# SISTEM PENGGAS ALIRAN BAWAH BIOMASS 20kWe

## *20 kWe BIOMASS DOWNDRAFT GASIFIER SYSTEM*


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# ABSTRAK

Sebuah system penggas yang mampu menghasilkan tenaga elektrik sebanyak 20kWe telah dibangunkan untuk menghasilkan tenaga elektrik untuk dibekalkan di kawasan pendalaman di Pusat pengajian Kejuruteraan Mekanik, Universiti Sains Malaysia. Di dalam kajian yang dijalankan, sistem penggas yang digunakan di dalam penggas mempunyai aliran rendah dengan kayu merupakan sumber biomass yang digunakan.

Pelbagai pengubahsuaian telah dijalankan seperti kerja kerja pemasangan dan pengubahsuaian semasa. Ini bertujuan untuk mengesuaikan dengan keadaan sekeliling dan untuk meningkatkan lagi prestasi sistem tersebut.

Ujikaji telah dijalankan dengan menggunakan kayu sebagi sumber bahan mentah didalam sistem penggasan. Prestasi sistem tersebut dapat dinilai dengan mencari kecekapan keseluruhan sistem, kandungan kelembapan nilai penggunaan diesel.

Ujikaji terhadap sistem penggasan juga telah dilakukan dalam membangunkan sistem panggas20kWe bersama denagn pemanas elektrik sebagai penyerap kuasa. Kecekapan keseluruhan bagi sistem ini pada kelajuan maksimum ialah 3.64% hingga 15.75% dan kelajuan minimum ialah 4.16% to 21.5%. Nilai peratusan ini bergantung kepada beban elektrik yang disambung kepada peanjana. Kadar alir udara juga meningkat berkadar denagn kelajuan penjana. Kandungan kelembapan kayu yang diuji agak rendah tetapi masih di dalam julat spesifikasi.

# ABSTRACT

A small scale downdraft gasifier that has producing 20kW biomass generator had been set to provide electrical power for the rural areas have been developed. The downdraft gasifier is erected in the laboratory at the School of Mechanical Engineering, Universiti Sains Malaysia (USM). In this research, gasification system in used is gasifier in lower flow with a wood as a biomass sources. Many modification were made during installation and this experimented to make it suit with surrounding condition and to improve the performance of the system.

Experiments have been performed of gasification of furniture wood as raw material. The system performance of the gasifier had been determined by finding the efficiency of the system, moisture content and diesel displacement.

The system of the downdraft gasifier also involved the development of power absorbing system using 24 kW electrical loading as heating element has been successfully done. The overall efficiency of the system at full speed is 3.64% to 15.75% and minimum speed is 4.16% to 21.5% depending on the electrical load used to absorb the power from the generator. Air flow rate of the producer gas also increase with the speed of generator. The moisture content of the wet wood is quite small but still in the range.

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# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Malaysia has been fortunate to be relatively well endowed with sources of energy. Generally energy can be separated into two main sources: fossil fuel as an energy that cannot be renewable and renewable energy. Fossil fuel such as petroleum, coal, natural gas and nuclear are the energy that widely being used in transportation, manufacturing industries sector and electricity generation. Sources of energy such as solar, biomass, wind, wave, hydro, tidal and geothermal are generally called renewable sources of energy because they are not depleted in time and one of most promising renewable sources of energy is the energy from biomass.

Base on National Energy Balance 2003 (Appendix A), Energy scenario in Malaysia growth significantly in the past year. Primary Energy Supply, which has recorded at 50,452 ktoe (kilo tonne of oil equivalent) in 2001, increased to 50,749 ktoe in 2002 (0.6%) and increase further to 54,194 ktoe in 2003 (6.8%). Final Energy Demand, which was recorded at 31,515 ktoe in 2001, increased to 33,290 ktoe in 2002 (5.2%) and increased further in 2003 to 34,586 ktoe (3.9%). The transport sector still retained its position as the largest consumer of energy in 2003, recording an increase of energy consumption from 13,442 ktoe in 2002 to 14,271 in 2003. The industrial sector is the second largest consumer of energy and recorded a consumption of 12,854 ktoe of energy in 2002 and 13,472 ktoe of energy in 2003. This energy resources will be decreasing varies with time being because of highly demands in the world. This scenario highly affects the world economic when year by year because of the increasing price of crude oil.

According to Department of Electricity and Gas Malaysia, 60 percent of electrical power supplied generated by using natural gas and 40 percent had been generating by using sources such as petroleum, coals and hydro. The field of using biomass to produce electricity is a proven technology and there are many related technology options to choose from like using a fixed bed system, stoker grate system or a fluidized bed system. Awareness about this problem, a small scale downdraft gasifier that has producing 20kW biomass generator set had been developed to provide electrical power for the rural areas. The downdraft gasifier is erected in the laboratory at the School of Mechanical Engineering, Universiti Sains Malaysia (USM). Experimental investigations have been done to determine the performance of the downdraft gasification system.

