PENJANAAN KUASA DARI SISTEM LAPISAN TERBENDALIR BIOMASS

(POWER GENERATION FROM BIOMASS FLUIDIZED BED SYSTEM)

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ABSTRACT

Present energy use is largely dependent on fossil fuels which make future sustainable development very difficult. Fossil fuels contain high amount of carbon dioxide (CO_2) and sulphur dioxide (SO_2) that may cause air pollution and global warming. Biomass fuels appear as the most suitable option to substitute the fossil fuels with the highest general worldwide potential. Fluidized Bed Gasifier (FBG) is one of the conversion techniques that can be used to converse the biomass into useful and clean gasses. This system has been designed at Universiti Sains Malaysia for researching process related.

The present work reports studies on the previous researches on fluidized bed and the development process of the designed system. The design parameters of fluidized bed are also studied for further understanding. The development process is including the piping installation of the system and the modification of the system. The modifications carried out depending of the problems occur after the piping installation. Most of the modification carried out focused on the gas inlet port connection. Besides, some experiments are also carried out in order to determine the bed material (sand) size, the density and the moisture content of wood chip fuel. Sands and wood chip are used in running the gasifier system. The results of the experiment then are compared with the design parameter to ensure either the sand purchased suitable for the gasifier experiment or not.

ABSTRAK

Sumber tenaga semasa lebih banyak bergantung kepada bahan api fosil dan ini menyebabkan pembangunan masa depan agak sukar. Bahan api fosil ini mengandungi jumlah karbon dioksida (CO2) dan sulfur dioksida yang tinggi yang akan menyumbang kepada pencemaran udara dan pemanasan global dunia. Biomass adalah pilihan yang paling sesuai untuk menggantikan bahan api fosil dengan asas prestasi yang tinggi di seluruh dunia. Sistem Penggas Lapisan Terbendalir (FBG) merupakan salah satu teknik yang boleh digunakan untuk menukar sumber biomas kepada gas yang bersih dan berguna. Sistem penggas ini telah direkabentuk di Universiti Sains Malaysia untuk kerja-kerja penyelidikan yang berkaitan.

Laporan yang sedang dijalankan adalah merangkumi kajian terhadap penyelidikan-penyelidikan yang lepas tentang lapisan terbendalir dan proses pembangunan sistem sedia ada. Parameter-parameter rekabentuk tentang lapisan terbendalir ini juga turut dipelajari untuk pemahaman lanjut. Proses pembangunan sistem ini turut merangkumi aspek pemasangan paip dan kerja-kerja pengubahsuaian. Kerja-kerja pengubahsuaian ini dilakukan bergantung kepada masalah yang timbul selepas proses pembangunan system selesai. Selain itu, beberapa eksperimen berkaitan juga dilakukan seperti dalam menentukan saiz pasir, ketumpatannya serta ujian kandungan kelembapan cebisan-cebisan kayu. Bahan-bahan ini bertindak sebagai agen lapisan dan bahan api untuk menjalankan sistem penggas ini.

CHAPTER 1

INTRODUCTION

1.1 Background

Energy is the material basis on which human beings rely and carry out economic development. Its reasonable development and efficient utilization relates to the future of the world. Renewable biomass energy occupies an important position and plays a decisive role in the present world energy structure. According to statistics, one seventh of the total world energy consumption is from biomass. In developing countries, the proportion of biomass in total energy consumption is even more. At present, about 1.5 billion of the world population has biomass as its main energy resource. Biomass has been considered as a major sustainable energy resource for electricity production. Large quantities of unused biomass material exist in the form of forestry waste and agricultural byproducts and the cultivation of arable energy crops is usually possible. Biomass is a common material in nature, for example, wood chip, corn straw, wheat stalks, rice stalk, cotton stalks and straw, etc, cortical hulls, rice hulls, corncobs, husks of sunflower seeds and melon seeds, peanut husks and cotton seed hulls, etc. All green plants belong to the category of biomass. There are different types of technologies for converting the biomass into useful energy or fuel forms such as biological, extraction and thermochemical. In thermochemical technologies, different process involve such as pyrolisis, direct combustion and gasification. The study of the project is basicly based on gasification process which the raw fuel gas exiting is a mixture of hydrogen, carbon monoxide, nitrogen, carbon dioxide, water vapour, low molecular weight hydrocarbon gases, organic vapours and aerosols containing complex organic compounds.

1.2 Gasification Principle

Gasification is the thermal decomposition of organic matter in an oxygen deficient atmosphere producing a gas composition containing combustible gases, liquids and tars, charcoal, and air, or inert fluidizing gases. Typically, the term "gasification" refers to the production of gaseous components, whereas pyrolysis, or pyrolization, is used to describe the production of liquid residues and charcoal. The latter, normally, occurs in the total absence of oxygen, while most gasification reactions take place in an oxygen-starved environment.

The quality of gas generated in a system is influenced by fuel characteristics, gasifier configuration, and the amount of air, oxygen or steam introduced. The output and quality of the gas produced is determined by the equilibrium established when the heat of oxidation (combustion) balances the heat of vaporization and volatilization plus the sensible heat (temperature rise) of the exhaust gases. The quality of the outlet gas is determined by the amount of volatile gases (H_2, CO, CH_4, C_2, etc.) in the flue gas stream. Considering the system equilibrium, it can easily be seen how the moisture content of the fuel can impact the gas quality. With the heat released by the char a fixed quantity (assuming a constant air flow), the more moisture in the fuel, the more heat consumed by evaporation. Less energy remains to for volatilization and sensible heat, so the fuel rate must be decreased. Consequently, less volatile are produced and the combustible gas quality and quantity is reduced. As the system output increases, the operating temperature is reduced. This is explained by the fact that, again for a fixed heat (of oxidation) release due to the constant air flow, the more fuel fed into the system, either wet or dry, the more energy is required for both volatilization and evaporation, and the less energy available to raise system temperatures via sensible heat increases. In effect, the latent heat fraction increases at the expense of the sensible heat. The result of this is that as more volatilization occurs, the combustible content of the outlet gas is increased and the overall heat content is improved. Thus, the highest gas quality occurs at the lowest temperatures; however, when the temperatures drop too low, the char oxidation reaction is suppressed and the overall heat release diminishes.

