PERFORMANCE OF TOTAL RENEWABLE ENERGY FUELED DIESEL GENERATOR USING PRODUCER GAS AND PALM OIL

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by

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LIST OF SYMBOLS

m_{water}	Mass of water, kg	51
ΔH_{water}	Specific heat for water, kJ/kg.K	51
ΔT	Temperature difference	51
x	Quantity	55
N	Number of measurement	55
$\bar{x}$	Mean, average	55
σ_x	Standard deviation	55
$\sigma_{\bar{x}}$	Standard deviation of the mean	55
$T_{cyclone}$	Temperature of exit cyclone, °C	67
$T_{precooler}$	Temperature of exit precooler, °C	67
T_{engine}	Temperature of entrance engine, °C	67
$P_{in,Biomass}$	Thermal input from biomass, kW	68
P_{Total}	Total thermal input from biomass and blower, kW	68
$P_{outpout}$	Thermal output, kW	68
ρ	Density, kg/m^3	120
μ	Viscosity,kg/ms	120
ν	kinematic viscosity, m^2/s	120
Pr	Prandtl Number	120
Gr	Grashof Number	120
Nu	Nusselt Number	121

LIST OF ABBREVIATION

AFR	Air Fuel Ratio
BFBG	Bubbling fluidized bed biomass gasifier
CFBG	Circulating fluidized bed biomass gasifier
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
CHP	Combined Heat and Power Plant
ER	Equivalence ratio
GC	Gas Chromatograph
PG	Producer gas
LHV	Low Heating Value
HHV	High Heating Value
LPG	Liquid Petroleum Gas
SEC	Specific Energy Consumption
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
CO	Carbon Monoxide
NO_x	Nitrogen Oxide
CO_2	Carbon Dioxide
UHC	Unburned Hydrocarbon
SFC	Specific Fuel Consumption
TRE	Total Renewable Energy
DD	Diesel Displacement
TDC	Thermal Conductivity Detector
GCC	Gas Cleaning and Cooling
TGA	Thermogravimetric analyzer

PRESTASI JANAKUASA DIESEL MELALUI TENAGA BOLEH DIPERBAHARUI MENGGUNAKAN HASILAN GAS DAN MINYAK SAWIT

ABSTRAK

Era ini, dunia menuju ke arah pengunaan tenaga hijau yang mempromosikan penggunaan tenaga kitar semula. Ini adalah disebabkan kekurangan sumber tenaga dan pencemaran alam yang semakin buruk dimana telah menonjolkan tenaga biojisim sebagai satu alternatif. Sebuah penggas aliran sedutan telah dipilih untuk penukaran tenaga kerana keupayaan untuk mengeluarkan haba yang lebih tinggi, mampu menerima pelbagai jenis bahan api dan kurangnya penghasilan tar. Penggas ini direka dengan diameter dalam 350mm dan tinggi 1.1m dimana mampu mengeluarkan 25kW tenaga haba. Ia disambungkan kepada satu sistem penyejukan dan pembersihan untuk mengeluarkan partikel dan kondensasi. Biojisim yang digunakan untuk proses penggasan ini adalah kayu buangan dan disambungkan kepada janakuasa enjin diesel untuk penjanaan eletrik. Didapati, nilai kalori rendah biojisim, $LHV_{Biomass}$ adalah 17.92MJ/kg, nilai maksima kalori gas, LHV_{PG} adalah 5.44MJ/m^3. Janakuasa diesel 5.5kW_e pada 1500rpm digunakan untuk kajian penggantian minyak (mod dua bahan bakar). Pada mod dua bahan bakar, penggantian diesel diperolehi setinggi 60% pada beban separa. Keluaran gas karbon monoksida (CO), hidrokarbon tak terbakar (HC) dan karbon dioksida (CO_2) dikaji dan didapati lebih tinggi dari diesel. Walau bagaimanapun keluaran NO_x adalah lebih rendah dari diesel pada mod dua bahan bakar. Minyak sawit yang banyak selain mempunyai tenaga simpan yang tinggi disesuaikan sebagai asas pengganti minyak berasaskan petroleum. Ujian makmal keatas enjin diesel dijalankan bagi ukuran prestasi dan kesan keluaran pada penggunaan minyak sawit. Percampuran minyak diesel kadar 20%, 40%, 60%, 80% and 100% minyak sawit dilabelkan P20, P40, P60, P80 dan P100 diujikaji pada beban penuh. Sifat ketumpatan dan kebendaliran meningkat pada peningkatan campuran. Ujikaji mennjukkan P20 menjanjikan prestasi kecekapan haba enjin yang baik termasuk keluaran gas berbanding diesel. Seterusnya, janakuasa diesel yang menggunakan sepenuhnya sumber boleh diperbaharui dilihat satu formula untuk penggantian kebergantungan kepada diesel secara 100%. Walaubagaimanapun, kajian mendapati prestasi menurun berbanding diesel pada semua beban yang dikenakan. Selain itu keluaran gas terdiri daripada CO adalah tinggi, dan NOx lebih rendah berbanding diesel.

