PORT INJECTION OF BIOMASS PRODUCER GAS FROM DOWNDRAFT GASIFIER IN A DIESEL ENGINE

by

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LIST OF ABBREVIATIONS

ATDC	After top dead centre
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
BTDC	Before top dead centre
BTE	Brake thermal efficiency
CA	Crank angle
CH_4	Methane
CI	Compression ignition
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CPG	Compressed producer gas
CR	Compression ratio
DD	Diesel displacement
DI	Direct injection
D/PG	Diesel/Producer gas
D-PCO	Diesel fuel-palm cooking oil
EGT	Exhaust gas temperature
GC	Gas chromatograph
H_2	Hydrogen
H_2O	Water vapour
HC	Hydrocarbon
HHV	Higher heating value for gas (MJ/Nm^3)

HHV	Higher heating value for solid and liquid (MJ/kg)
HRR	Heat release rate
IC	Internal combustion
IDI	In-direct injection
LHV	Lower heating value for gas (MJ/Nm^3)
LPV	Lower heating value for solid and liquid (MJ/kg)
LPG	Liquid petroleum gas
MC	Moisture content
MEP	Mean effective pressure (bar)
N_2	Nitrogen
NA	Naturally aspirated
NOx	Nitrogen oxides
O_2	Oxygen
P	Power (kW)
PCO	Palm cooking oil
PG	Producer gas
SC	Supercharged
SEC	Specific energy consumption
SI	Spark ignition
SP	Sampling point
UPG	Uncompressed producer gas
VO	Vegetable oil

LIST OF SYMBOLS

η_f	Fuel conversion efficiency
η_v	Volumetric efficiency
η_c	Cold gas efficiency
ρ_a	Density of air (kg/m^3)
ρ_{PG}	Density of producer gas (kg/m^3)
λ	Fuel to air ratio
$\dot{m}_b$	Mass flow rate of biomass fuel (kg/hr)
Ψ	Fuel-air equivalence ratio
N	Engine speed (rpm)
T_1	Temperature after gasifier (ºC)
T_2	Temperature after cyclone separator (ºC)
T_3	Temperature after heat exchanger (ºC)
T_4	Temperature after oil bath filter (ºC)
$\dot{V}_a$	Volumetric flow rate of air (m^3/s)
V_d	Displacement volume (m^3)
$\dot{V}_{PG}$	Volumetric flow rate of producer gas (Nm^3/hr)

SUNTIKAN LIANG GAS PENGELUAR BIOJISIM DARI PENGGASAN ALIRAN BAWAH KE DALAM INJIN DISEL

ABSTRAK

Gas pengeluar (GP), yang dijana dari proses penukaran termokimia melalui penggasan boijisim telah terbukti boleh digunakan sebagai bahan bakar alternatif untuk injin pembakaran dalam. Walaubagaimanapun, masalah utama GP apabila digunakan sebagai bahan bakar untuk injin pembakaran dalam ialah kehilangan kuasa atau penurunan taraf injin dan juga pencemaran ekzos yang tinggi disebabkan oleh pembakaran yang tidak lengkap. Antara sebab utama adalah nilai pemanasan GP dan ketumpatan tenaga campuran GP-udara yang rendah jika dibandingkan dengan bahan bakar gas alternatif yang lain. Berdasarkan kepada kajian lepas, faktor utama yang mempengaruhi kuasa keluaran dari injin pembakaran dalam yang menggunakan GP sebagai bahan bakar terutamanya injin disel adalah nisbah mampatan, nilai pemanasan GP dan cara laluan masuk udara ke dalam silinder injin.

Kaedah meningkatkan ketumpatan udara di dalam silinder injin telah dipilih, dan kajian penyelidikan ini berkaitrapat dengan pengecas lampau injin diesel menggunakan bahan bakar GP dengan mod bahan api duaan dan anjakan pemasaan suntikan bahan bakar. Kedua-dua GP dari penggasan aliran bawah dan udara dimampat secara berasingan, disuntik serentak dan dicampurkan didalam silinder injin melalui suntikan liang. Eksperimen telah dijalankan pada tekanan suntikan tetap 200 kPa, dengan kadar aliran suntikan yang diubah laras untuk kedua-dua GP dan udara pada kelajuan injin dan beban yang berbeza.

Kesan pemasaan suntikan bahan bakar dan pengecas lampau (PL) keatas prestasi, ciri-ciri pembakaran dan pencemaran ekzos injin disel satu silinder telah dikaji melalui eksperimen. Perbandingan telah dibuat keatas injin disel sahaja, pra-campuran bahan api duaan disel/GP dengan mod sedutan tabii (ST), pra-campuran bahan api duaan disel/GP dan bancuhan disel-minyak sayuran/GP dengan mod PL. Eksperimen dijalankan pada sudut putaran asal 14° dan pemasaan suntikan bahan bakar dianjakkan ke sudut putaran 17°, 20° and 23° sebelum titik mati atas. Penemuan penting dari eksperimen ini ialah pengurangan yang ketara keatas kuasa penurunan taraf dengan julat antara 28.12%-31.37% untuk pra-campuran bahan api duaan D/GP dengan mod ST kepada 1.64%-6.41% didalam pra-campuran bahan api duaan D/GP dengan mod operasi PL. Keputusan dari eksperimen menunjukkan kombinasi penggunaan kaedah PL dan anjakan pemasaan suntikan bahan bakar di dalam bahan api duaan injin GP, kecekapan haba brek dan penggantian penggunaan disel didapati telah meningkat dengan ketara. Didapati juga pengurangan yang ketara keatas penggunaan tenaga spesifik, suhu gas ekzos, kadar pencemaran nitrogen oksida dan karbon monoksida. Keputusan juga memperlihatkan pengurangan ke atas tunda nyalaan dan peningkatan tekanan puncak didalam silinder ke atas pra-campuran bahan api duaan D/GP dengan mod PL dibandingkan dengan mode operasi ST.