With this basic understanding of fluidization and gasification processes, it is possible to better understand the combined processes within a fluidized bed gasification system. The first design consideration is fluidizing velocity to the bed. This is determined by the size of the bed media used and establishes the air flow into the system. Upper air flow rates are limited by the entrainment velocities of the bed particles. Lower flow rates are determined by the minimum fluidizing velocities at which acceptable mixing occurs. These boundary conditions typically limit the fluidizing air flow to a 2-to-1 operating range.

1.3 Problem Statement

Present energy use is largely dependent on fossil fuels which make future sustainable development very difficult. Fossil fuels contain high amount of carbon dioxide (CO2) and sulphur dioxide (SO2) that may cause air pollution and global warming. There are drastic changes in the composition and behaviors of the atmosphere due to the rapid release of polluting combustion products from fossil fuels. A significant amount of the carbon dioxide emissions from the energy sector is related to the use of fossil fuels for electricity generation. As the demand for electricity is growing rapidly, emissions of carbon dioxide and other alternatives are made available. Further, the declining energy supplies and severe environmental constraints are needed for additional amounts of clean energy sources. Among the energy sources that can substitute fossil fuels, biomass fuels appear as the option with the highest general worldwide potential. In both the developed and the developing countries, the interest and activity for obtaining energy from biomass has expanded tremendously and dramatically in the last few years. Fluidized Bed Gasifier (FBG) is one of the conversion techniques that can be used to converse the biomass into useful and clean gasses. This technique is an application of the gasification process. Throughout many researches, FBG is one of the most suitable techniques in order to get a clean gas.

1.4 Objectives

A fluidized bed system to convert solid biomass into gaseous fuel has been designed at the School of Mechanical Engineering. The objectives of the project are;

a. to study the design of the bubbling fluidized bed gasifier system
b. to make some development with the design system before running the experiment
c. to run the fluidized bed system using wood chips

d. to determine the gas composition of the gaseous fuel known as ‘Producer Gas’.

The work involves experimental investigation on the biomass fuel and bed sand, the production of producer gas and testing its composition.

1.5 Scope

This project is about an experiment of Bubbling Fluidized Bed Gasifier (BFBG) system that that has been designed at the School of Mechanical Engineering, Universiti Sains Malaysia. It is an experiment of the system using a wood chip as a fuel and sand as a bed material. Some experiments on sand and wood chip are also taken before running the gasifier system. Since it is an initial experiment, some developments of the design have to taken in order to increase the achievement of the experiment. Some modifications of the system are taken especially in piping installation of overall system and a design of the gas inlet pipe.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, biomass becomes one of the most important materials for alternative energy. Large quantities of biomass source such as unused biomass material exist in the form of forestry waste and agricultural byproducts. There are several processes or technologies can be used for converting the biomass to useful energy or fuel forms such as biological, extraction or thermo chemical (pyrolisis, combustion or gasification) [1]. The gasification of biomass is a developing energy technology among various systems. Besides, the gasification is capable to convert a wide variety of solid fuels into heat and power with potentially higher efficiencies compared to combustion with steam generation [2]. Therefore, many researchers more concentrated in experiment in gasification.

Biomass gasification produces fuel gas through the chemical conversion of biomass [3]. It usually will involve the partial oxidation of the feedstock in a reducing atmosphere in the presence of air, oxygen and/or steam [3,8]. It offers advantages compared to combustion technologies cause of the higher global efficiency, which can be achieved in a process based on a gasification step coupled with a motor or turbine. F. Miccio [4] in their research also mentions that the biomass gasification is devoted to improve the quality of the producer gas. It is because of the higher concentration of tar and fine carbonaceous particles in the gas represents a negative drawback, and the cleaning of the gaseous steam is required downstream of the gasifier.

2.2 Gasifier System

Gasifier system is developed in various types. The type of gasifier depends on the size of the installation, the quality of fuel available, and the quality of gas required. Generally, there are two types of gasifier; (a) fluidized bed and (b) fixed bed. The fixed bed gasifier is further divided into the downdraft and updraft system.

2.2.1 Downdraft gasifier

The downdraft gasifier is designed to crack the condensed tars and oils produced by the counterflow, updraft gasifier. In this co-flow gasifier the wood waste and its gasification air both flow in the same direction - downward through the gasifier's fuel bed. As in the case of the updraft gasifier, the waste is admitted at the top. As the waste progresses down through the "reactor" it dries and its volatiles are pyrolyzed. The char is directed into a reduced diameter, cylindrical, "throat" section at the bottom of the gasifier. Gasification air is injected into the throat through openings in the throat wall. The high throat temperatures that ensure crack the tars and oils that tend to form in producer gas, particularly when the waste is wetter than about 20% moisture content (wet basis).The producer gas, leaving the bottom of the gasifier, is usually drawn up through an annulus which normally surrounds the downdraft gasifier reactor, thereby transferring its sensible heat to the fuel bed. The producer gas leaves from a side opening near the top of the gasifier. Because of the reduced tar and oil content, downdraft gasifiers are commonly used to fuel spark ignition and diesel engines. The producer gas is cooled before it is drawn into the engine in order to pack as many Btu's as possible into each cylinder.