## 1.2 BIOMASS AS RENEWABLE ENERGY

Biomass is one of the renewable resources that could play a substantial role in a more diverse and sustainable energy mix. Biomass may be defined as any renewable source of fixed carbon or non-fossil fuel organic material that is available for consumption on a renewable basis, which can be converted to energy as either electricity or liquid fuel. The term is generally used to describe plant material such as wood, wood residues, agricultural crops and their residues. Industrial and municipal wastes are often also considered as biomass due to their high percentages of food waste and fiber. Electricity generation is considered the most lucrative opportunity for commercial exploitation of biomass, by virtue of the high value of electricity. Biomass to electricity schemes already provides over 9 $GW_e$ of world-wide generating capacity.

**Advantages of Biomass**

Most biomass fuels are very cheap or sometimes even free. Biopower makes productive use of crop residues, wood-manufacturing wastes, and the clean portion of urban wastes. These useless wastes would otherwise be open-burned, left to rot in fields, or buried in a landfill. Wastes that rot in the field often produce methane, a greenhouse gas even more potent than carbon dioxide. Burying energy-rich wastes in a landfill is like burying petroleum instead of using it.

Using biomass does not add to global warming. Plants use and store carbon dioxide ($CO_2$) when they grow. This is then released when the plant material is burned. Other plants then use that released $CO_2$ in growing. So using biomass closes this cycle of storing carbon dioxide. Carbon dioxide is a gas that, when there's too much, can contribute to the "greenhouse effect" and global warming. So, the use of biomass is environmentally friendly because the biomass is reduced, recycled and then reused. It is also a renewable and sustainable resource because it comes from plants. This means it can be grown over and over again. Biomass power plants also have fewer emissions that cause acid rain because it does not contain any sulphur content.

## 1.3 ENERGY CONVERSION SYSTEM

Generally energy conversion system of biomass involves three types of processes. These processes are:

i) Direct combustion process
ii) Biological conversion process
iii) Thermochemical conversion process

### 1.3.1 Direct combustion process

- Direct combustion is an exothermic process that can be used for heating, cooking and for the production of steam that is then used to generate electricity. In fact open fire cooking and heating have been use for thousands of years since man discovered the benefits of fire. The main fuels for this application are wood, wood waste after logging, straw, etc. which are burned in stoves or open fires. Direct combustion is still a major source of energy in the developing countries and it is also applied in producing electricity and combustible engine. Although this process is the easiest way to produce energy, but this method had a lot of disadvantages such as:
- Wasting 70% to 80% of biomass energy during combustion
- Polluted air by producing carbon dioxide and carbon monoxide

### 1.3.2 Biological conversion process

Biological conversion process involves transformation of biomass into storable energy. It takes two forms: Fermentation and anaerobic digestion. Fermentation that takes place in the presence of an atmosphere containing oxygen and which produces alcohol as an end product while anaerobic digestion that requires an environment free of oxygen and which has methane as an end product. (An anaerobe is microorganism (1) *Mesophilic* (30°c – 40°C), (2) *Thermophilic* (50°C – 60°C) that can live and grow without air or oxygen. It gets its oxygen by decomposition of matter containing it.) The operational temperature up to 65°C and require moisture content at least 80%. Gas obtained from anaerobic digestion of organic wastes or animal excreta is known as biogas. The process of digestion of organic wastes for the production of combustible gas is a century old technology, but since oil, wood, coal and other combustible matter were then cheap, no attention was paid to the production of biogas for use as a combustible gas for cooking and heating.

### 1.3.3 Thermochemical conversion process

In thermochemical conversion process, there are two processes that are used to produce fuels from dry biomass;

i) Pyrolysis

ii) Gasification

Pyrolysis is the most fundamental process and is considered to occur in all thermochemical conversion processes. It is defined as the decomposition of biomass material in the absence of air or oxygen at elevated temperatures to yield a variety of energy rich products such as char, gas and oil

Gasification is similar to Pyrolysis except that the process occurs in limited presence of air or oxygen. The product is a low heating value fuel gas containing mainly carbon monoxide and hydrogen.

## 1.4 OBJECTIVES AND OVERVIEW OF THE RESEARCH WORK

The objective of the current research was to determine the performance of 20kWe downdraft gasifier bed system. This experimental and researches involve performance data including gas flows, heating value, efficiency of the system, specific biomass consumption (SBFC), gas analysis, effect of diesel fuel for power absorbing system using heating element as electrical loads.

During project period, there are several adjustments and developing process:

- 18kWe heating element for electrical loading from generator set
- Piping system to flow the producer gas from gasification system to generator set.
- Modification of diesel fuel metering
- Generator fuel rack

The theory and the chemistry of gasification reaction by using wood as biomass resource are elaborated in Chapter 2 so as to understand the phenomena of pyrolysis and gasification.

