

CERTIFICATION OF APPROVAL

PALM WASTE BRIQUETTE & BIO-BRIQUETTE AS POTENTIAL FUEL

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

KHAIRIL NIZAM BIN MOHAMAD DARUS

ABSTRACT

Excessive amount of Greenhouse Gas (GHG) emissions has increase global warming and is threatening our world right now. Fossil fuel burning for power generation is one of the major sources of those hazardous gases. Considering the current situation, a lot of study on the utilization of biomass to be used as alternative fuel is currently going on. This study is considering the utilization of palm shell and fibre to be used as fuel or either as supplement medium in coal co-firing power plants. Co-firing with biomass is one way to counter the excessive GHG emissions problem since the amount of carbon dioxide (CO₂) produced from combustion of biomass is equal to the amount of CO₂ absorbed during plant growth.

This report started with brief introduction of the study which includes the background of study, problem statements and objectives of the study. This report also includes some information in literature review parts where the author explains thoroughly on biomass, advantages and disadvantages, coal and co-firing. The author is considering three cases in the study which are:-

- Case 1: 100% Brown Coal
- Case 2: Bio-briquette – 50% Coal + 50% Palm-waste
- Case 3: Palm-waste briquette – 60% Shell + 40% Fibre

The report continues with the methodology of the project which includes the project milestone, work flow and details on tools and equipments used in the project. Next, results and discussion part is where analysis of ultimate and proximate results, and also analysis on calorific values of the samples are gathered. The main part of the project which are the results from modelling and simulations of the fuels combustions are also included in this section.

The report then followed by conclusions and recommendations from findings and analysis that had been made. For further clarification on the projects, the report ended with a list of references and appendices used throughout the project.

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LIST OF ABBREVIATIONS

GHG	Greenhouse Gas
CO ₂	Carbon Dioxide
EFB	Empty Fruit Bunches
POME	Palm Oil Mill Effluent
NO _x	Nitrogen Oxide
TGA	Thermogravimetric Analysis
CHNS	Carbon, Hydrogen, Nitrogen, Sulphur
DSSN	Dry Small Steam Nuts
CFD	Computational Fluid Dynamics
HHV	High Heating Value
CAD	Computer-Aided Design
DBR	Densified Biomass Residue
TNB	Tenaga Nasional Berhad
PDF	Probability Density Functions

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

1.1 Background of Study

Biomass is biological material derived from living, or recently living organisms [1]. In the context of biomass for energy, this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. Within this definition, biomass for energy can include a wide range of materials and it can be categorized to five main sources [2]:-

- **Virgin wood:** from forestry, arboricultural activities or wood processing
- **Energy crops:** high yield crops grown specifically for energy applications
- **Agricultural residues:** from agriculture harvesting or processing
- **Food waste:** from food and drink manufacture, preparation and processing, and post-consumer waste
- **Industrial waste and co-products:** from manufacturing and industrial processes.

In Malaysia, agricultural residues is said to be the most abundant biomass where more than 70 million tonnes of biomass are produced annually. Suitable weather condition such as high sunlight intensity/time and high rainfall is one of the main reasons that contribute to continuous biomass production throughout the year [3].

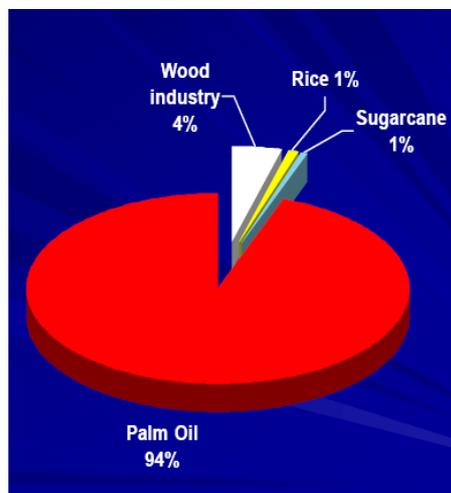


Figure 1.1: Biomass resources distribution in Malaysia [3]

As shown in Figure 1.1, the main contributor of biomass in Malaysia is the palm oil industry where it contributed 94% of the overall resources. Basically, there are five materials that can be obtained from palm oil industry and considered as biomass which are [3]:-

- Empty fruit bunches (EFB)
- Palm oil mill effluent (POME)
- Mesocarp fibre
- Palm kernel shells
- Palm kernel cake (residue)

This study is focusing on the utilization of palm fibre and shell as potential fuel. There are three cases involve in this study as described below:-

Case 1: Brown coal

Composition: 100wt% Brown Coal

Case 2: Bio-briquette

Composition: 50wt% Brown Coal and 50wt% palm waste briquette

Case 3: Palm waste briquette

Composition: 60wt% shell and 40wt% fibre (60:40)

This study is basically an extension from the author's supervisor's project on 'Energy from waste-development of alternative fuel briquettes from agricultural waste' [15].

1.2 Problem Statement

Fossil fuel burning to produce energy is one of the major sources of excessive emission of GHG especially CO₂ and Nitrogen Oxide (NO_x), thus increasing the threat of global warming to the earth. Since the industrial age, those gases emission have increased by one-third. Uncontrolled anthropogenic release of those gases had increased heat trapped in the atmosphere and consequently increase the earth temperature ranging from 0.6 - 2.5°C for the last 50 years and 1.4 - 5.8°C in the 21st century [3]. Fossil fuel burning to produce energy is identified as one of the major

sources of those gases and the threat of global warming has already created consciousness among people to find better alternatives. In addition, rising fossil fuels price, rapid depletion of fuels reserves and growing energy demand are also some of the reasons that further research on biomass as potential fuels is required [3].

1.3 Objectives and scope of study

The main objective of the project is to investigate the feasibility of palm waste to be used as fuel or supplement medium for coal-biomass co-firing in coal fired power plants with the benefits of reduced amount of carbon dioxide and nitrogen oxide produced during combustion. The sub-objectives of this project basically consist of:-

- 1.3.1 To gather, examine and analyze the data from bomb calorimeter experiment, ultimate and proximate analysis
- 1.3.2 To model and run combustion simulations using FLUENT software to see whether the required combustion temperatures are achieved and the concentration of CO₂ and N are reduced.
- 1.3.3 To make justification by comparing the results from simulation with gas analyzer results

Considering the global warming condition and the mass abundant of biomass resources available in Malaysia nowadays, this study is a relevant effort to be done.

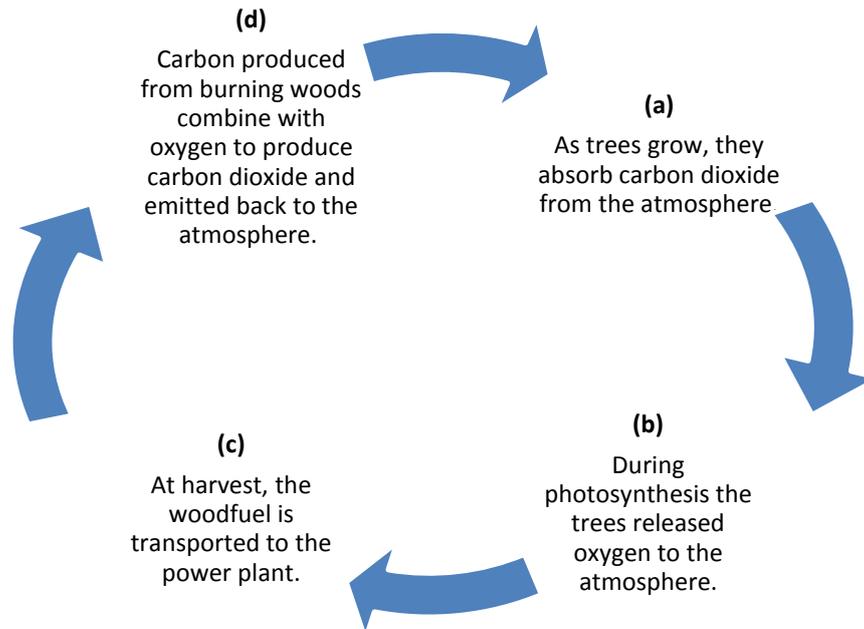


Figure 2.2: Biomass carbon cycle [2]

2.1.2 Advantages of using biomass

Biomass utilization brings a lot of benefits and advantages. Some of them are as describe and explained below:-

2.1.2.1 Renewable Energy Sources

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished) [4]. The biomass energy source is considered to be the renewable energy source because biomass is mainly obtained from plants where they are always available [5].

2.1.2.2 Reduced Greenhouse Effect [5]

Burning of biomass fuels does releases CO₂ gases just like the burning of fossil fuels. However, fossil fuels CO₂ gases are lying in the latent state since millions of years and their release in present times leads to the overall increase in the CO₂ content of the atmosphere. On the other hand, biomass is the plant material generated recently hence the CO₂ gas is lying dormant in it as the plant grows. CO₂ from the fossil fuels is new for the earth, while CO₂ from biomass is part of the growth of the plant in

present times. Thus the burning of fossil fuels adds new CO₂ to the atmosphere while burning of biomass balances the CO₂ absorbed by the plants during its growth [5].

2.1.2.3 Indigenous Fuels and Are Widely Available

The fuels from biomass materials can be produced indigenously and no high technology is required for it. Further, the biomass materials are available in almost all the countries. Producing the fuel from biomass materials reduces the dependence of the country on foreign resource for their fuel requirements [5].

2.1.2.4 Reduced Animal, Food Processing and Municipal wastes

Anaerobic digestion which is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen is used to convert wastes from livestock, food processing and households into energy [6]. Using this biomass as energy can yield the following benefits: production of heat or electricity, odour reduction, reduced risk of water contamination, and reduced exposure to disease-causing organisms [7].

2.1.2.5 Reduced Risk of Wildfire

The risk of catastrophic wildfire can be reduced by removing small diameter trees that act as a fuel for the flames. The removal of trees is a labour intensive and costly process, but the use of these biomass materials can create a market outlet and thereby help defer the costs of forest thinning activities [7].