PERFORMANCE OF TOTAL RENEWABLE ENERGY FUELED DIESEL GENERATOR USING PRODUCER GAS AND PALM OIL

ABSTRACT

Today, the world is implementing the use of green energy in promoting renewable energy. Mostly, the interest lies in the depletion of fossil fuel and the environmental degradation which has prompted the use of biomass as a source of energy. A suction biomass gasifier was thus selected for energy conversion due to reliable in thermal output, broad range of fuel sizes and the output producer gas with less tar content. The gasifier was designed with an inner diameter of 350mm, 1.1m in height and has a 25kW thermal output. It is attached to a gas cooling and cleaning system (GCC) to remove some of the particulate, water vapor and tar. In the study, a suction biomass gasifier was used to carry out the gasification experiments using wood waste and connected to a diesel engine-generator to generate electricity. Wood chip has a low calorific value, $LHV_{Biomass}$ of 17.92MJ/kg while producer gas has a typical LHV_{PG} of $4.2MJ/Nm^3$. Diesel generators with $5.5kW_e$ (rated speed of 1500rev/min) was used for the dual fuel experiment. In dual fuel mode operation, diesel displacement was 60% at partial load (1500 rev/min). Results show that the emission levels of carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbon (HC) are relatively higher than neat diesel. However, NO_X emission of dual fuel mode is always lower than neat diesel. Available alternative fuel is palm oil with high energy content that can be adopted as an alternative to petroleum based fuel. Research was carried out to evaluate the performance and emission by experimenting on palm oil as fuel in diesel engine. Diesel fuel with 20%, 40%, 60%, 80% and 100% palm oil (denoted as P20, P40, P60, P80, and P100) were tested separately with the engine at

full load. High density and viscosity were observed with increasing palm oil composition. The experiments show P20 blend promises good brake thermal efficiency together with emission comparable to neat diesel. Diesel generator fueled with total renewable energy (producer gas+P100) is an attractive formula for utilizing fully renewable fuels with 100% diesel displacement. However, experimental results observed poor performance at all loads compared to neat diesel. At all engine loads, CO emissions obtained were found to be higher while NO_x emitted were lower than neat diesel.

CHAPTER 1:

INTRODUCTION

1.0 Background

Scenario of increasing energy utilization and price causes an impact to power generation. The main sectors utilizing energy are industries, transport and household where demand is continue to rise. Most developing countries such as Japan, USA, Taiwan and China use energy to drive the economy. But, fossil fuel energy will be facing depletion in the next 40-50 years (Koh, 2003).

Fossil fuel resources such as oil, coal and gas release harmful pollutants as by-products in power generation. Utilization of fossil fuels releases green house gas emissions (GHG) such as CO_2 that cause significant adverse effect leading to global warming as well as climate change. For instance, based on information from Intergovernmental Panel on Climate Change (IPCC); global temperature will arise between 1.1°C to 6.4°C (IPCC, 2007). In order to reduce global warming, Kyoto Protocol was established in 1997 to enforce GHGs emission throughout developing countries.

Generally the rate of emission released is closely related to energy generation. Commercial activities which produced high CO_2 emissions are transportation, power generation and industries. Japan is committed to reduce its CO_2 emission by 6% in four consecutive years starting from 2008-2012. Japan has established a limitation for industries to suppress CO_2 emission where in 2005 Japan industrial sector has achieved 3.2% CO_2 emission reduction from 482tonnes (1990) to 466 million tonnes (2005) (Lee, 2009). Other than effort to reduce CO_2 emission, the Japanese government in 2003 has enforced energy supply mix which includes renewable energy (RE). Many countries have started to implement RE especially in power generation sector, and contribute to CO_2 reduction (RPS, 2002).

RE is seen as a potential substitute for fossil fuel as well as providing cleaner technology. Biomass is one of the alternatives that are abundant, relatively cheap, and widespread availability. Recognizing the profit from biomass, many countries have diversified in power producing by using combined heat and power plant (CHP) (Kramreiter, 2008). The CHP fueled from biomass contributes about 12% in primary energy on a world wide (Yusoff, 2006).

1.1 Overview of Biomass Energy in Malaysia

Malaysia is blessed with huge capacity of fossil fuel resources such as oil, gas, and coal as well as RE from biomass, solar and hydropower. From the past decades, Malaysia showed significant growth in economic activities and electricity demand (energy use per unit GDP) about 1.5 times based on several decades (Yusoff, 2006).

In Malaysia, power generation is fueled mostly by fossil-based: natural gas and oil (Zamzam, 2003). The fuel mix was encouraging Malaysia to move inline for RE. Introduction of Malaysian Fifth Fuel Strategy however include RE in the fuel mix with 5% energy supply by 2005 (Lee, 2009). Subsequently, RE source is targeted from oil palm residues and other agricultural industries such wood, sugar cane and paddy. Malaysia being the second largest palm oil producer in the world is able to produce approximately 19 million tones of crop residues per year in the form of empty fruit bunch, fiber and shell (Rahman, 2005). Table 1.1 shows the RE resources in Malaysia towards the goal of technology commercialization (Chua, 2011).

Table 1.1: Recent renewable energy potential in Malaysia.