A review of theory and previous work of generating gasification system has been elaborated in Chapter 3, starting with air-fuel ratio theory, equivalent ratio , moisture content of biomass, theory of biomass gasification system with loading loads and lastly the review of previous work of the system.

Beyond understanding the principles of biomass gasification and the types of gasifier, there was a need to be able to predict the performance of a particular design. The method of the experimenting downdraft gasifier is discussed in Chapter 4.

Chapter 5 discusses the experimental analysis that have been done involves moisture content test, gasification system with different electrical loading and mass balance of the experiment. All of the results will be calculates and discuss to determine the performance of the system.

Finally in Chapter 6, the report concluded with prospects for biomass gasification and recommendation for further work in this area.

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# CHAPTER 2
# BIOMASS GASIFICATION SYSTEM

## 2.1 INTRODUCTION

Gasification is the conversion of biomass (a renewable source of fixed carbon) into a fuel gas (called "producer gas"), which can be used in heat, power or combined heat and power applications. The process of gasification has also been called "starved combustion". Biomass gasification is also important in its role of providing a source of fuel for electricity and heat generation. The type of biomass gasification (2.2) will be describing more about gasification.

## 2.2 TYPE OF BIOMASS GASIFICATION

### 2.2.1 Pyrolysis gasification

Historically pyrolysis processes have been operated primarily to produce char and oil products, with some of the gas produced being burned to provide the heat for the process. However some processes burn the oil and the char to recover their heat in the form of higher yields of medium energy gas. The only gasifying agent in this process is heat.

### 2.2.2 Air gasification

Air gasification is the most common, simple and the cheapest type of gasification process. The gasifying agent for this process apart from heat is air. Air contains 79 % by volume of Nitrogen which does not react with the biomass. Thus when using air as the gasifying agent, the nitrogen dilutes the gas produced and hence lowers its heating value to about 4-5 $MJ/m^3$. However the gas produced is suitable for operation of boilers or engines but is too diluted to be efficiently transported in pipelines over long distances.

### 2.2.3 Oxygen gasification

If oxygen is used as gasifying agent instead of air, a medium energy gas of about 8 $MJ/m^3$ will be produced suitable for limited pipeline distribution. This gas can be used for industrial process heat or as synthesis gas to make methanol, gasoline, ammonia, methane or hydrogen.

### 1.24 Hydro gasification

Hydro gasification is a process when hydrogen is used as the gasifying agent producing methane as the product. This process is also called methanation. Hydrogen can be added to the system or generated in the reaction by the shift reaction between carbon monoxide and steam.

### 2.25 Steam gasification

Steam is sometimes added with air as gasifying agent to increase the quality of the gas produced and to reduce the high heat of reaction. The presence of small quantity of steam helps in the production of methane. The steam is also generated from the drying process of biomass.

## 2.3 CHEMICAL OF BIOMASS GASIFICATION

Chemical formula of wood as biomass given by:

$$\mathbf{CH_{1.4}\ O_{0.6}}$$

This is sufficiently accurate since wood is made up of which has a formula of cellulose:

$$\mathbf{CH_{1.66}O_{0.83}}$$

and Lignin which has a formula: $\mathbf{CH_{1.23}O_{0.38}}$

The ideal gasification reaction with oxygen can be written as follow:

$$CH_{1.4}O_{0.6} + 0.2\,O_2 = CO + 0.7\,H_2$$

The reaction of gasification is an endothermic reaction which requires heat to convert the solid wood into carbon monoxide and hydrogen. The wood can either be heated externally or can easily be heated internally by partially burning the wood. An additional amount of oxygen has to be supplied to provide the combustion heat for the gasification reaction. The above reaction becomes the theoretical global gasification reaction given by

$$CH_{1.4}O_{0.6} + 0.45O_2 = 0.7CO + 0.3CO_2 + 0.55H_2 + 0.2H_2O$$

## 2.3 Thermochemical reaction of biomass gasification

In biomass gasification process, there are four phase involves: (1) drying, (2) pyrolysis, (3) oxidation and (4)gasification. These reactions may be outlined as follows.

### 2.3.1 Drying phase

In this phase, the biomass is dried from the heat supplied through partial burning of biomass. As the result of drying process, the wet biomass will be dry and pruduce a steam. The equation of this phase had shown as below:

**Wet biomass + heat = dry biomass + steam**

### 2.3.2 Pyrolysis phase

Pyrolysis or devolatilisation is defined as the decomposition of biomass material in the absence of air or oxygen at elevated temperatures to yield a variety of energy rich products such as char, gas and oil. The phase occurs at a temperature greater than 200$^{o}$C producing char, gas and tar (vapour or liquid). The relative quantities of these products and their exact composition depend strongly on the rate of pyrolysis. The heat of pyrolysis $h_p$ is an important quantity for any engineering application of pyrolysis including gasification. It is defined as the heat required bringing the biomass surface to a temperature Ts somewhat above that required for pyrolysis in order to drive the reaction at a reasonable rate. The pyrolysis products then leave the biomass particle surface at a temperature $T_S$. The heat of pyrolysis is estimated to be in the range of about 2150kJ/kg (about 10 % of the heat of combustion).