2.1.2.6 Improved Watershed Quality

Reducing waste flows from livestock, food processing and city sanitation services can contribute to improved water quality. Preventing wildfires can improve water quality. Wildfires reduce the ability of soil to absorb water which leads to increased debris and sediments in the riparian area [7].

2.1.2.7 Economic and Social Benefits

Biomass benefits include creation and retention of local jobs in a rural economy. For biomass power systems, it is estimated that six full time jobs are created for each MW of installed capacity. Depending upon the capacity, this employment figure includes 15 to 20 or more personnel at the power plant and the balance of people hold jobs in fuel processing and delivery. For corn-based ethanol plants, 100 jobs per year would be created for a 15 million gallon/year facility. More than 66,000 jobs are supported by the biomass producing industry in the United States [7].

2.1.2.8 Clean environment

The biomass material is the waste generated by the plants, animals and human beings. It includes lots of municipal waste, garbage, paper water, industrial scrap etc. Using biomass as the fuel not only gives us the energy but also helps remove the garbage from the surroundings and keep the surroundings clean [5].

2.1.3 Disadvantages of using biomass

Despite all the advantages of using biomass as alternative fuel, there is also a list of disadvantages occurring from the utilization of this matter to produce energy. They are as listed and described below:-

2.1.3.1 Greenhouse gases produced by burning

Burning of biomass do produces greenhouse gases and contributes to global warming. Exhaust gas cleaning technology must be applied to biomass energy plants to make them truly environmentally-friendly [8].

2.1.3.2 Expensive to plant, harvest and process

It requires more cost and energy to plant, harvest and process the raw materials than it is worth to get a net energy gain especially when considering the large volumes required compared to fossil fuels [8]. The cost of installing and maintaining the

infrastructure for processing the biomass is also very expensive. It involves making infrastructure for collecting, processing, and then purifying the biofuel [9]. It also takes up more water from the earth and other fossil fuels to make the fertilizers and fuels for planting and harvesting, thus supposedly, takes up more land for the crops and trees.

2.1.3.3 Biomass crops not available all year (some cases)

Corn, wheat, barley and the like are seasonal crops. They are not available all year. Trees are also a slow growing resource even though they are renewable. This would also tend to be a negative on the side of biomass fuels [10].

2.1.3.4 Large scale crops production requires vast areas of land and water

Biomass energy depends largely on grown crops. If bio-fuels are to replace fossil fuels to a significant extent, these grown crops will take up huge tracts of land. It also takes up more water from the earth and other fossil fuels to make the fertilizers and fuels for planting and harvesting, thus supposedly, takes up more land for the crops and trees. Consequently, land might be deforested to clear those areas first. Those lands are in fact needed for feeding the growing population of billions of people [8].

2.1.3.5 Low energy produced

Biomass fuels usually have lower fuel economy than normal fossil fuels. They are not able to generate enough energy efficiently [9].

2.2 Coal

Coal is a readily combustible black or brownish-black sedimentary rock normally occurring in rock strata in layers or veins called coal beds or coal seams. The harder forms, such as anthracite coal, can be regarded as metamorphic rock because of later exposure to elevated temperature and pressure. Coal is composed primarily of carbon

along with variable quantities of other elements, chiefly sulphur, hydrogen, oxygen and nitrogen [11].

The fossil fuel, is the largest source of energy for the generation of electricity worldwide, as well as one of the largest worldwide anthropogenic sources of carbon dioxide emissions. Gross carbon dioxide emissions from coal usage are slightly more than those from petroleum and about double the amount from natural gas. Coal is extracted from the ground by mining, either underground by shaft mining through the seams or in open pits.

2.2.1 Types of coal

As geological processes apply pressure to dead biotic material over time, under suitable conditions it is transformed successively into [11]:-

2.2.1.1 Peat

Considered to be a precursor of coal, has industrial importance as a fuel in some regions, for example, Ireland and Finland. In its dehydrated form, peat is a highly effective absorbent for fuel and oil spills on land and water.

2.2.1.2 Lignite

Also referred to as brown coal, is the lowest rank of coal and used almost exclusively as fuel for electric power generation. Jet is a compact form of lignite that is sometimes polished and has been used as an ornamental stone since the Iron Age. Lignite can be separated into two types. The first is xyloid lignite or fossil wood and the second form is the compact lignite or perfect lignite [12].

2.2.1.3 Sub-bituminous coal

The properties of this coal range from those of lignite to those of bituminous coal and are used primarily as fuel for steam-electric power generation. Additionally, it is an important source of light aromatic hydrocarbons for the chemical synthesis industry.

2.2.1.4 Bituminous coal

A dense mineral, black but sometimes dark brown, often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities also used for heat and power applications in manufacturing and to make coke.

2.2.1.5 Steam coal

The grade is between bituminous coal and anthracite, once widely used as a fuel for steam locomotives. In this specialized use it is sometimes known as sea-coal. Small steam coal (dry small steam nuts or DSSN) was used as a fuel for domestic water heating.

2.2.1.6 Anthracite

The highest rank; a harder, glossy, black coal used primarily for residential and commercial space heating. It may be divided further into metamorphically altered bituminous coal and petrified oil, as from the deposits in Pennsylvania

2.2.1.7 Graphite

Technically the highest rank, but difficult to ignite and is not so commonly used as fuel: it is mostly used in pencils and, when powdered, as a lubricant.

The classification of coal is generally based on the content of volatiles matter.

2.3 Co-firing

Co-firing can be defined as simultaneous combustion of different fuels in the same boiler, provides one alternative to achieve emissions reduction [13]. This is not only accomplished by replacing fossil fuel with biomass, but also as a result of the interaction of fuel reactants of different origin, e.g. biomass and coal. The fuels used can be solid fuels, liquid fuels or gaseous, and its nature either fossil or renewable. Co-firing also creates less air pollution than power generation using fossil-based fuels alone. There are basically three options for co-firing: direct, indirect and parallel co-firing. Direct co-firing is combustion of biomass together with fossil fuel in a single combustion chamber. Indirect co-firing means combustion of fossil fuel

with previously gasified biomass, and parallel co-firing requires at least two boilers as biomass is burned in one and fossil fuel in another [14].

2.3.1 Direct co-firing method

In this configuration, biomass (as a secondary fuel) is included along with coal (as the primary fuel) into the same boiler. Direct co-firing is commonly used because of the lower operation cost. Direct co-firing method can be done in two ways. The first is the mixing and pre-treatment of biomass and coal are carried out together before being fed into the burner. Secondly, pre-treatment of biomass and coal are conducted separately, and then fed into the burner [14]. In addition, there are also two types of direct co-firing method which are co-milling and direct injection method. The bio-briquettes sample was processed using the co-milling direct co-firing method [15].

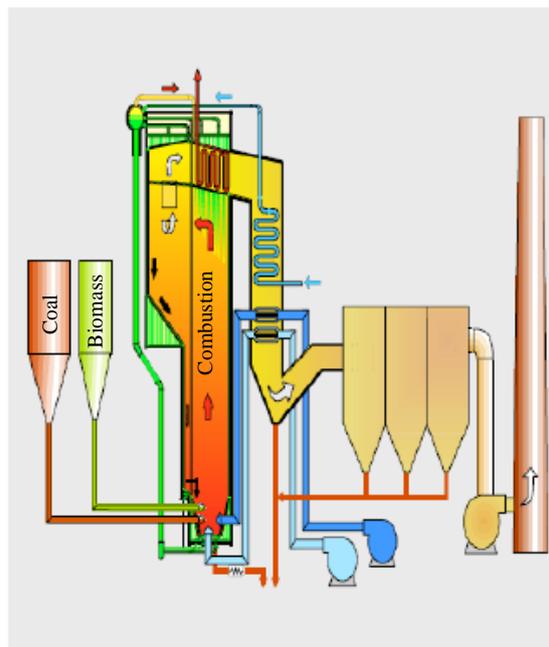


Figure 2.3: Direct Co-firing [13]

Figure 2.3 shows an example of direct co-combustion in CFB furnace. Coal and biomass are blended together in the fuel handling system and fed into the boiler.

2.3.2 Indirect co-firing method

Indirect co-firing configuration refers to the process of biomass gasification, where the gas is then fed into the burner and burned along with coal. This is also called indirect co-combustion with pre-gasification. By using this configuration, the ashes from biomass will be separated from the coal ashes with the capability of maintaining high ratio of co-firing. The only disadvantage of this method is the high investment cost [14]. Figure 2.4 below shows the configuration for the indirect co-combustion with pre-gasification. Initially, biomass is gasified by burning it at high temperature. Then the gas state biomass is used and burned with coal in the gas-fired boilers as shown in the right hand side of the picture.

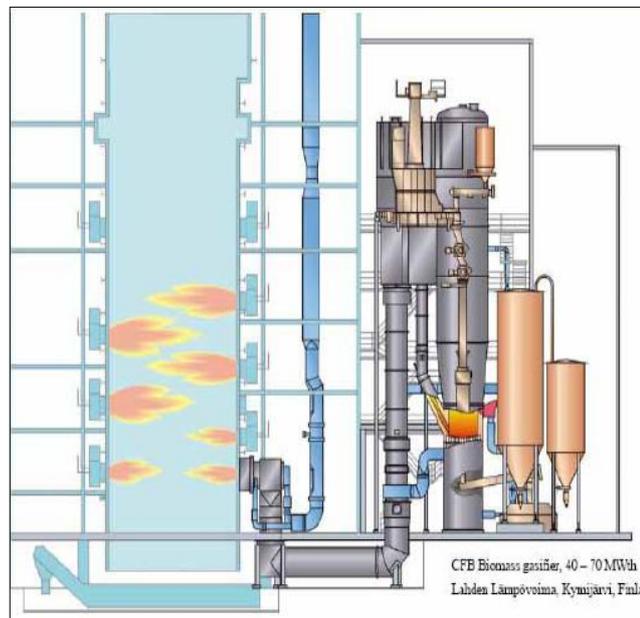


Figure 2.4: Indirect Co-firing with Pre-gasification [13]

2.3.3 Parallel co-firing method

Parallel co-firing method involves separate burners and boilers for biomass. The burned biomass will generate steam which will then be used on coal burning power plant circuit. Although this configuration requires a larger investment than direct co-firing, this configuration has the advantage of capability to use fuel with alkali metal and high chlorine content. Besides, ash from the burning of coal and biomass will also be produced separately (refer Figure 2.5) [14]:-