The disadvantages of downdraft gasifier are:

- Size, shape and moisture content of the biomass particles must be controlled within close limits.
- Quality of the gas fuel produced is generally good.

- The downdraft principle is only suitable for installations of less than about 1 MW electrical output.

2.2.2 Updraft gasifier

An updraft gasifier is different with the downdraft. As can be seen, waste is admitted to the gasification chamber from above, falls onto a grate and forms a fuel pile. Air from below the grate (sometimes accompanied by steam), is blown up through the fuel pile. Since the flow of fuel is downward, toward the grate, and since the flow of air is upward, up through the fuel pile, this type of gasifier is also called a "counterflow" gasifier. As the waste works its way down to the grate it dries, its volatiles are pyrolyzed and its fixed carbon (also known as "char") is converted to carbon monoxide. In the process some of the char is completely oxidized to liberate the heat needed for evaporation and pyrolyzation. The carbon dioxide, so formed, is usually reduced to carbon monoxide as it continues its way up through additional layers of char to the top of the fuel pile. The producer gas leaving the gasifier is at a low temperature. It is laden with condensed tars and oils from the pyrolyzation as well as particulate matter picked up during its passage up through the fuel bed.

There are some disadvantages of updraft gasifier such as;

- The updraft principle is only suitable for installations of 10 MW capacities.
- Size, shape and moisture content of the biomass particles are much less critical than with a downdraft gasifier.
- Quality of the gas produced tends to be poor.

2.2.3 Fluidized bed gasifier

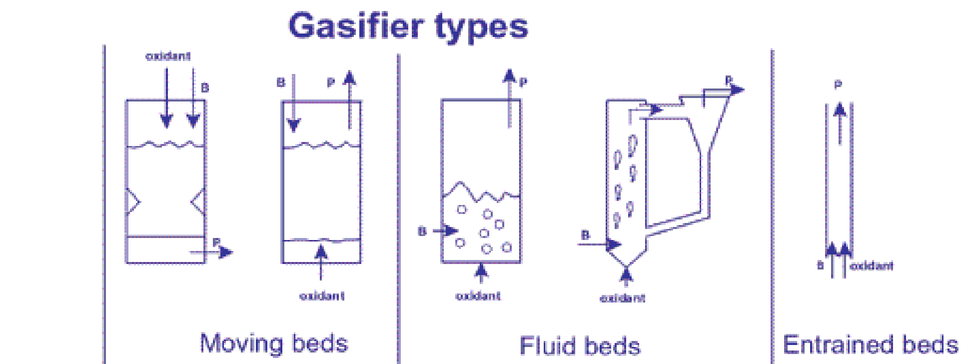
Updraft and downdraft gasifiers are limited in the moisture contents of the wood waste that they can readily gasify. Typically, updraft gasifiers are limited to a maximum of about 30% moisture content fuels, on a wet basis; downdraft gasifiers to about 20% moisture content. Above these moisture contents the resultant producer gases are laden with tars and creosote.

Fluidized bed gasifiers, because of their large thermal mass, can usually process higher moisture content fuels. It is not clear what their moisture content limits are.

The fluidized bed gasifier features a bed of sand, or of other inert solid granular particles, which is kept in suspension by high pressure gasification air admitted at the bottom of the bed through a perforated grid plate or through a series of individual nozzles. The amount of wood waste in then sand bed at any given time is small - normally less than 1% of the bed mass. The velocity of the air at which the bed just begins to fluidize, i.e., when the particles begin to be suspended, is called the minimum fluidizing velocity. Increasing air flow agitates the bed material further, promoting good mixing. Bubbles form in the bed and rise to the bed surface. With further increases in air flow the bed takes on the appearance of a briskly boiling fluid and the bed surface looses some of its definition. If the air flow does not increase much further then the fluidized bed gasifier is called a Bubbling Fluidized Bed Gasifier (BFBG).

However, if the air flow does increase significantly, so that the bed stretches to fill the entire reactor, and if a hot, refractory-lined cyclone is used to remove the significant amounts of particulate carried along with the exiting producer gas, then the gasifier is called a Circulating Fluidized Bed Gasifier (CFBG).

Fluidized bed gasifiers, in contrast to updraft and downdraft gasifiers, use the sand in the sand bed to physically abrade away the outer char layers on the waste particles contained in the fuel bed. This scrubbing action exposes more dried MSW waste for devolatilization thereby enhancing the conversion of waste to producer gas. In addition the large thermal mass of the sand bed acts as a flywheel, smoothing out performance swings due to variability in fuel size, fuel moisture content and fuel Btu value. CFBG's convert more char to producer gas than BFBG's because of their higher recycle rates. They also produce less tars/oils than BFBG's. However, the need for a high temperature, high efficiency cyclone, and the greater pressure loss this causes, means that the CFBG is more expensive than the BFBG and its electric power bill is higher. One of the drawbacks of the fluidized bed gasifier is the high particulate loading in the producer gas whether it is a BFBG or a CFBG.



