

**MODEL MATEMATIK UNTUK MENINGKATKAN
ARANG BATU YANG
BERGRED RENDAH**

*(MATHEMATICAL MODELING FOR UPGRADING
LOW RANK COAL TO
HIGH RANK COAL)*

Oleh
CHAN CHUN SENG
65394

Penyelia
PROF.MADYA DR. JALAL ABDULLAH AZIZ

Mac 2005

Disertasi ini dikemukakan kepada
Universiti Sains Malaysia
Sebagai memenuhi sebahagian daripada syarat untuk pengijazahan dengan kepujian
SARJANA MUDA KEJURUTERAAN MEKANIK



Pusat Pengajian Kejuruteraan Mekanik
Kampus Kejuruteraan
Universiti Sains Malaysia

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed..... (candidate)

Date

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

Signed..... (candidate)

Date

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and for interlibrary loan, and for the title and summary to be made available to outside organizations.

Signed.....(candidate)

Date

ACKNOWLEDGEMENT

First of all I would like to express gratitude to my supervisor, Associate Professor Dr. Jalal Abdullah Aziz, for the encouragement and passion. He guided us the right procedure to do the research, and the way to transfer the information to others from the knowledge we obtain. He was always being there whenever I needed him. He will continuously explain the thing until we understand. I also can learn the excellent attitude from him beside the knowledge and the information. For example his proper planning, hardworking and kindly are the fundamental attitude as an engineer.

I would like to express my appreciation to Mr. Phang Chee Hong, master student of school of Chemical Engineering for his guidance and advice. He was explained to me the process to run the pilot plant and the each function of the parts in the pilot kiln. According to the information which is provided from him will make my project more successful.

My special thanks to my course mates which are helping me, there are Hu Chee Yee, Tan Kean Hu, Ling Kee Leong and Hua shijie, Norman. They would assist me while using the software Ansys to do the simulation. Besides that, they also spend their time to have a discussion session about my project.

Lastly and the most important I wish to thank my parents and family for their continuous support and care during pursuing the goal of completing this thesis.

TABLE OF CONTENTS

	Page
Acknowledgement	i
Table of Contents	ii
List of Tables	v
List of Figures	vi
Nomenclature	ix
Abstrak	x
Abstract	xi
CHAPTER ONE	
INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	2
1.2 Objective	3
1.3 Scope	3
CHAPTER TWO	
LITERATURE REVIEW	4
2.1 Coal	4
2.1.1 Coal Creation	5
2.1.2 Component of Coal	6
2.1.3 Concept of Coal Rank	7
2.1.4 Coal Resources in Malaysia	8
2.1.5 Coal Consumptions in Malaysia	9
2.1.6 Coal Reserves in United State	10
2.1.7 Coal Consumptions in United State	10
2.2 Carbonization of Coal	11
2.3 Various Conditions in the Process Coal Carbonization	11

	2.3.1	Various Temperatures	11
	2.3.2	Various Coal Size	12
CHAPTER THREE	METHODOLOGY		
	3.0	Experimental Equipment and Design Specification of the Pilot Plant	18
	3.1	Air Intake System	19
	3.1.1	Three-Phase Motor and Air Blower	20
	3.1.2	Orifice Meter	21
	3.1.3	Inclined/ Vertical Manometer	22
	3.2	Pilot Kiln	22
	3.2.1	Air Distributor and Ash Collector Chamber	24
	3.2.2	Combustion Chamber	25
	3.2.3	Economizer Chamber	25
	3.2.4	Carbonization Chamber	25
CHAPTER FOUR	EXPERIMENTAL		27
	4.1	Raw Material	27
	4.2	Theory	27
	4.3	Experimental Procedure	28
	4.4	Analysis of the Product	30
	4.4.1	Proximate Analysis	30
	4.4.2	Gross Calorific Value	31
CHAPTER FIVE	MATHEMATICAL MODELING		33
	5.1	Mathematical Model	33
	5.1.1	Boundary Condition	35
	5.2	Boundary Condition at the Center of the Packed Coal Bed	35
	5.3	Endothermic Heat per Unit Volume of Coal	38

CHAPTER SIX	RESULTS AND DISCUSSION	39
	6.1 The Effect of Final Carbonization Temperature on the Properties of the Product	40
	6.1.1 Fixed Carbon	40
	6.1.2 Volatile Matter	40
	6.1.3 Moisture Content	41
	6.1.4 Ash	42
	6.1.5 Gross Calorific Value	43
	6.2 Sample Calculation	44
	6.3 Simulate the Packed Coal Bed using Ansys	50
	6.3.1 Result of Simulation	51
CHAPTER SEVEN	CONCLUSION	59
	7.1 Recommendation	60
REFERENCES		
APPENDICES		

LIST OF TABLES

	Page
Table 2.1 From Diessel (1992) indicates the difference in rank parameter with increase in rank.	7
Table 2.2 Known coal in Malaysia	8
Table 2.3 Analysis of 3mm lignites sample on a dry basis	14
Table 6.1 Experimental and calculate temperature distribution at different final average carbonization temperature	46
Table 6.2 Experimental and simulate temperature distribution at different final average carbonization temperature	55

LIST OF FIGURES

		Page
Figure 2.1	Coal formation	6
Figure 2.2	Coal fields in Malaysia	8
Figure 3.1	Overall view of the pilot plant for coal carbonization process	18
Figure 3.2	Schematic diagram of the pilot plant	19
Figure 3.3	Schematic diagram of the air intake system	20
Figure 3.4	Three-phase motor and air blower	20
Figure 3.5	Flow of contraction at the cross section	21
Figure 3.6	Schematic diagram of an inclined/ vertical glass manometer	22
Figure 3.7	Schematic diagram of the Pilot Kiln	23
Figure 3.8	Front view of the Pilot Kiln	24
Figure 4.1	Baligian lignite coal	27
Figure 4.2	Semi-coke product	29
Figure 4.3	Liquid chemical by product.	30
Figure 5.1	Temperature distribution from the gas phase into the surface towards the center of the cylinder packed coal bed	35

Figure 6.1	Percentage of the fixed carbon versus carbonization temperature	40
Figure 6.2	Percentage of the volatile matter versus carbonization temperature	41
Figure 6.3	Percentage of the Moisture content versus carbonization temperature	42
Figure 6.4	Percentage of the Ash versus carbonization temperature	42
Figure 6.5	Percentage of the Gross Calorific value versus carbonization temperature	43
Figure 6.6	Comparison between calculated temperature and experimental temperature at 400°C average final carbonization temperature	47
Figure 6.7	Comparison between calculated temperature and experimental temperature at 500°C average final carbonization temperature	47
Figure 6.8	Comparison between calculated temperature and experimental temperature at 600°C average final carbonization temperature	48
Figure 6.9	Comparison between calculated temperature and experimental temperature at 700°C average final carbonization temperature	48
Figure 6.10	Temperature Distribution in the Packed Coal Bed at 400°C	51
Figure 6.11	Graph Temperature Distribution in the Packed Coal Bed at 400°C	51
Figure 6.12	Temperature Distribution in the Packed Coal Bed at 500°C	52
Figure 6.13	Graph Temperature Distribution in the Packed Coal Bed at 500°C	52
Figure 6.14	Temperature Distribution in the Packed Coal Bed at 600°C	53