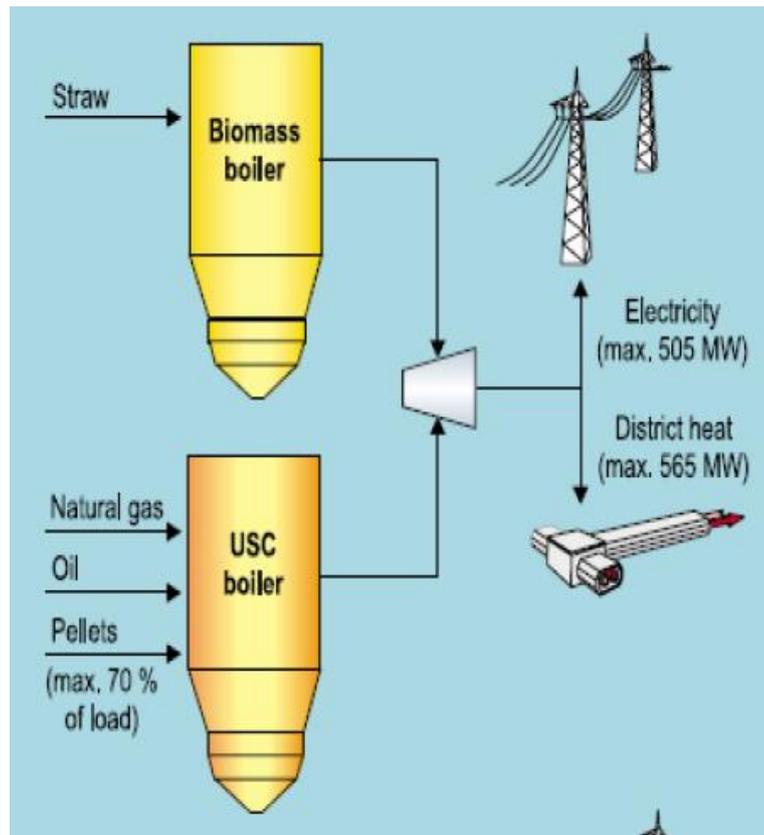


Figure 2.5: Parallel Co-firing [13]

2.3.4 Advantages of co-firing

Since burning biomass is carbon neutral, co-firing reduces the amount of greenhouse gases that are released. At the same time, co-firing can be used to lower the emission of some pollutants. For example, coal co-firing with biomass results in less sulphur emissions than burning coal by itself. The main advantage of co-firing is that it can be done in existing power plants with little or no modification, allowing for comparatively inexpensive and rapid reductions in greenhouse gases [14].

CHAPTER 3

METHODOLOGY

3.0 METHODOLOGY

As describe the scope of studies, this project consists of four stages that have been completed which are:

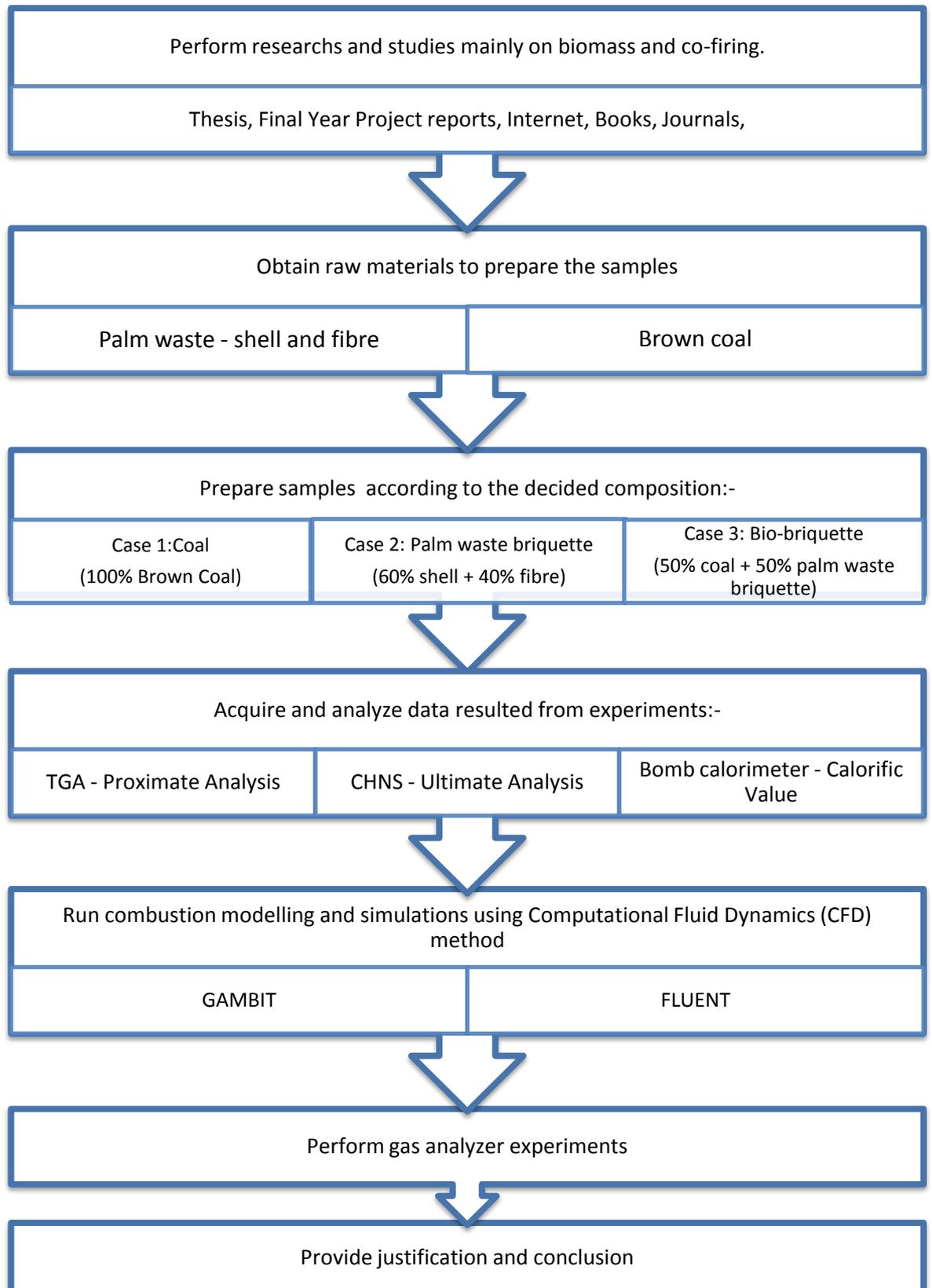
- Analyze ultimate and proximate analysis and calorific value results,
- Run modelling and simulations for combustion using GAMBIT and FLUENT software,
- Prepare samples and perform gas analyzer experiments
- Compare the results obtained and provide justification

Thermogravimetric Analysis (TGA), carbon, hydrogen, nitrogen, sulphur (CHNS-932) and bomb calorimeter were used to obtain the proximate and ultimate analysis, and calorific value results, respectively. Then, modelling and simulations of the combustion process were done using GAMBIT and FLUENT software and followed by gas analyzer experiments for final comparison and justification. The description and procedure for each tool, machine and software is discussed later in this chapter.

3.1 Project Activities and Milestone

Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Work Continues														
:- Obtain Brown coal, palm shell and fibre samples	X													
:- Process samples into fine powder samples		X												
:- Collect TGA, CHNS and Calorific Value data from Supervisor			X											
:- Analyze and examine gathered data														
Submission of Progress Report 1				X										
Project Work Continues														
:- Work on modelling and simulations				X	X									
:- Perform gas analyzer experiment														
Submission of Progress Report 2							X							
Seminar							X							
Project Work Continues														
:- Continue working on simulations							X	X	X	X	X	X	X	X
:- Provide comparison and justification														
Poster Exhibition										X				
Submission of Dissertation Draft														X
Oral Presentation	During Study Week													
Submission of Dissertation (Hardbound)	7 days after oral presentation													

3.2 Work Flow



3.3 Tools, Machines and Software Used

3.3.1 Thermogravimetric Analysis (TGA)

Thermogravimetric analysis or thermal gravimetric analysis (TGA) is a type of testing that is performed on samples to determine changes in weight in relation to change in temperature [16]. The output will give a plot of weight loss (%) versus temperature or time. In this project, TGA is used to analyze biomass and coal to obtain the proximate analysis which gives the weight percentage of moisture, volatile matter, fixed carbon and ash. Figure 3.1 shows an example of a TGA unit.



Figure 3.1: Thermal Gravimetric Analyzer (TGA) module

3.3.2 CHNS-932 Analyzer

A CHNS Analyzer is a scientific instrument which can determine the elemental composition of a sample. The analyzer uses a combustion process to break down substances into simple compounds which are then measured [17]. By using this device, organic carbon in a sample can also be measured by separating out inorganic carbon using a solvent. This equipment gives the Ultimate analysis of the samples which consists of the weight percentages of Carbon, Hydrogen, Nitrogen, and Sulphur composition in the solid fuel. Figure 3.2 shows a picture of CHNS-932 analyzer.



Figure 3.2: CHNS-932 Analyzer

3.3.3 Bomb Calorimeter

A bomb calorimeter is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction [18]. Bomb calorimeters have to withstand the large pressure within the calorimeter as the reaction is being measured. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. The temperature of the water allows for calculating calorie content of the fuel. In this project, it is used to calculate the High Heating Value (HHV) content of the fuel. Figure 3.3 shows an example of bomb calorimeter unit.



Figure 3.3: Bomb calorimeter

3.3.4 Gas Analyzer

It is used to analyze the gases combusted from co-firing from a bomb calorimeter. It can analyze and measure HC, CO, CO₂, O₂, NO_x (5 gas version), and Air Fuel ratio. The picture and steps to operate this equipment is incorporated in Appendix A.