PORT INJECTION OF BIOMASS PRODUCER GAS FROM DOWNDRAFT GASIFIER IN A DIESEL ENGINE

ABSTRACT

Producer gas (PG), generated from thermo-chemical conversion process of biomass gasification has been proven to be used as an alternative fuel for internal combustion engine. However, major problems of PG when used as fuel in internal combustion engine are loss of power or engine derating and high exhaust emissions due to incomplete combustion. The most possible reasons are due to low heating value of PG itself and low energy density of PG-air mixture as compared to other alternative gaseous fuel. Based on literature studies, the main factors influencing power output from internal combustion engine fuelled with PG, particularly diesel engine are compression ratio, heating value of PG and the way of air is introduced into the engine cylinder.

The method of increasing air density into engine cylinder has been selected, and the present research work deals with supercharging the diesel engine fuelled by PG under dual fuel mode with advanced fuel injection timing. Both PG from downdraft gasifier and air were compressed separately, and simultaneously injected and mixed into the engine's cylinder via port injection. The experiments were carried out at a constant injection pressure of 200 kPa, with varying injection flow rates of both PG and air at different engine speeds and loads.

The effects of fuel injection timing and supercharged on the performance, combustion characteristics and exhaust emission of single cylinder diesel engine have been experimentally investigated. Comparisons were made on diesel fuel alone, premixed dual fuel diesel/PG with naturally aspirated (NA) mode, premixed dual fuel diesel/PG and diesel-vegetable oil blends/PG with supercharged (SC) mode of operation. Experiments were conducted at standard 14° and advanced fuel injection timings of 17°, 20° and 23° crank angle before top dead centre. The important finding from this experiment is a major reduction of power derating that ranges between 28.12%-31.37% in a conventional premixed dual fuel D/PG with NA mode to 1.64%-6.41% in premixed dual fuel D/PG with SC mode of operations. Experimental results show that combination of using SC method and advanced fuel injection timing in dual fuel PG engine, brake thermal efficiency and diesel displacement were found increased significantly. There is a significant reduction in specific energy consumption, exhaust gas temperature, nitrogen oxides and carbon monoxide emissions. It was also observed a reduction in ignition delay and increased in cylinder peak pressure of premixed dual fuel D/PG in SC mode as compared to NA mode of operation.

CHAPTER 1

INTRODUCTION

1.1 Background

Most internal combustion (IC) engines use fuels that are based on hydrocarbon compounds which are derived from petroleum oil. The hydrocarbon fuels such as gasoline, diesel and kerosene exist in a liquid state, and later vaporized in the combustion chamber of IC engine for combustion process. However, fast depletion of the petroleum-based reserves and increase in energy demand worldwide have encourage studies to find alternative sources of fuels that are environmentally friendly, as well as non-depleting. The attention and major research focus nowadays are more on the development of alternative fuel engines with the aim to slow down the petroleum fuels shortage and, in addition, reducing the engine exhaust emissions.

Petroleum oil, coal and natural gas still remains as the most important primary energy sources which contributes nearly 85% of the total world's primary energy consumption in 2009, as shown in Table 1.1. As fossils fuels become more and more expensive and harder to find, renewable energy systems will become cheaper as their technology improves, and the related equipment and device are made on a larger scale.

For the past 15 years, intense interests have been shown in alternative gaseous fuels of both non-renewable and renewable energy sources. Natural gas and propane appears to be the most promising non-renewable alternative gaseous fuels, while gaseous from landfill (landfill gas), organic digester process (biogas) and gas manufactured through the conversion process of biomass material are considered as renewable alternative gaseous fuels. Among them, gas manufactured from biomass material is the most natural, efficient and environment friendly renewable energy for continuous power generation. Therefore, availability of all these alternative fuels, particularly renewable gaseous fuels together with their conventional and latest technologies should be fully utilized to overcome oil crisis in the coming decades.

Table 1.1 : Total World's Primary Energy Consumption in 2009 (EIA,2010)

Type of Energy	Fuel/Process	Percentage (%)
Non-renewable Energy	Petroleum Oil	37
	Natural Gas	24
	Coal	23
	Nuclear Power	8.0
Renewable Energy	Biomass Material	4.3
	Geothermal and Hydropower	3.1
	Solar and Wind	0.6

1.2 Overview of Biomass Energy Sources

Concerns on environmental issues generally are expressed over the release of carbon from the burning of fossil fuels. When fossil fuels are burnt, carbon from fuels react with oxygen in the air and produces carbon dioxide (CO_2). As CO_2 contributes almost 50% to the greenhouse effect, the use of renewable energy that has the potential to reduce the global warming effect is considered to be the only choice for energy sustainability.