Figure 6.15	Graph Temperature Distribution in the Packed Coal Bed at 500°C	53
Figure 6.16	Temperature Distribution in the Packed Coal Bed at 700°C	54
Figure 6.17	Graph Temperature Distribution in the Packed Coal Bed at 700°C	54
Figure 6.18	Comparison between simulated temperature and experimental temperature at 400°C average final carbonization temperature	56
Figure 6.19	Comparison between simulated temperature and experimental temperature at 500°C average final carbonization temperature	56
Figure 6.20	Comparison between simulated temperature and experimental temperature at 600°C average final carbonization temperature	57
Figure 6.21	Comparison between simulated temperature and experimental temperature at 700°C average final carbonization temperature	57

NOMECLATURE

Symbol	Description	Unit
A	Surface area	m ²
C _p	Specific heat	kJ/kg. °C
d	Diameter	m
h	Convection heat transfer coefficient	W/m ² .K
k	Thermal conductivity	W/m ² .K
Nu	Nusselt number	
Pr	Prandtl number	
\dot{q}_{end}	Heat absorbed per unit volume for Endothermic reaction	W/m ³
r	Distance	m
R	Radius	m
Re	Reynolds number	
T	Temperature	°C
v	Velocity	ms ⁻¹
ρ	Density	kg/m ³
μ	Viscosity	kg/m.s
\emptyset	Angular point to the azimuth direction	rad

ABSTRAK

Sebuah loji pandu mesra alam telah direka dan difabrikasi untuk mengkarbonkan arang batu bergred rendah kepada arang batu yang bergred tinggi. Hasil produk adalah arang batu atau semi-kok yang bergred tinggi dan tidak menghasilkan asap. Di samping itu, ia mengandungi karbon tetap yang tinggi, kandungan wap yang rendah dan mempunyai nilai kalori yang tinggi. Tujuan kita menggalakkan loji pandu ini disebabkan permintaan terhadap arang batu semakin bertambah. Maka kita harus mengkarbonkan arang batu yang bergred rendah yang terdapat di Malaysia, supaya kita dapat menjimatkan kos pemprosesan dan mengurangkan import dari Negara asing. Satu persamaan telah diterbitkan untuk mengganggu penyebaran suhu dalam kebuk pengkarbonan. Didapati lengkung taburan suhu yang cengkung berada di bahagian tengah kebuk. Ini menunjukkan bahawa tindak balas endothermic berlaku semas proses pengkarbonan (pirolisis) arang batu. Di samping itu, satu perisian Ansys telah digunakan untuk membuat analisis terhadap arang batu di kebuk pengkarbonan. Tidak dapat dinafikan bahawa dengan menggunakan perisian untuk membuat simulasi juga terdapat sisihan daripada nilai sebenar yang terdapat pada eksperimen. Berdasarkan keputusan-keputusan yang diperolehi, produk yang berkualiti tinggi ini dan loji pandu mesra alam in boleh dikomersialkan.

ABSTRACT

A plant was designed and fabricated to carbonize the low rank coal to high rank coal that is environmental friendly pilot plant. The outcome of the semi-coke or high rank coal which are smokeless fuel, high carbon content, low moisture content and high calorific value. The reason to construct this plant is because the trend has shown that demand of the high rank coal will be increased. In order to save the cost of the production cost, the raw material should be decrease. Therefore we must use the existing low rank coal in the Malaysia rather than depend on the imported high rank coal. Due to the low rank coal can not be used as a fuel for domestic and industrial purpose; therefore we have to find the way to change the quality of the coal in the Malaysia. Mathematical model equation had been constructed to estimate the temperature distribution inside the carbonization chamber. The temperature distribution curve show concave curves at the center. This indicates that the carbonization (pyrolysis) of the coal was an endothermic reaction. Besides that, the simulation with assist with the software Ansys to the cylindrical packed coal bed also have been done. Undeniable the result get from the simulation also have a small deviation compare to the experiment. The result is confirmed that the reliabilities of the product qualities and environmental friendly pilot plant are suitable for commercialization.

CHAPTER ONE

INTRODUCTION

1.1 Background

In recent times, with the growing problems of energy supply, attention is turned to low rank coals existing in Malaysia. These fuels have often tended in the past to be ignored, although some countries there is a substantial experience in these fields, especially where there are strong strategic energy or supply reasons. It seems likely that trends towards the use of low rank coals will be greatly intensified in the future, not only to increase the total bulk energy supply but also allow the higher grade coals increasingly to be used in more valuable ways, such as gasification and liquefaction [L. Grainger et al, 1981].

Low rank coals, such as lignite and sub-bituminous coals are typically softer, friable materials with a dull, earthy appearance; they are characterized by high moisture content levels and a low carbon and low energy content. Higher rank coals are typically harder and stronger and often have a black vitreous luster. Increasing rank is accompanied by a rise in the carbon and energy contents and a decrease in the moisture content of the coal. Anthracite is at the top of the rank scale and has a correspondingly higher carbon and energy content and a lower level of moisture.

Utilization of low rank coal is indispensable to qualify the future demand of energy due to the demand for the coals is increased. However, it has several disadvantages; therefore we should develop a new technology for using it effectively.

Around the world, low rank coal power stations have made an important contribution to electricity supply, generally with acceptable environmental impacts. The coal industry's most troublesome problem today is removing organic sulfur, a substance that is chemically bound to coal. All fossil fuels, such as coal, petroleum,

and natural gas, contain sulfur. When these fuels are burned, the organic sulfur is released into the air where it combines with oxygen to form sulfur dioxide. Sulfur dioxide is an invisible gas that has been shown to have adverse-effects on the quality of air we breathe. It also contributes to acid rain; an environmental problem that many scientists think adversely affects wildlife (especially fish) and forests [Isa.colorado.edu/summarystreet/texts/coal.htm].

The coal industry is also concerned about the carbon dioxide that is produced when coal is burned. Carbon from burning coal reacts with air to form carbon dioxide. When carbon dioxide accumulates in the earth's atmosphere, they form a shield that allows the sun's light and heat in, but doesn't let it out. This condition is called the greenhouse effect. It will increase the temperature in the earth and change the climate in the world. Both of these concerns can be attributed primarily to the high moisture content of such coals, resulting in larger and more expensive boiler plant and lower conversion efficiency.

Therefore, we have to discover the ways to reduce the cost of electricity and increasing the conversion efficiency of generation from brown coal. Several technologies were investigated including steam fluidized bed drying combined with integrated gasification combined cycle, and hydro thermal dewatering combined with direct coal-fired turbine [Chris M. Anderson et al, 1995]. From these investigations an innovative process called integrated drying and gasification combined- cycle (IDGCC) was developed.