3.3.5 Computational Fluid Dynamics (CFD)

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows [18]. The first step in CFD is called pre-processing. It involves building and analyzing a flow model within a computer-aided design (CAD) package, creating and applying a suitable computational mesh, and entering the flow boundary conditions and fluid material properties. Next step is solving by using calculations based on the mesh and produces the results required in the analysis. Final step is post-processing where it involves the organization and interpretation of the results.

3.3.6 GAMBIT 2.4.6

GAMBIT is a state-of-the-art pre-processor for engineering analysis. With advanced geometry and meshing tools in a powerful, flexible, tightly-integrated, and easy-to-use interface, GAMBIT can dramatically reduce pre-processing times for many applications [19]. GAMBIT is used to model the burner and meshed it to smaller quadrilaterals cells to enable the solver to compute data at the area.

3.3.7 FLUENT 6.3.2.6

FLUENT is a powerful and flexible general-purpose CFD package used for engineering simulations of all levels of complexity [20]. It offers a comprehensive range of physical models that can be applied to a broad range of industries and applications. The meshed files from GAMBIT are exported to FLUENT software for combustion modelling because of the availability of parameters.

CHAPTER 4

RESULTS & DISCUSSIONS

4.0 RESULTS & DISCUSSIONS

4.1 Samples details

The raw materials of the samples (i.e. palm shell and fibre) were collected from Felcra Nasaruddin, Bota and the coal from Tenaga Nasional Berhad (TNB) Janamanjung power plant. The samples were then dried in an oven, granulated using Granulator and crushed using Rocklabs to produce fine powder samples. These powder samples then were blended together according to the percentage of the three cases decided in the early stage of the project as shown in Table 4.1 below:-

Table 4.1: Cases of study

Case	Briquette Material	Composition
1	Coal	100% Brown coal
2	Bio-briquette	50% Brown coal + 50% Palm waste briquette (50:50)
3	Palm Waste Briquette	60% Shell + 40% Fibre (60:40)

One method of upgrading loose residue material to improve their handling and or combustion properties is by densification into pellets or briquettes of higher density than original bulk density of the material. It has been noted that, there is marked improvement in combustion characteristics of densified biomass residue (DBR) compared to loose biowaste. DBR's have been reported to have superior and comparable combustion characteristics to wood-based fuels [21].

The palm shell and fibre powder samples were then densified into briquettes under moderate pressure in a hydraulic press. Experiments were carried out to determine the chemical and mechanical properties of the samples. TGA was used to obtain the proximate analysis such as the degradation temperature, solvent residues and percentage of ash content. For ultimate analysis, CHNS-932 was used to get the composition in weight percentage of carbon, hydrogen, nitrogen, and sulphur gases. Bomb calorimeter experiments were also performed to obtain the calorific value of

the samples followed by experiments to determine the mechanical properties of the samples such as the impact, compressive strength etc. From those experiments, Palm Waste Briquette and Bio-briquette samples were found to have good chemical and mechanical properties.

4.2 Analysis of experimental results

4.2.1 Proximate analysis

The weight percentages of the samples content (i.e. moisture, volatile matter, fixed carbon and ash) are extracted from TGA graphs acquired from the experiments. Figure 4.1 below shows column chart with components composition for each case. Tabulated forms of the results are incorporated in Appendix B.

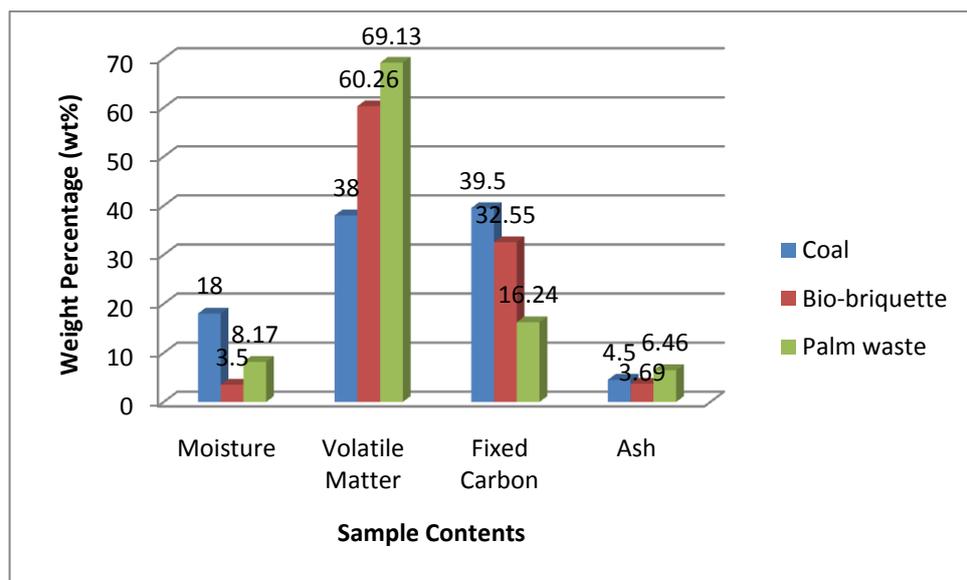


Figure 4.1: Proximate Analysis results

The result shows that fixed carbon content which is the main component of greenhouse gases CO_2 is highest in coal when compared with palm waste and bio-briquette. So initial assumption made is that burning 100% coal will produce the most CO_2 compared with the other two cases. When comparing the ash content of those three samples, it shows that palm waste has the highest percentage. According to Soraya (2008), usually ashes from combustion are sold and used, but in biomass firing, the ashes produced are in large quantity but low quality. Thus, they cannot be

sold for profit. Therefore, the percentage of biomass burned with the coal for co-firing need to be controlled to produce high quality ashes. There is also an increasing trend in the amount of volatile matter. It shows that the volatile matter is increasing with a reduction of coal percentage in the mixture.

4.2.2 Ultimate Analysis

The results obtained for ultimate analyses were converted to bar charts in Figure 4.2 for better interpretation. Tabulated forms of the results are incorporated in Appendix B.

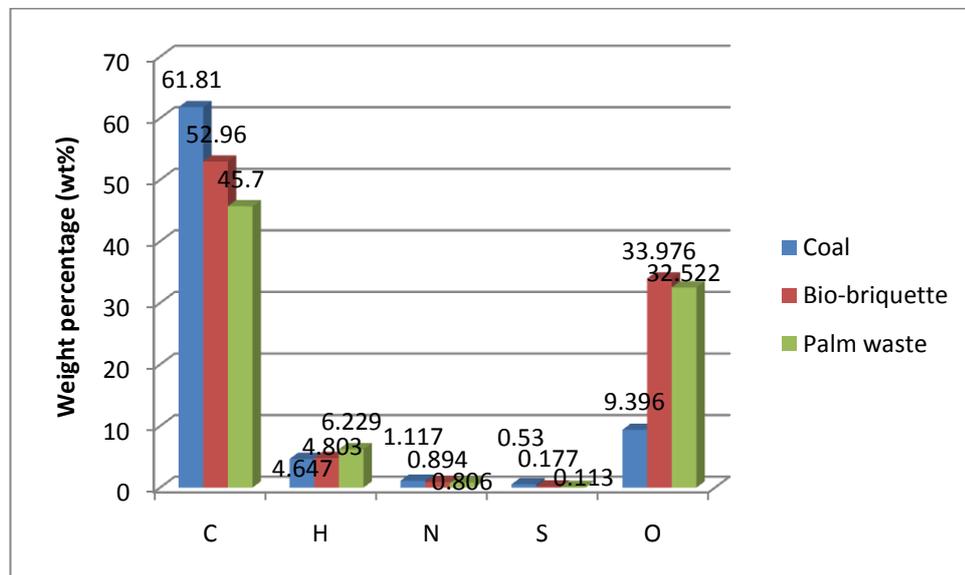


Figure 4.2: Ultimate Analysis results

Based on the results, it shows that there is downward trending of carbon, nitrogen and sulphur contents proportional to a reduction in the percentage of coal in the samples. Those three gases are the main content of GHG, so the amount of GHG produced will be reduced by increasing the percentage of coal in the fuel.

4.2.3 Calorific value analyses

The results for calorific value are analyzed using bar chart as shown in Figure 4.3 below. Tabulated form of the results can be obtained from Appendix B.

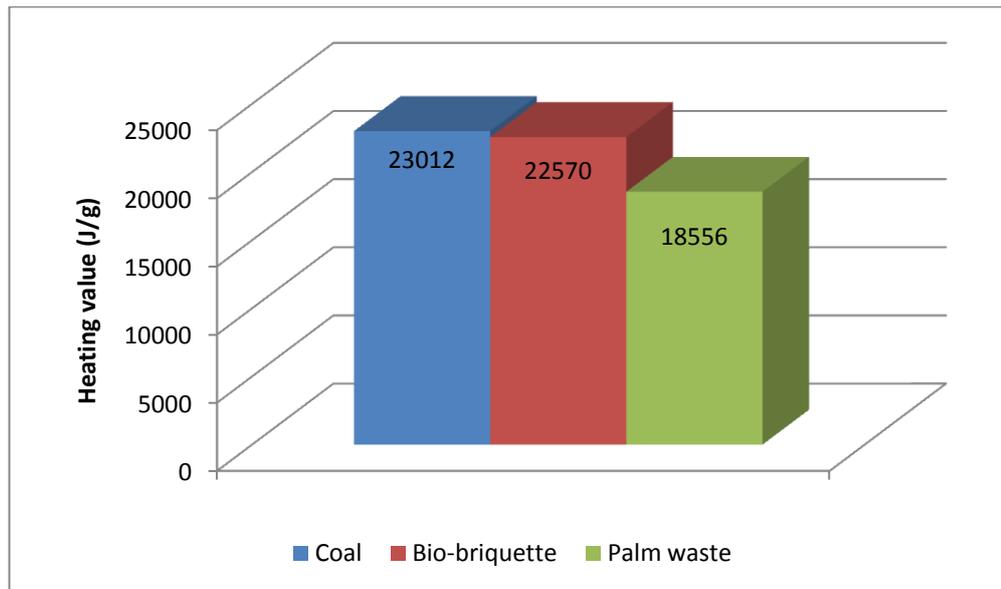


Figure 4.3: Heating Values

The values obtained from Bomb Calorimeter experiments were in calorific value (cal/g), so those values are converted into heating value (J/g) for discussion purposes. The values are converted by multiplying the calorific values with 4.184 since $1 \text{ cal/g} = 4.184 \text{ J/g}$. According to the graph, the lower percentages of coal in the mixtures make the heating values lower. This also proves that lesser amount of coal in the mixture will contribute to lower heat content, thus reducing the combustion temperature. Consequently, the steam produced will not be able to produce the required power for optimum electricity generation in power plants.