Renewable energy is estimated to contribute around 10%-14% of the total world’s energy supply in the future, estimated by 2050 (Demirbas,2005). Biomass, being one of the natural renewable energy sources other than solar, geothermal, wind, wave, ocean and thermal energies have been used widely as source of fuel for thousands of years. Estimates of potential global biomass energy vary widely in literature. The variability arises from the different sources of biomass and the different methods of determining estimates for those sources. A study conducted by Fischer and Leo (2001) estimated the total global biomass potential to be 91 to 675 Exajoule per year (EJ/year) for the years 1990 to 2060, and Hoogwijk et al (2003) estimated these figures to be 33 to 1135 EJ/year. Parikka (2004) estimated the total worldwide energy potential from biomass on a sustainable basis to be 104 EJ/year, of which woody biomass, energy crops and straw contributed of 40.1%, 36% and 16.6%, respectively.

The terms biomass refers to green plants that converts sunlight into plant material through a process called photosynthesis, and it includes all land and water based vegetation, as well as all organic wastes. In the context of biomass for energy, it is often used to mean plant based material, but generally biomass can equally apply to both animal and vegetable derived materials. Most of common biomass materials include forest products and their residues, agricultural crops and their residues, woody wastes, municipal solid wastes, animal manure, aquatic plants and algae.

Biomass materials for energy offer several advantages including production of oxygen (O_2) from growing biomass crops and at the same time capture of CO_2 by the growing plants. Biomass materials generally have lower energy densities as compared to fossil fuels, or in other words, a larger volume of biomass fuel is required to generate the same amount of energy. Biomass materials provide a unique opportunity as an energy source as solid, liquid and gaseous fuels can be derived from them. Moreover, biomass materials are not dependent on geographical factors such as climate and weather patterns and could be used on demand, as long as the material stock is readily available.

Solid biomass materials can be converted into gaseous fuel source through a process known as gasification. Gasification basically can be defined as the process of converting solid biomass fuel into a gaseous fuel through an endothermic thermo-chemical conversion process. Biomass gasification is actually incomplete combustion process, resulting in production of gas that is known as producer gas. In general, producer gas is a combine mixture of combustible gaseous of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and non-combustible gaseous of CO_2, nitrogen (N_2) and water vapour (H_2O). Although producer gas has lower heating value as compared to other gaseous fuels, the gas can nonetheless be used as fuel for power generation in IC engine and in boiler-turbine generator systems.

Since producer gas contains mainly N_2 with a small fraction of H_2 and CO, operating of the engine with producer gas under wide engine load however is very difficult due to its low calorific value (Ali Mohammadi et al.,2006). Besides, the presence of CO which is poisonous, producer gas also contain high impurities such as tar, acids, fine dust and ash (Shashikantha and Parikh,1999).

1.3 Motivation for this Work

Many clean burning alternative gaseous fuels have been studied and investigated as fuels in IC engine for both spark ignition (SI) and compression ignition (CI) engines. Gaseous fuels such as compressed natural gas (CNG), propane and hydrogen have been used as fuels for stationary and automotive applications, that can provide both good environmental effect and energy security (Selim,2004). Likewise, landfill gas and biogas have been widely used in stationary power plants for industrial use, particularly in the remote areas. Operation of IC engines with lean alternative gaseous fuel mixture can improve engine efficiency, higher fuel economy, reduce exhaust emission and longer operational life as compared to petroleum oil (Bade and Ghazi,2006). The gas engines are more durable than CI or SI engines using liquid fuels because of fewer abrasive and carbon particles in the combustion system (Jesper et al.,2001). Moreover, lean mixture operation using alternative gaseous fuel is associated with significantly low burning and energy release rates which resulted in increased unburned hydrocarbon emissions.

Among the advantages offered by gaseous fuels are better control of combustion, has no difficulty regarding mixing with air , lower and less harmful to the environment, and great savings in terms of economical point of view. Storage system is one of the drawbacks in using gaseous fuels due to its high specific volume. The high specific volume also results in displacement of air in premixed combustion systems, and because of that the engine may experience poor volumetric efficiency (Ganesan,2004).

Producer gas is one of the potential alternative gaseous fuel to replace fossil fuels in IC engines, and is suitable for relatively small gas engines because they have higher thermal efficiency. Producer gas can be used for fuelling SI engine operated on producer gas alone, CI engine as a partial substitute for diesel in dual fuel mode, and converted CI engine operated on producer gas alone to run in SI engine mode (Shasikantha et al.,1994). However, producer gas from the gasification process cannot be used directly in IC engine due to its higher temperature and impurities (Tewari et al.,2001). The gas needs to be cooled to room temperature and cleaned before entering into the engine combustion chamber. The cooling helps in two ways, it improves the volumetric efficiency of the engine as well as cleaning of the gas. Cleaning of the gas is essential, otherwise the impurities mainly tar in the producer gas can form sticky deposits and will cause problems to the various internal parts of the engine (Bhave et al.,2008).