1.2 Problem Statement

Difficulty to get the exact average final carbonization temperature and hard to control the heat supplied from the combustion chamber to the carbonization chamber. Could not find out the value of the emissivity and Stefan-Boltzmann constant for the low rank coal, therefore we have to neglect the radiation heat transfer mode. It is also impractical to get the value for the contact resistance between the coal particles.

1.3 Objective

To reduce the imported high rank coal from others country, we oblige to find the best way to upgrade the low rank coal in Malaysia. Besides that we need to consider the costing for upgrading the low rank coal which existing in Malaysia.

Low rank coal (LRC) upgrading technologies being developed include evaporative and non-evaporative drying and mild pyrolysis/gasification. An obstacle facing their development is the stability of the product with regard to dusting, moisture reabsorption, and spontaneous combustion [Chris M. Anderson et al, 1995].

Consequently the objective of this project is to convert low rank coal to high rank coal which can be used as cheap as possible, high calorific value and environment friendly fuel. The plant is environmental friendly pilot plant process for upgrading low rank coal to high rank coal as an alternative useful fuel in Malaysia. This pilot plant was developed at chemical engineering school in USM. The pilot plant distributed to 3 parts that is pilot kiln, pilot pollution prevention chamber, gravity settler tank and outlet piping.

Mathematical modeling equation has been generated to calculate the temperature distribution inside the carbonization chamber which is at the top of the pilot kiln. This is to ensure which temperature of the operation having the good quality of the semi-coke. Besides that, also have to know the temperature distribution inside the carbonization chamber, to ensure the low rank coal inside the carbonization chamber was finished upgrading uniformly. Furthermore the software Ansys also been using to do the simulation the coal packed bed in the carbonization.

1.4 Scope

The air flow rate at the pilot kiln is limited to the 10m³/hr, because the air flow rate at this situation will be more efficient. This project is only considered the effect to the brown coal at the different average final carbonization temperature in the carbonization chamber.

CHAPTER TWO

LITERATURE REVIEW

2.1 Coal

Coal is a general term referring to a family of solid fossil fuels with a wide range of physical and chemical compositions. Coal is formed from large accumulations of plant material that have been preserved from complete decay and later altered by chemical and physical conditions in the accumulation. With time the plant debris was covered with sediments and undergone various changes of temperature and pressure which produces a sequence of coals beginning with peat and terminating with anthracite. Coal is classified into four types according to the degree of metamorphism: anthracite, bituminous, sub-bituminous and lignite.

Coal is readily combustible rock containing more than 50 percent by weight of carbonaceous material, formed from compaction and indurations of variously altered plant remains similar to those in peat. Most coal is fossil peat. Peat is an unconsolidated deposit of plant remains from a water-saturated environment such as bog or mire; structures of the vegetal matter can be seen and when dried, peat burns freely.

Coal is actually a heterogeneous rock composed of different kinds of organic matter which vary in their proportions in different coals, and no two coals are absolutely identical in nature, composition or origin [Dr. Kamar Shah Ariffin et al, 2003]. The rank of a coal refers to the degree of coalification endured by the organic matter. It is estimated by measuring the moisture content, carbon content, and specific energy, reflectance of vitrinite or volatile matter.

2.1.1 Coal Creation

Between 200 and 300 million years ago, long before there were any reptiles, birds or mammals, in many parts of the world there existed warm and human climatic conditions. These conditions favored the growth of huge tropical ferns and giant trees, which grew and died in vast swamp areas.

The dead plants fell into the boggy waters, which tended to exclude oxygen and bacteria, so that they only partially decomposed to produce a peat-like material. This fossilized plant debris was the beginning of coal, but only the beginning. Vegetation continued to grow for many generations and centuries, forming vast, thick peat beds which were later to turn into coal.

After a time the areas of swamp gradually became submerged by shallow seas, where they were covered by sediment. These sediments would later become sedimentary rock. This cycle of swamp followed by submersion was often repeated a number of times, so that a sequence of horizontal bands of peat and inorganic, sedimentary rock was built up. This formed the first stage, called the biochemical stage. Coal formation occurred in other geologic periods as well. . Subsequently, the bands of peat were altered by the action of pressure and temperature during the second, or geochemical stage, to form the various kinds of coal found today.

As much as a 20-fold reduction in the thickness of the original plant deposits sometimes occurred. During the course of time these horizontal coal seams were further altered as they became folded, tilted and eroded. Much of this action was due to the motion of the continents, as mountains formed and were then worn away. The study of fossils is called paleontology. The creation of coal from fossils is part of geology.

Coal is formed by the physical and chemical alteration of peat (coalification) by processes involving bacterial decay, compaction, heat, and time. Coal is an agglomeration of many different complex hydrocarbon compounds, some of which owe their origin to the original constituents in the peat. Peat deposits are actually quite

varied and contain everything from pristine plant parts (roots, bark, spores, etc.) to decayed plants, decay products, and even to charcoal if the peat caught fire. Peat deposits typically form in a waterlogged environment where plant debris is accumulated; peat bogs and peat swamps are examples. In such an environment, the accumulation of plant debris exceeds the rate of bacterial decay of the debris. The bacterial decay rate is reduced because the available oxygen in organic-rich water is completely used up by the decay process. Anaerobic (without oxygen) decay is much slower than aerobic decay. In order for the peat to become coal, it must be buried by sediment. Burial causes compaction of the peat and, consequently, much water is squeezed out during the first stages of burial. Continued burial and the addition of heat and time, cause the complex hydrocarbon compounds in the deposit to start to break down and alter in a variety of ways. The gaseous alteration products (methane is one) are typically expelled from the deposit and the deposit becomes more and more carbon-rich (the other elements drop out). The stages of this trend proceed from plant debris, peat, lignite, sub-bituminous coal, bituminous coal, anthracite coal, to graphite (a pure carbon mineral) [Dr. Kamar Shah Ariffin et al, 2003].