The reaction associated with pyrolysis is thus as follows:

$$\textbf{Dry biomass heat} = C_{(char)} + CO + CO_2 + H_2 + H_2O + CH_4 + C_nH_m + \text{Tar}$$

### 2.3.3 Oxidation or combustion

Char and the volatiles produced in the pyrolysis phase are completely burned to provide the necessary heat for further pyrolysis and also for the char gasification or reduction reactions. The product of the shown as equation below:

$$C + O_2 \rightarrow CO_2$$

$$H_2 + 0.5O_2 \rightarrow H_2O$$

$$CO + O_2 \rightarrow CO_2$$

The oxygen is supplied from air as the gasifying agent. In downdraft gasifiers the pyrolysis products will have to pass through the combustion zone thereby cracking the tar and thus lowering its content to about 0.1 % of the weight of the feedstock.

$$\text{Tar} + O_2 = CO + H_2 + CO_2 + H_2O$$

### 2.3.4 Reduction or gasification process

This is sometimes known as char gasification or reduction phase is the phase when char (carbon) undergoes reaction which liberate gases from the char. The following are the reactions associated with char gasification.

The heterogeneous reaction of carbon with limited supply of oxygen or air results in incomplete combustion of char as in equation (iii) to form carbon monoxide. This is an exothermic reaction according to :

$$C + 0.5O_2 \rightarrow CO$$

Similarly the product of combustion, carbon dioxide reacts with the char to form a heterogeneous Bouduard reaction which is an endothermic reaction.

$$C + CO_2 \rightarrow 2CO$$

Another endothermic reaction is the heterogeneous water-gas reaction between the char and the water vapour formed from the drying, pyrolysis or the tar cracking processes.

$$C + H_2O \rightarrow CO + H_2$$

The final heterogeneous reaction is the methane formation involving the char and the hydrogen.

$$C + H_2O \rightarrow CH_4$$

However the above reaction is unstable and the methane converts to form carbon monoxide and hydrogen through a homogeneous reaction between the methane and water vapour.

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

The Buoduard and the water-gas reactions can be combined to form the shift reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$

## 2.4 ADVANTAGES OF GASIFICATION SYSTEM

Conversion of solid biomass into combustible gas has all the advantages associated with using gaseous and liquid fuels such as clean combustion, compact burning equipment, high thermal efficiency and a good degree of control. In locations, where biomass is already available at reasonable low prices (e.g. rice mills) or in industries using fuel wood, gasifier systems offer definite economic advantages. Biomass gasification technology is also environment-friendly, because of the firewood savings and reduction in $CO_2$ emissions. Biomass gasification technology has the potential to replace diesel and other petroleum products in several applications, foreign exchange.

# CHAPTER 3

# LITERATURE REVIEW

## 3.1 INTRODUCTION

During this chapter, there are several theories used to generate gasification system for variable electrical loads. This theory involves:

- Air- fuel ratio theoretical gasification processes
- Equivalent ratio
- Moisture content of biomass
- Low Heating Value of wood ($LHV_{wood}$)
- Theory of biomass gasification system with electrical loads

## 3.2 AIR- FUEL RATIO THEORETICAL GASIFICATION PROCESSES

The air-fuel ratio is essential to determine the amount of air required to gasify a known quantity of biomass material. From the Global Chemical Reaction as follows:

$$\mathbf{CH_{1.4}O_{0.6} + 0.45(O_2 + 3.76N_2) \rightarrow 0.7CO + 0.3\,CO_2 + 0.55H_2 + 0.2H_2O + 1.692N_2}$$

Composition for each gas:

- $CH_{1.4}O_{0.6}$ = 12 + (1 x 1.4) + (16 x 0.6) = 23 kg
- $O_2$ = 0.45 (2 x 16) = 14.4 kg
- $N_2$ = (0.45 x 3.76) x (2 x 14) = 47.4 kg
- CO = 0.7(12 + 16) =19.6 kg
- $CO_2$ = 0.3(12 + 16x 2) = 13.2 kg
- $H_2$ = 0.55 x 1x 2 = 1.1 kg
- $H_2O$ = 0.2(2 x 1 + 16) = 3.6 kg
- $N_2$ = 1.692 x 2 x14 = 47.4 kg

By substituting the gas value into the equation,. The above equation becomes,

$$\mathbf{23CH_{1.4}O_{0.6} + 14.4O_2 + 47.4N_2 \rightarrow 19.6CO + 13.2CO_2 + 1.1H_2 + 3.6H_2O + 47.4N_2}$$