In SI engine fueled only by producer gas, the combustion of producer gas-air mixture in the compression stroke is ignited by spark plug as in the common gasoline SI engine. For converted CI engine operated in SI engine mode, spark plug replaces the diesel injector. The basic modification needed is the provision of a producer gas–air mixer instead of a carburetor, and the engine control is performed by using a control or throttle valve. However in a dual fuel CI engine, the engine induces and compresses a mixture of producer gas-air that is prepared in the external mixing device. In a compression stroke, the compressed mixture is then ignited by energy from the combustion of the diesel fuel spray, which is called pilot fuel. The main reason diesel fuel is still required for combustion process is because the producer gas which is known as primary fuel has poor ignition delay and ignition characteristics, therefore the temperature and pressure are not sufficient to ignite producer gas-air mixture (Singh et al.,2007a).

The amount of pilot fuel required for ignition of dual fuel CI engine depends on the diesel engine operation and its design parameters, but usually between 10% and 20% of the operation on diesel alone at normal working loads (Sahoo et al.,2009). In case there is a lack or shortage of gaseous fuel, one of the advantages of dual fuel is that the engine switches from dual-fuel mode to diesel mode. As in SI engine, modification required for dual fuel producer gas engines are only at the intake region, in which the intake air and producer gas line are connected with suitable producer gas-air mixing device and its control system (Francisco et al.,2006).

A major problem associated with producer gas engines is loss of power or power derating. Power derating is due to the engine operating at less than their rated maximum power, which is mainly caused by insufficient or reduction of air entering the engine's combustion chamber. Engine operated at high altitude, high temperature of surrounding air, and high water content in the air or humidity are the factors affecting engine power derating. The phenomenon of derating in producer gas engine can be defined as the maximum power output generated being lower than the output of an equivalent engine operated on petroleum fuels (Stassen,1995). Percentage of derating for dual fuel CI engine recorded using producer gas is in the range of 20%-30% (Stassen,1995 ; Tewari et al.,2001). The figure is higher in SI engine and converted CI engine running on SI mode because of 100% producer gas is used as a main fuel (Banapurmath et al,2008).

The most possible reason of power derating as concluded by a number of researchers for the past 20 years is due to lower heating value of producer gas itself or reduction of the heating value of producer gas-air mixture. It was reported that almost 35% power loss is expected in dual fuel producer gas engine due to the lower energy content of producer gas-air mixture (FAO,1986). The findings by Reed and Dass (1988) concluded that an engine derating was due to less energy content of a stoichiometric producer gas-air mixture as compared to liquid fossil fuels. Shashikanta and Parikh (1999) claimed that the reason of engine derating is because of low heating value of producer gas and insufficient quantity of combustible mixture supplied to the engine due to limitation of engine cubic capacity.

Experimental work carried out by Tewari et al (2001) revealed that the engine power deration is due to less energy content of producer gas-air mixture and reduction in volumetric efficiency due to lower density as compared to petroleum fuel. Literature review conducted by Bharadwaj (2002) concluded that lower heating value of producer gas-air mixture is the main cause of reduction of peak temperature and pressure in the cycle. Stassen and Knoef (2004) mentioned that the engine power derating is due to lower heating value of stoichiometric mixture of producer gas-air compared to natural gas-air. Finally, study conducted by Singh et al (2007b) also showed that reduction in heating value, lower combustion temperature and drop in the pressure of producer gas entering the air inlet of the engine are the causes of power derating.

The reasons for power derating as described earlier are accepted because the IC engines used particularly in dual fuel mode are naturally aspirated engine. In naturally aspirated engine, both SI and CI engines operating on producer gas will generally lead to reduced power output due to lower heating value of the combustible gas mixture (Roy et al.,2009). According to Dasappa (2001), the primary factors that influence power output from producer gas engines are heating value of producer gas, engine compression ratio (CR), and the way air is introduced into the engine's cylinder. The heating value of producer gas, even though is almost eight to ten times lower than natural gas, its energy density (stoichiometric air-gas mixture) is only about 20%-35% lower than energy density of natural gas (Reed and Das,1988). This is because stoichiometric air to fuel ratio for producer gas is 1.2 to 1.4 as compared to 17 for natural gas (Sridhar et al.,2001). Even if compared to petrol and diesel fuels, the different in terms of energy content is about 15% and 32% lower, respectively (Ulf Bossel,2003). The overall comparison of heating values and energy densities of stoichiometric fuel-air mixture of common liquid and gaseous fuels is presented in Table 2.2 in Section 2.3.

In terms of engine compression ratio, thermal and mechanical efficiencies of IC engine increases with increase of CR, implying that the power output increases with CR under given set of operating conditions. The technique of increasing CR in improving the performance of producer gas engine is not new, it has been carefully investigated by Sridhar et al (2001) and Sridhar et al (2005a). Therefore, the way the air is introduced into the engine cylinder is seen the other potential factor to improve the engine power output, particularly in producer gas engine. Even though most of stationary CI engines with larger capacity today equipped with turbocharger in their operations, however small capacity engines mostly still operating in naturally aspirated mode.