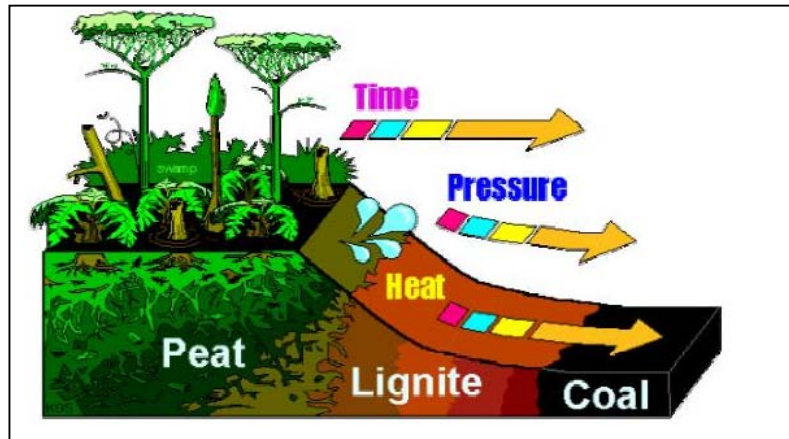


Figure 2.1: Coal formation

2.1.2 Component of coal

Coal contains two major constituents, which is useful bits and useless bits. The useful bits are the parts of the coal which are of direct benefit to a process because

they produce heat, or used as a source of carbon. This part is usually termed the organic part of the coal substance, and originated mainly from the carbon in the original plant material. The useless bits are those parts of the coal which have no value to the utilization of the coal. The inorganic part of the coal substance and is present in the form of minerals which remains in the coal substance by virtue of inert substance contaminating the plant material as it was being laid down in the peat swamp, and present in the form of minerals (which produce ash). The coal moisture is retained within the porous coal structure and on the coal surface.

2.1.3 Concept of Coal Rank

The rank of a coal refers to the degree of coalification endured by the organic matter. It is estimated by measuring the moisture content, specific energy, reflectance of vitrinite or volatile matter and carbon content [Larissa Gammidge et al, 1981].

Table 2.1: From Diessel (1992) indicates the difference in rank parameter with increase in rank.

Rank Stages	%carbon (daf)	%volatile matter (daf)	specific energy (gross in MJ/kg)	% in situ moisture	% vitrinite reflectance	
					random	max
wood	50	>65	-	-	-	-
peat	60	>60	14.7	75	0.20	0.20
brown coal	71	52	23	30	0.40	0.42
sub-bituminous	80	40	33.5	5	0.60	0.63
high volatile bituminous coal	86	31	35.6	3	0.97	1.03
medium volatile bituminous coal	90	22	36	<1	1.47	1.58
low volatile bituminous coal	91	14	36.4	1	1.85	1.97
semi-anthracite	92	8	36	1	2.65	2.83
anthracite	95	2	35.2	2	6.55	7

2.1.4 Coal Resource in Malaysia

Malaysia's coal resource to date is estimated about 1.050 million tonnes of various qualities, ranging from lignite to anthracite: bituminous to sub-bituminous coal however forms the bulk of this amount. Of the total amount about 69% is found in Sarawak, 29% in Sabah and 2% in Peninsular Malaysia.

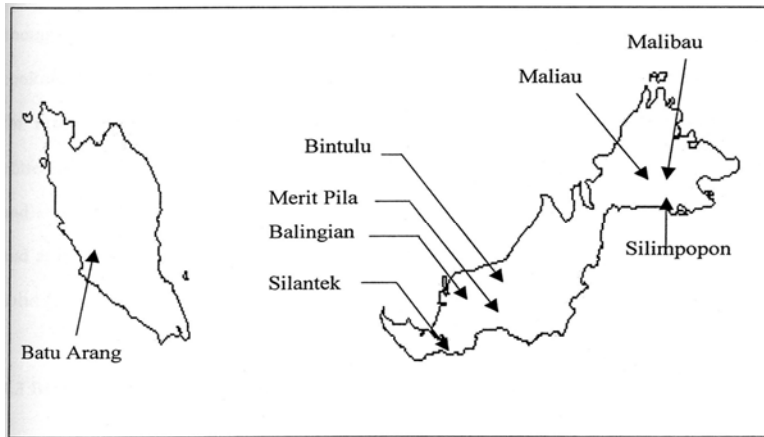


Figure 2.2: Coal fields in Malaysia

Table 2.2: Known coal in Malaysia (in Million Tonnes), John Thaddeus et al,2004

LOCATION	RESERVE			COAL TYPE
	Measured	Indicated	Inferred	
SARAWAK				
1. Silantek	7.25	10.60	32.40	Coking coal semi-anthracite, anthracite
2. Merit-Pila	176.20	107.80	121.84	Sub-bituminous
3. Bintulu			120.00	
4. Mukah-Balingan	43.60	8.30	98.10	
Sub-total	227.05	125.98	372.34	
SABAH				
1. Silimpoon	4.80	1.50	7.70	Sub-bituminous
2. Labuan			8.90	Sub-bituminous
3. Maliau			215.90	Bituminous
4. Malibau		17.90	25.00	
5. SW Malibau		26.00		
Sub-total	4.80	45.40	257.50	

PENINSULAR				
1. Batu arang			17.00	Sub-bituminous
Sub-total			17.00*	
Grand Total	231.85	171.38	646.84	

*15 mt already mined out.

2.1.5 Coal Consumptions in Malaysia

Malaysia's total coal consumption in 1998 was 3 million tonnes of which 1.7 million tonnes were used by the power stations while the cement industry used 1.3 million tonnes. Virtually all of the coal was imported.

Coal utilization mainly as fuel for power plants is expected to increase significantly from about 4.2 million tonnes in the year 2000 to about 13 million tonnes in 2005. The increase is due to commissioning of new coal fired power stations and the government licensing of independent Power Producers (IPP). Consumption by the cement industry is also expected to increase from about 1.8 million tonnes in the year 2000 to about 2 million tonnes in 2005. Thus the demand for coal by 2005 is forecast to be 15 million tonnes per annum [John Thaddeous et al, 2004].

In 2000, the fuel mix for electricity generation was 74.9% natural gas, 5% petroleum products, 9.7% coal and 10.4% hydro. From the Sectoral analysis said Tenaga Bhd. could more than double its coal consumption by 2010 with MIDF sisma projecting that the fuel's share would rise to 20% and gas fall to 59% [John Thaddeous et al, 2004].

Seem the coal consumption would be increase and become more important; therefore we may not only depend on the imported high rank coal from the other country. In point of fact Malaysia also has mine the coal. But most of it is low rank coal. Low rank coal is not preferable to be used for domestic fuel because it contains some portion of gases that do not burn completely in small fireplaces. Therefore combustion of these coals produces large level of air pollution [Wirtgen et al., 2001]. Using the low rank coal in the industry may cause the environment problem. Acid rain

which cause by the organic sulfur is released into the air where combines with oxygen to form sulfur dioxide and the greenhouse effect are the problem of using the low rank coal in the industry [Isa.colorado.edu/summary/texts/coal.htm].

