cost for retrofitting or modifying newer technologies into the existing system.

6.2 Method of firing

For this project, the method of blending biomass with coal in the bunker or fuel yard was chosen. This was because it was the least cost approach rather than injecting rice husks separately to the furnace or gasyfying.

Besides that, the direct method of firing is also utilised. Besides being safer and requires much less space than the bin system, it is also incorporated in most coal fired power plants in Malaysia.

6.3 Fuel Considerations

From the comparison made for the Abok and Ulan coal, it was found that the Abok coal is able to produce adiabatic flame temperatures of closer to the optimal temperature stated by P.K. Nag (2002). From that, it can be concluded that lower electricity consumption of the forced draught fan can be achieved by using the Abok Coal.

The same scenario occurs for the comparison for the 95:5 and 90:10 fuel blend, where the 90:10 fuel blend mixture requires more consumption to supply higher flow rates of air into the combustion chamber.

Therefore, for this project the Abok Coal and 95:5 coal-rice husk blend was chosen to be modelled to understand its combustion behaviour.

6.4 Excess Air

According to P.K. Nag (2002), the optimal temperature in the combustion chamber or furnace should be about 2000K to 2100K. From the modelling of the flame temperatures with respect to the percentage of excess air, it was found that the maximum adiabatic flame temperatures of both these fuels are able to produce temperatures greater than this value. Therefore, in order to achieve the optimal temperature as stated above, excess air can be fed to the combustion chamber in order to lower the adiabatic flame temperatures.

6.5 Emissions

It is a fairly important aspect in a power plant to consider the emission of its pollutant produced. There are many pollutants being emitted from a power plant. However the main pollutants are known to be CO_2, NO_x and SO_x.

6.5.1 CO_2 Emission

Through co-firing, it is believed that the CO_2 emissions will be reduced. This is because co-firing generally reduces the amount of fossil fuel used in combustion. The CO_2 produced from the rice husk used will not produce CO_2 emissions because it generally recycles the amount of CO_2 used during the growing cycle of rice husks.

6.5.2 NO_X Emission

NO_X refers to all oxides of nitrogen. According to Talal Yusaf (personal communication, August 20, 2004), the formation of NO_X relies solely on high temperatures and the availability of unused oxygen. There are three types of formation of NO_X which are:

i. Thermal NO_X: which is formed by the reaction of atmospheric nitrogen and oxygen at high temperatures.
ii. Fuel NO_X : oxidation of fuel bound nitrogen
iii. Prompt NO_X : formed by reaction of hydrocarbon fragments with atmospheric oxygen.

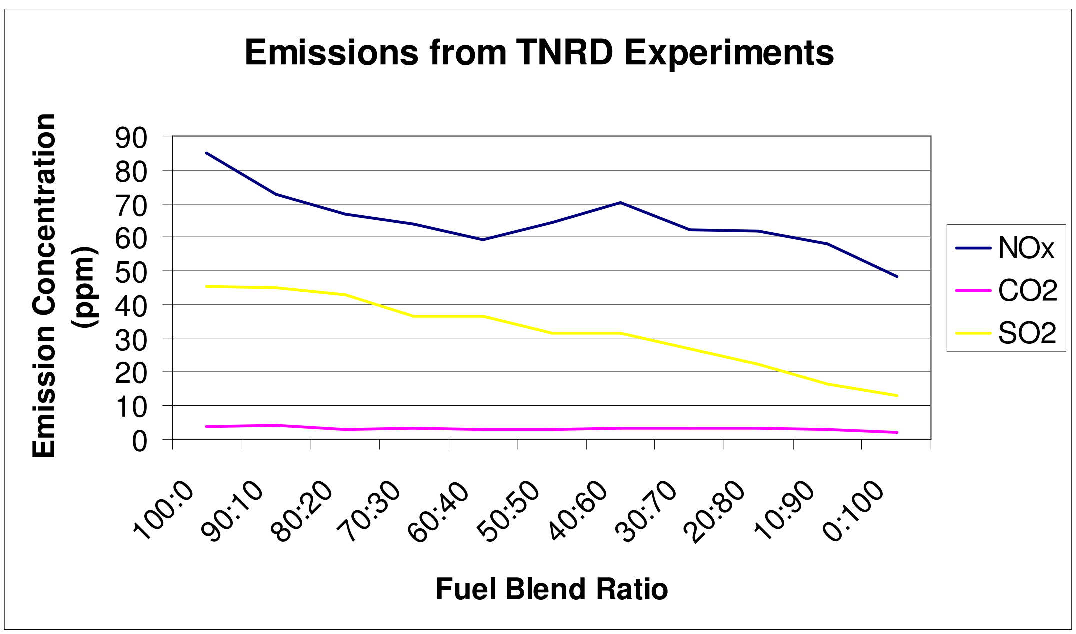
Methods of mitigating NO_X include the design of the burner, where low NO_X designs are incorporated to increase the lean combustion area, recirculation of exhaust gas, air or fuel staging, water and steam injection in the combustion zone. Besides that, LowNox technology also states that the pre-heated air of 300 degree Celsius should not be exceeded as it increases the exhaust gas temperature (Saacke LowNox Technologies, 2001).