Divide the equation with 23, the final equation is become:

$$\mathbf{CH_{1.4}O_{0.6} + 0.626O_2 + 2.06N_2) \rightarrow 0.852CO + 0.574CO_2 + 0.024H_2 + 0.157H_2O + 2.06N_2}$$

For 1 kg of $CH_{1.4}$ $O_{0.6}$, the amount of $O_2$ required is 0.626 kg. Therefore the amount of air which is used as the gasifying agent per kg of biomass is given by

**0.626 kg/0.233 = 2.687 kg**

Therefore the gravimetric air-fuel ratio for theoretical gasification process is given by

$$\mathbf{(A/F)_{theoretical} = 2.69}$$

The volume of air required for theoretical gasification will be about

**2.69/1.2 = 2.24 $m^3$/kg of biomass**

The above air fuel ratio shows that for 1 kg of biomass material the amount of air required is about 2.24 $m^3$. The value is regardless of the rate of biomass material consumed and the flow rate of the air supplied. There is a balance whereby the higher the flow rate of air supplied, the higher is the rate of biomass consumed. However the higher the flow rate of air supplied, the higher is the rate of gasification and hence the higher the flow rate and the rate of energy output of the producer gas.

## 3.3 EQUIVALENT RATIO

In order to reduce the number of parameters on which the performance of the biomass gasifier depends, an equivalence ratio is defined to reflect the combined effect of air flow rate, rate of wood supply and duration of the run.

The equivalence ratio for each run is calculated by:

$$\textbf{Equivalence ratio, Ø} = \frac{(A/F)_{teori}}{(A/F)_{stoichiometric}}$$

$$= \frac{\text{(Flow rate of air supply)} \times \text{(Duration of the run)}}{\text{(Mass input of wood)} \times \text{(A=F for =1):}}$$

(A=F ) for =1 is 5 :22 m 3 of air =kg of wood. The equivalence ratio for the gasifier is found to be in the range 0.268 –0.43, which is within the range for ideal and theoretical gasification (0.19 –0.43).

The amount of air required for complete combustion of the biomass material to form carbon dioxide and water vapour can be represented by

$$\mathbf{CH_{1.4}O_{0.6} + 1.05\ O_2 \rightarrow CO_2 + 0.7\ H_2O}$$

In mass form,

$$\mathbf{(23)\ CH_{1.4}O_{0.6} + (32)1.05\ O_2 \rightarrow (44)CO_2 + 0.7\ (18)H_2O}$$

The amount of oxygen required per kg of biomass material is 1.46 kg. Therefore the air - fuel ratio becomes 6.27 kg of air/ kg of biomass or in terms of volume, 5.22 $m^3$/ kg of biomass.

Hence for equivalent ratio (ϕ) of unity, the air-fuel ratio is 5.22 $m^3$/kg of biomass. The equivalent ratio and air/wood ratio of gasification shown on Table 3.1.

Table 3.1: Air/ fuel ratio of gasification

| | Combustion | Theoretical gasification | Ideal gasification |
|---|---|---|---|
| Equivalence ratio | 1 | 0.43 | 0.19 |
| Air/wood ratio (kg air/kg biomass) | 6.26 | 2.69 | 1.19 |

Similarly the equivalent ratio can also be determined from the number of moles of oxygen used in the reaction. For equivalent ratio of unity the number of mole of oxygen is 1.05. Hence for ideal gasification where the number of moles of oxygen used is 0.2, the equivalent ratio is 0.19. Likewise for theoretical gasification where the number of moles of oxygen is 0.45, the equivalent ratio is 0.43. Therefore the equivalent ratio for gasification is 0.19-0.43 ranging between the ideal gasification and the theoretical gasification.

## 3.4 MOISTURE CONTENT OF BIOMASS

The presence of moisture is of prime importance for the success of the gasification process and tends to reduce the heating value of the biomass. From Appendix B**,** H.E.M. Stassen and H.A.M. Knoef given the value of moisture content of the wood is around 10% to 60% and $LHV_{wood}$ is between ranges of 8400kj/kg to 17000 kJ/kg. Carre et al (1989) has given the following equation relating the lower heating value and the moisture content of biomass wood. They considered that the lower heating value of ash free dry biomass wood has an approximate LHV of 18.8 MJ/kg.

The moisture content is given by:

$$MC(\text{dry basis}) = \frac{\text{Weight of dried biomass - Original weight of biomass}}{\text{Weight of dried biomass}}$$

$$MC(wet\ \text{basis}) = \frac{\text{Weight of dried biomass - Original weight of biomass}}{\text{Weight of original biomass}}$$

## 3.5 LOW HEATING VALUE OF WOOD ($LHV_{wood}$)

The LHV of the gas product decreases as the moisture content of the feed increases. The gas compositions in particular CO and $CO_2$ are very much affected by the increase of moisture content in the biomass feed. The concentration of CO reduces whilst $CO_2$ increases as a result of the reaction between CO and steam. $CH_4$ increases slightly due to the reaction between carbon and hydrogen. From the Table 3.2 below show the Low Heating Value for combustible gas.