4.3 FLUENT Simulations

4.3.1 2 Dimensional (2D) Modelling of the furnace

A single burner was modelled using GAMBIT software in order to model the flame occurring. The model created was adapted from a real coal power plant in TNB Kapar, Selangor and the real dimensions of the furnace were approximately given by [22]:-

- Height: 11m
- Width: 7m
- Length: 9m

The model of the furnace was then simplified and created using a control volume of 7m by 1.45m [22]. The model of the burner is shown in Figure 4.4 below:-

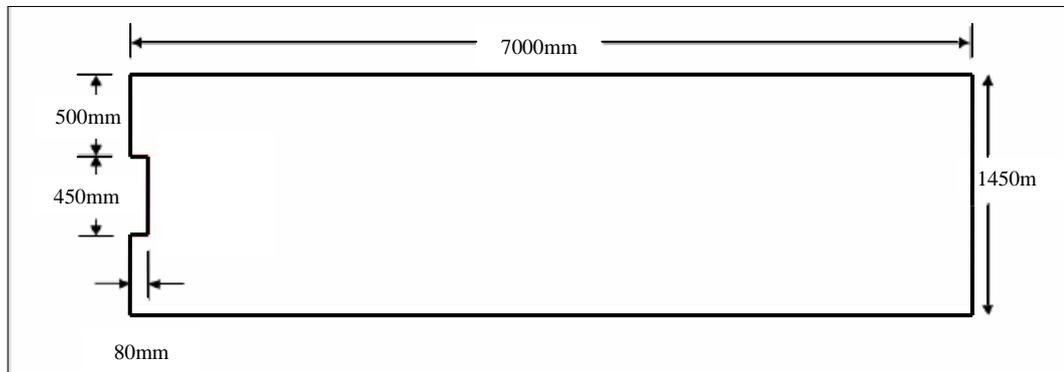


Figure 4.4: Dimension of control volume adapted for modelling [22]

After meshing 101140 faces, the mesh produced was as shown in Figure 4.5 below.



Figure 4.5: Model of the meshed burner and combustion chamber in GAMBIT 2.4.6

4.3.2 Modelling with FLUENT

Due to the limitation to the chemical database for solid fuels in FLUENT, a modified definition of the fuel mixture was made to allow the solver performing the calculations needed. The definition of fuel was made by first creating a pre-Probability Density Function (pre-PDF) file where the file consists of the concentration of fuel being fed at the burner.

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 temperature of fuel at 373K, oxidizer at 613K and the secondary air to be preheated to 500K [22].

In FLUENT, the k-epsilon equation was utilised because the mixture of fuel and air is assumed to be fully turbulent and the effects of molecular viscosity are negligible [22]. The fuel inlet was set by definition of injection, but 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 samples. The data used were tabulated in table form in Appendix B. The particles are also assumed to be in spheres shapes.

4.3.3 Results from FLUENT

4.3.3.1 Temperature profiles

The results from the contour of static temperature for those three cases are shown in the figures below:-

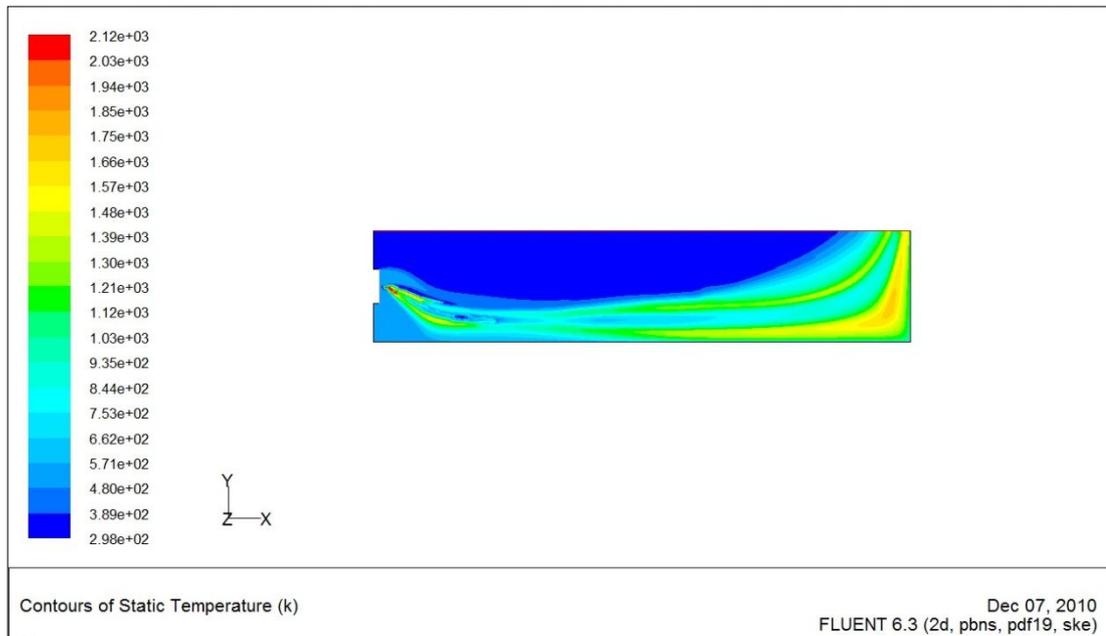


Figure 4.6: Static Temperature (Coal)

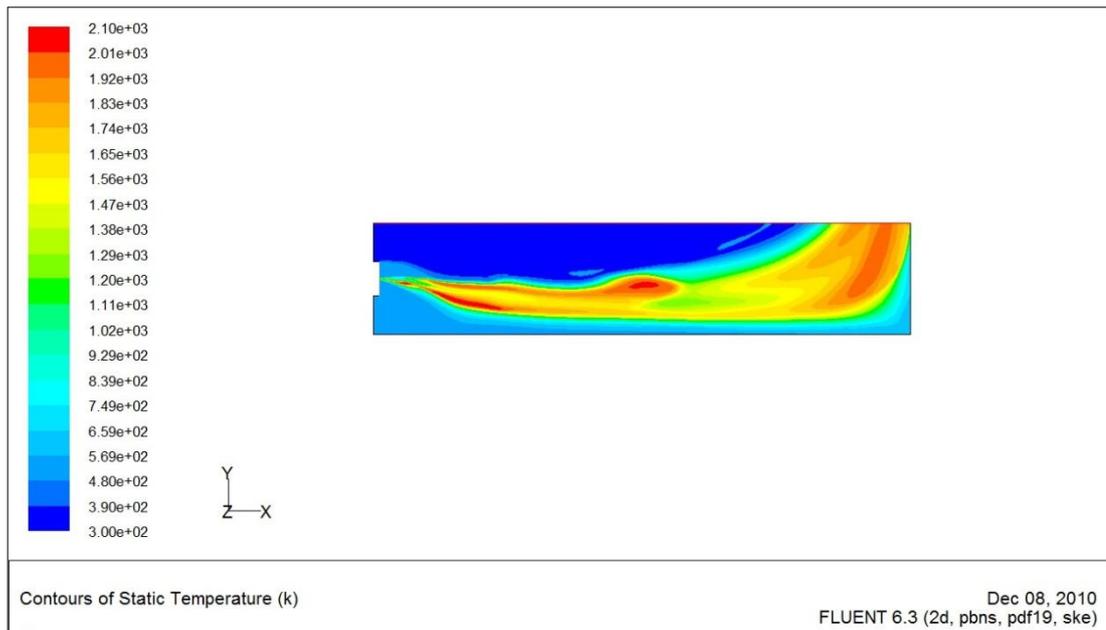


Figure 4.7: Static Temperature (Bio-briquette)

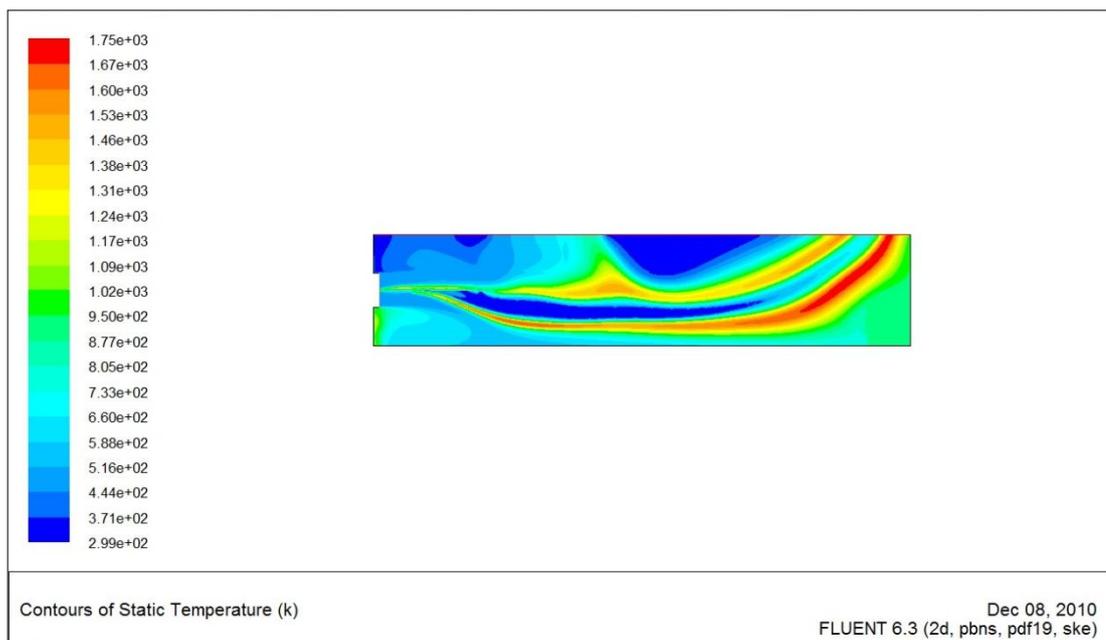


Figure 4.8: Static Temperature (Palm-waste briquette)