According to Dr. Hamdan (personal communication, 12 August 2004) from Tenaga Nasional Research Development Centre, tests have been carried out to combust Abok Coal with rice husk. The emissions of NO_X and SO_X have been generated through experimentation using. Table 6.1 shows the tabulation of emissions in ppm:

Table 6.1 Output of Rice husk and Abok Coal from TNRD

Blend Ratio	Nox	SO2	Excess Air	CO2	Eff
100:0	85.04	45.41	38.53	3.86	51.45
90:10	72.81	44.82	35.04	4.12	51.32
80:20	66.71	42.75	54.52	2.94	47.06
70:30	64.02	36.66	50.81	3.17	46.62
60:40	59.5	36.5	51.31	3.11	45.67
50:50	64.5	31.75	51.36	3.11	44.73
40:60	70.18	31.67	50.09	3.21	44.62
30:70	62.13	26.91	50.94	3.36	43.62
20:80	62	22.11	51.39	3.22	37.22
10:90	58.09	16.5	55.32	2.93	33.82
0:100	48.17	13.21	62	2.19	32.38

Figure 6.2 Emissions from TNRD Experiments



From that, we can see that lower emissions of NO_X and SO_X are produced with every increase of rice husk percentage in the blend. Dr. Hamdan (personal communication, 12 August 2004) also stated that this was due to the lower percentage of Nitrogen and Sulphur contained in the fuel and also high moisture content of the fuel.

6.6 Modelling

The model for Abok coal was assumed to be the target in creating a standard for the 95:5 coal-rice husk blends to achieve. Therefore, the proper identification of both the separate fuels was undertaken using the pre-PDF file.

After obtaining the results from the model, it can be seen that both the fuel are able to produce flame temperatures above the specified range of 2000K to 2100K as specified by P.K Nag (2002). The maximum temperature for both flames as can be seen occurs at the centre of the flame which is also known as the fuel rich zone. This is generally desirable because there is adequate oxygen surrounding the combusting particles to obtain a complete combustion mechanism.

In the pollution aspect, the contour of Nitrogen concentration for the coal-rice husk blend was found to be lower than of the Abok coal. This generally means that the probability of resulting in NO_X formation to be lower as there is less concentration of Nitrogen atoms or molecules to be oxidized to nitrogen oxides.

6.7 Economic Aspect of Co-firing

From this project, the amount of rice husk found to be of utilisation will be 5 percent of the total amount of coal used. Therefore, there exists an amount of cost being saved up from the supplementation of rice husks. Calculations had been done to compare the amount of fuel saved:

Table 6.3 Savings from co-firing 95:5 coal blends per year

Type of Blend	Fuel Feed Rate tonnes/anum	Amount of Abok Coal used	Savings
100% Abok Coal	0.693 million tonnes per anum	0.693 million tonnes per anum	none
95:5 coal blend	0.712 mullion tonnes per anum	0.658 million tonnes per anum	54 million kg per anum

From these values, there exists a cost saving on the amount of coal being used which is approximately 54 million kilograms per annum.

Chapter 7

Conclusions and Proposals for Further Work

7.1 Conclusions

The conclusions which are extracted from this project can be divided to several categories which are:

7.1.1 Performance

This project has concluded theoretically that, co-firing rice husk with coal in small percentages such as 5 percent is able to produce or generate the same amount of steam required to generate 300MW of electricity. With the abundance of rice husks in Malaysia and burden by farmers to dispose them, rice husks may eventually become a valuable asset for the country.

7.1.2 Pollution

Besides reducing the amount of formation CO_2 produced in the flue gas, it was also found that, through co-firing the blend, pollution emission of NO_X can be seen to reduce. This is a positive and cheaper method of reducing the NO_x emissions rather than installing other costly burners.

7.1.3 Cost

The amount of rice husks being fed with coal to generate electricity will in turn reduce the amount of cost needed to produce electricity. As discussed previously, the supplementation of rice husks has reduced the amount of coal to be used and therefore results in a reduction of capital costs for coal.

7.2 Proposals for Further Work

The proposals for further work for this dissertation includes:

- To perform modelling for a blend of different types of mixture of coal with rice husk.
    - Due to the fluctuations of coal supply, different types of coal which is in the specification of Tenaga Nasional Berhad can be used. However, the difference of properties in the fuel may also cause fluctuations to the amount of flow rate and the amount of excess air. Therefore, through the modelling of these blends, a better understanding can be reached according to the real case scenario rather.

- To perform modelling of the combustion process with higher percentage of rice husks through a separate injection.
    - Based on the previous chapters, it was noted that co-firing using a separate injection mechanism may result in higher percentages of biomass to be fed into the boiler. With the increase in the percentage of biomass, the cost for coal can be lowered due to the decrease in flow rate. Thus, a better understanding of the system may be reached through this step.

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Appendix A

Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	LEE, VEN HAN
TOPIC:	COFIRING WITH RICE HUSK FOR ELECTRICITY GENERATION IN MALAYSIA.
SUPERVISOR:	DR. GUANGNAN CHEN
ASSOCIATE SUPERVISOR:	DR. TALAL YUSAF
ENROLMENT:	ENG4111 – S1, XP, 2004 ENG4112 – S2, XP, 2004
PROJECT AIM:	This project investigates the effectiveness, and optimises the use of rice husks as biomass in coal co-firing for power plant.

PROGRAMME: Issue A, 22nd March 2004

1. Research the different methods of biomass combustion and properties of rice husks.
2. Determine the optimum combustion method based on cost, pollution and performance aspects.
3. A mathematical model is to be developed to study the chemical and physical properties of the Malaysian coal and rice husk. This will be used to evaluate the combustion behaviour of both fuels.
4. To develop a 2D CFD model to evaluate the adiabatic flame temperature and flame propagation process using FLUENT.
5. The model in point 4 will be used to optimise the co-firing process in a power plant.
6. Design an optimised combustor for coal co-firing based on the results from points 3, 4 and 5.