Table 3.2: Low heating Value for combustible gas

| Gas | LCV (MJ/kg) |
|---|---|
| CO | 11.97 |
| $H_2$ | 10.22 |
| $CH_4$ | 33.95 |
| $C_2H_6$ | 60.43 |

## 3.5 THEORY OF BIOMASS GASIFICATION SYSTEM WITH ELECTRICAL LOADS

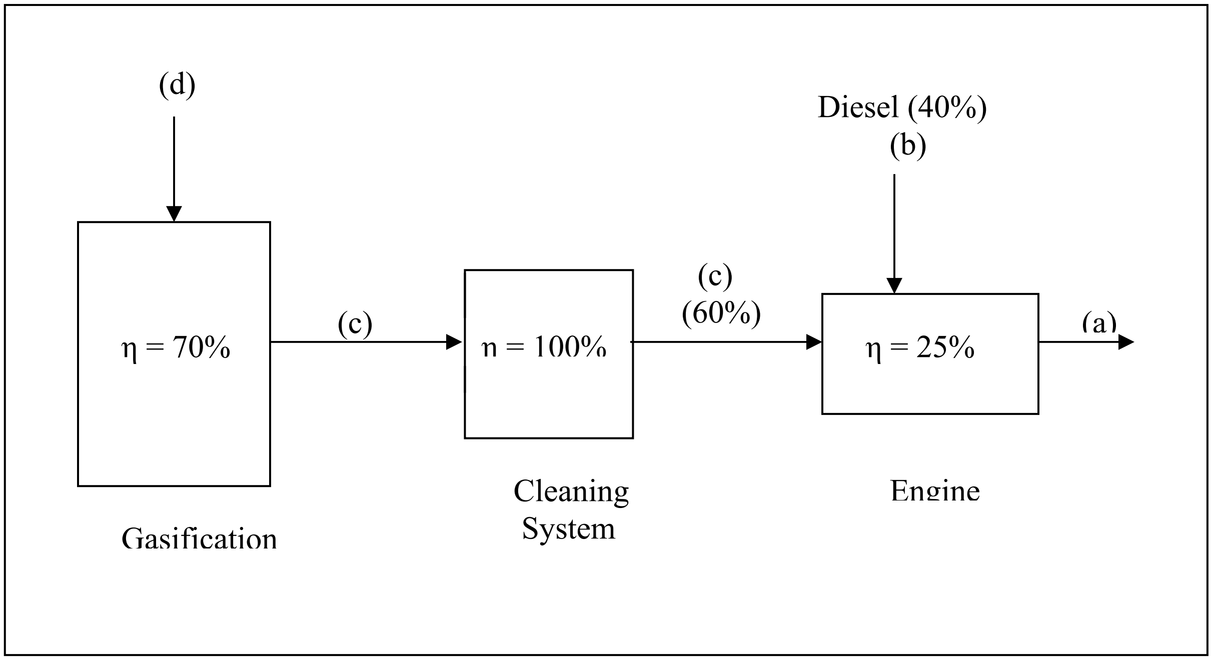


Figure 3.1: Biomass power generating system

Where:

a = Electrical loading (3kWe – 18kWe)

b = Thermal power of diesel fuel entering the engine (kWt)

c = Thermal power of producer gas entering the engine (kWt)

d = Thermal power of biomass wood entering the downdraft gasifier

To determine the output power of gasification system, there is several assumptions that should been taken:

**Assumption:**

- Engine efficiency, $\eta = 25\%$
- Cleaning system efficiency, $\eta = 100\%$
- Gasifier efficiency, $\eta = 70\%$
- Percentage of diesel fuel entering the engine = 40%
- Percentage of producer gas entering the engine = 60%

- Calorific value of producer gas, CV = 4 $MJ/m^3$
- Energy content of woods = 15 MJ/kg

**Data:**

- Calorific value of diesel fuel, CV = 43.2 $MJ/m^3$
- Density of diesel fuel, $\rho$ = 828 kg/ $m^3$

**Calculation:**

According to Figure, to producing electrical power W= 18kWe heating element connecting with the generator set, the thermal input, $W_{in}$:

- Loading heating element (18kWe), $\eta$ = 25%

  For $\eta$ = 100%:

  $W_{in}$ = (18 / 25) x 100% = 72 $kW_t$

- $W_{in}$ = 40% from diesel fuel and 60% from producer gas

  a) Power output from producer gas, $P_{out}$ = 0.6x72 = 43.2 kWt

  b) Power output from diesel fuel, $P_{out}$ = 0.4x72 = 28.8 kWt

- Assume that $\eta$ = 100% at cleaning system, Power input from producer gas entering the cleaning system, $P_{in}$ = 43.2 kWt

