PRESTASI ENJIN PEMBAKARAN DALAM DENGAN MENGGUNAKAN BIOJISIM SEBAGAI BAHANAPI

(PERFORMANCE OF INTERNAL COMBUSTION ENGINE USING FUEL FROM BIOMASS)

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A	Area of piston, (m^2)
A/F	Air fuel ratio
a	Crank radius, (m)
B	Bore, (m)
Bmep	Brake mean effective pressure, (kPa)
Bsfc	Brake specific fuel consumption, (g/kWh)
bp	Brake power, (kW)
CI	Compression ignition
CPO	Crude palm oil
DI	Direct injection
fp	Friction power, (kW)
HRR	Heat release rate
IC	Internal combustion
ip	Indicated power, (kW)
L	Length of stroke, (m)
LCV	Lower calorific value, (kJ/kg)
l	Length of connecting rod, (m)
m_a	Mass of dry air
m_s	Mass of water vapour
$\dot{m}_a$	Air mass flow rate, (kg/s)
$\dot{m}_f$	Fuel mass flow rate, (kg/s)
N	Engine speed, (rpm)
n	Number of cylinder
P	Pressure, (bar)
p_b	Brake mean effective pressure, (Pa)
p_i	Indicated mean effective pressure, (Pa)
ppm	Parts per million

Q	Heat release (kJ/kg)
$Q_{net,v}$	Net calorific value of the fuel
R	Distances of load cell from the center line of dynamometer
s	second, (s)
sfc	Specific fuel consumption, (g/kWh)
T	Torque, (Nm)
T_i	Inlet temperature, $(^\circ C)$
T_o	Outlet temperature, $(^\circ C)$
TDC	Top dead center
t	Time, (s)
V	Volume, (m^3)
V_c	Clearance volume, (m^3)
W	Net load, (N)
WCO	Waste cooking oil
ω	Moisture content
y	Distance between the crank axis and the piston pin axis, (m)
η_{BT}	Brake thermal efficiency, (%)
η_M	Mechanical efficiency, (%)
θ	Crank angle, ($^\circ$)

ABSTRAK

Penggunaan biojisim untuk menjanakan tenaga semakin mendapat perhatian hal ini kerana tenaga simpanan seperti gas dan minyak semakin kurang. Baru-baru ini, gasifikasi biojisim telah wujud sebagai satu lintasan teknikal yang terkenal untuk menghasilkan gas bahanapi untuk kegunaan enjin. Penggunaan *'producer gas'* sebagai bahanapi pilihan kepada minyak diesel dalam enjin telah memberi kelebihan dari segi ekonomi dan alam sekitar. Sumber biojisim mudah diperolehi dan tenaga biojisim dapat mengatasi masalah pembuangan sampah dan pencemaran alam yang semakin meningkat di merata dunia. Kini dengan adanya teknologi pembaharuan tenaga tersebut, penggunaan petroleum atau diesel dalam enjin dapat dikurangkan dan boleh digantikan dengan bahanapi pilihan. Objektif projek ini adalah mendirikan satu tapak kemudahan untuk eksperimen penggunaan *'producer gas'* dalam enjin diesel dan mempamerkan keputusan eksperimen. 20 kW_{th} *'downdraft gasifier'* telah digunakan untuk menghasilkan *'producer gas'* dan ketulan kayu yang mengandungi kandungan wap sebanyak 6.2% digunakan sebagai bahan mental biojisim. *'Cussons Single Cylinder Engine Test Bed'* yang tediri daripada *'Yanmar L60AE-DTM single cylinder diesel engine'* dan dinamometer juga digunakan dalam eksperimen tesebut. Perbandingan antara ciri-ciri pembakaran dan ciri-ciri prestasi untuk enjin diesel dan enjin dengan campuran diesel dan *'producer gas'* telah dibuat. Keputusan telah menunjukkan bahawa enjin yang menggunakan campuran *'producer gas'* dan minyak diesel sebagai bahanapi mempunyai ciri-ciri pembakaran yang hampir sama dengan enjin diesel. Prestasi enjin yang menggunakan campuran bahanapi minyak diesel dan 'producer gas' adalah rendah jika dibanding dengan enjin diesel. Penggunaan *'producer gas'* dalam enjin diesel dapat mengurangkan kegunaan minyak diesel sebanyak 170% untuk process pembakaran. Selain itu, pengajian dengan menggunakan campuran minyak diesel dengan minyak masak terbuang juga disembahkan untuk tujuan perbandingan.

ABSTRACT

The use of biomass for energy generating is getting increasing attention because of the energy reserves such as gas and oil is decreasing. At present, biomass gasification is taken as a popular technical route to produce fuel gas for application in engine. The use of producer gas as an alternative to diesel in engines has advantage from both economic and environmental perspective. The sources of biomass are easy to found and the biomass energy reduce the level of disposal and pollution in this world. Today, with this renewable energy technologies petroleum or diesel consumption can be reduced and substituted partly by alternative fuels in engine. The objective of this project is to assembly the experimental rig of a diesel engine using producer gas from gasification system and also to present some experimental result. The 20 kW_{th} downdraft gasifier was used to produce gas with off-cut furniture wood with moisture content 6.2% used as biomass material. Cussons Single Cylinder Engine Test Bed which consists of Yanmar L60AE-DTM single cylinder diesel engine and dynamometer has also been used in this experiment. The combustion characteristic and performance characteristic for diesel engine and mixture of diesel and producer gas were compared. The result indicated that dual fuel engine has similar combustion characteristic to diesel engine. The performance of dual fuel engine is lower compared to diesel engine. The usage of producer gas in diesel engine can reduce the consumption of diesel fuel for combustion process which is about 170%. In addition, studies using blend of diesel and waste cooking oil are presented for comparison.