As time permits,

7. To model the combustion process of co-firing with separate injection of biomass.

AGREED:

______________________ (Student) ____________________(Supervisor)

Lee, Ven Han (0050012454) Dr. Guangnan Chen

____________________ (Associate Supervisor)

Dr. Talal Yusaf

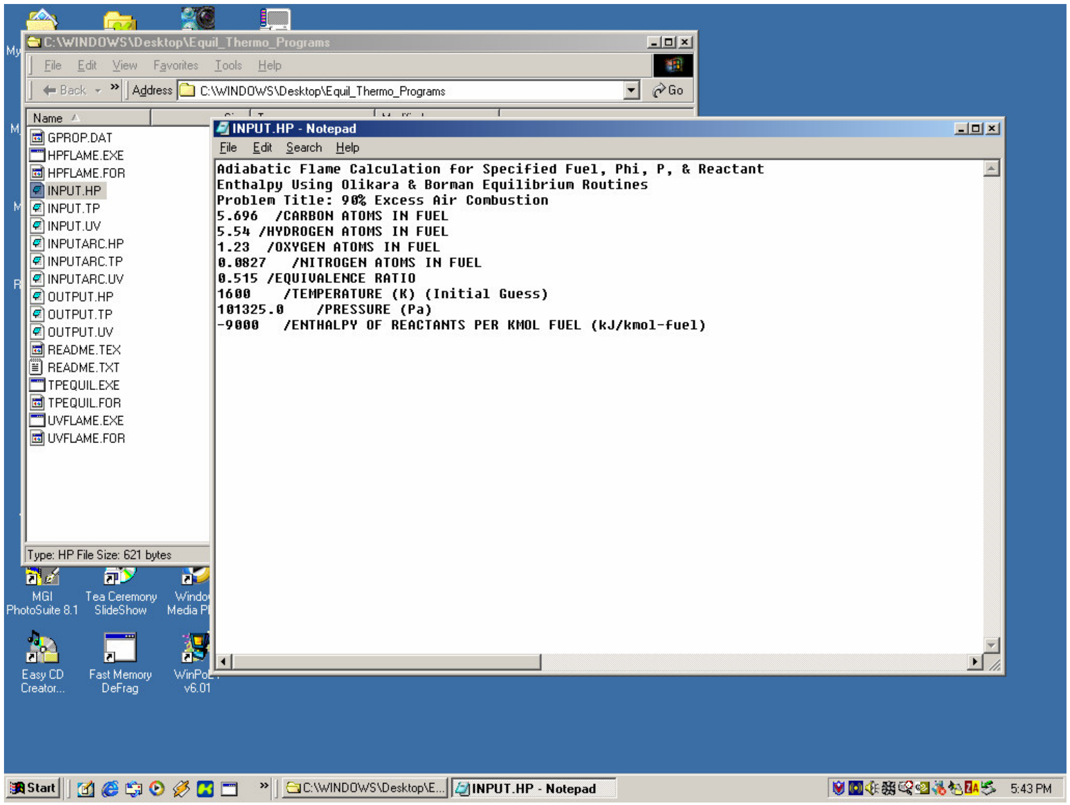
(date) _____ / _____ / _________

Appendix B

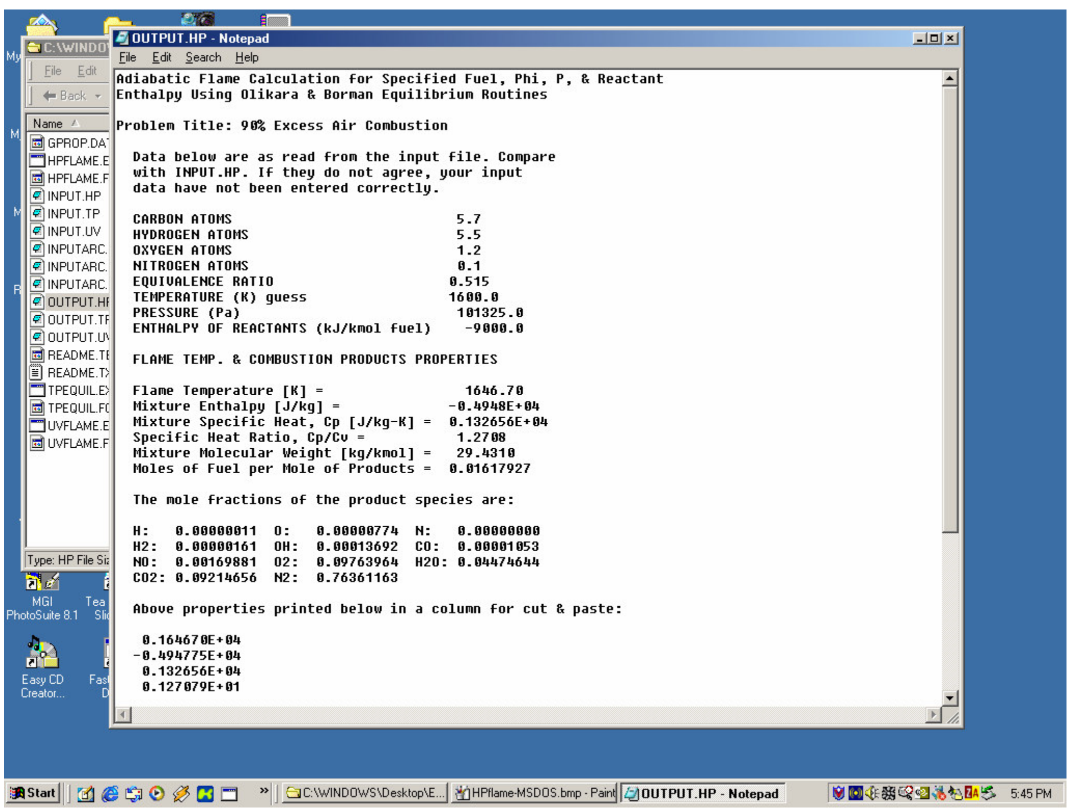
Information on Turns (2000) Software

The Turns (2000) software contains computer codes for equilibrium products for hydrocarbon and air combustion. The codes include a file name HPFLAME, which is an executable module for a constant pressure adiabatic combustion. It calculates the adiabatic flame temperature and properties of the products of combustion with input of the specified fuel composition, reactant enthalpy, pressure and equivalence ratio. The fuel compositions to be input to the module consist of the number of atoms of Carbon, Oxygen, Nitrogen and Hydrogen.