Renewable energy	Residue	Electrical potential (MW)
Oil palm	Empty fruit bunches	570
	Fibres	1080
	Shells	550
	Palm Oil Mill Effluent	330
Paddy	Rice husk	72
	Paddy straw	83.9
Sugar	Bagasse	0
Wood	Sawn timber	50.1
	Plywood & veneer	3.6
	Moulding	2.2

Source: Malaysia Energy Centre, Comprehensive Biomass Study 2005

In view of technology commercialization, concern parties should use the RE resources for energy supply demand illustrated in Figure 1.1 (Gan, 2008). Ensuring sufficient continuous supply of biomass seems to be the biggest challenge in Malaysia. Although it was reported by several studies, commercialization of research findings has not been fully undertaken on a large scale.

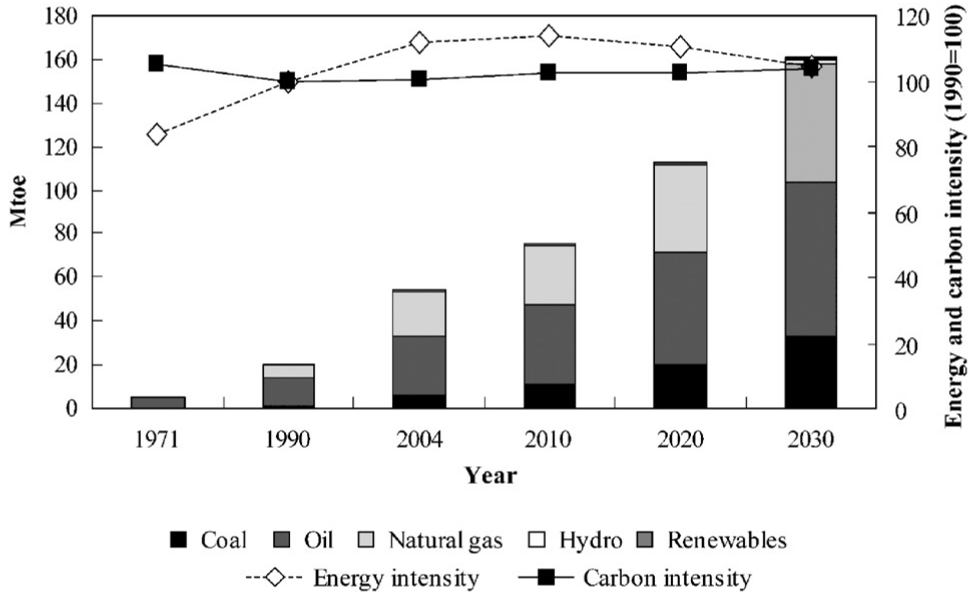

Figure 1.1: Energy demand in Malaysia (Gan, 2008)

On the other hand, Malaysia has successfully implemented biodiesel fuel for the transportation sector that will reduce dependence on fossil fuel. In 2007, Malaysia has commercialized blending of 5% biodiesel (B5) in commercial diesel fuel for domestic market. Until now, Malaysian government has targeted renewable energy for power generation and as transport fuel (Gan, 2008).

1.2 Outlook of Development of Biomass Energy

Many countries have started and established biomass energy conversion technology to produce power. In line with efficient energy utilization, Japan has moved ahead and implemented bio-energy guided by the principle of “Biomass Nippon Strategy” early 2002. Based on the principle, Japan promotes utilization of biomass by research funding, various regulation and framework. In Japan, the prospect of woody bio-energy in 2050 would be expected in “regional” utilization (Takuyuki, 2005). This plan is the main energy utilization for small scale and decentralized system for bio-energy production. On the other hand, biomass and coal will be used in coal-fired power plant on a larger scale.

Finland was Europe's second largest bio-electricity behind Germany in 2005 with 8.9 TWh. Biomass-based fuels are used nearly completely in heat and CHP production. The number of large scale CHP plants in Finland is nearly 100MW and the total capacity is over 1500 MW. The Alholmens Kraft CHP plant in Pietarsaari, Finland, is the largest biofueled power plant in the world. The plant produces steam for the adjacent paper mill and for a utility generating electricity and heat (Demirbas, 2009).

1.3 Problem Statements

Power generation is normally fueled by fossil fuel such as coal, petroleum, and natural gas. The concern for depletion of these fossil fuel reserves and the adverse effect on the environment has resulted in utilizing renewable energy sources which are less environmentally harmful. Potential of available biomass such as forest residues, palm oil wastes increases renewable energy utilization. In rural areas, limitation on electricity supply from the grid could be an advantage for small scale biomass fueled electricity generation. A system consisting of a suction downdraft gasifier system has been used for bio-energy conversion due its flexibility and high carbon conversion rate. Adopting producer gas from biomass into diesel engine generator could conserve the use of fossil fuel. Besides fuel displacement in dual fuel mode (diesel +producer gas) operation, a total renewable energy (TRE) fuel comprising of producer gas and palm oil will also drive the diesel engine generator.

1.4 Objective

The objectives of this experiment are;

1. To develop a suction downdraft gasifier with gas cooling and cleaning system.
2. To characterize the performance of the suction gasifier system.
3. To investigate the performance and emission of 5.5 kWe diesel engine fueled by blended diesel (palm oil diesel blends), dual fuel (diesel and producer gas) and total renewable energy (palm oil and producer gas).

1.5 Scope of Work

The scopes of the study are as follows.