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Energy becomes the first priority to all the people in this world. The need for energy and fuels is one of the common threads throughout history and is related to almost everything that man does or wishes to do. Energy is a basic element that influences and limits human standard of living and technological progress. The things such as automobiles, factories and power generation stations need energy to work. It is clearly an essential support system for all of human.

However, the increasing of population in this world and industrial sectors has caused the energy resources such as petroleum is getting scarce due to continue usage in daily life. As a result, intensive research programs were started to develop renewable energy resources such as active and passive solar energy, photovoltaic, wind and ocean power system, and biomass.

Biomass is defined as nonfossil, energy-containing forms of carbon and includes all land-and water-based vegetation and such materials as municipal solid wastes, forestry and agricultural residues, municipal biosolids, and some industrial wastes. Biomass is the only indigenous renewable energy resource that capable of displacing large amounts of solid, liquid, and gaseous fossil fuels. Nowadays, there are many biomass energy systems have been developed due to its reliability, economically, and discovered easily. In addition, the potentially of damaging environmental effect of continued fossil fuel usage is another reason that will why biomass energy usage becomes popular.

Practically, biomass which produced by burning the organic matter such as wood waste, sawdust and bark, can be burned for energy. Biomass systems can be used for generating electric power, industrial processing, and space heating for offices, schools, hotels and institutions. Beyond that there is biomass gasification technology which can produce gas that can be used in internal combustion engine as transportation fuel energy. The producer gas has become developed as potential candidate of alternative fuels.

The producer gas is a burnable gas and the components of the gas are typically, carbon monoxide, hydrogen and methane. The history of usage of the gasification process to produce a burnable gas had been known since the last one hundred years ago. Before natural gas was plentiful, or even available, cities built “gas works” to make “city gas” of various varieties for lighting and cooking. At the beginning of this century, before the arrival of spreader stokers and traveling grates, a number of utility boilers were built with coal gas producers instead of furnaces. During World War II, trucks and automobiles in occupied Europe were fuelled with producer gas. The latest surge of interest in gasification occurred during the oil shortage of the 1979’s occasioned by the Yom Kippur War in 1973 and the fall of the Shah of the Iran 1978. Today, the main interest in wood waste gasification is primarily in Europe.

Basically, gasification is a process of pyrolysis. In the case of gasification, all the solid wood waste is converted into a burnable gas; there are no oil, tar or charcoal byproducts. For the purpose of using producer gas as alternative fuel of the engine, seen to sources of petroleum becomes scarceness, there are development of the dual fuel engine had been processed. Dual fueling is good concession between diesel savings, convenience and ease of operations.

1.2 PROBLEM STATEMENT

Increasing human population and industrialization took place rapidly has resulted in a large energy demand. Larger human populations mean more human activities and thus higher energy consumption.

The three main sources of energy for the world are petroleum (42.94%), coal (30.56%) and natural gas (17.74%). These three nonrenewable fossil fuels contribute to about 91% of total supply of the world [Islam, 2000]. However it is unfortunate that the reserves for these fuels are limited. Based on the reserve to production ratio of the world, petroleum can last for only another 39.51 years, natural gas 60.18 years and coal 207.42 years.

Therefore it is very important to developed and increase the use of renewable alternative fuels so that to improve the efficiency of energy utilization as well as to promote energy conservation strategy especially in transportation field.

1.3 OBJECTIVE

The purpose and objective of the investigation is:

1. To determine the performance and combustion characteristic of a diesel engine using producer gas from biomass downdraft gasifier.
2. Determine heat release rate diagram for the engine using producer gas.
3. Compare the results with engine using diesel alone and producer gas.

1.4 SCOPE

This project is to conduct an experiment to run internal combustion engine using 5kW producer gas from biomass gasification system.

After the completion of the experiment, the performance and combustion characteristic of the engine is verified. Then, the comparison is made between dual fuel engine and diesel engine. The characteristic of performance that will be determined as shown below:

- Indicated Power, ip
- Brake Power, bp
- Mechanical Efficiency, η_M
- Brake Mean Efficiency Pressure, $Bmep$
- Brake Thermal Efficiency, η_{BT}
- Brake Specific Fuel Consumption, $Bsfc$
- Air Fuel Ratio, A/F

The heat release of the engine will also be determined. The moisture content of wood chips which used for biomass gasification system is also considered as one of the variable parameter.

CHAPTER 2: LITERATURE REVIEW

This is section in which describe about the relevant literature that related with this task. For that purpose, the information about this project such as biomass, gasification technology, internal combustion engine, alternative fuels had been collected and research had also been done before experiment is started.

2.1 BIOMASS

As late as the mid 1800s, biomass has been a major energy source and supplied the vast majority of the world's energy and fuel needs and only started to be phased out in industrialized countries as the fossil fuel era begin. The gradual change in the energy consumption pattern of the United States from 1860 to 1990 was illustrated in Figure 2.1.

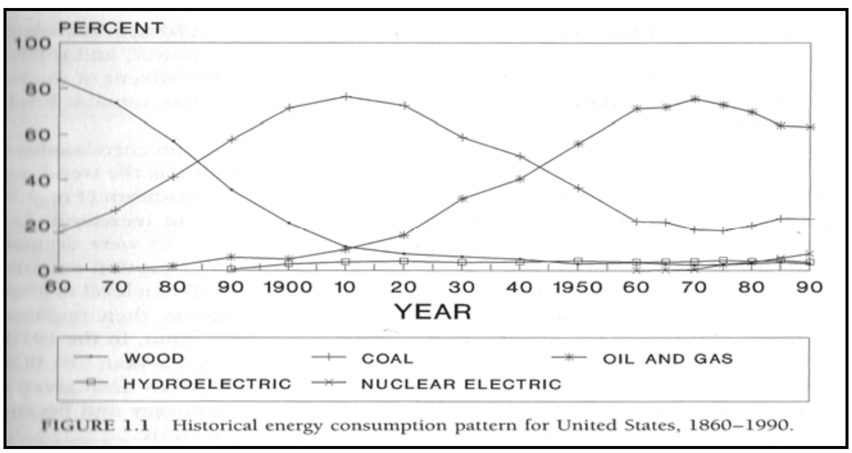

Figure 2.1: Historical energy consumption pattern for United State, 1860-1990 [Donald L. Klass 1988]

In the mid-1800s, biomass, principally woody biomass, supplied over 90% of U.S. energy and fuel needs, after which biomass consumption began to decrease as fossil fuels became the preferred energy resources.