Appendix B- Figure 1 Input Frame for Turns 2000 Software



Appendix B- Figure 2 Output Frame for Turns 2000 Software

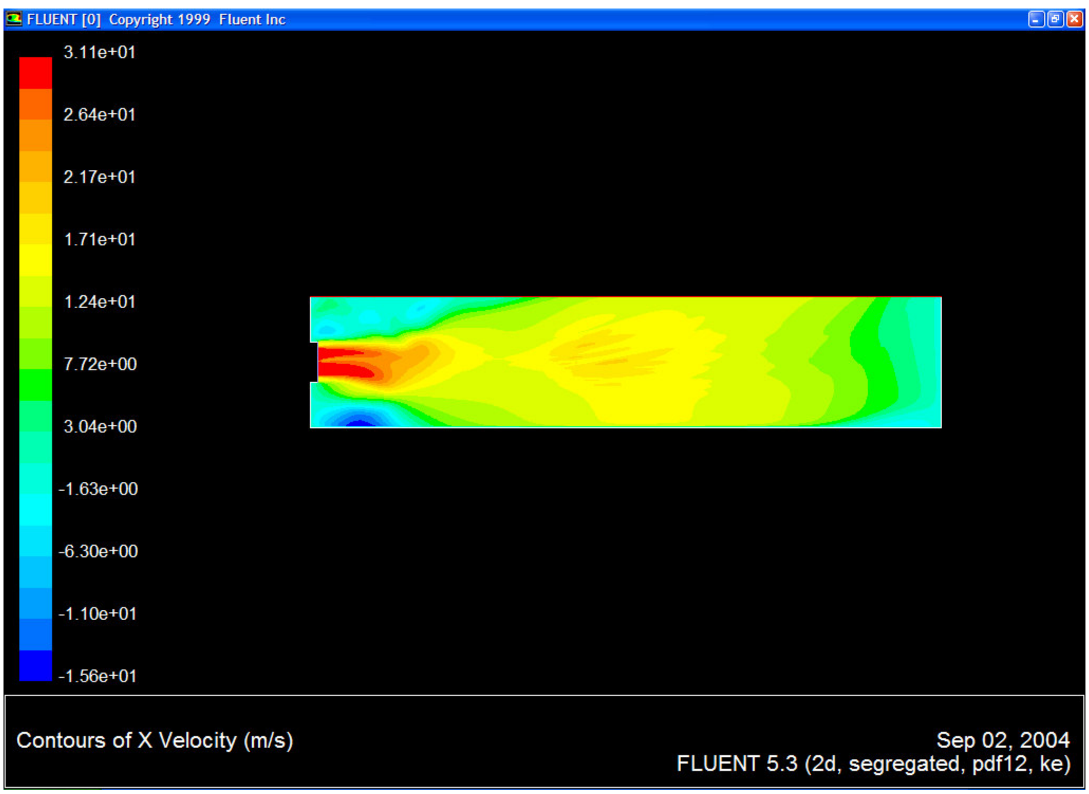


Appendix C

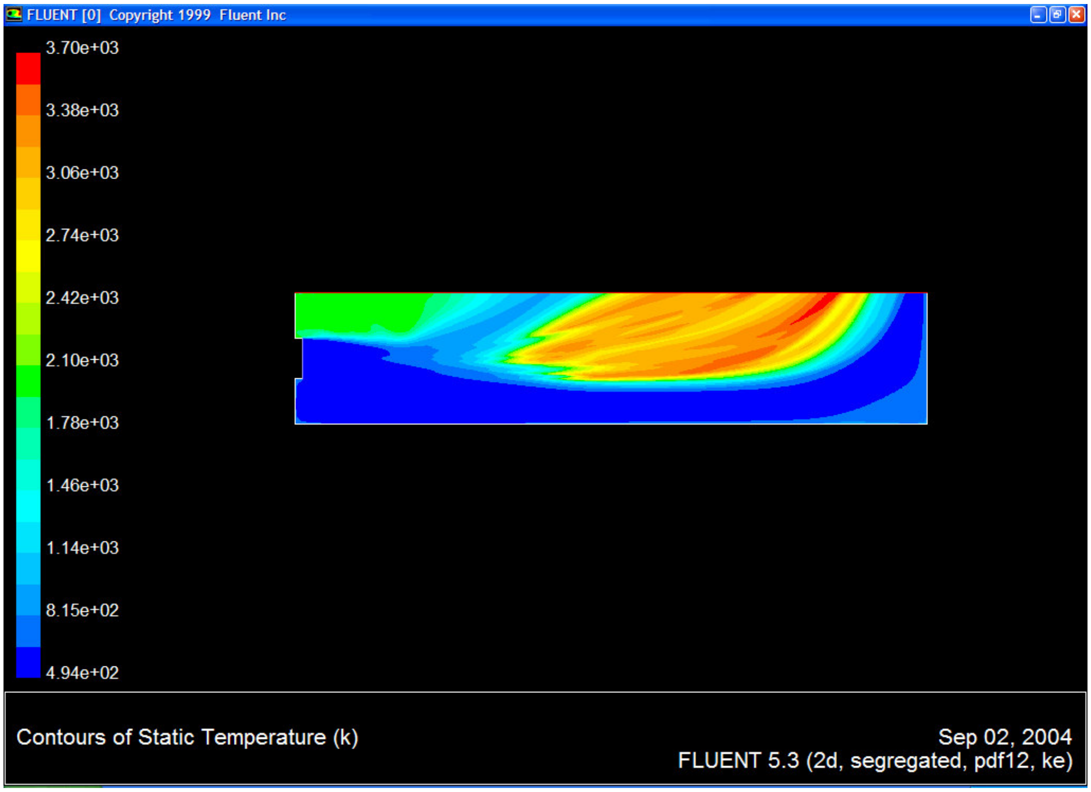
Plots from FLUENT 5.3

a. Abok Coal Combustion Model

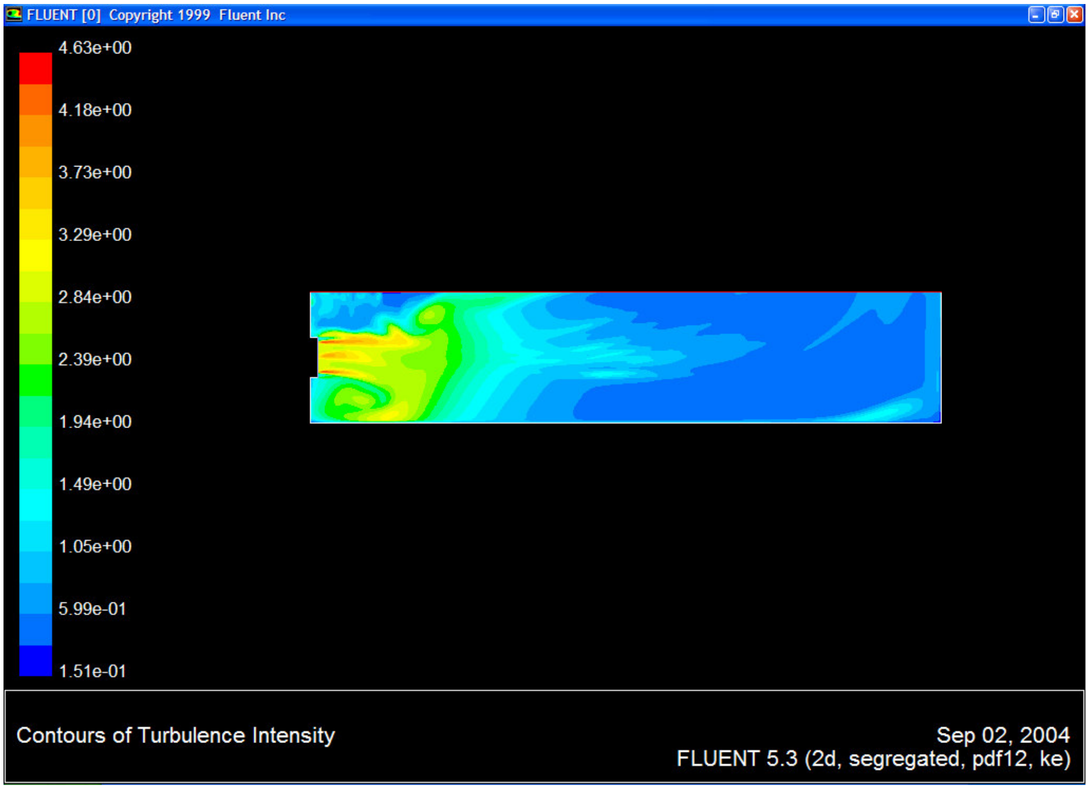
Appendix C - Figure 1 Contour of X-direction velocities for Abok Coal flame