4.3.3.2 Discussion

According to Lee (2004), the optimum temperature in power plant's combustion chamber or furnace should be above 2000K. From the modelling the combustions obtained, it shows that 100% coal and the 50-50 mixture of coal and biomass manage to achieve the required temperature where the temperatures are 2120K and 2100K,

respectively but the highest temperature obtained by for palm waste briquette which consists of 100% biomass is 1750K, which did not achieve the optimum temperature. Basically, the temperature decreases with the increase in biomass percentages. This is due to the high moisture and volatility of biomass which reduces the flame temperature of fuel rich zone [22]. The summary of the contour plots of static temperature is shown in Figure 4.8 below, which clearly shows the downward trending:-

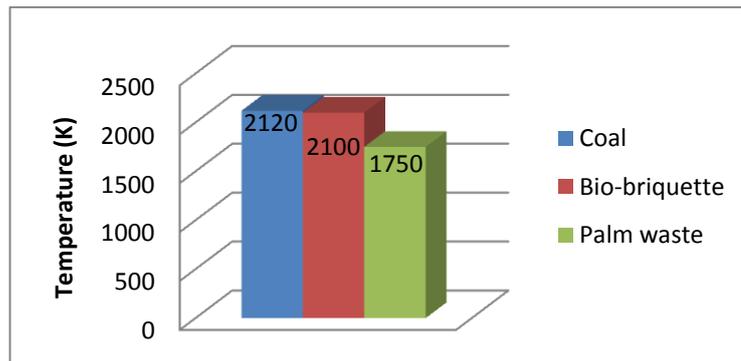


Figure 4.9: Summary of Contour Plots of Static Temperature

4.3.3.3 Carbon Dioxide Concentration

Figures below shows the modelling results for CO₂ concentration for all three cases:-

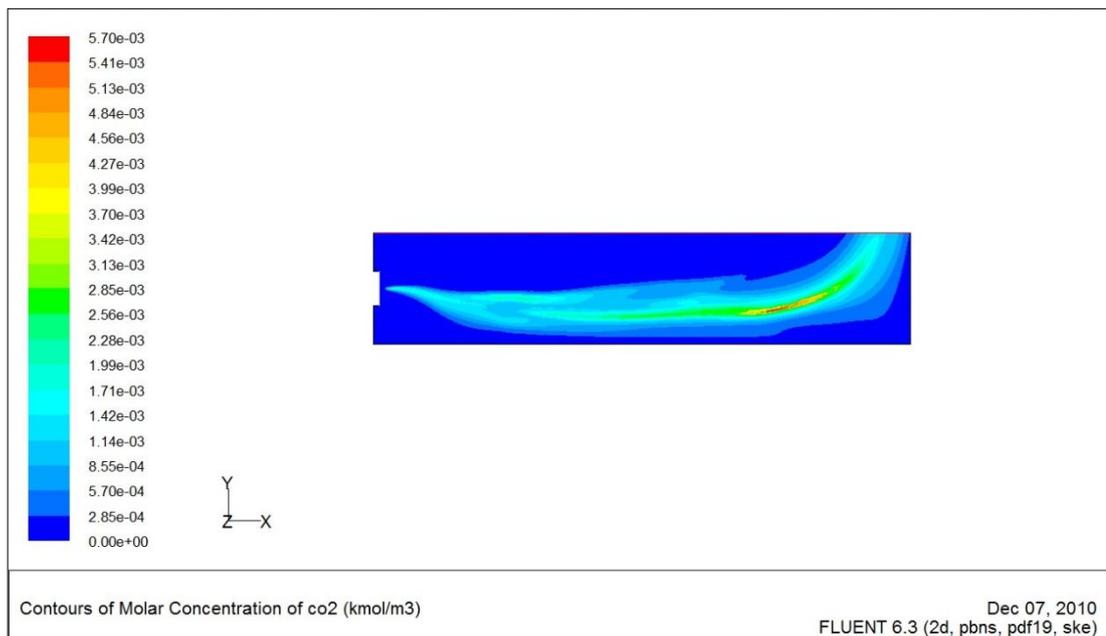


Figure 4.10: Carbon Dioxide Concentration (Coal)

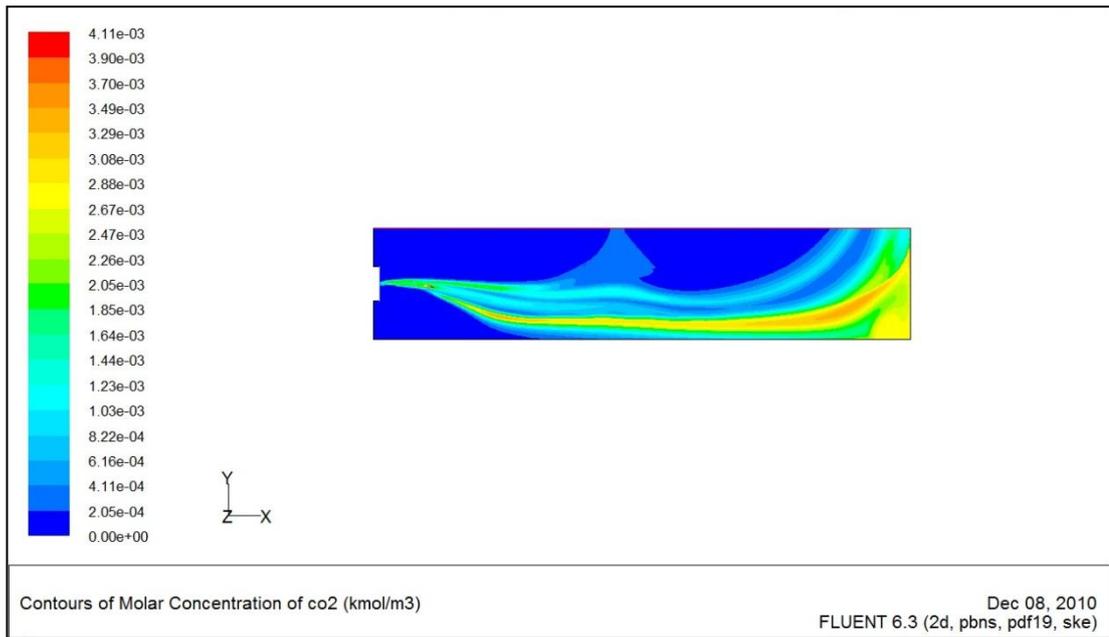


Figure 4.11: Carbon Dioxide Concentration (Bio-briquette)

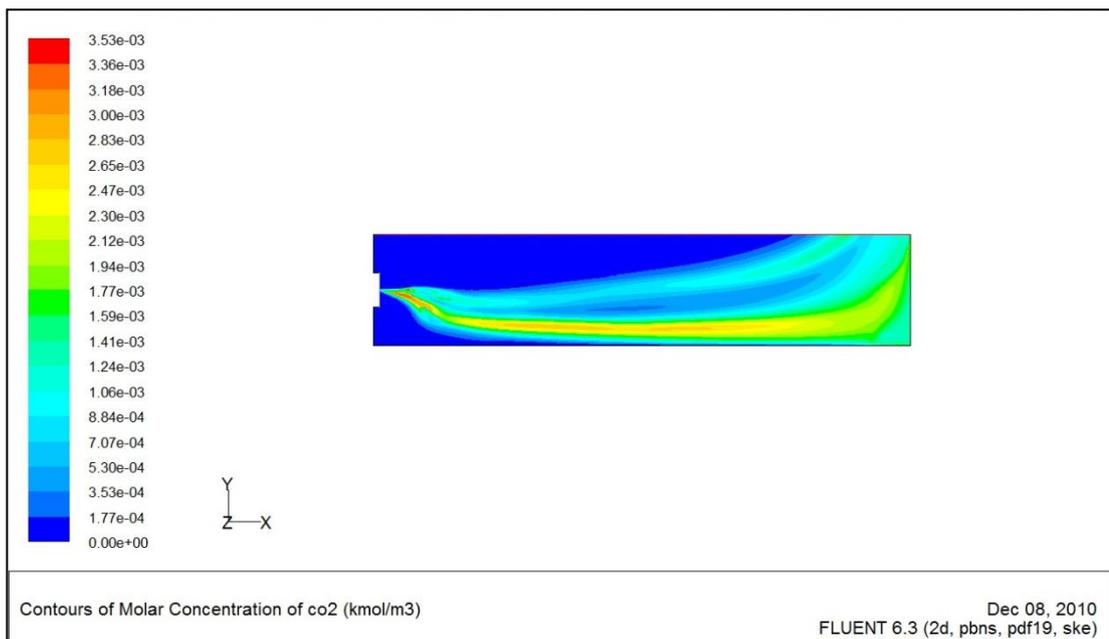


Figure 4.12: Carbon Dioxide Concentration (Palm waste briquette)

4.3.3.4 Discussion

The concentration of CO₂ produced is reduced with the reduction of coal percentages. This is because coal is a high carbon content matter compared to biomass, so the formation of CO₂ will also increase. In this case, the simulation of 100% palm waste produced the lowest amount of CO₂ concentration. This might be

the most ideal solution to solve the excessive emission of CO₂, but it is not capable of achieving optimum required temperature for power plant's furnace (above 2000K). This is why coal co-firing with biomass is introduced. The combustion of both coal and biomass such as the bio-briquettes manages to satisfy the requirements to achieve the required temperature and reduce the amount of CO₂ produced. From the simulations, coal burning shows 5.70×10^{-3} kmol/m³ molar concentration of CO₂, while bio-briquette and palm waste burning give 4.11×10^{-3} and 3.53×10^{-3} kmol/m³, respectively. Figure 4.12 summarizes the CO₂ concentration results for blending from 100% coal to 100% biomass and clearly shows the downward trending:-

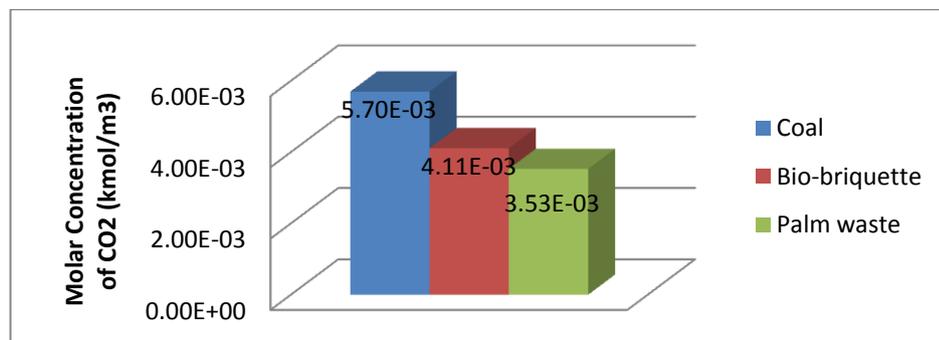


Figure 4.13: Summary of Carbon Dioxide Concentration results

4.3.3.5 Nitrogen Concentration

Figures below show the simulation results for Nitrogen concentration.