2.1.6 Coal Reserves in United States

Experts estimate that the United States has about 265 billion tons of coal reserves. If we continue to use coal at the same rate as we do today, we will have enough coal to last 285 years. This vast amount of coal makes the United States the world leader in known coal reserves. Coal deposits can be found in 38 states. Montana has the most coal--about 120 billion menial tons. Other top coal states in order of known reserves are: Illinois, Wyoming, Kentucky, West Virginia, Pennsylvania, Ohio, Colorado, Texas, and Indiana. Western coal generally contains less sulfur than eastern coal (which is good for the air when coal is burned), but not always. The federal government is by far the largest owner of the nation's coal beds. In the west, the federal government owns 60 percent of the coal and indirectly controls another 20 percent. Coal companies must lease the land from the federal government in order to mine this coal. [Isa.colorado.edu/summarystreet/texts/coal.htm]

2.1.7 Coal Consumptions in United State

Electricity is the main use. Last year 88 percent of all the coal used in the United States was for electricity production. (Other energy sources used to generate electricity include nuclear power, hydropower, and natural gas.) Another major use of coal is in iron and steelmaking. The iron industry uses coke ovens to melt iron ore. Coke, an almost pure carbon residue of coal, is used as a fuel in smelting metals. The United States has the finest coking coals in the world. These coals are shipped around the world for use in coke ovens. Coal is also used by other industries. The paper, brick, limestone, and cement industries all use coal to make their products. Contrary to what many people think, coal is no longer a major energy source for heating American

homes or other buildings. Less than one percent of the coal produced in the U.S. today is used for heating. Coal furnaces, which were popular years ago, have largely been replaced by oil or gas furnaces or by electric heat pumps. [lsa.colorado.edu/summarystreet/texts/coal.htm]

2.2 Carbonization of Coal

Carbonization is the term used to denote the heating of coal in the absence of air. In these circumstances, volatile matter is removed. The volatiles are higher in hydrogen content than the basic coal, which therefore increases in carbon. Carbonization processes in the past sometimes had the production of these volatiles as a main objective. However, although the volatile by products are still significant in the economic balance of carbonization processes, the main incentive in recent times has been the physical, chemical and mechanical properties of the residue, mainly carbon remaining after the carbonization process.

On heating particles of the coal, depending on their rank, they may become more or less plastic and swell as gaseous products are generated by the break down of the coal substance, resulting in bubbles or cenospheres. When finely ground coal is heated in bulk over about 400°C, it forms a coherent porous plastic mass, which can swell to fill a container larger than the original volume. On further heating and subsequent cooling the mass contracts and some cracking occurs but quite large strong lumps of coke can remain. Although less reactive, and therefore more difficult to ignite, than the input coal, the coke can be a useful domestic or industrial boiler fuel, which burns smokeless.

2.3 Various Conditions in the Process Coal Carbonization

2.3.1 Various Temperatures

Coke is manufactured from the carbonization of prime coking coals. Carbonization is performed for three main objectives: To make a smokeless fuel for domestic/industrial applications, provide a coke for some other process (most

importantly blast furnaces) and produce a combustible gas. However other important products are formed including coal tar which in the past was a very important chemical feedstock.

Increasing the temperature of coking coals in the absence of oxygen results the devolatilization and the formation of a solid fuel, coke which has a porous structure. Two types of coke can be made, hard and soft. The difference is in the temperature of carbonization. Soft coke is carbonized at lower temperatures 600-700°C. This results in a product with a reduced volatile content of the order 9% and hence better combustion characteristics. Hard coke is carbonized at higher temperatures and resulting in devolatilization and loss of porosity. Combustion characteristics are reduced making these cokes only suitable for more specialist purposes such as manufacture of carbon electrodes or in blast furnaces.
[www.fundutimes.com/tutorials/CHEMISTRY/FUEL.HTML]

2.3.2 Various Coal Size

The distribution of coal substance between size fractions in carbonization charges also are an important factor, since it determines their coking quality (particularly when using petrographically heterogeneous coals). It assumes particular importance when developing and introducing different methods of charge preparation and establishing the optimum degree of crushing. Whereas the size analysis of a charge determines the caking surface area and, through the bulk density effect, influences the temperature distribution inside the coke oven, the quality of the individual size fractions determines the local stress levels attained during the carbonization process and hence the shatter index of the coke. The caking behavior of each grain depends on its petrographic constitution and size. The caking capacity of a given blend can often be enhanced by optimizing the coal substance distribution between size fractions at the preparation stage, e.g., by adopting selective crushing with pneumatic separation rather than the traditional methods of preparation (crushing before blending, crushing after blending, etc.) [Fomin, A.P. ; Konyakhin, A.P. ; Martynyuk, I.I. et al, 1981].

Krivoshein, V.T. et al, (1976). A procedure has been developed and proposed for taking direct temperature measurements on and at various positions within coke-oven brickwork under actual commercial conditions, with particular reference to the end sections of the heating walls. It has been established that the wall surfaces exposed to fresh charge are drastically cooled over a short period (within 5 min of charging), and that steep temperature gradients are set up in the brickwork. These may obviously be responsible for the rapid failure of oven end sections. Data obtained under commercial conditions can be relied upon for the reliable calculation of temperature distributions in coke-oven brickwork. The proposed procedures for studying temperature distributions should prove useful in analyzing the causes of failure in the end-section brickwork and developing effective countermeasures. Thus, coke-oven brickwork undergoes repeated and serious thermal shocks and the surface temperature gradients become very considerable. This probably explains its premature failure, particularly in the end sections of the walls.

M. Elalaoui et al, (1994) studied the effect of temperature and pressure on the electrical property evolution of the formed green coke. The carbonization of an industrial coal-tar pitch was studied by using a tube bomb, as a function of carbonization temperature (SSOY-SSOOC) and inert gas pressure (1-20 bar), and resultant green cokes were evaluated according to electrical resistivity determined using the Van der Pauw method. At 550°C, the carbonization pressure increase leads to an uniaxial arrangement of the produced green coke sample and to a progressive increase of the resistivity component perpendicular to the tube bomb axis. At 580°C, these changes appear only above 15 bar. These results are in good agreement with those obtained in the first part of this work, confirming the intimate correlation between carbonization temperature and pressure and the necessity of a compromise between them, to produce green cokes with oriented uniaxial texture.

M.S. Celik et al,(1999) studied the new physical process for desulfurization of low rank coal. The carbonization tests were performed in a 10-cm diameter

cylindrical retort with a volume of 1500 cm³. The discharged gases were transferred to a cooling system via a screwed gate. The tests were conducted with 200 g samples devoid of any moisture. The furnace was preheated to the desired temperature and the temperature in the majority of the tests was maintained at 600°C. After a prescribed period of treatment, the sample was taken out, cooled, and determinations made of the weight loss, volatile matter and total sulfur contents, and in some cases, the particle size analysis. From the treatment of low-rank coals at temperatures above 450°C appears to influence not only the pyritic sulfur but also the organic sulfur in coal. A substantial reduction not only in total sulfur but also in organic sulfur has been achieved under the optimum conditions. A major portion of the organic sulfur is shown to bind with iron present in coal. The result are shown as table below.

Table 2.3: Analysis of 3mm lignites sample on a dry basis

Item	I		II		III	
	Untreated ^a	Semicoked	Untreated ^a	Semicoked	Untreated ^a	Semicoked
Ash (wt%)	27.1	39.3	16.1	21.7	14.0	19.2
Volatile matter (wt%)	35.1	16.1	43.5	24.6	44.0	22.8
Fixed carbon (wt%)	37.8	44.6	40.4	53.7	42.0	58.0
Total sulfur (wt%)	2.5	2.1	4.4	4.0	4.1	3.4
Calorific Value (Kcal/kg)	4510	4605	5728	5670	5828	5815

^a As received (untreated) coal contains 35.1, 33.9 and 34.2% moisture for samples I, II and III, respectively.