1. The mass flow rate of wood chip, air and producer gas will be measured, varied and the calorific value analyzed to determine the effect on suction gasifer.
2. Mass balance of the system will be made to check for char collected from gasifier and the amount of condensate in the producer gas. Energy balance will also be carried out.
3. The 5.5 KWe diesel generators will be coupled to a suction gasifier to measure the performance and emission in dual fuel mode operation.
4. Use of palm oil and diesel blend will be introduced into the diesel generator to study effect of the performance and emission level.

In this work it is proposed to use wood waste material as biomass feedstock. Despite using of diesel in dual fuel mode operation, a TRE fuel comprising of producer gas and palm oil will also drive the diesel engine generator. For diesel testing studies, injection timing will not be changed and wear characterization will not be investigated.

1.6 Thesis Outlines

The thesis is organized in 5 chapters. Chapter 1 gives brief information about the overview, benefit and development of RE including objectives and scope of this project. Chapter 2 reviews previous studies on biomass gasification process, type of gasifier, gas cleaning methods, performance and emission of the diesel engine using producer gas and palm oil in dual fueled mode operation. Chapter 3 presents experimental description. Results and discussion are presented in Chapter 4 followed by error analysis. Finally, the thesis ends with several conclusions in Chapter 5.

CHAPTER 2:

LITERATURE REVIEW

2.0 Overview

The use of biomass as alternative fuel has been studied by many researchers from the past decades up to now. Their studies have been carried out through experimental and commercial plants. This chapter is aimed at providing some of the related information regarding the research carried out pertaining to the use of biomass from different researchers across the globe.

The literature review begins with the study of biomass gasification process. It follows with reviewing the types of gasifier, and industrial experience on gasification system. Lastly, the summary of important information is done to justify the current work.

2.1 Biomass Gasification Process

Renewable biomass is an organic material that in commonly derived from plant matter. Biomass wastes are prominent feedstock from forestry, industry and agriculture sectors. Biomass chemical composition universally consists of carbohydrates and lignin (Tokareva, 2007). Burning the biomass would produce carbon dioxide and water as end products. Chlorophyll in plants captures carbon dioxide from the atmosphere and converts through photosynthesis into carbohydrates, offering carbon neutralization in atmospheric greenhouse gases. However the combustion of fossil fuel, lead to a net increase of CO_2 in the atmosphere.

Biomass energy resources such as wood and charcoal and others have been used for a long time ago. It is renewable, pollution free, easy to obtain and convenient in collection, justify reasons of using biomass wastes as an energy resource. Energy from the biomass is capable to be used in broad applications such as in reciprocating engines, as fuel in furnace, boiler, and gas turbine. Solid biomass can be converted into gaseous fuel via gasification. It is a thermo chemical conversion process with limited supply of air as gasifying agent. The gas is called producer gas with heating value of 4-5MJ/m^3 (Giltrap, 2003; Yamazaki et al., 2005).

Biomass gasification is accomplished by drying, pyrolisis, oxidation and gasification processes. Drying process removes surface moisture from the biomass by evaporation process. In the pyrolysis zone the biomass is decomposed into volatile and charcoal. The rate of volatile release depend on the particle size and temperature within the biomass particle (Sheth, 2009). The temperature in the region is sufficiently high to thermally ‘crack’ the pyrolysis products into components of low molecular weight (Giltrap et al., 2003). It is followed by oxidation where the volatile and char are oxidized in highly exothermic reaction resulting in a rapid rise of temperature (Dogru, 2002). Then finally the gasification process take place where char is converted into combustible gases. Researchers have reported varying temperature of gasification zone, ranging from 600°C to 950°C (Dinesh, 2006; Boateng, 2007).

Basically the chemical reactions during gasification are divided into exothermic and endothermic reactions and are listed below (Alexander, 2003; Rezaiyan et al., 2005):

Homogenous reaction

$$CO + H_2O \longrightarrow CO_2 + H_2 \text{ (Water gas shift)}$$

$$CO + 3H_2 \longrightarrow CH_4 + H_2O \text{ (CO methanation)}$$

(Endothermic)

Heterogeneous reactions

$$C + O_2 \longrightarrow CO_2 \text{ (Oxidation)} \quad \text{(Exothermic)}$$

$$C + CO_2 \longrightarrow 2CO \text{ (Bourdard reaction)}$$

$$C + 2H_2 \longrightarrow CH_4 \text{ (Hydro-gasification)}$$

$$C + H_2O \longrightarrow CO + H_2 \text{ (Water gas reaction)}$$

(Endothermic)

The gasification agent (air, oxygen/steam, H_2) and process operating condition affect the heating value and application of the producer gas. The producer gas consists of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen. The factor that influenced the gas composition are the biomass material, moisture content, reaction temperature, and the extend of oxidation of pyrolysis products (Bridgwater, 2003).

Depending on the gasifying agent, three types of calorific value (CV) that are listed below can be produced (Kendry, 2002):

Low CV	4–6 MJ/Nm^3	using air and steam/air
Medium CV	12–18 MJ/Nm^3	using oxygen and steam
High CV	40 MJ/Nm^3	using hydrogen and hydrogenation

Many researchers found that the low calorific value of producer gas for air/steam varies from 4.2 to 5.4MJ/m^3 (Bacaicoa, 1994), and 3.5-4.7MJ/m^3 (Yamazaki et al., 2005).