In the basic fundamentals of IC engine, the power delivered in reciprocating engine is directly proportional to the mean effective pressure (MEP) developed in the engine cylinder. The relationship between power (P) and MEP are based on the following equations (Heywood,1988) :

$$\mathrm{P} = \frac{\eta_f \eta_v N V_d LHV \rho_a \lambda}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.1$$

$$\mathrm{MEP} = \eta_f \eta_v N V_d LHV \rho_a \lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1.2$$

Where $\eta_f, \eta_v, N, V_d, LHV, \rho_a$ and λ are fuel conversion efficiency, volumetric efficiency, engine speed (rpm), displacement volume (m^3), lower heating value of liquid fuel (J/kg), density of air (kg/m^3) and fuel to air ratio, respectively. Based on equations 1.1 and 1.2, power and MEP are directly proportional to the inlet density of air entering the engine. Therefore, force induction increases the air charge density, which effectively increases volumetric efficiency, and as a result increases both power and MEP. Forced induction also produces an artificially high compression ratio, in which the actual compression of the intake charge is greater than the geometrical compression ratio as determined by cylinder volume.

Power delivered by the gas engine as compared to liquid fuel engines of comparable cylinder capacity is a major point that is generally considered related to the performance. Therefore, the choice of suitable set of engine parameters for a given combustion chamber design are required to maximized the engine power output. Based on the primary factors that influences power output from producer gas engines and direct proportional of MEP to the air inlet density in the IC engine fundamentals, supercharging the engine is seen the potential factor to improve engine performance, as well as exhaust emissions. Supercharging is a well known method that could improves the combustion characteristics by boosting the intake pressure above atmospheric pressure (Heywood,1988). Higher intake air pressure and air temperature of the engine reduces ignition delay with a lower rate of pressure rise in the combustion chamber.

1.4 Objectives of Research Work

The present study is aimed at investigating experimentally the performance, combustion characteristics and exhaust emissions of supercharged dual fuel engine operating on producer gas-diesel and producer gas-blended diesel/vegetable oil, in which the producer gas is generated with a downdraft biomass gasifier. Therefore, the objectives of this research work can be summarized as follows :

a) to develop a compressed producer gas from continuous operation of a biomass downdraft gasifier.

b) to determine the engine performance, exhaust emissions and diesel displacement of a supercharged dual fuel single cylinder direct injection diesel engine.

c) to compare the performance of supercharged dual fuel engine with that of conventional premixed producer gas-diesel dual fuel and diesel fuel alone.

1.5 Scope of this Work

The current research work deals with : a) diesel fuel, b) blended diesel/vegetable oil, c) dual fuel producer gas-diesel, and d) dual fuel producer gas-blended diesel/vegetable oil operating on both naturally aspirated and supercharged conditions. The work presented here concerns the development and usage of compressed producer gas generated from a downdraft gasifier using off-cut furniture wood as biomass fuel. The diesel engine has been modified at the intake manifold to suit the use of premixed producer gas-air in naturally aspirated, and compressed producer gas and air in supercharged conditions. The diesel engine operated on dual fuel mode was chosen for this project because most of the present hardware design of producer gas engines are adopted based on this type of engine. In addition, the dual fuel CI engine has attracted number of researchers in recent years due to lower running cost, better fuel efficiency, high power output and greater thermal efficiency as compared to normal SI engine.

1.6 Overview of Thesis

The literature review of biomass and power generation from gasification process are elaborated in Chapter 2. Classification of biomass gasifier and its characteristics which are related to this study are briefly introduced. The dual fuel producer gas-diesel and producer gas-diesel/vegetable oil blend are discussed with emphasized on the operating parameters and limitation of CI engine.

Chapter 3 describes the experimental apparatus and methods employed during the present study. Four major equipment used in this study are gasifier system, air compressor, single cylinder CI engine and engine test bed. The concept of supercharged dual fuel CI engine using compressed fuel producer gas-diesel and compressed producer gas-diesel/vegetable oil blend are also discussed.

Engine performance, combustion characteristics and exhaust emissions of diesel alone, premixed dual fuel and supercharged dual fuel of compressed producer gas-diesel and compressed producer gas-diesel/vegetable oil blend were measured and recorded. Various engine speeds and advanced fuel injection timings were used in the experiment. The overall results obtained are discussed and presented in Chapter 4.

The results and discussions are presented in Chapter 4 with further analysis. Finally, Chapter 5 summarises and concludes the findings of the study and gives recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Biomass Gasification

2.1.1 Introduction

As briefly introduced in Chapter 1, gasification is an old technology which has been studied and developed since in the end of the 18th century, specifically around 1788-1791. A century later, during 1877-1881, a producer gas from gasification process of coal was first used to substitute fossil fuel in a stationary IC engine. In the early part of 20th century, during 1901-1905, producer was used as a fuel for the first time in vehicular engines (Shashikantha and Parikh,1999). However, the activities of biomass gasification technology disappeared for more than two decades after the World War ll (1939-1945), when petroleum fuel became cheaper and easily available. The interest in the biomass gasification technology was renewed after the energy crisis of 1970's. The technology began as an alternative for small scale industrial and utility for power generation, especially in developing countries suffering from high petroleum prices but had sufficient sustainable biomass resources. Today, due to the fast depletion rate of petroleum oil, increase in fuel prices drastically and the global environmental concern, there is a renewed interest on this old technology. In addition, the technologies that are being commercialized today are primarily for thermal applications and electricity production, therefore continuous development of commercial biomass gasification technologies are options for future energy supply.