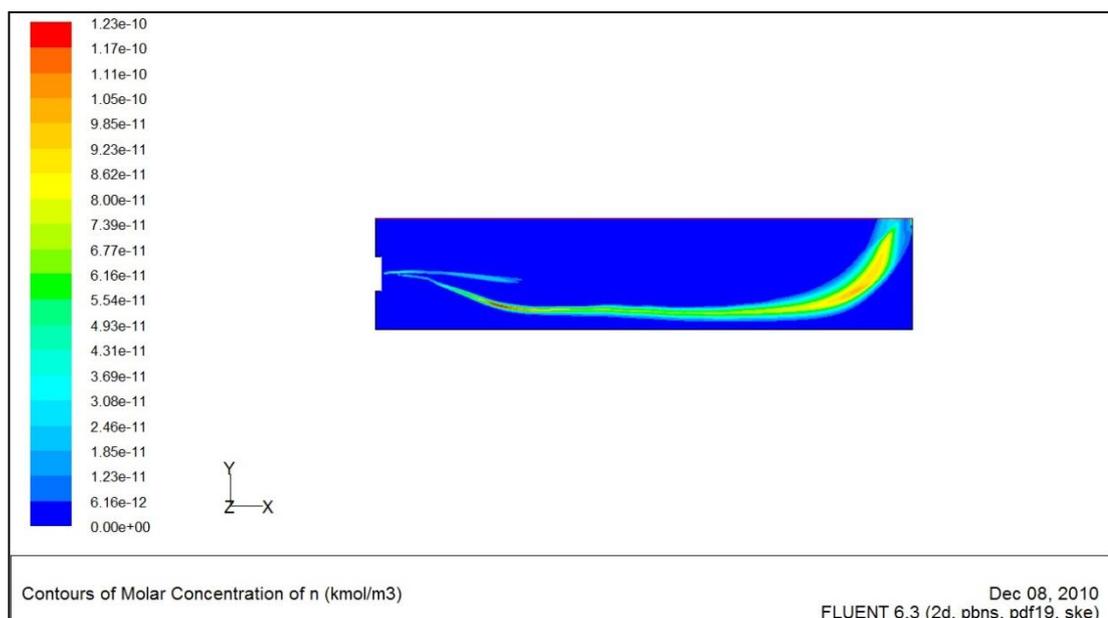


Figure 4.14: Nitrogen Concentration (Coal)

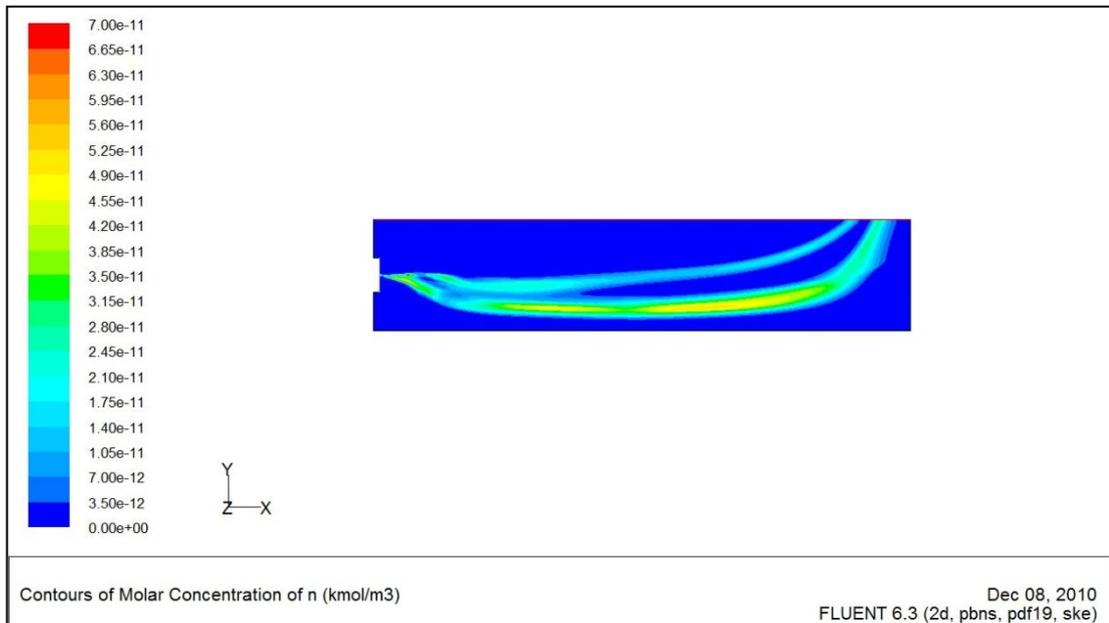


Figure 4.15: Nitrogen Concentration (Bio-briquette)

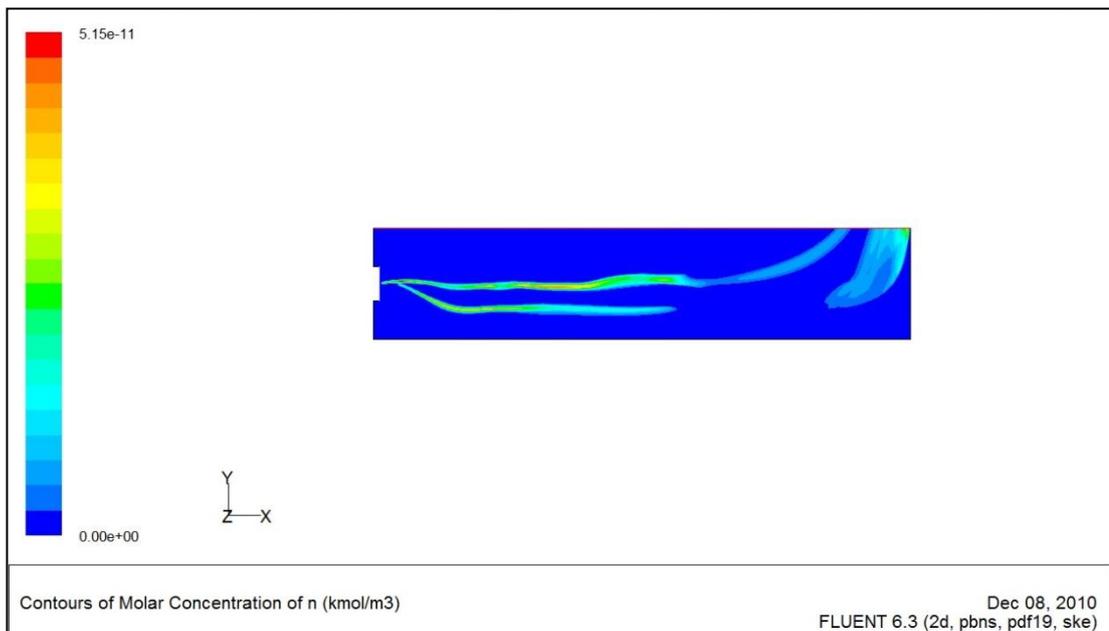


Figure 4.16: Nitrogen Concentration (Palm waste briquette)

4.3.3.6 Discussion

Nitrogen concentration also shows downward trending with increasing biomass percentages and reduction in coal percentages. The reduction in the concentration of nitrogen will basically reduce the amount NO_x produces since there will be lesser

amount of nitrogen atoms which is able to react with oxygen to form NO_x in spite of forming due to high combustion temperature [22]. From the simulations, coal burning shows 1.23×10^{-10} kmol/m³ molar concentration of N, while bio-briquette and palm waste burning give 7.00×10^{-11} and 5.15×10^{-11} kmol/m³, respectively. Figure 4.16 below summarizes the Nitrogen concentration results from simulation for the 3 types of samples used:-

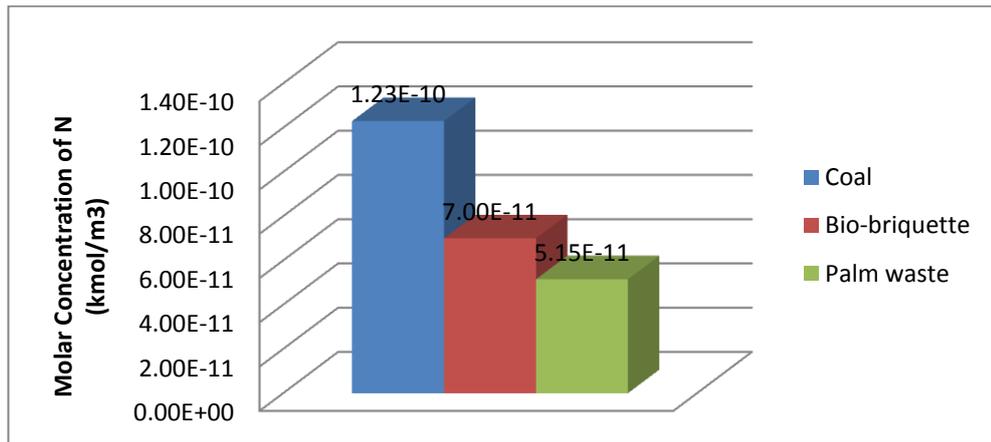


Figure 4.17: Summary of Nitrogen Concentration results

4.4 Gas Analyzer Results

4.4.1 Results

In order to verify and prove the reliability of the results obtained from the simulations, those results are compared with the results acquired from experiments using bomb calorimeter and gas analyzer. The graph in Figure 4.17 below shows the results of gas analyses and the tabulated data are incorporated in Appendix C.