Biomass is one of the few renewable, indigenous, widely dispersed, natural resources that can be utilized to reduce both the amount of fossil fuels burned and several greenhouse gases emitted by or formed during fossil fuel combustion processes. [Donald L. Klass 1988, 2] Even though its role is presently diminished in developed countries, it is still widely used in rural communities of the developing countries for their energy needs in term of cooking and limited industrial use. Biomass, besides using in solid form, can also be converted into gaseous form through gasification route.

2.2 GASIFICATION

Gasification is a thermo chemical process, where it is the destructive decomposition of wood waste-using heat-into combustion gas. The burnable components of the gas are, typically, carbon monoxide, hydrogen and methane, and the gas is known as “producer gas”. [Malcolm D. Lefcort, 1995]

2.2.1 Gasification Technology

The advantage of gasification compared to normal biomass combustion is the very compact equipment. In combustion-based systems, the energy output is limited to production of the water (e.g. for district heating) or steam for relatively low-efficiency processes (typically below 24% efficient), while in gasification based systems the efficiency may exceed 30%

2.2.2 Advantages of the Gasification Process

The advantage of the gasification process is that the inhomogeneous biomass waste is converted into a homogenous gas with a considerably higher level of application:

- The product gas may, without any cleaning, be used for gas-fired steam boilers combined with steam turbines or for increased steam superheating (and consequently higher power efficiency) at e.g. municipal solid waste energy plants.
- The product gas may, after a modest clean-up, be burned using low NOx gas burner technology in connection with indirectly fired power technologies (such as indirectly fired gas turbines and Stirling engines) with efficiency exceeding 28%
- After adequate clean-up the product gas may even be used for direct firing of gas turbines and gas engines (with a potential efficiency exceeding 32%), and in the future also for powering fuel cells (with efficiency exceeding 40%).

2.3 BIOMASS GASIFICATION

Gasification of biomass is taken as a popular technical route to produce fuel gas for application in boilers, engine, gas turbine or fuel cell. [G Chen, J Andries 2004, 345] Biomass gasification processes are generally designed to produce low-to medium-energy fuel gases, synthesis gases for the manufacture of chemical or hydrogen. More than one million small-scale, airblown gasifier for wood and biomass-derived charcoal feedstocks were built during World War II to power vehicles and to generate steam and electric power. Units were available in many designs. Thousands were mounted on vehicles and many were retrofitted to gas-fired furnaces. The Swedish automobile manufactures Volvo and Saab have ongoing programs to develop a standard gasifier design suitable for mass production for vehicles. Much effort has been devoted to the commercialization of biomass gasification technologies in United States since the early 1970s. [Donald L. Klass 1998, 271]

2.3.1 Gasification Process Variations

Basically, there are three types of biomass gasification process, pyrolysis, partial oxidation, and reforming. [Donald L. Klass 1998, 272]

The primary products from the pyrolysis of biomass are gases if the temperature is sufficient. At high temperature, charcoal and liquids are either minor products or not present in the product mixture. On of the more innovative pyrolytic gasification process is an indirectly heated, fluid-bed system. [cf. Alpert 1972; Bailie 1981; Paisley, Feldmann and Appelbaum 1984]

Partial oxidation process (direct oxidation, starved-air or starved-oxygen combustion) are those that utilize less than the stoichiometric amounts of oxygen needed for complete combustion, so partially oxidized products were formed. An example of the gasification of biomass by partial oxidation in which air is supplied without zone separation in the gasifier is the molten salt process. [Yosim and Barclay 1976]

Steam reforming, steam-oxygen and steam air-reforming are examples of biomass gasification by reforming. Steam reforming processes involve reactions of biomass and steam and of the secondary products formed from biomass and steam.

Under idealized conditions, the primary products of biomass gasification by pyrolysis, partial oxidation, or reforming are essentially the same where the carbon oxides and hydrogen are formed. Under certain conditions, Methane and light hydrocarbon gases are also formed. Equations as shown below illustrate the examples of some stoichiometries by using cellulose as a representative feedstock.

Pyrolysis : $C_6H_{10}O_5 \rightarrow 5CO + 5H_2 + C$

Partial Oxidation : $C_6H_{10}O_5 + O_2 \rightarrow 5CO + CO_2 + 5H_2$

Steam reforming : $C_6H_{10}O_5 + H_2O \rightarrow 6CO + 6H_2$

The energy content of the product gas from biomass gasification can be varied. Low-energy gases (3.92 to 11.78 MJ/m^3 (n), 100 to 300 Btu/SCF) are generally formed when there is direct contact of biomass feedstock and air. Medium-energy gases (11.78 to 27.48 MJ/m^3 (n), 300 to 700 Btu/SCF) can be obtained from directly heated biomass gasifiers when oxygen is used and from indirectly heated biomass gasifiers when air is used and heat transfer occurs via an inert solid medium. High-energy product gases (27.48 to 39.26 MJ/m^3 (n), 700 to 1000 Btu/SCF) can be formed when the gasification conditions promote the formation of methane and other light hydrocarbon, or processing subsequent to gasification is carried out to increase the concentration of these fuel components in the product gas. Methane is the dominant fuel component in natural gas and has a higher heating value of 39.73 MJ/m^3 (n) (1012 Btu/SCF). [Donald L. Klass 1998, 273]