Gasification technology is capable of processing any carbon-based feedstock to produce synthesis gas for the production of electricity, steam, hydrogen, fuels and chemical products. Compared to combustion systems, gasification is the most efficient and environmentally friendly technology for producing low-cost electricity from solid biomass fuels.

2.1.2 Thermo-chemical Conversion Process

In general, the products from complete combustion of biomass materials contain gaseous of CO_2, N_2, H_2O and surplus of O_2. However, gasification is usually termed as controlled partial oxidation which is achieved by supplying limited oxygen at equivalence ratios of 0.2-0.43 (Bharadwaj,2002 and Samir et al.,2008). This incomplete combustion process will lead to chemical breakdown of the biomass fuel through internal reactions, resulting in production of gaseous fuel known as producer gas.

Gasification of biomass materials can be separated into four basic categories : direct combustion, thermo-chemical, bio-chemical and agro-chemical processes (Pratik and Babu,2009). The thermo-chemical conversion process offers a number of advantages such as the use of any type of biomass materials, better burning properties, and the product gas can be converted into a variety of fuels (Sivakumar and Krishna,2010). The major disadvantages, however are the high cost associated with cleaning the product gas from tar and undesirable contaminants like alkali compounds, inefficiency due to the high temperatures required for the process and the gas is not suitable as transportation fuel (Kumar et al.,2009). Basically, there are three main processes in the thermo-chemical conversion : namely pyrolysis, gasification and combustion processes (McKendry,2002b). The gasification process occurs between pyrolysis (thermal degradation in the absence of oxygen) and combustion (thermal degradation with access of oxygen) processes, and at temperatures ranging between 500ºC-1400ºC (Milne and Evan,1998).

The thermo-chemical conversion of solid biomass into raw producer gas takes place in a reactor, called gasifier. In the case of air gasification, air is supplied to a gasifier by a rotary blower. The solid biomass is then converted into a producer gas through a complex series of chemical processes of drying, pyrolysis, partial oxidation and reduction reactions in separate zones. The overall performance of biomass gasifier and the quality of raw producer gas obtained are influenced by a number of parameters such as physical dimensions of the gasifier, biomass fuel property and type of gasification agent used (Sheeba et al.,2009). The raw producer gas can be used for many process applications, either direct burning in a boiler and heating purposes, or via cleaning and cooling processes for used in internal combustion engines.

2.1.3 Composition of Producer Gas

The producer gas consists of about 30%-40% combustible gaseous mainly CO, H_2 and some CH_4, while the remaining gaseous are non-combustible. The gas composition in producer gas depends on the various factors such as type of biomass fuel, design of gasifier and operating conditions (Sridhar et al.,2005b). For reference, the percentage of typical composition of producer gas obtained from biomass gasification process over the last three decades is shown in Table 2.1.

Table 2.1 : Typical Composition of Producer Gas from Downdraft Gasifier

Gas Component	FAO (1986)	Shashikantha et al., (1994)	Zainal et al., (2002)	Banapurmath et al., (2009)
CO	15-30	15-25	24.04	19 ± 3
H_2	10-20	15-20	14.05	18 ± 2
CH_4	2-4	1-3	2.02	3
CO_2	5-15	10-15	14.66	10 ± 3
N_2	45-60	40-50	43.62	50
H_2O	6-8	1-2	1.61	-

Besides gas composition, heating value of producer gas obtained depends on the gasifying agent used. Based on Table 2.1, almost 40%-50% of the gas constituent is composed of non-combustible gas N_2. Although it may be beneficial to use oxygen instead of air for gasification, the cost and availability of oxygen could be a limiting factor in this regard. Therefore, in most applications, air is the common gasifying agent that gives a low heating value of producer gas between 4-6 MJ/Nm^3 and medium heating value of 12-18 MJ/Nm^3 is achieved when oxygen or steam is used (McKendry,2002c). The average low heating value of air gasification of biomass fuel as reported by number of researchers are shown in Table 2.2.

Table 2.2 : Typical Heating Value of Biomass Air Gasification

Reseachers	Heating Value (MJ/Nm^3)
Zainal et al., (2002)	4.65
Uma et al., (2004)	4.60
Sridhar et al., (2005b)	4.50-4.90
Singh et al., (2007a)	4.33-4.39
Banapurmath et al., (2009)	4.19

2.2 Classification of Biomass Gasifier

2.2.1 Introduction

Over the past decades, biomass gasifiers basically can be grouped into three major classifications :

a) Fixed bed – downdraft, updraft and cross draft gasifiers

b) Fluidized bed – bubbling, circulating and internally circulating fluidized bed gasifiers.