2.2 Type of gasifiers

In general, gasifiers can be broadly classified as fixed bed: updraft and downdraft gasifier, and fluidized bed gasifier: bubbling fluidized bed gasifier (BFBG) and ciculating fluidized bed gasifier (CFBG) (Bridgwater, 2003).

2.2.1 Fixed Bed Gasifier

Generally, fixed bed gasifiers are normally used with charcoal (Bahng et al., 2009). This gasifier technology is simple and proven for fuel with uniform size. The gasifiers can be divided into downdraft and updraft-fixed bed gasifiers. This classification is based on the direction in which air moves through the bed and output of producer gas.

Fixed bed gasifiers have grate at the bottom to hold the biomass feedstock. The grate is shaken by external handle or stationary type to ensure proper bed reaction. In a downdraft gasifier the biomass gradually moves down the bed and air is introduced and reacts at the throat that supports the gasification reaction. Both the biomass and gas produced move downward in co-current manner. The reactions that take place in the downdraft started at the top of gasifier with drying process followed by pyrolysis, combustion and gasification processes. In updraft gasifier air is introduced counter-current upward and contact with biomass. The fixed bed classification is shown in Figure 2.1 (Dong et al., 2009).

Downdraft gasifier offer low tar in the producer gas. A relatively clean gas with low tar and high carbon conversion was found by using downdraft gasifier (Bridgewater, 2003; Warnecke, 2000). The typical amount of tar is about 0.1% of the biomass feed (Zainal, 1996). Some tar has been collected in the range of 10-6000mg/Nm^3 for a downdraft gasifier (Hasler, 1999). By using small scale open-top gasifier of IISc/Dasag, tar concentrations are lower than 1g/Nm^3 (Hasler, 1999). Hence downdraft configuration is suitable to be use in reciprocating engines and turbines (Advesh, 2009; Chen et al., 2004). The bed temperature for oxidation zone varies from 900°C to 1050°C and the pyrolysis zone: 260°C and 550°C (Sheth, 2009; Dogru, 2002). Advantages of downdraft are; high char conversion, low tar and ash, quick response to load, different solid wastes and simple construction. The downdraft and updraft gasifier are shown in Figures 2.1(a) and (b) respectively.

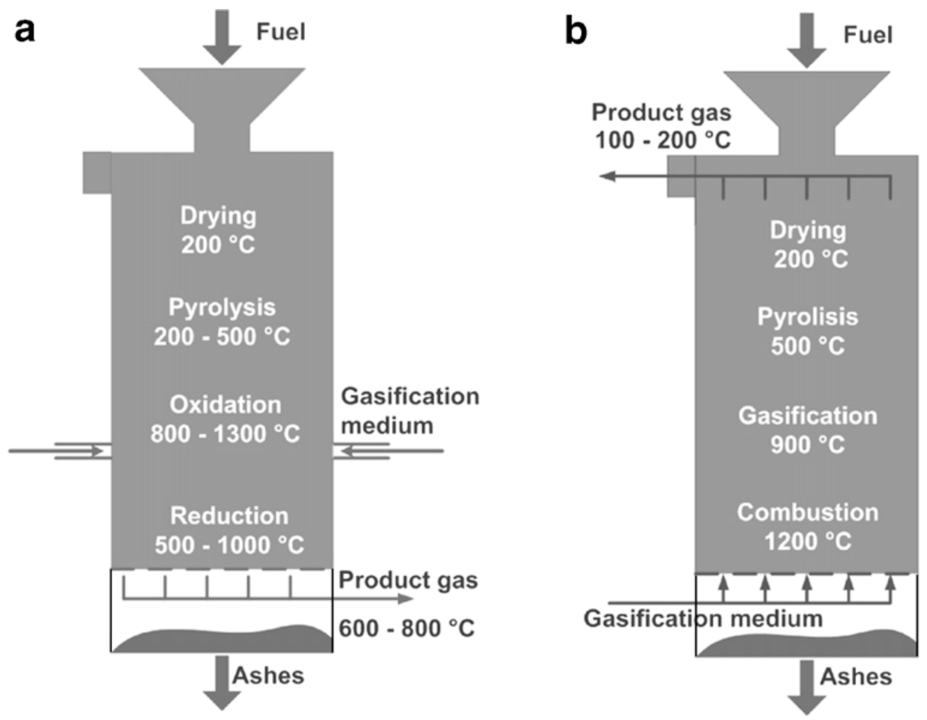

Figure 2.1: Diverse Gasifier: (a) Downdraft (b) Updraft (Dong et al., 2009)

In the basic form of an updraft gasifier, air is introduced below the grate and diffuses up through the bed of biomass and char. As countercurrent flow, the bed reaction consists of drying, pyrolysis, gasification and combustion zones from the top of gasifier. From the combustion zone (~1000°C), the hot gases pass through the bed, reduced to H_2 and CO and cooled to 750ºC (Jeng, 2006). The hot gas continues to pyrolyze the downward dry biomass and leaves the gasifier at about 200°C. The major disadvantage of updraft gasifiers is high tar content consisting of 10% to 20% by weight, thereby needing extensive cleaning system for engine or turbine application (Jeng, 2006). Updraft gasifiers are more popular using charcoal and produces much less tar (Dong et al., 2009).