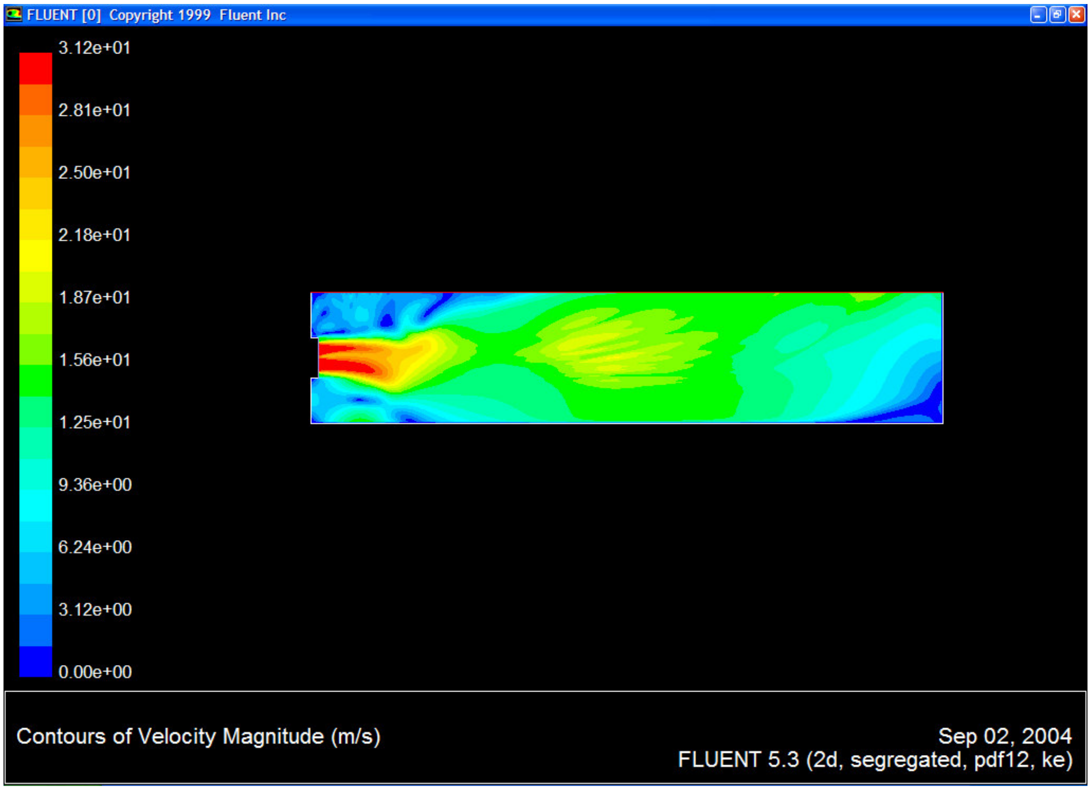
Appendix C - Figure 2 Contour of static temperature for Abok Coal flame



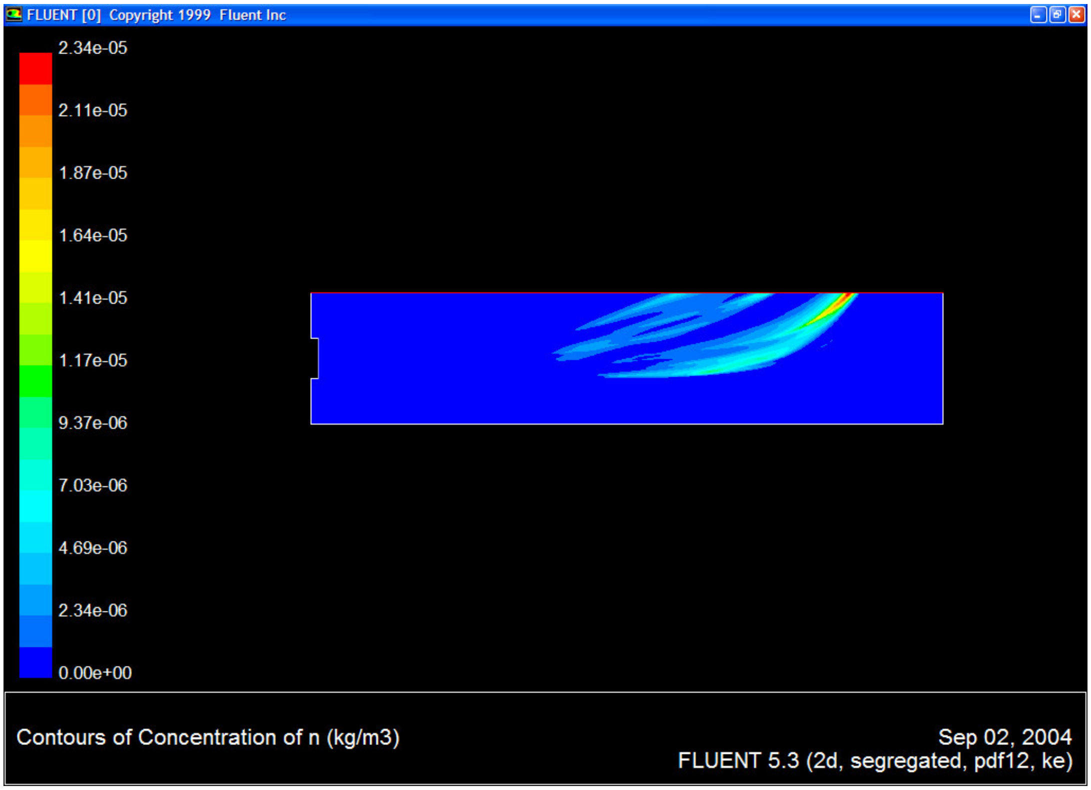
Appendix C - Figure 3 Contour of turbulence intensity for Abok Coal flame