Xuguang Liu et al, (1999) used the hydrothermal water treatments and supercritical SC water treatments of lignite were performed to examine the feasibility of upgrading low-rank coals. The treatment below 400°C was found to be effective enough to keep high gasification reactivity at high temperature, as well as to suppress spontaneous combustion. The pyrolysis and gasification behaviors of raw and pretreated coals were examined by thermogravimetry (TG). The kinetic analysis was carried out based on a new distributed activation energy model DAEM presented by Miura K. Miura, *Energy & Fuels*,(12) , 864–869 (1998). According to this method,

thermo gravimetric curves measured at two or more different heating rates were needed to obtain the activation energy distribution function $f(E)$ of a given coal sample. It was found that in the case of pyrolysis, the peak values of $f(E)$ curves for upgraded coal samples are nearly 300 kJ/mol, whereas, the peak value of $f(E)$ curve for their parent coal is about 200 kJ/mol. In the case of gasification, where only single reactions occur, the application of this new DAEM can give the changes of activation energy during reaction. Some interesting results occur, which may hint at some changes in the rate-controlling step of reaction or in the physical structure of coal during gasification.

Lenart et al. (2001) studied the production of smokeless fuel from Velenje lignite using electrical laboratory scale rotary kiln reactor at different temperature. For these tests, 5kg of coal were carbonized for each test run. The total residence time of the coal in the reactor amounts was fixed by the rotation rate and inclination of the kiln to 45 minutes. The semi-coke was collected in a drum at the end of the kiln. The pyrolysis gas was transported to the cooling system by a membrane pump with a vacuum controller. In the cooling system the tar and moisture were condensed. Results from the study showed the constant decreasing of the volatile matter content from 17.8% at 550°C to 5.9% at 750°C, while the ash content increased from 20.4% to 27.4%. The carbon content increased by up to 93% and the yield decreased from 48.4% to 38.5% at 550°C and 750°C respectively. The semi-coke sample, produced at 750°C has specific area of 919m²/g, while at 700°C was 667m²/g

Mahidin, Yuji Ogaki et al, (2003) established a new upgrading method for low-rank coals by a combined process of vacuum drying and tar coating has been developed, and some advantages have been observed. In the vacuum drying stage, West Banko coal (an Indonesian low-rank coal) of 400 g with particle diameter passthrough of 3.35 mm (6 mesh under) was heated up in an autoclave for 1 h to a temperature of 200 °C, while maintaining a vacuum of 160 Torr. After holding the conditions of 200 °C and 160 Torr for 2 h, the vessel was then allowed to cool. This stage of the process removed almost all of the moisture and significantly reduced the

volatile matter. The second stage consisted of the tar coating process, whereby the mixture of the coal and tar and small amount of the coal tar (2–5 wt.% of the raw coal) was placed under vacuum for a further 10 min and heated to 270–300 °C, at the heating rate of 5 °C/min. Since the moisture and volatile were already removed in the first stage and the amount of the added tar was relatively small, the maximum pressure at 300 °C was only 0.5 MPa. During the heating and cooling processes in this second stage, tar vaporized and deposited onto the surface of coal. This upgrading technique is able to produce upgraded coals comparable to a bituminous coal; the surface of the coals can be effectively coated in order to suppress low-temperature oxidation and spontaneous combustion. The dewatering rate in the vacuum drying stage at 200 °C reached up to 93.81%, and degree of devolatilization significantly increased with elevation of upgrading temperature, from 15.7% at 200 °C to 35.9% at 300 °C. Furthermore, the specific surface area and susceptibility toward the low temperature oxidation of coals were influenced by the upgrading treatment. From the result carbon content in the upgraded products slightly increased with the increase in the upgrading temperature and tar dosage to values comparable to bituminous coal. By the vacuum treatment, degree of dewatering rate reached a level of 94% and partly reduced the surface area, susceptibility to the oxygen attack, low-temperature oxidation, spontaneous combustion and self-ignition of coal. The present upgrading process wholly provided an important contribution on the modification of the pore structure of the coals and the upgraded coals have a lower propensity to low-temperature oxidation, spontaneous combustion and self-ignition.

Yoshiki Sato et al, (2003) studied the thermal upgrading of low-rank coal with solvent at 380–440 °C under an initial nitrogen pressure of 2 MPa was studied as a possible method for producing clean solid fuel with a high heating value and less spontaneous ignition behavior. Upgrading of Buckskin coal (USA, subbituminous coal) in the presence of t-decalin (non hydrogen-donor solvent) at 440 °C gave 11.4 wt.% of gas, 5.3 wt.% of oil and 74.1 wt.% of upgraded solid product with a small amount of water. The gaseous product consisted mainly of carbon dioxide (67 wt.%),

methane, carbon monoxide, hydrogen and a trace of C₂ and C₃ hydrocarbon gases. The oil product from coal contained BTX, phenol, and their alkyl-derivatives. The heating value of the upgraded solid product from the Buckskin coal increased to 31.0 MJ/kg in dry base as compared to the heating value of wet base of the untreated raw coal, which was 19.3 MJ/kg. Spontaneous ignition behavior was greatly reduced by the upgrading. The effect of catalyst and additives on the upgrading was investigated in terms of product distribution and the quality of the solid product. Taiheiyo (Japan, subbituminous) and Yallourn (Australia, brown) coals were also studied.

CHAPTER THREE

METHODOLOGY

3.0 Experimental Equipment and Design Specifications of the Pilot Plant



Figure 3.1: Overall view of the pilot plant for coal carbonization process

Figure 3.1 is the overall view of the pilot plant for coal carbonization which is located in the school of chemical engineering, engineering campus University Sains Malaysia. This pilot plant can be used to upgrade the low rank coal to the high rank coal.