2.3.2 Biomass Gasifier Designs

Design of gasifier depends upon type of fuel used and whether gasifier is portable or stationary. Gas producers are classified according to how the air blast is introduced in the fuel column. Basically, biomass gasifiers can be categorized into several reactor design groups: a descending bed of biomass, often referred to as a moving or fixed bed, with countercurrent gas flow (updraft); a descending bed of biomass with cocurrent gas flow (downdraft); a descending bed of biomass with crossflow of gas; a fluidized bed of biomass with rising gas; an entrained-flow circulating bed of biomass; and tumbling beds. History of gasification reveals several designs of gasifiers. [Donald L. Klass 1998, 273] The most commonly built gasifiers are classed as:

2.3.2.1 Updraft Gas Producer

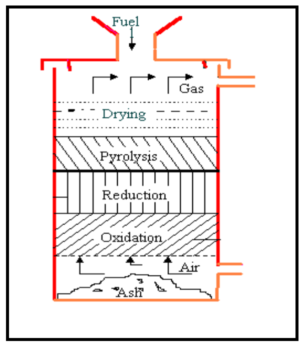

Figure 2.2: Updraft Gasifier

An updraft gasifier has clearly defined zones for partial combustion, reduction, and pyrolysis. Air is introduced at the bottom and act as countercurrent to fuel flow. The gas is drawn at higher location. The updraft gasifier achieves the highest efficiency as the hot gas passes through fuel bed and leaves the gasifier at low temperature. The sensible heat given by gas is used to preheat and dry fuel. Disadvantages of updraft gas producer are excessive amount of tar in raw gas and poor loading capability. Hence it is not suitable for engine application.

2.3.2.2 Downdraft Gas Producer

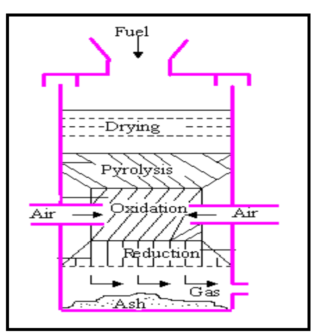

Figure 2.3 Downdraft Gasifier

In the updraft gasifier, gas leaves the gasifier with high tar vapour which may seriously interfering the operation of internal combustion engine. This problem is minimized in downdraft gasifier. In this type, air is introduced into downward flowing packed bed or solid fuels and gas is drawn off at the bottom. A lower overall efficiency and difficulties in handling higher moisture and ash content are common problems in small downdraft gas producers. The time (20-30 minutes) needed to ignite and bring plant to working temperature with good gas quality is shorter than updraft gas producer. This gasifier is preferred to updraft gasifier for internal combustion engines

2.3.2.3 Crossdraft Gas Producer

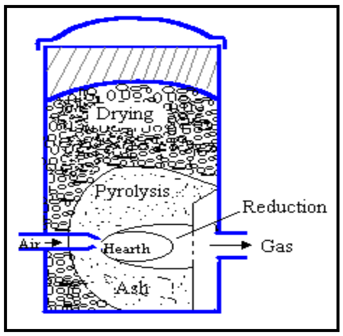

Figure 2.4 Crossdraft Gasifier

Crossdraft gas producers, although they have certain advantages over updraft and downdraft gasifiers, they are not of ideal type. The disadvantages such as high exit gas temperature, poor CO_2 reduction and high gas velocity are the consequence of the design. Unlike downdraft and updraft gasifiers, the ash bin, fire and reduction zone in crossdraft gasifiers are separated. This design characteristic limit the type of fuel for operation to low ash fuels such as wood, charcoal and coke. The load following ability of crossdraft gasifier is quite good due to concentrated partial zones which operates at temperatures up to 2000 ^{o} c. Start up time (5-10 minutes) is much faster than that of downdraft and updraft units. The relatively higher temperature in cross draft gas producer has an obvious effect on gas composition such as high carbon monoxide, and low hydrogen and methane content when dry fuel such as charcoal is used. Crossdraft gasifier operates well on dry air blast and dry fuel.

2.3.2.4 Fluidized Bed Gas Producer

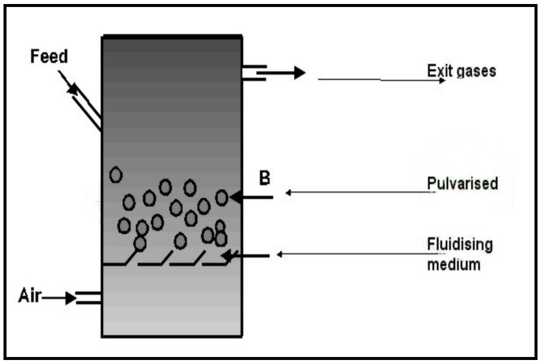

Figure 2.5: Fluidized Bed Gasifier

In a fluidized bed gasifier, the bed material can either be sand or char, or some combination. The fluidizing medium is usually air; however, oxygen and/or steam are also used. The fuel is fed into the system either above-bed or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed velocities. The fluid bed gasifier can use a variety of fuels having a range in size up to four inches, moisture contents as high as fifty percent and high in ash content. Fluidized-beds have the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed conditions and efficient reactions. Fluidized bed technology is more suitable for generators with capacities greater than 10 MW because it can be used with different fuels, requires relatively compact combustion chambers and allows for good operational control [Morris 1998]. The two main types of fluidized beds for power generation are bubbling and circulating fluidized beds. [Alexander Klein 2002]

2.3.3 Gasification of Wood Waste

The combustion of wood waste always includes a stage of gasification. Consider, for example, the case of a fresh log placed on top of a stack of logs already burning in a fireplace. The new log hisses while its moisture is driven off; the heat of evaporation coming from the already burning logs in the fireplace. After the log has dried tongues of flame can be seen extending upward, along the length of the log. With time the number of tongues of flame increases. Finally, the flames die out and the now, fissured, black log glows red and yellow as it slowly burns down to a grey, powdery ash. In this fireplace example, the tongues of flame are burning forms of producer gas. The fissured log is made up of fixed carbon. [Malcolm D. Lefcort 1995]

This process is made possible in gasified where the air supplied is limited. A gasifier system basically comprises of a reactor where the gas is generated, and is followed by a cooling and cleaning train which cools and cleans the gas as shown in Figure 2.6. The clean combustible gas is available for power generation in diesel-gen-set while for thermal use the gas from the reactor can be directly fed to the combustor using an ejector.