	Co-current	Counter current	dense	circulating	
T°C	700-1200	700-900	< 900	< 900	≥1500
tars	low	very high	intermediate	intermediate	absent
control	easy	very easy	intermediate	intermediate	very complex
scale	< 5 MW_t	< 20 M_t	10<MW_t<100	20<MW_t<?	> 100 MW_t
feedstock	very critical	critical	less critical	less critical	very fine particles

Figure 2.1 Parameter comparison between gasifier types

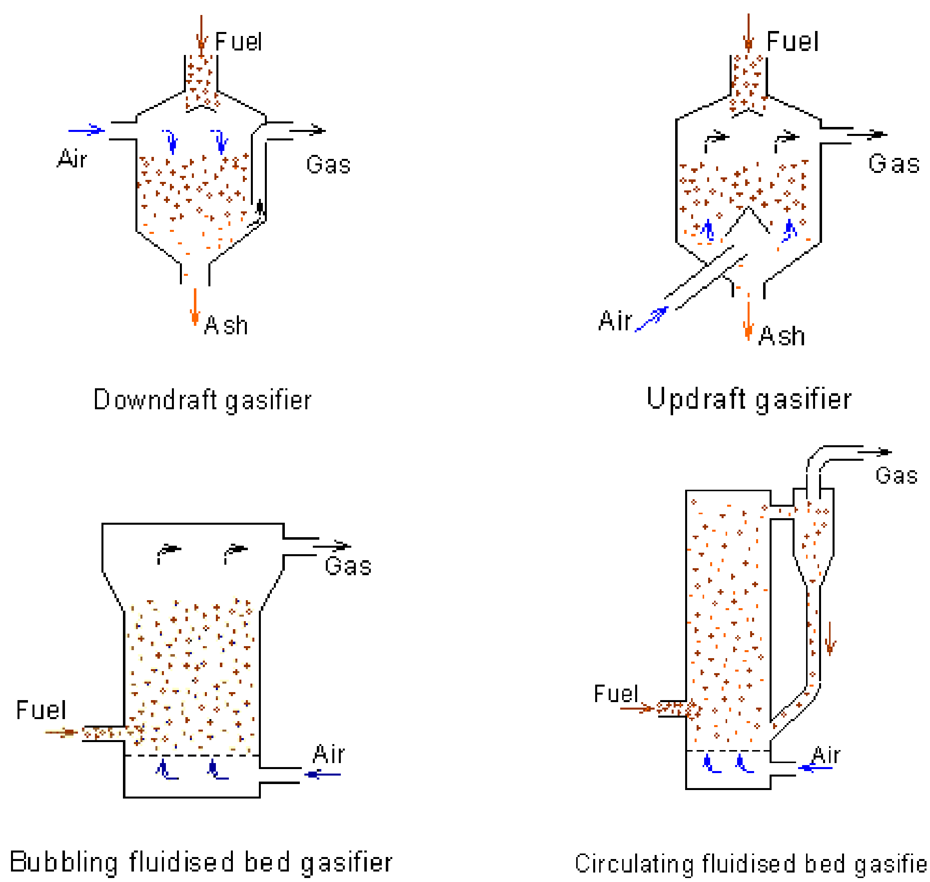


Figure 2.2 Different process of gasifier

F. Miccio [4] and Luis Augusto Barbosa Cortez [5] have done their researches concerning the biomass gasification in bubbling fluidized bed. In order to get a series of parameter, functions of the gasification air factor have to be measured such as lower heating value, heat losses, cold and hot gas thermal efficiency and gas yield [5]. Besides, the biomass gasification operated at atmospheric and pressurized condition. Huge generations of fine particles occur in both inert and oxidant atmospheres for a biomass char. The particle can be fragmented to sub particles during the fuel devolatisation. The mechanical abrasion operated by the bed material on the char surface produces fines, which can easily escape the bed [4].

2.3 Bubbling Fluidized bed

Bubbles form in the bed and rise to the bed surface. With further increases in air flow the bed takes on the appearance of a briskly boiling fluid and the bed surface looses some of its definition. If the air flow does not increase much further then the fluidized bed gasifier is called a Bubbling Fluidized Bed Gasifier (BFBG).

A fluidized bed consists of a vessel containing a bed of solid particles, generally inert material such as sand. Air is blown upward through the solids to produce a buoyant force on the particles through the perforated plate. When the buoyancy force of the air is sufficient to overcome the weight of the particles, the bed becomes suspended in the air stream. Further increase in the air flow creates a “bubbling” effect within the vessel which appears to be very similar to a pot of boiling water, hence the term, “fluidization,” or “fluidized bed.” This boiling action generates tremendous turbulence within the bed resulting in significant mixing of fuel and air within the system and creates very good characteristics for combustion or gasification reactions to occur. Because the sand and air mixture behaves more like a fluid, any foreign objects introduced into the bed will "float" or "sink" depending upon their density, much the same as if they were dropped into a tank of water. The fuel is fed into the system directly into the bed, depending upon the particle sizing and density. Under normal operation, the bed media is maintained at a temperature between 750 - 800°C. When a fuel particle is introduced into this environment, its drying and pyrolyzing reactions proceed rapidly; driving off all gaseous portions of the fuel at relatively low temperatures. The remaining char is oxidized within the bed and provides the heat source or the drying and de-volatilizing reactions to continue.

Within the bed, the municipal solid waste particles are subjected to an intense abrasion action from the fluidized sand. This etching action removes any surface deposits (ash,char, etc.) from the particle and continually exposes a clean reaction surface to the surrounding gases. As a result, the residence time of a fuel particle is measured in seconds, as opposed to minutes or even hours in other types of gasifiers.