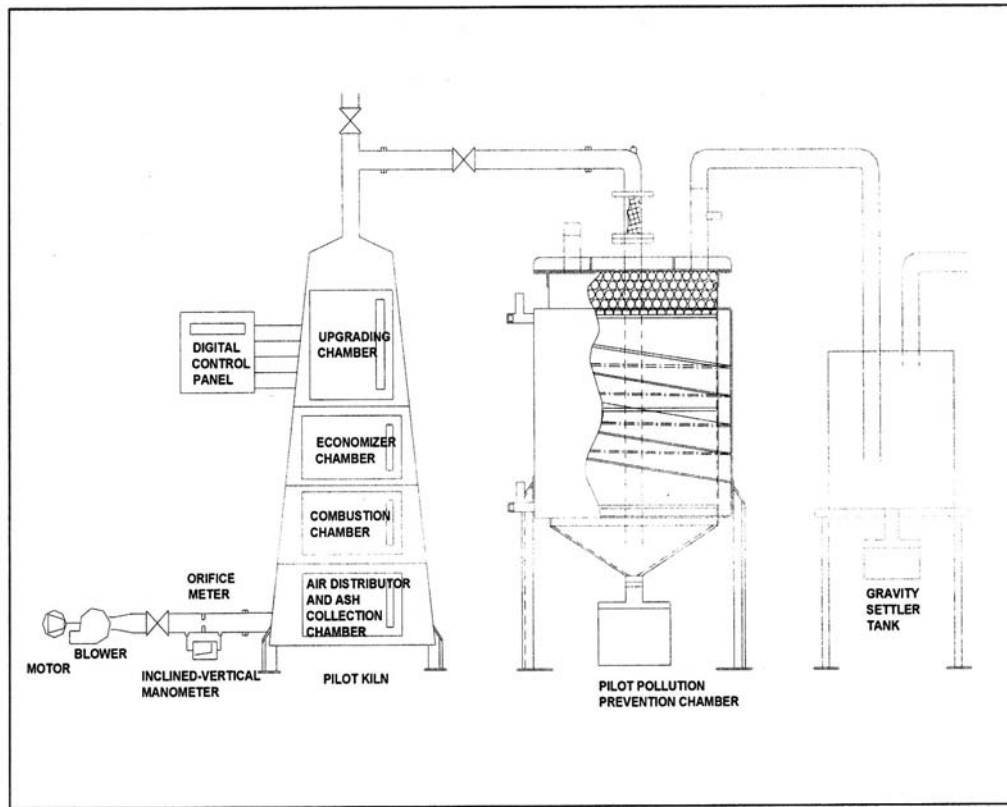


Figure 3.2: Schematic diagram of the pilot plant

Figure 3.2 is show the schematic diagram of the pilot plant. From here we can see that it consists of four main components that are air intake system, pilot kiln, pilot pollution prevention chamber, and gravity settler tank.

3.1 Air Intake System

Figure 3.3 show the schematic diagram of the air intake systems. It consists of three phase motor coupled with air blower, gate valve, orifice meter, and inclined/vertical manometer. The function of this system is to control and measure the air flow rate entering the pilot kiln.

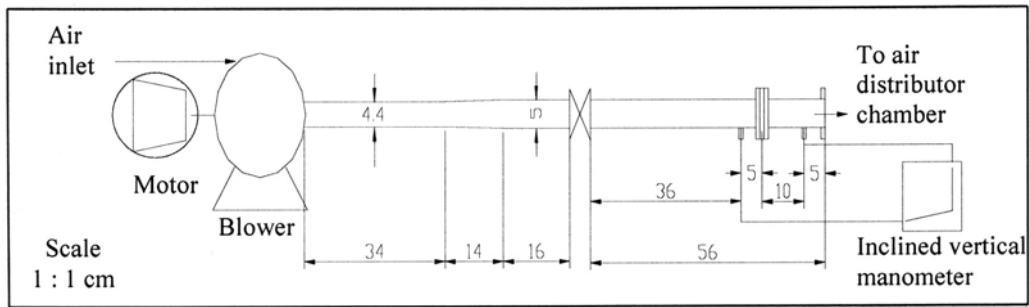


Figure 3.3: Schematic diagram of the air intake system

3.1.1 Three-Phase Motor and Air Blower

Figure 3.4 shows the motor and air blower for the air intake system. The 2 HP, 420V and frequency of 50Hz of three-phase china made motor is coupled with centrifugal air blower to provide the motive force to induce the air to flow from the outside to the air distribution chamber consists of 40 radial-blades, each of 11 cm length.

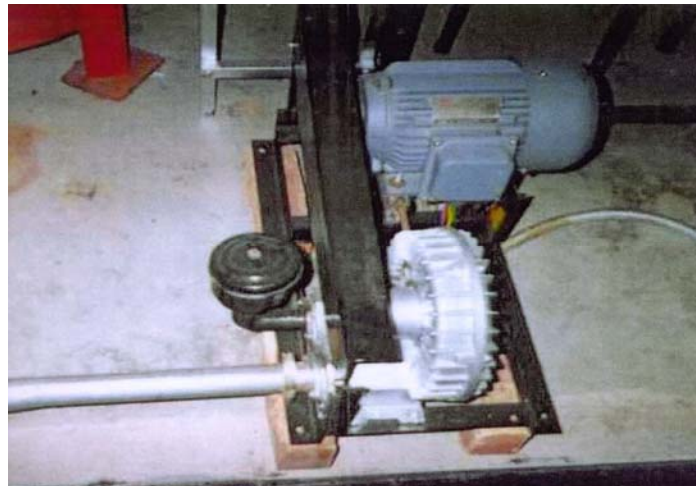


Figure 3.4: Three-phase motor and air blower

The outlet of the blower is connected to a pipe of diameter 4.4 cm and length of 34 cm. This pipe is fitted with a pipe of diameter 5 cm by 16 cm length, gate valve, and an orifice meter. The orifice meter is fitted through the upstream and downstream taps to an incline/ vertical manometer.

3.1.2 Orifice Meter

The orifice meter is made from a brass plate of diameter 5cm and thickness 3 mm. An orifice-rounded edges opening of diameter 1cm is drilled at the center of the plate. The orifice is flanged to the piping system and connected through a short pipe of length 15 cm and diameter 5 cm to the pilot kiln. This orifice plate is designed and fabricated to achieve accurate and high discharge coefficients for all range of air flow rate.

In order to measure the pressure differential for the orifice plate, a pair of radius pressure taps is used. Radius taps are a static hole, located one pipe diameter upstream and one-half pipe diameter downstream from the plate. Therefore the taps radius of 2.5 mm is placed at 5 cm before and 7.5 cm after the orifice plate. According to Perry and Green (1984), the radius taps are the best from the standpoint because the downstream pressure tap is located at about the mean position of the vena contracta, and the upstream tap is sufficiently far so that it is not affected by distortion of the flow in the immediate vicinity of the orifice as shown in figure 3.5.

