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Wood Gas from the Suction Gasifier-An Experimental Analysis

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Abstract: In respect to global issues of sustainable energy, biomass energy represent as a potential means for substituting conventional sources. This energy can be produced through the gasification process. In the study, a suction biomass gasifier is used to carry out the gasification experiments with the wood waste and connected to diesel engine-generator to generate electricity. The moisture content of the wood waste was measured and determined as 11.4% (dry basis) and the calorific value was found approximately 20.6 MJ kg^{-1}. The proximate analysis shows that the wood contains 11.36% of fixed carbon, 78.12% of volatile matter and 0.22% of ash on dry basis. The producer gas from the gasification process is comprised of a combustible gaseous which can be used to generate electricity. The diesel displacement rate gains 53.4% at 3 kW as a function of electrical power. The dual fuel mode engine efficiency reduced to 13.9% compared to diesel alone mode 23.1% at 3 kW, respectively. The concentration of the pollutions such as carbon monoxide (CO), Nitrogen Oxides (NO_x) was carefully measured. Result shows that the emission level of CO increased, while the NO_x decreased in dual fuel mode.

Key words: Suction gasifier, biomass, gasification, internal combustion engine, wood gas

INTRODUCTION

Biomass is seen as an interesting and as a very promising technology to substitute the conventional energy source (Lim and Zainal, 2008). Today, due to the increase of fuel prices and the environmental issues, biomass becomes an important source of renewable energy for securing a sustainable energy and for tackling climate change. The advantages of the biomass are low cost by-product in agriculture and forestry, low ash and sulfur contents (Wander *et al*., 2004).

The biomass can be converted to gaseous state through a process called gasification. The gas known as producer gas is more versatile than the original solid biomass itself (Pratik and Babu, 2009). The average composition gas are mainly combustible gas on a dry basis where CO = 13-25%, CH_4 = 0.25-2.5%, H_2 = 15.1%, while the non-combustible gas or inert gas consist of CO_2 = 8-19%, N_2 = 45-60% and hydrocarbon (which also include tar) (Garcia-Bacaicoa *et al*., 1994). The energy produced from the producer gas is usually in the range of 3.5-5.5 MJ m^{-3} (Zainal *et al*., 2002; Jain and Goss, 2000).

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Generally, the type of gasifier can be categorized based on the direction of the gas flow such as updraft, downdraft, cross-draft and fluidized bed. Each type of the gasifier has a different reactions and tar composition. According to Sharma (2009), the gasification through the downdraft gasifier is a cheapest method compare to other types and it can produce the producer gas with less tar content. Many researchers have done their work used the downdraft gasifier. Zainal *et al*. (2002) have investigated the experimental on a downdraft gasifier using wood chips and charcoal. Pratik and Babu (2009), developed an imbert downdraft gasifier and used about 4.06 and 4.48 kg h^{-1} of furniture woods waste for the gasification. Patel *et al*. (2006) also has tested the open core gasifier for the thermal application and Wander *et al*. (2004) have carried out the studies on the wood gasification where produced a producer gas and able to be burned in an internal combustion engine.

In the study, a suction biomass gasifier is used to carry out the gasification experiments with the wood waste and connected to diesel engine-generator to generate electricity. The suction gasifier is a type of the downdraft gasifier. The gasification through the suction downdraft gasifier will be discussed. The producer gas is exhaled from the suction downdraft gasifier using an ejector system and feeding into a diesel engine is presented.

EXPERIMENTAL SETUP

The suction downdraft biomass gasifier system that was constructed in this work is shown in Fig. 2. The system comprises of suction downdraft gasifier, air compressor, ejector unit, cyclone separator, producer gas pre-cooler heat exchanger, expansion tank, oil bath filter and a diesel engine with an alternator. A suction downdraft biomass gasifier with an inner diameter of 360 and 25 mm thick refractory lining was constructed. The air is drawn from the top of the gasifier and passes two way air entries port at the bottom area that permit air into the reaction zone. The total height is 1.05 m. A suction gasifer is a laboratory scale designed with a nominal capacity of 28 kW_T corresponding to approximately 8 kg h^{-1} of biomass feeding rate. It is served to operate on atmospheric pressure and the combustible gas was supplied into the diesel engine that performed as the output. In addition, the gas treatment functions as a cooling as well as cleaning system to the producer gas. Figure 1 shows the photograph of the suction gasifier system to generate electricity.