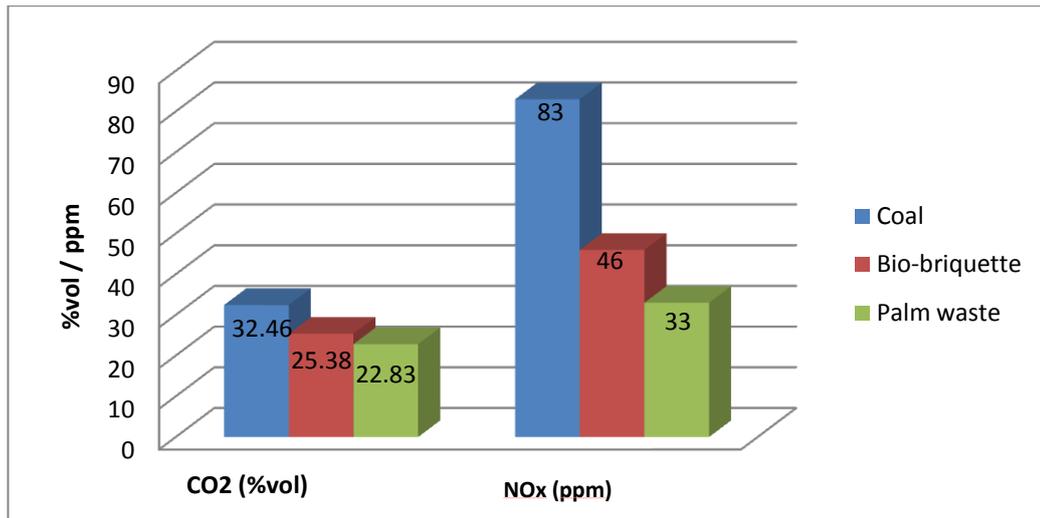


Figure 4.18: Gas Analyzer results

4.4.2 Discussion

Based on Figure 4.17, it shows that percentage volume of CO₂ and NO_x concentration decrease with the reduction of coal percentages. This is basically due to less carbon and nitrogen elements in palm fibre and shell used as biomass. This data also verify the reduction of CO₂ and Nitrogen concentration shown in the simulations. From gas analyzer experiments, coal burning shows 32.46% vol and 83ppm NO_x, bio-briquette burning shows 25.38% vol and 46ppm NO_x, while palm waste briquette burning gives 22.83% vol and 33ppm NO_x. From the simulations, the reduction of CO₂ from bio-briquette to palm waste briquette is 8.38% while the gas analysis shows a reduction of 11.17%. For NO_x, the reduction shows in the simulation from bio-briquette to palm waste briquette is 26.43 % and gas analyzer gives a reduction of 28.26%. The calculations are available in Appendix C. For more accurate results, the emissions of both gases need to be examined more thoroughly with higher precision of gas analyzer settings.

The comparison for Nitrogen content is actually more complicated than CO₂ content due to various factors affecting the NO_x emission. NO_x refers to all oxides of nitrogen. According to Lee (2004), the formation of NO_x relies solely on the temperatures and the availability of unused oxygen. There are three types of formation of NO_x which are:-

- i) Thermal NO_x: formed by the reaction of atmospheric nitrogen and oxygen at high temperatures
- ii) Fuel NO_x: oxidation of fuel bond nitrogen
- iii) Prompt NO_x: formed by reaction of hydrocarbon fragments with atmospheric oxygen

Due to some reasons, the results from simulation and experimentation are slightly different. This is basically because:-

- i) Simulations were done in perfect condition where they were not influenced by any external factors, whereby experiment considers all the external factors such as the ambient temperature, wind, flame and moisture
- ii) The software will simulate based on the input given and so the results would depend a lot on factors such as human errors.
- iii) The results are also highly dependent on the accuracy and precision of the equipments used, for example the gas analyzer.

As for time being, the results obtained are enough to prove that FLUENT simulation is reliable to predict the temperature profile, CO₂ and NO_x emissions concentration.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As for conclusion, the author manages to complete the project and at the same time successfully acquires the objectives stated in the early stages of the project:-

- i) It is proven that palm shell and fibre are feasible to be used as fuel for boiler in power plant given that it is co-fired with coal in order to achieve the optimum temperature and at the same time reduces GHG emissions
- ii) The modelling and simulations show that coal and bio-briquette burning achieves the required combustion temperature, and bio-briquette reduces the CO₂ and NO_x emissions concentrations. While palm-waste briquette burning unable to achieve the required temperature but reduces the amount of CO₂ and NO_x emissions concentrations significantly.
- iii) Based on the comparison on the percentage of reduction between results from simulations with gas analyzer results, the best candidate to be used as boiler fuel is bio-briquette. Although it reduces the temperature in combustion chamber, it is still in an acceptable range considering its contribution in reducing the CO₂ and NO_x emissions concentrations.

5.2 Recommendations

For future studies, it is recommended to consider the effects of different particle sizes and shapes other than spherical shape assumed in this project, to the chemical, mechanical properties, calorific values and also to the temperature profile and carbon dioxide and nitrogen concentrations. Besides, further studies could also consider increasing the range of ratio used for the samples, thus a better solution and justification can also be made. Finally, it is also recommended to research the feasibility of other types of biomass that can be utilized as supplement medium in coal co-firing power plants.

CHAPTER 6

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CHAPTER 7

APPENDICES

Appendix A: Steps to Operate Gas Analyzer [23]

1. Plug the PowerLab (a data acquisition system that records the information picked up by the gas analyzer) into the computer. Plug the gas analyzer into the PowerLab by plugging the BNC chords and the I2C chord into the appropriate outlets.
2. Check the exhaust ports of the gas analyzer to make sure they are clear of any obstruction and turn on the analyzer. Lights should come on to indicate that it is on. To make sure the internal pump is functioning properly, flick the pump on switch so its indicator is on and the pump is heard. Allow the gas analyzer to warm up for 10 minutes.
3. Turn on the PowerLab and open the Lab Chart. The status indicator on the gas analyzer will glow green.
4. Select CO₂ or O₂ from the proper channel pop-up menu to preview the gas analyzer's signal. The CO₂ or O₂ dialog box will appear.
5. Record data in absolute or difference mode. Difference mode will record changes in gas concentration from ambient levels.
6. Click "Units" to open the Units Conversion dialog box. Enter different values depending on how you calibrated your gas analyzer. If you did not calibrate it, put in the default units.
7. Record the gas concentration by setting the pump to breathe across rather than directly into the sampling tube. Record your findings in the Lab Chart.



Figure 7.1: Gas Analyzer unit

Appendix B: Results for Proximate, Ultimate Analysis and Calorific Value [15]

Table 7.1: Proximate Analysis (wt%)

	Moisture	Volatile Matter	Fixed Carbon	Ash
Coal	18	38	39.5	4.5
Bio-briquette	3.5	60.26	32.55	3.69
Palm waste	8.17	69.13	16.24	6.46

Table 7.2: Ultimate Analysis (wt%)

	C	H	N	S	O
Coal	61.81	4.647	1.117	0.53	9.396
Bio-briquette	52.96	4.803	0.894	0.177	33.976
Palm waste	45.7	6.229	0.806	0.113	32.522

Table 7.3: Calorific Value (cal/g)

Material	1	2	3	4	Average
Coal	5500	5500	5500	5500	5500
Bio-Briquette	5305.6	5398.7	5395.2	5442.8	5429.5
Palm Waste Briquette	4434.96	4434.96	4434.96	4434.96	4434.96

APPENDIX C: Constants used for modelling

Table 7.4: Constants used for modelling

	Coal	Bio-briquette	Palm waste
Thermal Conductivity	0.0454		
Density	1300 kg/m ³		
Specific Heat	1000		
Volatile Component	38	60.26	69.13
Binary Diffusivity	5 X 10 ⁻⁴		
Particle Emissivity	0.9		
Scattering Factor	0.6		
Swelling Coefficient	2		
Burnout Ratio	2.67		
Combustible Fraction	39.5	32.55	16.24

APPENDIX D: Gas Analyzer Results

Table 7.5: Gas analyzer results

	Coal	Bio-briquette	Palm waste
CO ₂ (%vol)	32.46	25.38	22.83
NO _x (ppm)	83	46	33

Gas Analyzer Calculations for Percentage Reduction in Emissions

1. Percentage reduction for CO₂ (%) =

$$\frac{\text{Bio - briquette content} - \text{Palm waste briquette content}}{\text{Palm waste briquette content}} \times 100\%$$

Simulations:

$$\frac{[(4.11 \times 10^{-3}) - (3.53 \times 10^{-3})] \text{ kmol/m}^3}{(3.53 \times 10^{-3}) \text{ kmol/m}^3} \times 100\% = 16.4\%$$

Gas Analysis:

$$\frac{[(25.38) - (22.83)] \% \text{vol}}{22.83 \% \text{vol}} \times 100\% = 11.17\%$$

2. Percentage reduction for NO_x (wt%):

$$\frac{\text{Bio - briquette content} - \text{Palm waste briquette content}}{\text{Bio - briquette content}} \times 100\%$$

Simulations:

$$\frac{[(7 \times 10^{-11}) - (5.15 \times 10^{-11})] \text{ kmol/m}^3}{(7 \times 10^{-11}) \text{ kmol/m}^3} \times 100\% = 26.43\%$$

Gas Analysis:

$$\frac{[(46) - (33)] \text{ ppm}}{46 \text{ ppm}} \times 100\% = 28.26\%$$