2.2.2 Fluidized Bed Gasifier

The systems of fluidized bed gasifier promise an ability of achieving high heat and mass transfer inside the bed (Skoulou, 2008). The gasifier consists of three separating zones: bed zone, freeboard and disengaging zone (Marcio, 2004). In the bed zone, fine sand is often used as heat transfer medium (Scott, 1999). Air for gasification is supplied through the distribution plate at the bottom.

This gasifier can be divided into two types: bubbling fluidized bed gasifier (BFBG) and circulating fluidized bed gasifier (CFBG) shown in Figure 2.2 below (Dong et al., 2009). BFBG tolerate with wide variations of particle size (Bahng et al., 2009; Warnecker, 2000; Skoulou, 2008). In contrast for CFBG, the biomass particles are introduced into a circulating fluidized bed of hot bed material (sand). However, problem like bed sintering, agglomeration and deposition that appear due ash melting are the major obstacle (Bahng et al., 2009) of fluidized bed gasification. Narvaez et al. (1996) observed 19g/m^3 of tar for a BFBG at 700°C gasification temperatures.

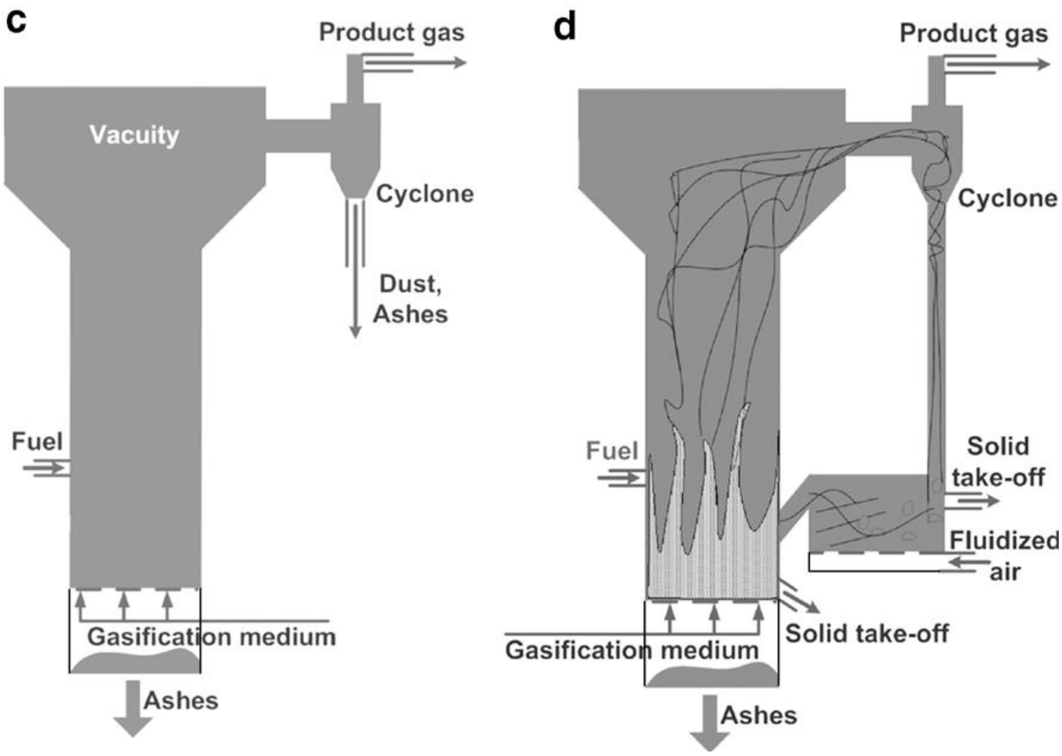

Figure 2.2: Diverse Gasifier: (a) Bubbling Fluidized Bed (b) Circulating Fluidized Bed (Dong et al., 2009)

The important parameters can be summarized in Table 2.1.

Table 2.1: Importance parameters of four types of gasifiers (Warnecke, 2000)

	Downdraft	Updraft	BFBG	CFBG
Carbon Conversion Efficiency	High	High	Low	Low
Quality of Gas	High	Low	Low	Low
Tar Byproduct	Low	High	High	High

2.3 Industrial Experience on Fixed Bed Downdraft Gasification System

Dassapa (2003) used biomass gasification in industrial application for heating. The mild steel reactor lined with ceramic refractory in inner side, consists of high temperature resistance block and high alumina tiles. The 500kg/h of producer gas is induced into the burners via gas cooling and cleaning system (GCC) with an installed capacity of 2MW thermal output replacing fossil fuel (diesel) consumption in a range of 120 ~ 150L/h. The furnace was used for heat treatment at a temperature of 873 ~ 1200K.