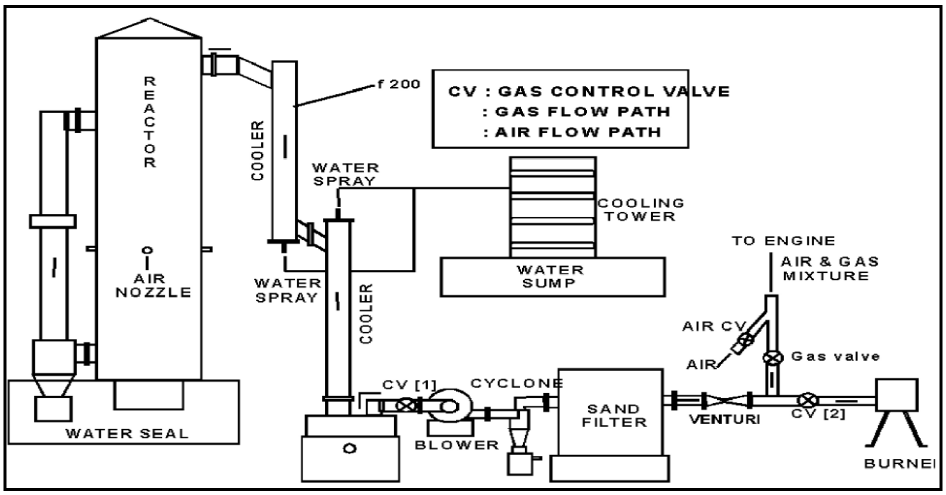

Figure 2.6: Schematic of Wood Gasifier for Power Generation Application

2.3.4 Summary of Gasifier

- Gasifiers are devices which convert solid biomass into gaseous fuels for combustion in furnaces or in engines
- Gasifiers give a precise control of instantaneous power some thing not possible in solid fuel combustors.
- Woody biomass gasifiers are of down draft, updraft and crossdraft types ; Downdraft gasifiers can be either closed or open top
- For engine applications downdraft gasifier is the most suitable. For engine applications involving variable load/ power demand, open top downdraft gasifiers are most suitable.

- Updraft gasifiers may be the most appropriate if the biomass is contaminated, unsized and of a variety of shapes making downdraft gasification difficult. The applications are only thermal.
- Crossdraft gasifiers are most appropriate for thermal applications and one can design for higher moisture loadings in biomass.

2.4 INTERNAL COMBUSTION ENGINE

The main purpose of internal combustion engines is the production of mechanical power from the chemical energy contained in the fuel. In internal combustion engines, the fuel is burned or oxidized to release energy. The fuel-air mixture before combustion and the burned products after combustion are the actual working fluids. The work transfers which provide the desired power output occur directly between these working fluids and the mechanical components of the engine. [John B. Heywood 1988, 1]

2.4.1 Historical

The early engines developed for commercial use by J.J. E. Lenoir (1822-1900), burned coal –gas air mixtures at atmosphere pressure where there was no compression before combustion. Then a more successful development with an atmospheric engine introduced in 1867 by Nicolas A. Otto (1832-1891) and Eugen Langen (1883-1895). The pressure rise resulting from combustion of the fuel-air mixture is used to accelerate a free piston and rack assembly. To overcome this engine's shortcomings of low-thermal efficiency, an engine cycle with four pistons strokes had been proposed by Otto and began the first ran in 1876. By 1890, almost 50,000 of these engines had been sold in Europe and the United States.

By the 1880s, several engineers had successfully developed two-stroke internal combustion engines where the exhaust and intake processes occur during the end of the power stroke and beginning of the compression stroke. Substantial carburetor and ignition system developments were required, and occurred, before high speed gasoline engines became available in the late 1880s.

In 1982, the German engineer Rudolf Diesel (1858-1913) outlined in his patent a new form of internal combustion engine with concept of initialing combustion by injecting a liquid fuel into air heated solely by compression permitted a doubling of efficiency over other internal combustion engines. However, five years of effort had been taken to develop a practical engine. [John B. Heywood 1988, 3-4]

2.4.2 Engine Classification

There are many types and arrangements of internal combustion engines. Therefore, they can be classified and the method as shown in the table below.

Table 2.1: Classification of Engine

Application	Automobile, truck, locomotive, light aircraft, marine, portable power system, power generation
Basic Engine Design	o Reciprocating engines (in turn subdivided by arrangement of cylinders: e.g., in-line, V, radial, opposed) o Rotary engines (Wankel and other geometries)
Working Cycle	Four-stroke cycle: o naturally aspirated (admitting atmospheric air) o supercharged (admitting pre compressed fresh mixture) o turbocharged (admitting fresh mixture compressed in a compressor driven by an exhaust turbine) Two-stroke cycle: o crankcase scavenged, and turbocharged.