With assume that gasifier efficiency is about 70%, the thermal power input supplies into gasifier can be determined by:

- Biomass (wood), $P_{in}$ = (43.2/70 ) x 100% = 61.71kWt

  Feed rate of biomass (wood), $\dot{m}$ = 61.71/15000 = 0.0041 kg/s

  $\dot{m}$ = 14.81 kg/hours

a) Producer gas:

With producer gas power output, $P_{out}$ = 43.2kWt, a flow rate of the producer gas can be determined:

- Assume that calorific value of producer gas, CV = 4MJ/$m^3$

Flow rate of the producer gas, $V_g = P_{out}/CV$ = 48kWt / 4MJ/$m^3$ = 0.0108 $m^3$/s

$V_g$ = 38.88 $m^3$/hours

b) Diesel fuel:

With producer gas power output, $P_{out}$ = 28.8kWt, a flow rate of the diesel fual can be determined:

- **Data:**

Calorific value of diesel fuel, CV = 43.2 MJ/$m^3$

Density of diesel fuel, ρ = 828 kg/ $m^3$

Flow rate of the diesel fuel, $V_g = P_{out}$ / (CV x ρ)

= 28.8kWt / (43.2 MJ/$m^3$ x 828 kg/ $m^3$ )

= 8.05 x $10^{-7}$ m3/s

$V_g$ = 0.8 ml/s

In the way to determined air flow rate input there are two methods can be used:

1. Air- fuel ratio theory, $(A/F)_{theory}$ = 2.69 and the air volume need for every 1 kg biomass(wood), $V_{air}$ = 2.24 $m^3$/kg biomass

   Air flow rate, $V_{air}$ = 2.24 $m^3$/kg x 14.81 kg/hours

   $V_{air}$ = 33.17 $m^3$/hours

2. Nitrogen ratio of $N_2$ air to nitrogen, $N_2$ producer gas:

   Composition theory for nitrogen in both condition is :

   $(N_2)_{air}$ = 79%

   $(N_2)_{producer\ gas}$ = 45%

   $V_{air}$ = (45 / 95) x 33.17 $m^3$/hours

   $V_{air}$ = 15.71 $m^3$/hours

*This calculation repeats for different loading of heating element and the data shown in table below:

Table 3.3: Performance data of gasifier system with electrical loading.

| No of loads | Loads (kWe) | $P_{th}$ Prod. Gas (kWt) | $P_{th}$ Diesel (kWt) | $V_g$ (Prod.Gas) ($m^3/h$) | $V_g$ Diesel ($m^3/h$) | $V_g$ Diesel (ml/s) | V air ($m^3/h$) |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 7.20 | 4.80 | 6.48 | $13 \times 10^{-6}$ | 0.13 | 2.62 |
| 2 | 6 | 14.40 | 9.60 | 12.96 | $27 \times 10^{-6}$ | 0.27 | 5.24 |
| 3 | 9 | 21.60 | 14.40 | 19.44 | $40 \times 10^{-6}$ | 0.40 | 7.86 |
| 4 | 12 | 28.80 | 11.52 | 25.92 | $53 \times 10^{-6}$ | 0.53 | 10.47 |
| 5 | 15 | 36.00 | 24.00 | 32.40 | $67 \times 10^{-6}$ | 0.67 | 13.09 |
| 6 | 18 | 43.20 | 28.80 | 38.88 | $80 \times 10^{-6}$ | 0.80 | 15.71 |

# CHAPTER 4

# BIOMASS GASIFIER SYSTEM

## 4.1 INTRODUCTION

Generally gasifier system can be defined as a process in which solid biomass fuels are broken down by the use of heat in an oxygen-starved environment, to produce a combustible gas. A biomass gasifier system consists primarily of a reactor into which fuel is fed along with a limited (less than stoichiometric or that required for complete combustion) supply of air. Heat for gasification is generated through partial combustion of the feed material. The resulting chemical breakdown of the fuel and internal reactions result in a combustible gas usually called 'producer gas'. In this chapter will be discuses more about type of biomass gasifier and the design of gasifier system that have been develop for this project.