Once this bed sand has been heated, it provides a tremendous thermal capacity to maintain operating temperatures even with very wet fuels. This large thermal capacity plus the intense mixing within the fluid bed enable this system to handle a much greater quantity and/or a much lower quality of fuel. Experience with existed fluidized bed gasifier has indicated the ability to utilize fuels with up to fifty five percent moisture with high ash contents in excess of twenty five percent. The fluid bed can operate and control at much lower temperatures than other gasifiers thereby reducing the potential of slagging and ash fusion and enabling this unit to utilize high slagging fuels.

2.4 Fluidization Behaviors and Gas Analysis

Researches in the bubbling fluidized bed gasification had been done before. The researchers use the biomass fuels such as rice husk, hazelnut shells, sugarcane bagasse and wood for gasification conversion.

2.4.1 Rice Husk

Chuang Zhi Wu [7] A. E. Ghaly [7,8] and E. Natarajan [9], had done some research based on rice husk. Chuang Zhi Wu with his group of researcher [7] had design and operated of a Circulating Fludized Bed Biomass gasification and power generation (BGPG) system for rice husk in early 2002. The system consists of a gas cleaner, power generation subsystem and also a wastewater treatment system. The experiment was held in Putian Huanguang Miye Ltd., China using the 1 MW CFB BGPG. The main performances of the experiment are: capacity: 1500 kg/h, gasification efficiency: 65%, risk husk consumption: 1.7-1.9 kg kW/h and total efficiency about: 17%. Through the experiment, they found out that the fluidization of rice husk can be improved by mixing it with other small solid particles and forming a multi solid system [7,9].

During running the system, they found that the gasifier contains rice husk together with char and ash. The fluidization velocity was changed causes of the workload condition of the gasifier that keeps on varying. Besides, they suggested that the system should be connected with a gas cleaning system to prevent erosion, corrosion and environmental problems. Poor gas cleaning up system will cost less but will decrease the life of power machines. The process of the gas cleaning also included the use of water treatment system. A lot of water will be used in gas cleaning and become contaminated with ash, char and tars. In controlling the temperature of the gasifier, it has to be maintained within the range 700-850 °C. At lower temperature the efficiency of gasification is lower and the tar content of the gas is excessive. High temperatures can be controlled by decreasing the air feed, and increasing the rise husk feed rate. Then, the power output could be adjusted according to the power demand through increasing feed-in and air flow rate slowly with keep the temperature within 700-850 °C.

A.E. Ghaly [8] in 1999 has done a research with other researcher based on air gasification of rice husk in a dual distributor type fluidized bed gasifier. Their research is discussed the effect of varying fluidization velocity and equivalence ratio on the gasifier performance. The rice husk used was a relatively uniform material and did not require any treatment before use. They used a alumina sand as inert bed material in the fluidized bed gasifier with main and specific main characteristics. The results of the experiment show that the gasifier temperature increased with increases in fluidization velocity. Also, the temperature increased with increasing the equivalence ratio. It can be explained by the fact that at higher equivalence ratios more air (or oxygen) per unit weight of fuel was available.

Besides, the experiment shows that the pressure drop profiles are a function of distance from the main distributor plate at various fluidization velocities and equivalence ratios. The pressure drop in the dense bed dropped whereas the pressure drop in the freeboard region remained constant. In doing the analysis of the gas higher heating value, the results indicated that the effect of the fluidization velocity on the product gas higher heating value was dependent on the equivalence ratio. Lower values of the higher heating value of the gas were obtained at the highest fluidization velocity due to the higher concentrations of combustion products caused by the increase of the air flow rate. The analysis of gas yield tells that the gas yield increased linearly with increasing equivalence ratio and hence with temperature [9], but not appreciably affected by the changes in the fluidization velocity. The energy output of the gasifier can be expressed as the heating value of the gas produced per kg of the fuel on a dry ash free basis from the product of the gas heating value and gas yield. They were also mention that the carbon conversion as one of the important parameter in any biomass conversion process. The carbon conversion increased due to decreased char formation as the equivalence ratio was increased. As the conclusion of the experiment, they conclude that the air gasifation of rice husk in the fluidized bed system showed that the reactor temperature, pressure drop, gas composition, gas higher heating value, gas yield and carbon conversion were affected by both the equivalence ratio and fluidization velocity.

As an overview of combustion and gasification of rice husk in fluidized bed reactors, E. Natarajan [9] had done the research with his group of researcher in 1998. The research specifically done for bubbling fluidized reactors. They had referred to about more than 20 references of researches with different constructional detail of fluidized bed reactor till 1998. Through the study, they had summarized that the quality of fluidization is one of the most important factors that influences the gasification efficiencies. Fluidization quality can be controlled by changing superficial air velocity, within the permissible limit for a chosen particle size. Operating the fluidized bed in the gasification mode can reduce or eliminate the bed particle coating and fouling problems encountered. In summarizing the effect of equivalent ratio, the ratio determines the fraction of the fuel that is gasified in the reactor. It will affect fluidization quality and bed temperature. There are two limit of equivalent ratio that are lower limit and upper limit. The lower limit is decide by minimum quantity of air required (1) to burn a part of the fuel to release enough heat to support the endothermic reactions, (2) to attain required carbon conversion efficiency, (3) to meet sensible heat losses in gas, char and ash, and (4) to maintain the required temperature of the reactor. While the upper limit is determined by the combined consideration of the reactor temperature, fluidization quality, gas heating value and tar content in the gas.