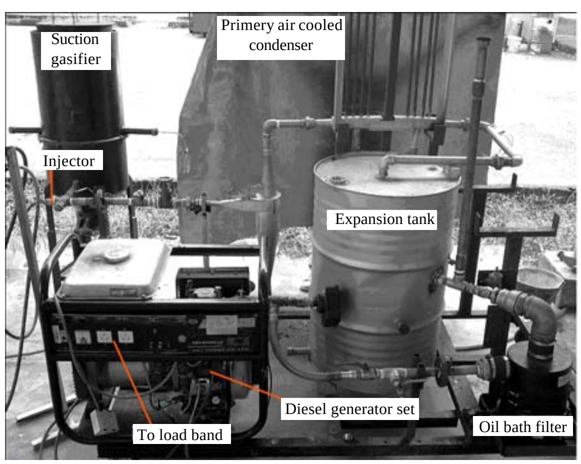

Fig. 1: Photograph of suction gasifier system to generate electricity

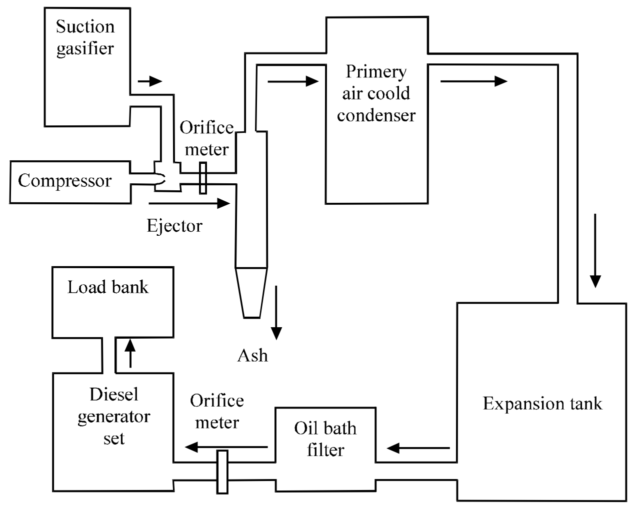

Fig. 2: Schematic diagram of the suction gasifier system connected to diesel generator

The Suction Gasifier Test Unit

The suction gasifier consisted of a drying, pyrolysis, combustion and gasification zone. In the gasification zone, the outlet of combustible gases leaves the gasifier between 290-340°C. A grate has been placed below the gasification zone to act as a bottom platform to place the biomass material. A LPG combustion port was fabricated for the start up purposes. The amount of 2 kg charcoal is dumped into the reduction zone of the gasifier above the grate before the biomass feeding started.

The biomass is burned up to 10 min before the biomass feeding take place. Small pieces of sized wood, approximately in the uniformity size of 3×3.5× 5 cm, were accepted as a fuel. A fuel feeding system is a manual method, consist of commercial weighing. In order to regulate the feeding capacity, the biomass then weighted for every fed into gasifier to gain the feeding rate in kg h^{-1}. The experiment feeding rate of 5 kg h^{-1} was carried out continuously with a few intervals. The corresponding fuel feeding rate is 17.5 kW of thermal output.

The Gas Cooling and Cleaning

Steady state temperatures at different locations inside the gasifier are measured using type-K thermocouple. Four thermocouples were placed 100, 200, 300 and 400 mm from the grate to measure the zone temperature. Another three thermocouples were installed along the downstream of cooling and cleaning components to measure the heat loss of this gas. These temperatures are placed at the gasifier outlet, at inlet of the cyclone separator and after the pre-cooler.

The cyclone separator was used in order to separate solid particle before it is flowed into the downstream of cooling and cleaning components. The cooling and cleaning component is meant to remove moisture and tar condensate in the producer gas. The pre-cooler; natural convection heat exchanger brings the gas temperature cooled around 40°C. The gas then flows into the expansion tank. The expansion tank is made of steel meant to collect the additional moisture content. The outlet gas temperature was approximately remains 38-40°C before entrance the oil bath filter. In order to collect additional tar in gas flow, the oil bath filter was installed. Inside it, the tars were trapped and trickled down into the oil bath filter.

The Suction and Air Supply Section

The suction capacity is of great importance in suction gasifier as it acts as a medium to promote inside gasifier reaction. It consists of a compressor, a main valve to control the air flow rate, air flow meter with a maximum flow capacity of 300 min^{-1} and a simple ejector unit. An ejector unit comprise of a nozzle that enable an inlet supply of a motive air. In the ejector system, there is a device like a venturi aspirates which act to carry out the producer gas produced from the gasifier. The suction characteristic basically is regulatory on the size of the nozzle (means that the pressure drop and will form motive air). Experimental work were carried out by using 1 to 5 mm nozzle as shown in Fig. 3 to perform a relation nozzle size due to the suction capacity. Table 1 shows the suction of producer gas performance that produces the combustible gas. An orifice meter was coupled to a water manometer to obtain the mixture flow rate of the producer gas and air. The flow meter was installed to measure the air flow rate independently.