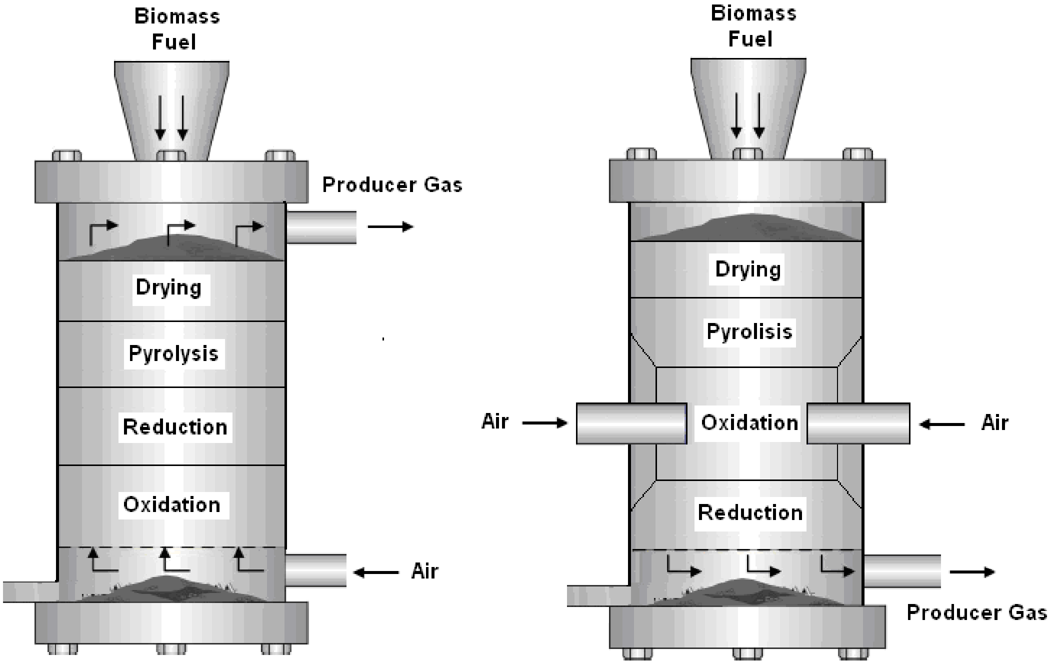
c) Suspension bed – cyclone gasifier

The classifications of above gasifiers are made based on their approach and fuel characterization, and two of the commonly used reactor types of biomass gasification are fixed bed and fluidized bed gasifiers. The composition of producer gas and the level of contamination vary with the biomass fuel used, type of gasifier and operating conditions.

2.2.2 Fixed Bed Gasifier

Fixed-bed gasifier is easy to design and simple in operation but limited in capacity, therefore this type of gasifier is suitable and preferred for a small to medium scale applications. Two basic types of traditional fixed-bed gasifier can be classified according to the ways the gasifying agent is introduced into the gasifier, and can be further classified as updraft and downdraft gasifiers. Both reactor types are based on slow descending fuel flow caused by gravity.

Updraft gasifier is more suitable for biomass containing high ash up to 15% and can be up to 50% of moisture content (Chopra and Jain,2007). Biomass fuel is fed from the top of gasifier, falls into a grate and forms a fuel bed. Air from below the grate is blown up through the fuel bed as shown in Figure 2.1(a). Since the flow of fuel and air are downward and upward respectively, this type of gasifier is also known as a counter-current gasifier. During gasification process, the temperature at combustion zone reaches about 1000ºC, and the producer gas leaves the upper part of the gasifier at temperature of about 200°C (Carolyn,2010).



(a) Counter Current Gasifier (b) Co-current Gasifier

Figure 2.1 : Type of Fixed Bed Gasifier (Warnecke,2000)

The producer gas from an updraft gasifier contains between 10%-20% tar which is difficult to remove especially for IC engine use (Dennis et al.,2004). Therefore, the producer gas from updraft gasifiers are mostly used in thermal applications such as in a steam boiler and drying process (McKendry,2002c). In such applications, the updraft gasifier is usually referred to as heat gasifier. Updraft gasifier normally uses charcoal where the amount of tar in the producer gas is very low in the range of about 0.1% by weight (Reed and Dass,1988).

In a downdraft gasifier, biomass fuel is fed from the top and air is introduced at or above the oxidation zone, and producer gas exits from the bottom of the gasification bed as shown in Figure 2.1(b). Since the flow of fuel and air are both in downward direction, the downdraft is also known as co-current gasifier. Temperature at the oxidation zone is around 900ºC to 1200ºC, and the producer gas leaves the gasifier at a temperature between 200ºC-300°C (Dogru et al.,2002). In this conditions, most of the tars are cracked in the oxidation zone, and the final product of producer gas has typically less than 0.1% of tar content by weight (Reed and Dass,1988).

The main advantage of downdraft gasifier over updraft gasifier is the possibility of producing gas with low tar content, low ash and particulate concentrations. Other advantages include suitability with various biomass fuels, easy to control, high conversion rate and the most suitably used in combined heat and power generation (Dogru et al.,2002). Higher gas outlet temperature, and limited up to 25% moisture content of biomass fuel are amongst the common disadvantages of this type of gasifier (Warnecke,2000).

The updraft and downdraft gasifiers can have capacities up to10 MW_T and up to 2 MW_T, respectively (Carolyn,2010). Producer gas from downdraft gasifier is well known for generating clean gas that is suitable to be used in IC engine for power generation, therefore is sometimes called power gasifier (Bridgwater,1995).

However, for the purpose of power generation in IC engine, the producer gas from downdraft gasifier need to be cleaned to remove dust, particles and tars, then the gas has be cooled to increase its energy density (Demirbas,2005). Tar content in producer gas is a major operational challenge because it can cause clogging problem in engine valves resulting in high maintenance cost.