Appendix C - Figure 4 Contour of velocity magnitude for Abok Coal flame

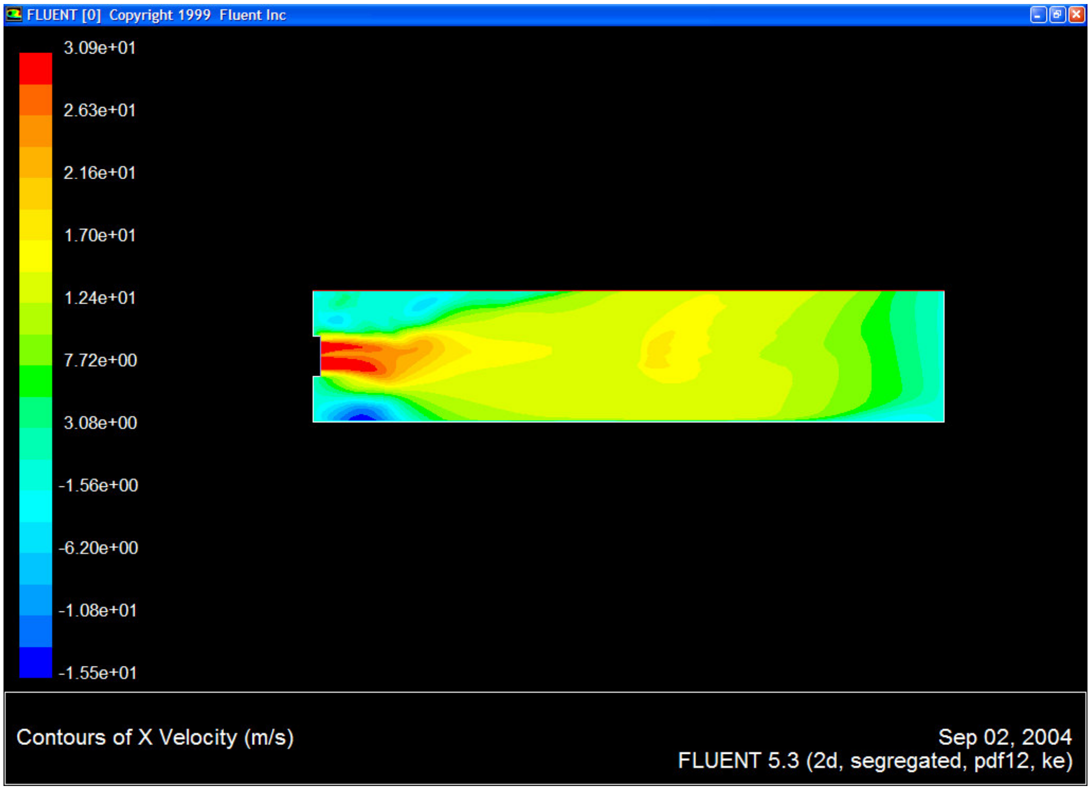


Appendix C - Figure 5 Contour of molar concentration of Nitrogen for Abok Coal flame