Valve or Port Design and Location	Overhead (or I-head) valves, underhead (or L-head) valves, rotary valves, cross-scavenged porting (inlet and exhaust ports on opposite sides of cylinder at one end), loop-scavenged porting (inlet and exhaust ports on same side of cylinder at one end), through-or uniflow-scavenged (inlet and exhaust ports or valves at different ends of cylinder).
Fuel	Gasoline (or petrol), fuel oil (or diesel fuel), natural gas, liquid petroleum gas, alcohols (methanol, ethanol), hydrogen, dual fuel.
Method of Mixture Preparation	Carburetion, fuel injection into the intake ports or intake manifold, fuel injection into the engine cylinder.
Method of Ignition	Spark ignition (in conventional engines where the mixture is uniform and in stratified-charge engines where the mixture is non-uniform). Compression ignition (in conventional diesels, as well as ignition in gas engines by pilot injection of fuel oil).
Combustion Chamber Design	Open chamber (many designs: e.g. disc, wedge, hemisphere, bowl-in-piston), divided chamber (small and large auxiliary chambers; many designs: e.g. swirl

	chambers, prechambers).
Method of Load Control	Throttling of fuel and air flow together so mixture composition is essentially unchanged, control of fuel flow alone, a combination of these.
Method of Cooling	Water cooled, air cooled, uncooled (other than by natural convection radiation)

All these distinction are important to illustrate the breadth of engine designs available.

2.4.3 Engine Performance Parameters

The testing of internal combustion engine consists of running them at different loads and speeds and taking sufficient measurements for the performance criteria to be calculated. [McConkey 1993, 437] The main consideration of practical engine performance parameters are power, torque, and specific fuel consumption. Power and torque are depending on an engine's displaced volume. The relative importance of these parameters varies over an engine's operation speed and load change. Then over the whole operating range, and most especially those parts of that range where the engine will operate for long periods of time, engine fuel consumption and efficiency, and engine emissions are important. Since the operating and emissions characteristics of spark-ignition and compression-ignition engines are substantially different, each engine type is dealt with separately. [John B. Heywood 1988, 824]

2.4.4 Spark Ignition Engine

Spark ignition engine is knows as petrol engine. In spark ignition engines the air and fuel are mixed together in the intake system prior to entry to the engine cylinder by using a carburetor or fuel-injection. In automobile applications, the temperature of the air entering the intake system is controlled by mixing ambient air with air heated by contact with the exhaust manifold. The petrol engine will operate on air-fuel ratios in the range 10/1-22/1, but not necessarily satisfactorily at the extremes.

Small spark ignition engines can be used in many applications as example in portable power generation, outboard motorboat and motorcycles engines. These are often single-cylinder engines where gives only one power stroke per revolution (two-stroke cycle) or two revolutions (four-stroke cycle).

2.4.5 Compression Ignition Engine

Compression ignition engine is also known as diesel engine. In compression-ignition engines, air alone is induced into the cylinder where the fuel is injected directly into the engine cylinder just before the combustion process is required to start. Load control is achieved by varying the amount of fuel injected each cycle; the air flow at a given engine speed is essentially unchanged.

The compression ignition engine is designed into great variety which in use in a wide range of applications like automobile, truck, locomotive, marine, power generation. The operation of a typical four-stroke naturally aspirated CI engine is illustrated in Figure 2.7. The compression ratio of diesels is much higher than typical SI engine values, and is in the range 12 to 24 which depending to the type of diesel engine and whether the engine is naturally aspirated or turbocharged. The valve timings used are similar to those of SI engine. In the two-stroke CI engine cycle, compression, fuel injection, combustion, and expansion processes are similar to the equivalent four-stroke cycle processes; it is the intake and exhaust pressure which are different.

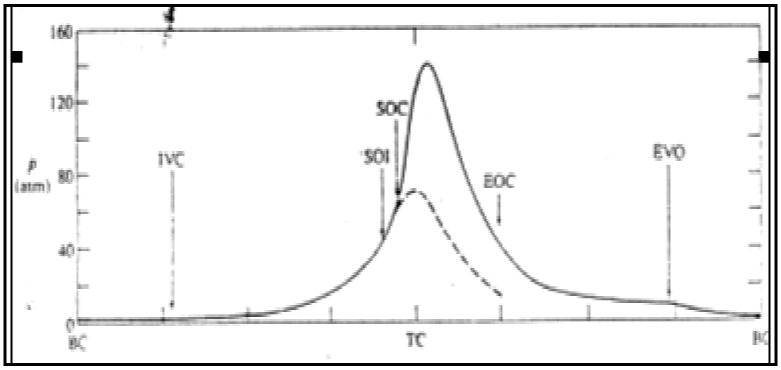

Figure 2.7: Sequence of events during compression, combustion and expansion processes of a naturally aspirated CI engine operating cycle. [John B. Heywood 1988, 28]

2.4.5.1 Factors Influencing Performance

The effect of compression ratio in the compression engine is a bit simpler than in the spark ignition engine. The normal range of compression ratios is 13/1 to 17/1, but may be anything up to 25/1. [McConkey 1993, 446]

The combustible mixture in the SI engine is formed before compression while this mixture of the CI engine has to be formed after compression and also after injection begins. This phenomenon leads the delay periods in CI engine which are greater than those in the SI engine. Figure 2.8 illustrated the phases of combustion in CI engine.

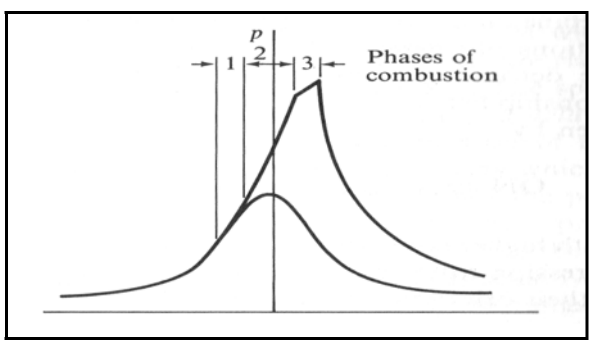

Figure 2.8: Phase of combustion in CI engine

The delay period forms the first phase of the combustion process, and is depend on the nature of the fuel. A long delay period means more combustible mixture has had time to form, and so more charge will be involved in the initial combustion. As the speed increase, the rate of pressure rise in this phase also increases. The second phase consists of the spread of flame from the initial nucleus to the main body of the charge. There is a rapid increase in pressure during this phase and the rate of pressure rise depends to some extent on the availability of oxygen to the fuel spray, which in turn depends on the turbulence in the cylinder. During the third phase of combustion the fuel burns as it is injected into the cylinder, and this phase gives more controlled combustion than that of phase two. One of the main factors in a controlled combustion is the swirl which is induced by the design of the combustion chamber.