2.2.3 Fluidized Bed Gasifier

Fluidized-bed gasifier was developed for the purpose to overcome the operational problems faced by fixed-bed gasifier in terms of high ash and high moisture contents of biomass fuel (Warnecke,2000). Fluidized-bed basically can be divided into bubbling fluidized bed and circulating fluidized bed gasifiers. The size of biomass fuel in fluidized bed gasifier is reduced to a specified particle size, and fed at the bottom of the reaction chamber.

Gasifying agent, usually air is blown through a hot bed of inert granular solid material such as sand or ceramic at sufficient velocity to keep these particles in suspended solid. The biomass fuel are mixed with the hot bed materials and heated up to the temperature for gasification, relatively at temperature around 750°C-900°C (McKendry,2002c). The producer gas from this gasifier can be used to run an external combustion unit, with an output range from 1 MW_T up to 1000 MW_T (Lopamura,2005). The major drawbacks of the fluidized-bed gasifiers are high tar content up to 500 mg/Nm^3, more particulates, incomplete carbon combustion and poor response to load changes (Kumar et al.,2009 ; Ciferno and Marano.,2002).

The advantages and disadvantages of each type of gasifiers have been carefully summarized by (Warnecke,2000). Gasifiers also can be categorized by the method of heat source provided for the endothermic gasification reactions. Heat can be supplied to the gasifier directly or indirectly. In a directly-heated gasifier, part of biomass is allowed to combust inside the gasifier, the combustion then raises the temperature and provides the required heat for the endothermic gasification reactions. In the case of an indirectly heated gasifier, biomass is combusted in a separate chamber and heat exchanger tubes conduct the heat from the combustion chamber to the gasification chamber (Huber et al.,2006).

2.3 Gasification Characteristics

The performance of biomass gasifier is influenced by a number of parameters such as biomass fuel properties, physical dimension of the gasifier and operating parameters (Kumar et al.,2009). The following sections consider the most important characteristics of biomass gasification used in this research project.

2.3.1 Efficiency of Gasifier

One of the important parameters used in determining the actual technical operation of a gasifier is the gasification efficiency. The cold efficiency of the gasifier can be defined as the energy content of the producer gas in relation to the energy content of the biomass fuel, in which the typical cold efficiency is in the range between 70% - 80% (Reed and Das.,1988 ; Sivakumar et al., 2008). The cold gas efficiency, η is normally used to refer to the temperature of producer gas of almost room temperature well below the gasification temperature. The following equation is used to determine the cold gas efficiency (Jain and John,2000) :

$$\eta_c = \frac{LHV_{PG} \times \dot{V}_{PG}}{LHV_b \times \dot{m}_b} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

Where :

LHV_{PG} = lower heating value of the producer gas (MJ/Nm^3)

$\dot{V}_{PG}$ = volumetric flow rate of the producer gas (Nm^3/h)

LHV_b = lower heating value of the biomass fuel (MJ/kg)

$\dot{m}_b$ = mass flow rate of the biomass fuel (kg/h)

2.3.2 Fuel-Air Equivalence Ratio

The fuel-air equivalence ratio (Ψ) for gasification can be defined as stoichiometric fuel/air ratio to the actual fuel/air ratio of biomass combustion, as shown in the following equation :

$$\Psi = \frac{(F/A)_{\mathrm{stoich}}}{(F/A)_{\mathrm{actual}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

Therefore, the fuel-air equivalence ratio for each run of gasifier can be calculated based on the following equation (Zainal et al.,2002) :

$$\Psi = \frac{(\text{Flowrate of air supplied}) \times (\text{Duration of the run})}{(\text{Mass input of wood}) \times (\text{Air fuel ratio for } \varnothing = 1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where stoichiometric air-fuel ratio (∅) = $\frac{(A/F)_{\mathrm{stoich}}}{(A/F)_{\mathrm{gasifier}}}$.

The stoichiometric air-fuel ratio of biomass fuel in gasification is 5.22 m^3 of air per kg of wood consumed, and the ideal and theoretical gasification of Ψ is in the range of 0.268–0.43 (Zainal et al.,2002), and between 0.2–0.4 (Tewari et al.,2001). The typical fuel-air equivalence ratio for steady operation of gasifier as reported by Reed and Dass (1988) is approximately of Ψ=0.25.

2.3.3 Moisture Contents

Moisture content (MC) of biomass fuel has significant effect on the overall performance of a gasifier. Thermal conversion of biomass fuels requires low MC, typically less than 50%. Any MC of biomass fuels higher than 30% makes ignition difficult, and reduces the heating value of the producer gas as an additional evaporation process is required before gasification can occur (McKendry,2002a). The MC on dry-weight basis is given on the following expression, applied to the sample weight of the biomass fuel (Reed and Dass,1988) :

$$\mathrm{MC} = \frac{\text{Wet weight - Dry weight}}{\text{Dry weight}} \qquad \text{………………………………………..2.4}$$

2.3.4 Heating Value of Solid Biomass Material

In general, heating value is defined as the amount of heat produced from complete combustion of a specific amount of fuel. Heating value can be divided into two basis : higher heating value (HHV) and lower heating value (LHV). HHV is referred to the heat released from the fuel with liquid water as the product, while the LHV is based on water vapour as the product (Cengel,1998). HHV of biomass fuel can be determined experimentally using an adiabatic bomb calorimeter which measures the entalphy changes between reactants and products.