In accordance to Table 1, the optimum nozzle capability is 3 mm where, it can have suction by play role a high pressure drop an average value of 1.1 k Pa across gasifier and ejector unit. The pressure drop was measured by a manometer through two pressure taps, one at suction piping and the other is free to ambient pressure. The vacuum is an agent of suction provided by a 2 hp compressor at a pressure 2.2 bar for 3 mm nozzle. The maximum supply mass flow rate is 7.31 kg h^{-1}, while the total mass flow rate (mixing of air and producer gas) hold an average value 23.4 kg h^{-1}. A 3 mm nozzle then was used for further investigation on the suction downdraft gasifier. There is a good agreement between the relation of 3 mm nozzle and the outlet gas temperature within the range of 290-340°C.

A Diesel Engine

In this experiment, thermal output of 17.5 kW from the gasifier was utilized to generate electricity between 1-5 kW ranges through a diesel generator. A diesel generator with a maximum output of 4.2 kWe was used for power generation. The detailed technical specification of the engine generator is shown in Table 2. The performance and emission was investigated on diesel alone and dual fuel mode at a different load condition. The dual fuel

Table 1: Comparison of different size of nozzle

	Parameter		
Nozzle (mm)	Supply pressure (bar)	Flow rate (producer gas+air) (kg h^{-1})	Suction pressure drop (kPa)
1	6.5	5.90	0.82
2	2.7	18.90	1.04
3	2.2	23.40	1.10
4	1.9	14.50	0.53
5	1.7	12.52	0.42

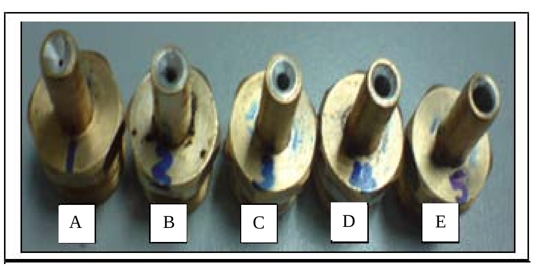

Fig. 3: Different size of nozzle from 1 to 5 mm used in ejector system

Table 2: Technical specifications of the diesel generator

Technical specification	Values
Make	DEK
Fule	Diesel
	Single-cylinder
	4-stroke, direct
Type	Injection diesel
Bore and stroke	86×70 mm
Alternator	
Rated AC power	4.2 kW at 50 Hz
Voltage	240 V

mode was conducted by supplying the gas-air mixture into the engine through the inlet manifold. With an orifice meter and valve before the engine, the amount of air and gas that flows into the engine varies. With the increasing of gas flow, the air-fuel ratio reduces in all conditions. The electrical load for this engine is from the load bank and it consists of 1 to 5 kW output as a function of electrification. Beside of the load measured, the emission composition in diesel alone and dual fuel mode such as CO (%), CO_2 (%), NO_x (ppm) and O_2 (%), is also measured using KANE Gas Analyzer.

RESULTS AND DISCUSSION

Biomass Characteristics

The wood waste is used as a selection biomass in the present gasification studies. The parameter studied is moisture content, calorific value and the proximate analysis. Table 3 shows the result of proximate analysis which was carried out using TGA7 together with TG controller. There are no significant differences between the experiment finding and the finding of Babul (Panwar *et al.*, 2009). The moisture content was always between 9.6 and 11.5%. Generally, the upper limit that acceptable for a downdraft gasifier considered to be around 40% on dry basis (Dogru *et al.*, 2002). High Heating Value (HHV) of wood from the experiment is 20.6% on dry basis and it differs only 4.3% from the reference. As shown, the ash content from the experiment is 0.22% on dry basis, differs only 0.83% from the reference data. An ash content is very important parameter that affecting the composition and calorific value of the gas. Miskam *et al.* (2009) reported that as the lower amount of ash content determined, the better producer gas obtained.

Efficiency of Engine-Generator Set

Figure 4 shows the efficiency of engine-generator as a function of electrical power for a diesel alone operation and dual fuel mode operation. By taken calorific value of the producer gas as 4 MJ m^{-3} and diesel as 43.2 MJ kg^{-1} (Tata Energy Research Institute, 1987), the maximum engine-generator efficiency at the same load in diesel alone and dual fuel mode was 23.1 and 13.9%. The similar result on the reduced efficiency of dual fuel operation was reported by Asokan (1990) and Bhattcharya *et al.* (2001).