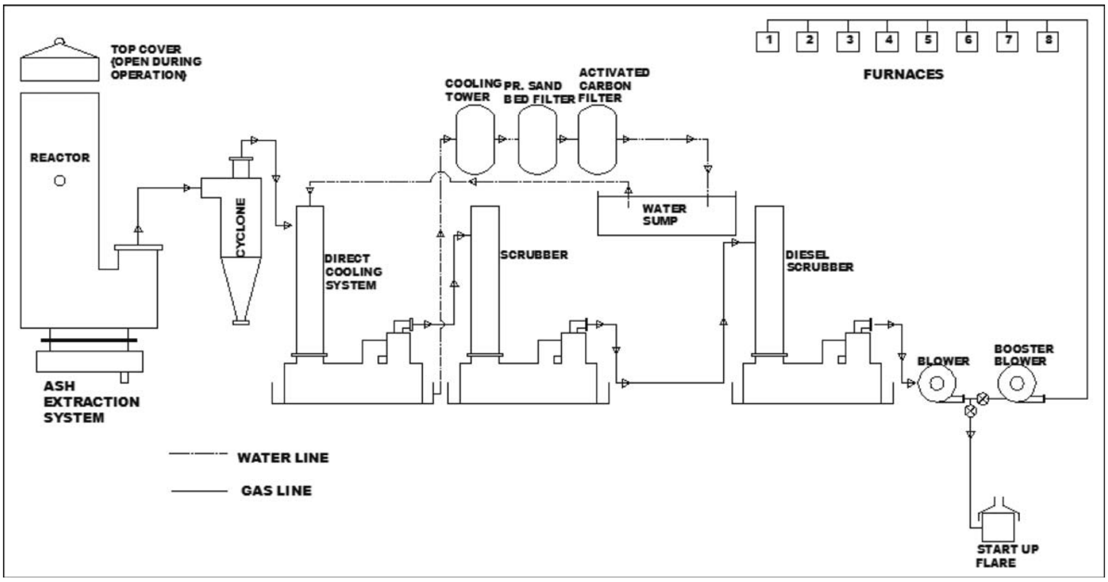

Figure 2.3: Schematic of the gasifier system at Synthite Industrial Chemicals Pvt. Ltd, India (Dassapa, 2003)

In rural India, biomass gasifiers provide electricity for household application. Generally, the application is provided for lighting, pumping water for domestic used and also operating flour mill. Somashekhar (2000) used open-top downdraft gasifier type with ceramic lining with water sprayed cooler installed to cool the outlet of producer gas. The gas was then taken through coarse and fine-sand bed filters. The diesel generator capacity was $20kW_e$, with diesel displacement of over 70%. The overall efficiency was 21%. Typical combustible gases were 18 ± 2% CO, 18 ± 2% H_2, and 1-2% CH_4 with a calorific value of 4.5 MJ/kg. The tar and particulate were 25±5 mg/Nm^3 and 30±5 mg/Nm^3 respectively especially while the cold gas efficiency was about 78%. The system also reported that the specific wood consumption was in range of 1.15 to 1.35 kg/kWh.

2.4 Performance Studies of Suction/Stratified Downdraft Gasifier

A study explores the range of fixed bed performances limited to suction/stratified downdraft gasification systems. The focus is on the gasifier characteristic and system efficiency. Furthermore, the power generation such as internal reciprocating engine, an external combustion for boiler fueled by producer gas is also addressed.

Basically in a suction/stratified downdraft system, both gas and feed stock move downward as the reaction proceeds. Air required for gasification is partly drawn from the top of the gasifier and the remaining is from air nozzle (air tuyeres) which is located at the combustion zone. The required suction for this process is obtained from the blower. The gasifier is a batch fed down-draft insulated from outside with refractory cement. Biomass after drying and pyrolyzing in the upper zone undergoes combustion as it reaches the oxidation zone. These product gases undergo gasification, yield a combustible mixture. The hot gas exits the gasifier bottom.

Sheth (2009) performed an experimental study on imbert downdraft gasifier using rose wood. This type of gasifier has throated combustion zone and different diameter for pyrolysis and gasification zones unlike stratified downdraft gasifier. The total height of this gasifier is 1.1 m where the height of the gasification zone is 100 mm, and the oxidation zone is 53 mm. Gasification zone was fabricated with 150 mm diameter while pyrolysis is 310 mm. The movable grate is introduced at the bottom of gasifier for ash removal. This also prevents clogging and bridging of the biomass. The experiment used 500g of charcoal as start up and biomass was fed as combustion commenced. Biomass feed rate vary from 1.0 to 3.6kg/hr. The oxidation zone temperature was 900^{o}C to 1050^{o}C and that of pyrolysis zone between 260 ^{o}C and 550^{o}C. The producer gas result obtained the maximum calorific value of 6.34MJ/Nm^3.

Performance of the throated downdraft gasifier is related to air fuel ratio. Dogru (2002) discussed the production of clean gas using a 5kWe throated downdraft gasifier system. The system developed consists of downdraft gasifier, packed bed scrubber, filter box, and a pilot burner. It is suggested for output of 5kWe, downdraft gasifier should be operated at 3.69–3.71kg/h of the feed rate, at 2.28–2.34m^3/kg of the air fuel ratio in order to achieve good quality gas and to avoid clinker formation at the throat of the gasifier because of high ash content of sewage sludge. The high-quality combustible gas, which was 3.82–3.84MJ/m3 of LHV were produced at the referred air fuel ratios.