The air-fuel ratios used in CI engines lie between 20/1 and 25/1. AS these mixtures are much weaker than the stoichiometric proportion then the *imep* will be limited, and is also means that for a given fuel consumption the swept volume of the engine will be greater than that of the equivalent SI engine. [McConkey 1993, 447]

2.4.5.2 Heat Release Rate

Figure 2.9 shows a general shape of the rate of heat release curve which typical of DI engine over its load and speed range. A rate of release diagram corresponding to the rate of fuel injection and cylinder pressure data. The heat-release rate plotted is the net heat release rate. It is sum of the change of sensible internal energy of the cylinder gases and the work done on the piston. It differs from the rate of fuel energy released by combustion by the heat transferred to the combustion chamber walls. The heat loss to the wall is 10 to 25 percent of the fuel heating value in smaller engines; it is less in larger engine sizes. This net heat release can be used as an indicator of actual heat release when the heat loss is small.

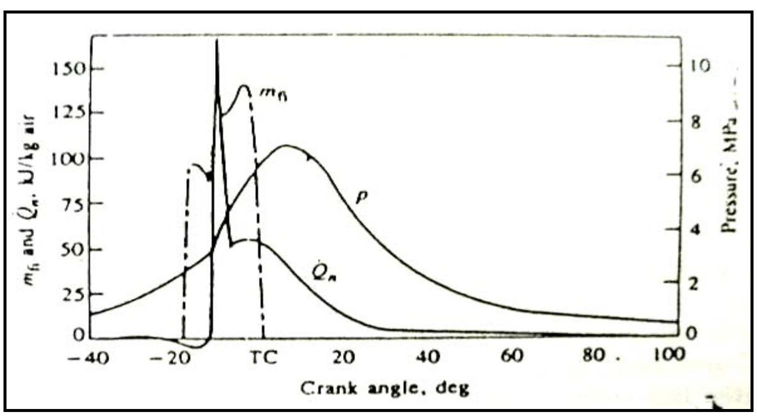

Figure 2.9: Cylinder pressure, net heat release rate versus crank angle for small CI engine [John B. Heywood 1988, 504]

During the combustion process the burning proceeds in three distinguishable stages:

First stage **–** the rate of burning is generally very high and lasts for only a few crank angle degrees. It corresponds to a period of rapid cylinder pressure rise.

Second Stage **–** This stage corresponds to a period of gradually decreasing heat-release rate. This is the main heat release period and lasts about 40^{o}. Normally about 80 percent of the total fuel energy is released in the first two periods

Third Stage **–** This stage corresponds to the 'tail' of the heat release diagram in which a small but distinguishable rate of heat release persists throughout much of the expansion stroke. The heat release during this period usually amounts to about 20 percent of the total fuel energy.

A summary observation had been developed by Lyn after from studying the rate of injection and heat release diagrams over a range of engine loads, speeds and injection timings.

- The total burning period is much longer than the injection period.
- The absolute burning rate increases proportionally with increasing engine speed; thus on a crank angle basis, the burning interval remains essentially constant.
- The magnitude of the initial peak of the burning rate diagrams depends on the ignition delay period, being higher for longer delays.

2.4.6 Dual Fuel Engine

The dual fuel engine is of considerable industrial interest which that the engine can operate with two types of fuel. Some diesel engines, naturally aspirated or turbocharged can be used as dual-fuel engines. They are started on diesel oil and then run on an available gaseous fuel such as methane, natural gas, sewage gas, coal gas and so on.

There are research works world-wide involving the use of natural gas in internal combustion engines have been intensified due to environmental concern or exhaustion of conventional fossil fuels. [Karim & Ali 1975] The renewable energy sources, natural gas, bio-derived gases and liquids appear to be greener alternative sources for internal combustion engines. The fuel system of a natural gas engine is some what different from that of the liquid fuel engine. Means for utilization of natural gas in SI engines are well established and documented whilst development efforts are still going on towards its use in compression ignition CI engines.

In the gas-fumigated dual-fuel engine, the primary fuel is mixed with air outside the cylinder before it is inducted into the cylinder. A mixture of gas and air is compressed during the compression stroke and before the end of the stroke; a pilot quantity of diesel fuel which depending on the operating conditions is injected to initiate combustion. The combustion processes of dual-fuel engines lie between that of the CI and SI engines. The longer burning rate of the gas allows more time for heat transfer to the end gas resulting in a tendency to knock [Moore & Mitchell 1955].

In CI engines, knocking is due to combustion of premixed fuel and the degree of knock depends on the period of ignition delay. [Goodge 1980; Needham Doyle 1983 & Heywood 1988] The present study was designed to investigate knock characteristics of dual-fuel engines using natural gas as primary fuel. The use of natural gas in CI engines involves an evolution of two stages of ignition and combustion processes resulting in three types of knock: diesel knock, spark knock and erratic knock due to spontaneous ignition of the primary fuel. The dual fuel engine knock was seen to depend on engine load and speed, combustion temperature, pilot fuel/gas ratio and turbulence in the cylinder. The operating condition was improved by increasing pilot fuel and reducing the primary fuel.