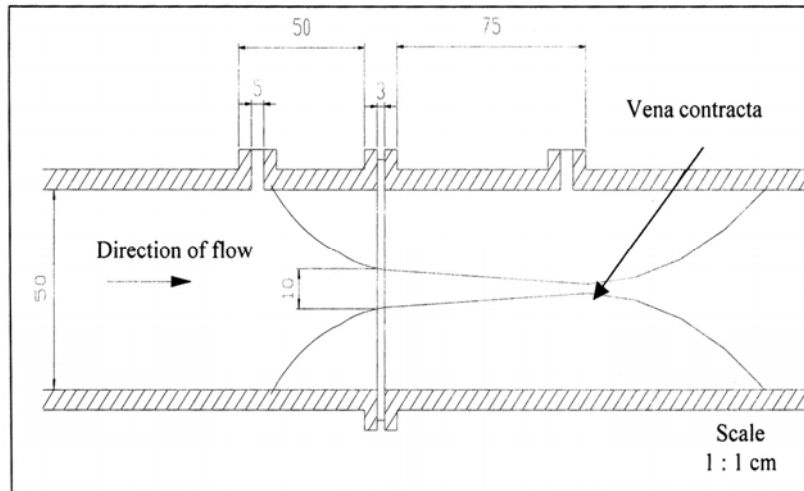


Figure 3.5: Flow of contraction at the cross section

3.1.3 Inclined/ Vertical Manometer

Figure 3.6 show the inclined/ vertical glass manometer. The inclined/ vertical manometer is used to measure the pressure drop across the orifice plate and the flow rate of air in m^3/hr to the pilot kiln. The inclined part is used for low-pressure drop while the vertical part is used for high-pressure drop. The length for the both incline and vertical sections are 40 cm with the inclination angle is 28° . The internal diameter of the manometer and the bulb are 0.5 cm and 5.0 cm respectively. The manometer, colored water is used as fluid. The manometer is calibrated to measure air flow rate of $0\text{-}16 \text{ m}^3/\text{hr}$.

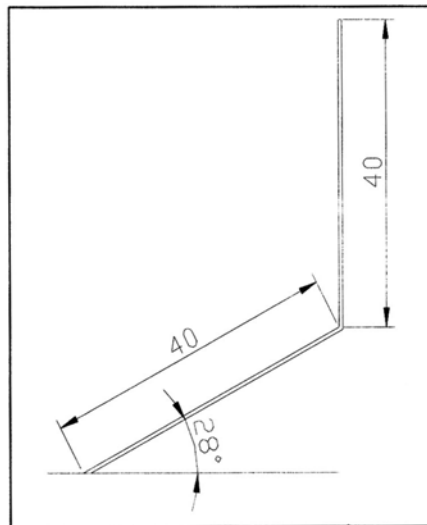


Figure 3.6: Schematic diagram of an inclined/ vertical glass manometer

3.2 Pilot Kiln

Figure 3.7 show the schematic diagram and the front view of the pilot kiln respectively. It consists of a tower made from the cast iron with four chambers. From the bottom to the top, it consists of air distributor and ash collector chamber, combustion chamber, economizer chamber, and carbonization chamber. All chamber are together to form the pilot kiln of 125 cm in height with internal diameter of 60 cm at the bottom and 30 cm at the top.

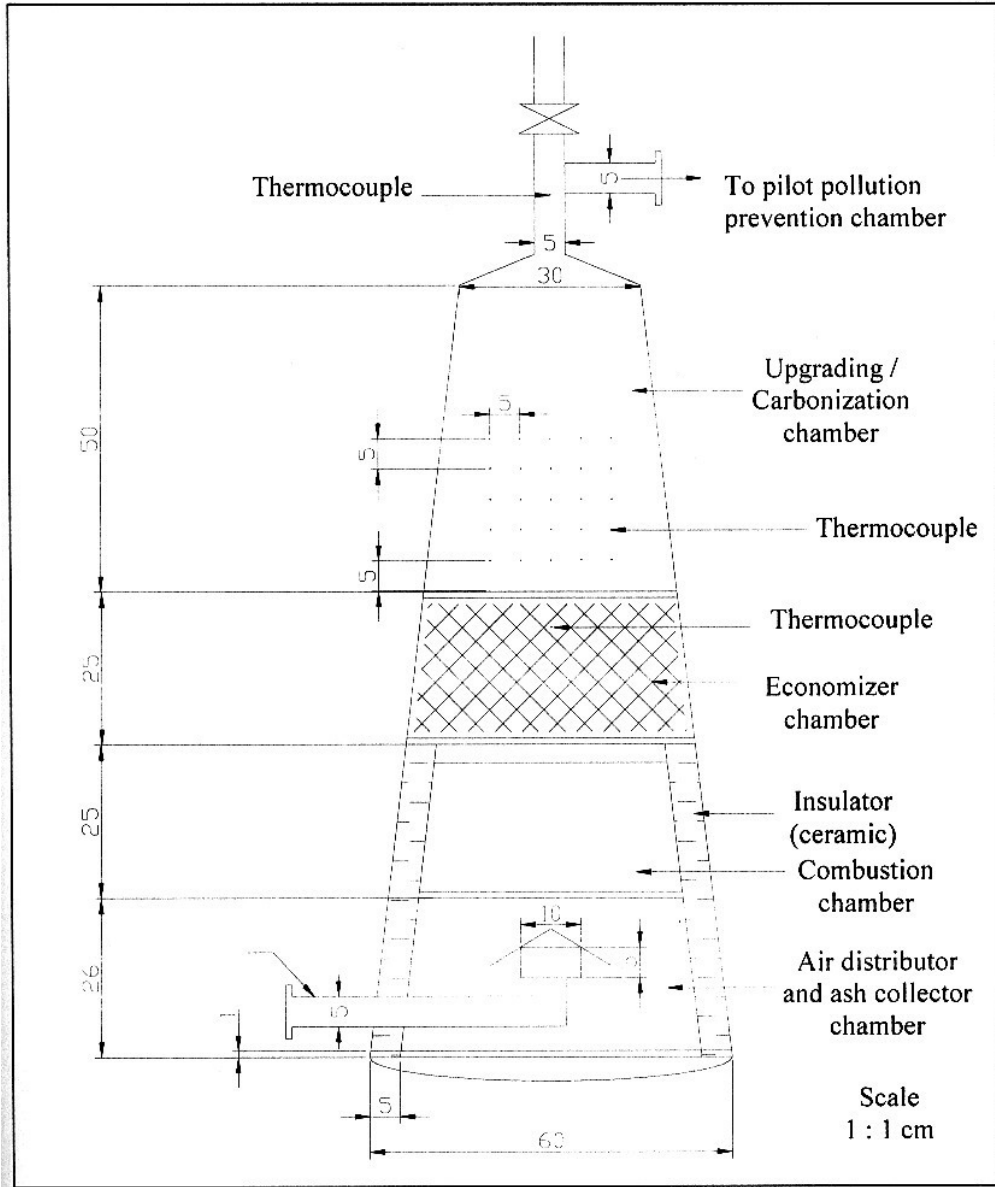


Figure 3.7: Schematic diagram of the Pilot Kiln



Figure 3.8: Front view of the Pilot Kiln

3.2.1 Air Distributor and Ash Collector Chamber

Ash collector chamber is fitted with an air distributor to uniform distribute the intake air into the combustion chamber. The remaining space of the chamber is used as space to collect the ash, which is falling from the upper chambers. The chamber is 25 cm is height with lower internal diameter of 60 cm and upper internal diameter of 55 cm. The volume of the chamber is 9.0 L. The dimensions of the door are 30 cm width and 20 cm height. The gas distributor of 5 cm height and 5 cm in diameter is located at the middle of the chamber. It consists of an outlet pipe in the chamber with