Another study mentioned that equivalence ratio (ER) is a factor affecting successful gasification (Wander, 2004). The study used a small stratified gasifier with internal gas circulation at a capacity 12kg/h rate of wood residue. For the gasifier without circulation, the air fuel ratio must be above 1.5 (with ER of 0.35) to achieve good gasification. Gasifier, cold gas efficiency was 60%. Anil (2000) investigated the ER of gasification using open core throat less rice husk gasifier. It was found the best operating ER was 0.4 with gasifier efficiency was around 65%. Specific gasification rate of around 192.5kg/h-m^2 seems optimum value for designing 3-15kW biomass gasifier.

Pathak (2008) evaluated the throat-type down-draft gasifier for thermal application. A scaled-up 375kg/h of gasifier was tested. The study was operated at a flow rate of 460m^3/h with a wood consumption of 181kg/h. The cold gas efficiency was 70-73%. The gasifier system was also tested continuously for 10 hours without any problem and it produced good quality gas consistently with average calorific value 5.27MJ/m^3. In application of similar type of gasifier, 6.5kg of liquefied petroleum gas (LPG) is fully replaced by 38kg of sized wood on hourly basis for burner application (Panwar, 2009).

2.5 Process Outcomes

2.5.1 Gas Cleaning Methods

The gasification byproduct contains char, moisture and tar. When considering producer gas for use in internal combustion (IC) engine, it is necessary to cool the producer to almost ambient temperature, and clean it from tar and particulates. Phuphuakrat et al. (2010) studied a gas cleaning system at a pilot-scale fixed bed downdraft gasifier for a dual-fuel diesel engine. The gas cleaning system consists of venturi scrubber to capture the tar and dust in approximately 47–74%.

Tar and particulate in the producer gas need to be lower than to 100mg/m^3 and 50mg/m^3 respectively, or the sum of which must than be lower than 150 mg/m^3 (Bhave, 2008). The moisture content should be at minimum to maintain the LHV of producer gas. Cyclone is widely use as a separator for particulate from a gas stream. An effective cyclone could collect up to 15μm of particulate size and with removal efficiency of 90% (Sinnot, 2005). Cooling towers are usually used after cyclones as the first wet scrubbing units. The "heavy tar" components will condense at this unit. However, "light tar" in the form of mists are entrained by the gas flow, thus rendering the tar removal rather inefficient. Venturi scrubbers are usually the next step (Milne et al., 1998).

Bhave (2008) gave solution of GCC in an integrated way and suites for small scale application. A packed wet scrubber reported to remove particulate, tar and moisture from a producer gas in one compact vertical tower. This system promises clean gas with total tar and dust below 150 mg/m^3 a reduction by 450 mg/m^3 .The diagram of the system is shown in Figure 2.4.

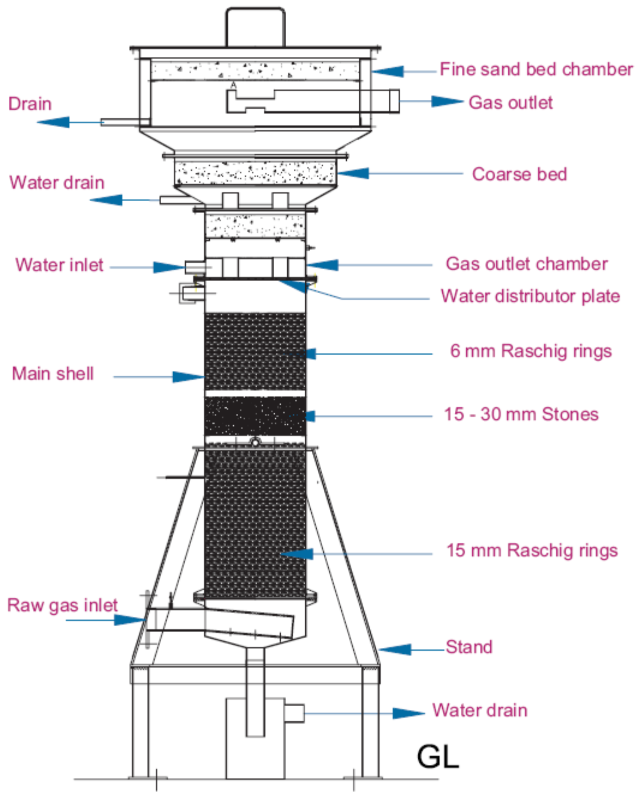

Figure 2.4: Schematic drawing of wet packed wet scrubber

2.6 Performance and Emission Studies of Dual Fuel Mode via Diesel Engine

Gasifiers are coupled with internal combustion engines to convert energy from producer gasifier power generation. This is done in dual-fuel mode using diesel fuel and producer gas. In dual-fuel, the mixture of air and gaseous fuel is prepared in external mixing device such as ‘T-junction’ and carburetor. The engine then induces and compressed both fuels for combustion in the combustion chamber.

In the dual fuel mode, it is difficult to ensure uniform producer gas quality as it is affected by flow conditions through the gasifier system, the pressure drop across the gasifier system and the gas temperature at the gasifier outlet, varying with both engine design and operating conditions. Furthermore gasifier systems operating on engine suction encounter pulsating gas flow to the engine. The pulsations of