The combustion process requires a pilot injection of oil which amounts 7-10% of the full power supply when running as a diesel engine. Displacement of diesel by gas can be done automatically or manually. To supply the pilot injection of oil a second set of pumps is required which delivers fuel to the standard injectors. [McConkey 1993, 427]

2.5 FUEL

Fuels have a major impact on engine development. The earliest engines used for generating mechanical power gas. Gasoline and lighter fractions of crude oil, became available in the late 1800s and various types of carburetors were developed to vaporized the fuel and mix it with air.

There were few problems with gasoline (before 1905); though compression ratios were low (4 or less) to avoid knock, the highly volatile fuel made starting easy and gave good cold weather performance. However, a serious crude oil shortage developed, and to meet the fivefold increase in gasoline demand between 1907 and 1915, the yield from crude had to be raised. Through the work of William Burton (1865-1954) and his associates of Standard Oil of Indiana, a thermal cracking process was developed whereby heavier oils were heated under pressure and decomposed into less complex more volatile compounds. These thermally cracked gasoline satisfied demand, but their higher boiling point range created cold weather starting problems. Fortunately, electrically driven starters, introduced in 1912, came along just time.

2.5.1 Alternative Fuels

Alternative fuel is described as any fuel suggested for use in transportation vehicles other than gasoline or diesel fuel. Through experimentation with alternative fuels, it soon became clear that alternative fuels had inherent environmental advantaged as well. Each alternative fuel has some characteristic that gives it an environmental advantage over petroleum fuels. Most are less damaging to the environment if spilled, and, in general the emissions from alternative fuels are less reactive. [Richard L. Bechtold 1997, 1-2] The alternative fuels which most likely candidates for use in internal combustion engines and future energy conversion devices are alcohols (methanol and ethanol), natural gas, LP gas, vegetable oils, and hydrogen.

2.5.1.1 Producer Gas

Producer gas is a gaseous fuel having a rather low calorific value. It is obtained from gasification of low-cost biomass and the temperature is kept high enough during the production process. [Rohit P. Datar 1991] Producer gas is fuel gas consisting chiefly of 2.02% Methane gas (CH_4), 24.04 % carbon monoxide (CO), 14.66% carbon dioxide (CO_2), 43.62% nitrogen (N_2), 1.69% oxygen (O_2), 14% of hydrogen (H_2) and C_2H_6 detected as traces in most of the runs with a concentration of 0.01%. [Z.A Zainal 2002] The heating value of the producer gas is about 4 MJ/m^3 and the specific biomass fuel consumption is about 1.5 kg/kWh. [Z.A Zainal 2004]

It is prepared in a furnace or generator in which air is forced upward through a burning fuel of coal or coke. Although the fuel is introduced through the top, no air is admitted there. The carbon of the fuel is oxidized by the oxygen of the air from below to form the carbon monoxide. The nitrogen of the air, being inert, passes through the fire without change. When steam is introduced with the air, the final gaseous product contains hydrogen also. [www.encyclopedia.com]

Because producer gas has a low calorific value, transportation costs are an important factor. It is widely used in industry because it can be made with cheap fuel. As a result, its main use is as an industrial fuel produced close to where it is needed. [John T. McMullan 1997] When producer gas contains hydrogen, it is also a source material for the manufacture of synthetic ammonia.

2.5.1.2 Waste Cooking Oil

The use of cooking oil (WCO) as an alternative to diesel in engines has advantages from both economic and environmental standpoint. WCO is produced after repeated frying process and is unsafe for consumption. The use of WCO as fuel can prevent illegal dumping which causes water pollution.

Waste cooking oil can be used as an alternative fuel for diesel engine without major modifications. Typical of vegetable oils, WCO has a higher viscosity and poses difficulty in the fuel delivery system. So, it only requires some changes to the fuel system to enable continuous smooth flow of WCO. The combustion characteristic of WCO was actually as good as those of diesel. In addition, with WCO, the engine experienced lower maximum power. This was due to the lower calorific value of WCO as well as the consequent of higher head loss at fuel which causes fuel starving. The problem can be solved by raising the fuel tank level and enlarging the filter size. [Yu Chee Wei 2001]

CHAPTER 3: METHODOLOGI

3.1 THEORETICAL ANALYSIS

3.1.1 Moisture Content

The specific humidity (moisture content) is the ratio of the mass of water vapour to the mass of dry air in a given volume of the mixture, and is denoted by the symbol ω,

$$\omega = \frac{m_s}{m_a} \qquad (3.1)$$

where the subscript s denotes the vapour, and the subscript a denotes the dry air.

3.1.2 Internal Combustion Engine

3.1.2.1 Criteria of Performance

An engine is selected to suit a particular application, the main consideration being its power or speed characteristic. In order that different types of engines or different engines of the same type may be compared, certain performance criteria must be defined. These are obtained by measurement of the quantities concerned during bench tests, and calculation is by standard procedures. The results are plotted graphically in the form of performance curves. The following part shows the formula and concept of the criteria performance.

i. Indicate Power, ip

Indicated power is defined as the rate of work done by the gas on the piston as evaluated from an indicator diagram obtained from the engine. An indicator diagram has the form shown in Figure 3.1

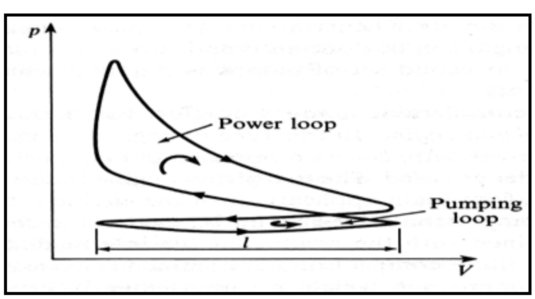

Figure 3.1: Pressure-volume diagram for a reciprocating engine