## 4.2 TYPE OF BIOMASS GASIFIER

There are two different types available in gasifier system:

i) Fixed bed gasifier

ii) Fluidized be gasifier

### 4.2.1 Fixed bed gasifier

Fixed-bed gasifier describe by the gas flowing directly through the gasifier. There are three type of gasifier (H.E.M. Stassen and H.A.M. Knoef) available:

- Upward gasifier
- Downdraft gasifier
- Horizontal gasifier

### 4.2.1.1 Updraft or counter current gasifier

The simplest type of gasifier is updraft gasifier. The biomass is fed at the top of the reactor and moves downwards as a result of the conversion of the biomass and the removal of ashes. The air intake is at the bottom and the gas leaves at the top. The biomass moves in counter current to the gas flow, and passes through the drying zone, the distillation zone, reduction zone and the oxidation zone. The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high gasification efficiency. In this way also fuels with an high moisture content (up to 50 % wb) can be used. Major drawbacks are the high amounts of tar and pyrolysis products, because the pyrolysis gas is not lead through the oxidation zone. This is of minor importance if the gas is used for direct heat applications, in which the tars are simply burnt. In case the gas is used for engines, gas cleaning is required, resulting in problems of tar-containing condensates. Figure 4.2 below show the updraft gasifier process.

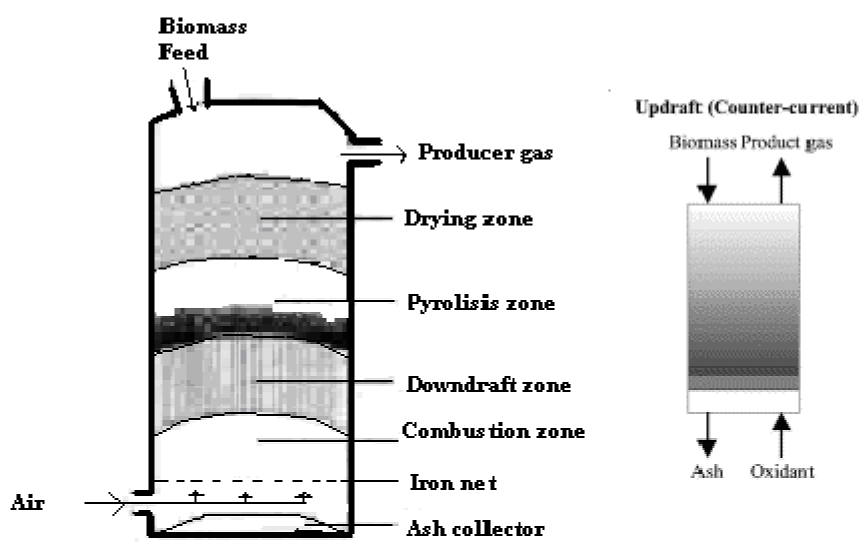


Figure 4.1: Updraft gasifier

### 4.2.1.2 Downdraft gasifier or co-current gasifier

By the conventional downdraft gasifier biomass is fed at the top of the reactor and air intake is at the top or from the sides. The gas leaves at the bottom of the reactor, so the fuel and the gas move in the same direction. The pyrolysis gasses are lead through the oxidation zone (with high temperatures) and or more or less burnt or cracked. Therefore the producer gas has low tar content and is suitable for engine applications. In practice however, a tar-free gas is seldom if ever achieved over the whole operating range of the equipment. Because of the lower level of organic components in the condensate, downdraft gasifier suffers less from environmental objections than updraft gasifier. Figure 4.2 below show the downdraft gasifier process.

Drawbacks of the downdraft gasifier are:

- the high amounts of ash and dust particles in the gas;
- the inability to operate on a number of unprocessed fuels, often pelletisation or briquetting of the biomass is necessary
- the outlet gas has a high temperature leading to a lower gasification efficiency;
- the moisture content of the biomass must be less than 25 %.

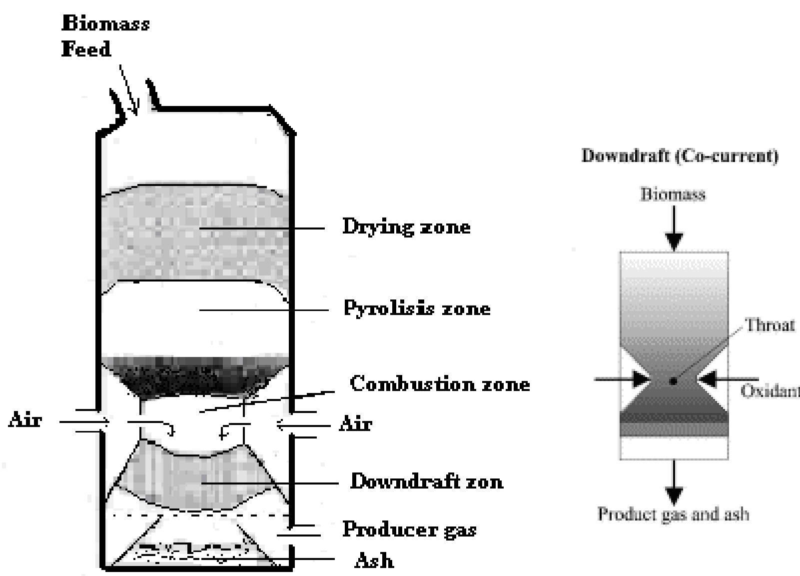


Figure 4.2: Downdraft gasifier