In the aspect of temperature limits, E. Natarajan found out that the lower temperature in the gasification process is determined by the condition for complete carbon conversion. It may also depend on the elemental composition of husk and the equivalence ration [8]. The concentration of CO, H_2, and CH_4 mainly determines the heating value of the gas, since CO_2 and N_2 are inert and other combustibles are negligibly small. The heating value of the gas decreases with increasing bed temperature, which demands for higher equivalence ratio and subsequent dilution. In determines the gasifier efficiency, hot gas and cold gas efficiency could be used. The hot gas efficiency is defined as the ratio of chemical energy plus thermal heat in the gas to the chemical energy in the fuel while the cold efficiency is define as the ratio of chemical energy in the gas to that in the fuel. They found out that the cold gas efficiency could be achieved for more than 60% in fluidized bed gasifiers. The tar that contained in the gas is considered highly undirerable. The tar is defined as a mixture of condensable heavy hydrocarbon with higher molecular weighs.

2.4.2 Sugarcane Bagasse

Besides the rice husk is used for gasification conversion, other biomass is also suggested such as waste wood, straw [7], hazelnut and sugar bagasse. The experiment that will be carried out only need a little change for be done. Luis Augusto Barbosa Cortez [5] in 1999 had done a research with his group using a sugarcane bagasse as a biomass fuel for fluidized bed air gasifier. Most of the discussions made for the experiment in define the gas analysis and fluidization behaviors remain the same with the rise husk analysis. A series of parameters, such as lower heating value, heat losses, cold and hot gas thermal efficiency and gas yield were measured as a function of the gasification air factor. In addition, they found out that the heat losses to the environment include (1) losses in the soot at the cyclone exit, (2) losses in the tar leaving the reactor, (3) losses in the form of non-gasified carbon which remained in the reactor bed, (4) lack of proper equipment insulation and (5) error in estimating the pellet flow rate. In the conclusion, they decide that the sugarcane bagasse was low density and brittleness. These features lead to feeding difficulties, such as clogging and bridging. The high losses to the environment obtained are most likely due to the heat losses through the reactor non-insulated metal walls and to errors in quantifying the ungasified carbon.

2.4.3 Mixture of Coal and Sawdust

T.R. McLendon [11] in 2003 has done a research abut high-pressure co-gasification of coal and biomass in fluidized bed. The purpose of his research was to provide highly instrumented, steady- state operating data for numerical simulation matching and verification. Through the research, he made a comparison of CO, H_2, Cone Temperature, and Bed Pressure Drop for all coal/biomass tests reported compared to the base case. The general experiment proof that biomass is easy to gasify but not coal char. There is more reactive gas available to consume the coal char with less coal char, since the gas flow rates were unchanged. He also concludes that synergies with sub bituminous coal/biomass mixtures are not readily apparent in gasification. A most significant synergy exists with gasification of highly caking coals and biomass in the FBG since without the biomass, such coal cannot be processed at all. The particulate flow patterns in the FBG for swelling bituminous coals are greatly altered compared to particulate flow pattern for sub bituminous coals. Carbon utilization for the FBG is about the same as similar fluidized bed gasifiers using biomass.

2.5 Design of Fluidized Bed Reactor

Most of the report done by the researchers in their researches not included their reactor prototype. They only reported their result and discussion on the fluidization behaviors. Only a few of them included their reactor prototype in their report for easier reference according to their researches. Luis Augusto Barbosa Cortez [5] has included the reactor prototype that being used in Campinas, Brazil. The reactor is quite similar with the prototype in School of Mechanical Engineering, Universiti Sains Malaysia (USM) in Penang, Malaysia. The gasification system prototype consists of a series of modular components. Each module is connected by flanges facilitating access to the various components and to the inside of the reactor. Besides, it allows the maintenance and replacement of component. The whole system was assembled on top of a carbon steel structure constructed with U-type bars. The main construction features of the reactor are;

i) *The reactor main body (bed zone)*. It consists of refractory concrete cylinder covered on the exterior with carbon steel sheets (3.2 mm thick).
ii) *The air distributing plate*. It is use to avoid possible plugging which might occur when perforated plates are used.
iii) *The fuel feeder* with a screw feeder. It consists of a screw-type feeder.
iv) *The free-board zone*. It also defined as the height reached by the particles which leave the bed surface.
v) *The disengaging zone*. It is located above the free-board zone by which the gas exits the gasifier. In this section, the gas and ascending particles speed is reduced, enabling the majority of particles to fall back into the bed zone.
vi) *The gas cleaning equipment*. It consists of a cyclone placed after the gas disengaging zone. The cyclone separates the fine particles in the gas (ashes and free carbon) from the fuel gas.
vii) *The gas flare*. The produced gas is flared in a LPG burner, and the flue gas is discharged to the atmosphere through a 6m stack.
viii) *The inert bed material*. White electro-melted aluminium oxide with average particle diameter of 0.379mm is used.

The gasifier is designed for thermal capacity of 280 kWth producing 252.68 Nm^3/h of gas at an operating temperature of 760°C and the energy conversation was assumed to be 60% for the equipment calculations.

In 2003, T.R. McLendon [11] also includes the reactor prototype through their report. The reactor used in the experiment quiet different and upgraded but the general concepts of the reactor almost the same. The reactor provided with numerous internal thermocouple and differential pressure gauges are used. He gauges are used to determine particulate densities in the Fluidized Bed Gasifier (FBG). Then, solids are removed in three places; (1) underflow where the heavier particles come out the very bottom, (2) overflow where the medium particles come out at the level of first freeboard junction and (3) fly ash is removed in the cyclone. The issue of temperature is important, so that any thermocouple inside the gasifier reads the local temperature.