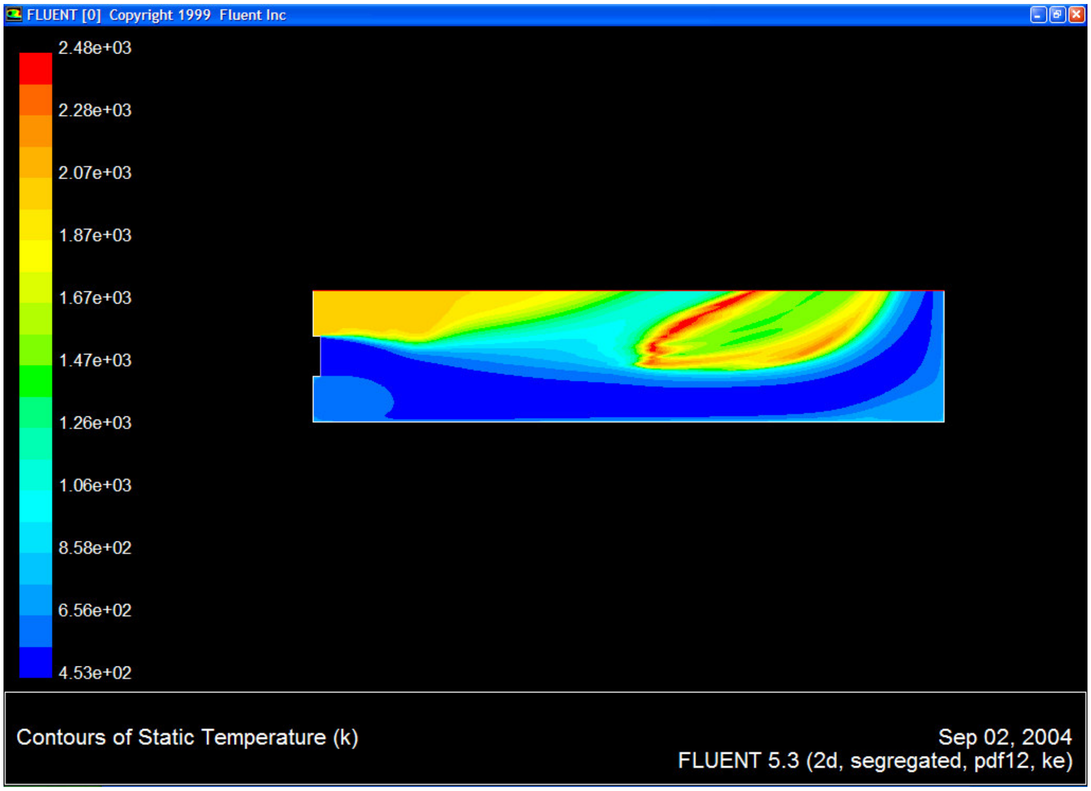


b. The 95% and 5% Rice Husk Blend

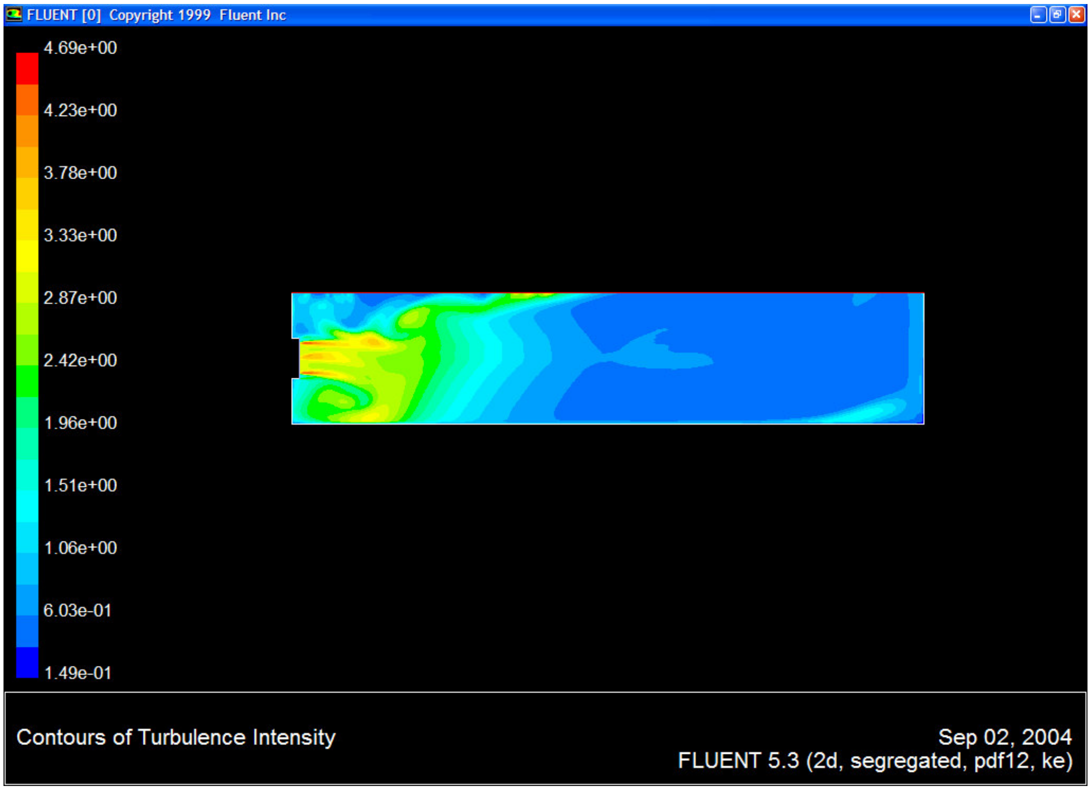
Appendix C - Figure 6 Contour of X-direction velocities for 95:5 Coal-rice husk flame



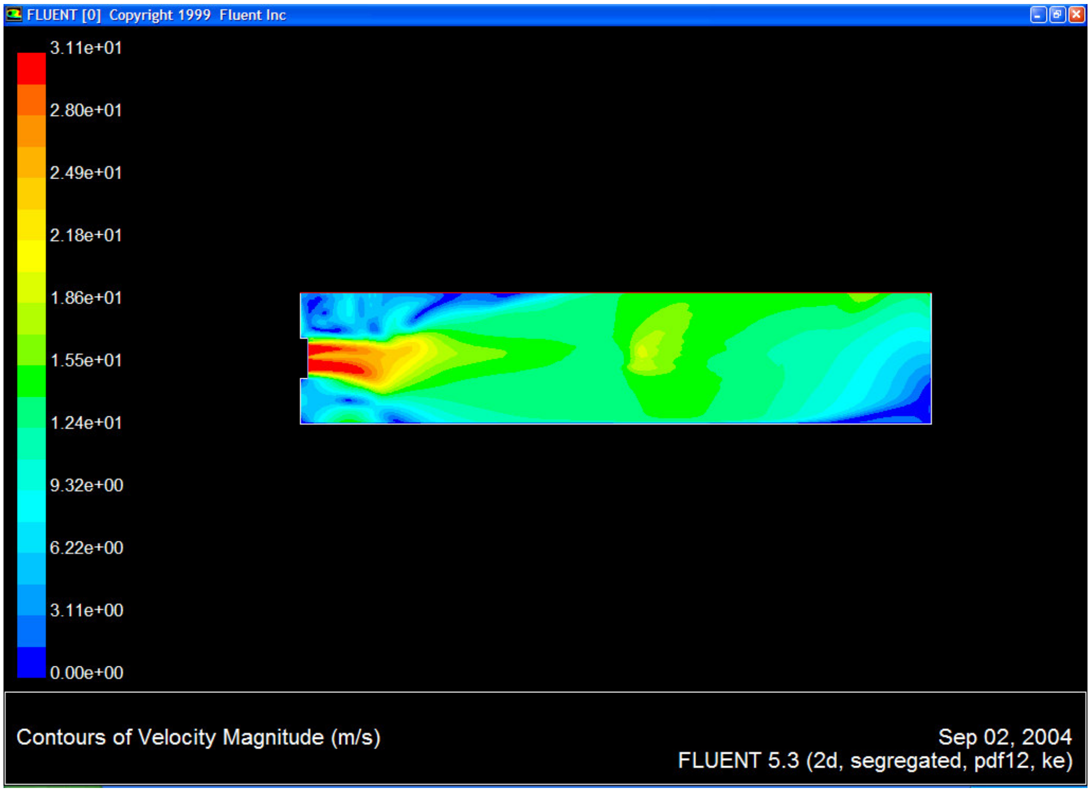
Appendix C - Figure 7 Contour of static temperature for 95:5 Coal-rice husk flame



Appendix C - Figure 8 Contour of turbulence intensity for 95:5 Coal-rice husk flame



Appendix C - Figure 9 Contour of velocity magnitude for 95:5 Coal-rice husk flame



Appendix C - Figure 10 Contour of Nitrogen molar concentration for 95:5 Coal-rice husk flame