CHAPTER 3

DESIGN AND CALCULATIONS

3.1 Introduction

The gasification system that had been designed consists of a series of components. Each component is connected by flanges facilitating access to the various components and to the inside of the reactor. It also helped during the maintenance and replacement processes. The reactor is divided by different parts such as the plenum, the bed zone and the free board zone. There are also the disengaging zones where the gases will exits the gasifier. The gasification system is also supported with another system such as the fuel feeding system, the air distribution system, and the gas cleaning system. The cyclone ash collector is used for removal of elutriated solid particles in cleaning system.

The gasifier is designed for a thermal capacity power input of 700 kWth and expected to have thermal power output of 500 kWth and electric power output of 200kWe. The energy conversion efficiency is assumed to be 70% for the equipment design calculations.

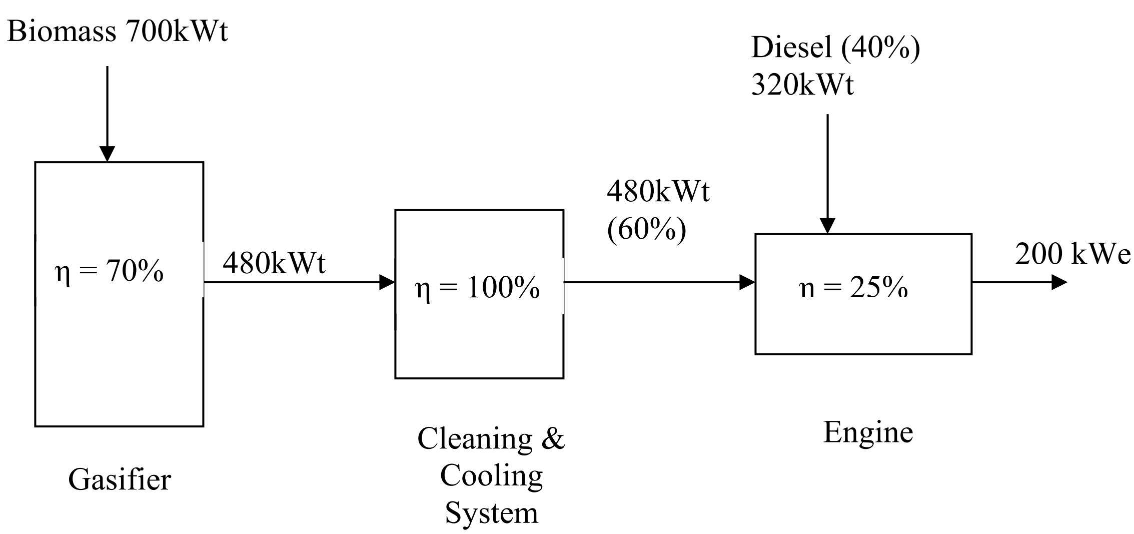


Figure 3.1 Power Generation System of 200kWe

3.2 The Components

The whole gasification components are built with carbon steel and assembled with U type bars. The structure is fixed to concrete ground using large fixed bolts. The details drawing of each component are included in Appendices.

3.2.1 The Bed Zone

The bed zone is a reactor main body. It consists of a 80 mm refractory concrete cylinder covered on the exterior with carbon steel, 3.5 mm thickness. It is 920 mm height and 560 mm diameter. It is connected to the screw feeder at rear. Inside the bed zone, it also include the air distributing plate or the bubble caps that being used to bubble the air supply to fluidize the fuel and sand. It also used to avoid possible plugging which might occur when perforated plates are used.

3.2.2 The Plenum

The plenum is situated below the bed zone. At the rear of the plenum, there is an ignition port for a burner and at bottom; it is connected with the blower. The ignition port is designed for LPG burner. The plenum is 550 mm height and 400 mm diameter.

3.2.3 The Free Board Zone

The Free board zone is located above the bed zone with 920 mm height. It is consists of a zone situated between the fluidized bed upper surface. It can also be defined as the height reaches by the particles which leave the bed surface.

3.2.4 The Disengaging Zone

The Disengaging zone is the part which the gas exits the gasifier. It is located above the free board zone. In this section, the gas and ascending particles speed is reduced, avoiding most of the particles to fall back into the bed zone. This zone diameter is twice more than the reactor internal diameter. It is built using 2.5 mm steel sheets.

3.2.5 The cyclone

The cyclone is one of the gas cleaning equipment. It is placed after the gas disengaging zone. It is functioned to separate the fine particles in the gas (ashes and free carbon) from the fuel gas. It is also built using 2.5 mm steel sheets.

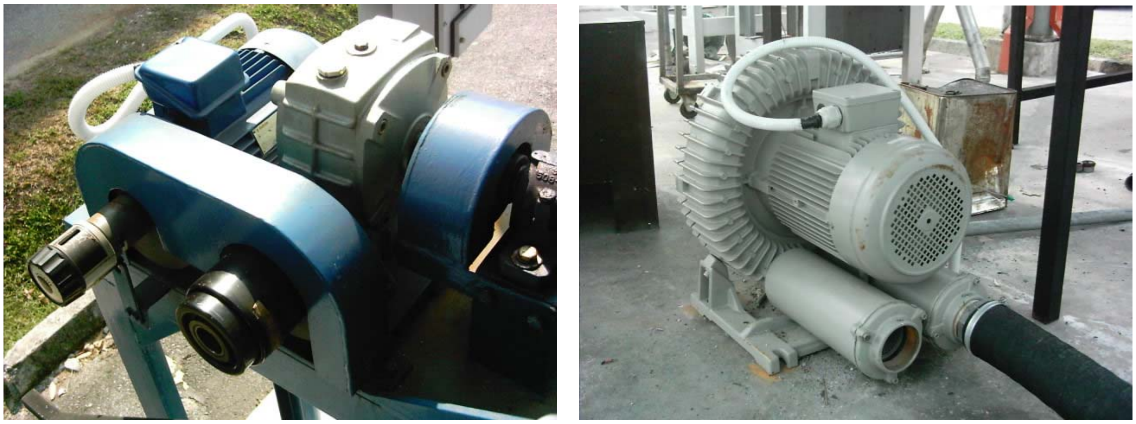
3.3 The Supporting System

The supporting systems are connected to the main gasification system. They are connected by flanges with fixed bolts.

3.3.1 The Feeding System

The Feeding system consists of a screw feeder with a variable thread of 150 mm diameter. It is operated by a concentric speed reducer driven by an electric motor. It is also joined with a hopper which functioned for fuel fed and sand inserting. The motor specifications used are;

Model	: Elektrim TEFC – A112M
Voltage	: 380 – 415 V
Frequency	: 50 Hz
Power	: 2 kW
Rotation	: 1440 / min
Capacity	: 45 kg



(a) (b)

Figure 3.2 (a) the feeding system (b) the air blower system

3.3.2 The Gas Cleaning System

The first phase design of the gas cleaning system only includes the cyclone that placed after the disengaging zone. The system should be linked with another ash collector. The development of this system and the whole gasification system had been done in second phase (development phase).

3.3.3 The Air Distributing System

The air distributing system is normally known as a blower. The blower is connected to the bottom of the reactor. There is also include the bubble cap design that is used to avoid possible plugging which might occur when perforated plates are used.

3.3.4 The Air Blower System

The air blower is used to blow the air into the gasifier. It is connected with ball valve to control the air flow rate. The specifications of the blower used are;

Model	: Relec, Type ES-729 Phase 3
Power	: 5.5 kW

Supply	: Δ 240 V, 21 A
	: Y 415 V, 12 A
Frequency Current	: 50 Hz
Rotation	: 2935 RPM
Maximum Capacity	: 8.8 m^3/min
Maximum Pressure	: 2900 MMAQ

Figure 3.3 The Gasifier System located in School of Mechanical Engineering, USM

3.4 The Design Parameter of Fluidized Bed

Some hydrodynamic study is needed in order to design the gasifier. Those values will be used to calculate some parameters and will be act as references for further design.

3.4.1 The Gasifier

Before a gasifier put into operation, it is essential to determine several important hydrodynamics parameters in the fluidized bed system so that it can be design effectively. Some of the hydrodynamics parameters are:

- Minimum fluidizing velocity
- Terminal velocity
- Flexibility of operation
- Slugging condition
- Bubble size and Velocity
- Transport Disengaging Height (TDH)

In order to determine the parameters, a few assumptions made as a reference. They are;

I. The fluidizing medium is air with viscosity (μ g) and density (ρ g) of 1.8838×10^{-5} $kgm^{-1}\ s^{-1}$ and $1.156\ kg\ m^{-3}$ respectively.

II. The bed material is sand with diameter (d_p) and density (ρ_p) of 7×10^{-4} m and 2550 $kg\ m^{-3}$.

III. The gravity, g is $9.81\ m\ s^{-2}$.

The prediction of minimum fluidization parameters are made by referring to Ergun Equation for fluidized beds.

$$\frac{1.75}{\varepsilon_f^3 \Phi} R_{ep_f}^{\ 2} + \frac{150(1-\varepsilon_f)}{\varepsilon_f^3 \Phi^2} R_{ep_f} = N_{GA}$$

if e_{mf} and Φ are not known, a modification of the Ergun Equation is used to estimate the minimum fluidization velocity. The modified Ergun Equation is rewritten as;

$$K_2 R_{ep_{mf}}^{\ 2} + K_1 R_{ep_{mf}} = N_{GA}$$

$$\text{where } K_1 = \frac{150(1-\varepsilon_{mf})}{\varepsilon_{mf}^3 \Phi^2} \text{ and } K_2 = \frac{1.75}{\varepsilon_{mf}^3 \Phi}$$

Then, Wen and Yu stated that K_1 and K_2 stay nearly constant over a wide range of particles and for $0.001 < R_{ep\ mf} < 4000$; thus giving a prediction of $V_{o\ mf}$ with a 34% standard deviation. This will let the equation become;

$$R_{ep\,mf} = \sqrt{\left(\frac{K_1}{2K_2}\right)^2 + \frac{1}{K_2} N_{GA}} - \left(\frac{K_1}{2K_2}\right)$$

for which Wen and Yu determined;

$$\left(\frac{K_1}{2K_2}\right) = 33.7 \text{ and } \frac{1}{K_2} = 0.0408$$

(a) <u>Minimum Fluidizing Velocity (U_{mf})</u>

Minimum fluidizing velocity is the gas velocity at which the pressure drop created is enough to balance the weight of the bed and at this point the bed is fluidized. This parameter is calculated in order to know the minimum gas velocity required to fluidize the bed. Before proceeding to calculate the minimum fluidizing velocity, it is vital to find the value of Archimedes number, N_{GA} or A_r;

$$N_{GA} = \frac{d_p^3 \rho(\rho_p - \rho)g}{\mu^2}.$$

$$= \frac{1.156 * (7x10^{-4})^3 (2550 - 1.156) 9.81}{(1.8838x10^{-5})^2}$$

$$= 27937.96$$

To find the minimum fluidizing velocity, V_{of} or U_{mf}, , from equation

$$R_{ep\,f} = \frac{\rho V_{of} d_p}{\mu}$$

Minimum fluidizing velocity, U_{mf}, is

$$U_{mf} = \mu_g / \rho_g d_p \; R_{ep\,mf}$$

and