Diesel Replacement Rate

The diesel replacement rate is an important indicator of the gasifier-generator system performance. Diesel replacement rate under different load conditions is recorded. It have been calculated from diesel consumption in diesel alone mode and dual fuel mode. The diesel replacement varied between 29.8 and 53.4% as shown in Fig. 5. Uma *et al.* (2004) also wrote the diesel displacement is in between 67 and 86%. The result observed at low and high load condition the diesel displacement rate decrease and the maximum diesel replacement is at 3 kW in term of electrical power.

Table 3: Proximate analysis of wood

	Proximate analysis					
Wood	Fixed carbon (% dry basis)	Volatile matter (% dry basis)	Ash (% dry basis)	Moisture (% wet basis)	Mj kg^{-1} (% dry basis)	Bulk density (kg m^{-3})
Experiment	11.36	78.312	0.22	10.29	20.6	450.8
Reference (Panwar *et al.*, 2009)	15.53	83.42	1.05	10.2	16.3	395.0
Percentage difference	4.17	5.3	0.83	0.09	4.3	55.8

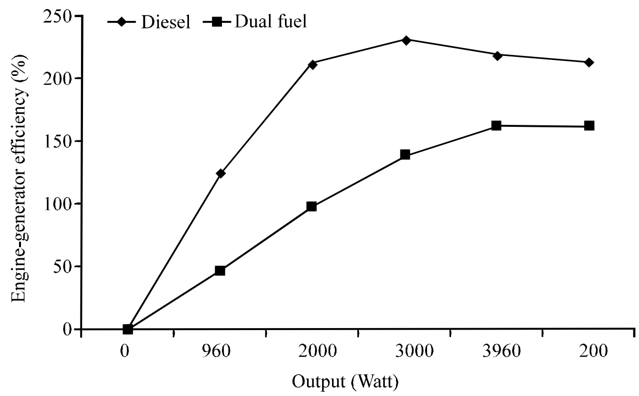

Fig. 4: Engine-generator efficiency of diesel alone and dual fuel mode

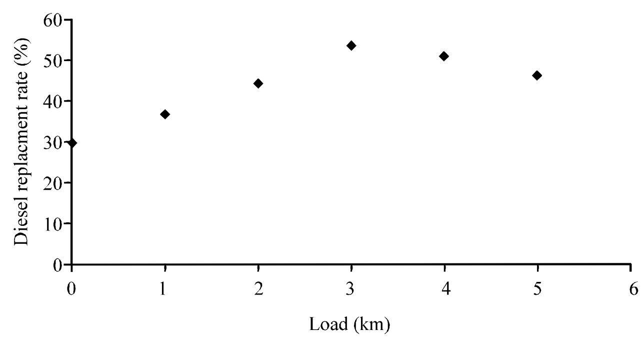

Fig. 5: Diesel displacement rate at different load conditions in dual fuel mode

Emission Load

Figure 6 shows the NO_x emission per unit of electrical load in the diesel alone and dual fuel mode. It observed that the NO_x emission in the dual fuel mode is lower than diesel alone. It is because of the low peak cylinder temperatures and residence time in the combustion chamber. Sridhar *et al.* (2005) also found the similar results as authors.

The result of the CO emission in the diesel alone and dual fuel mode is shows in Fig. 7. It shows the opposite trend where high CO emission obtained in the dual fuel mode compare to diesel alone. The higher concentration of CO emission is cause of incomplete combustion due to combination of factors such as low heating value of producer gas, low adiabatic flame temperatures and low mean effective pressure (Uma *et al.*, 2004).

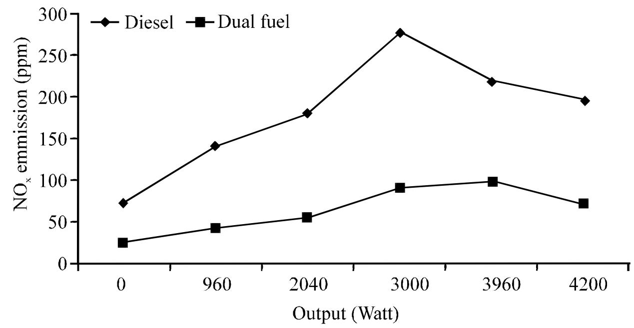

Fig. 6: NO_x emission of the engine at different load

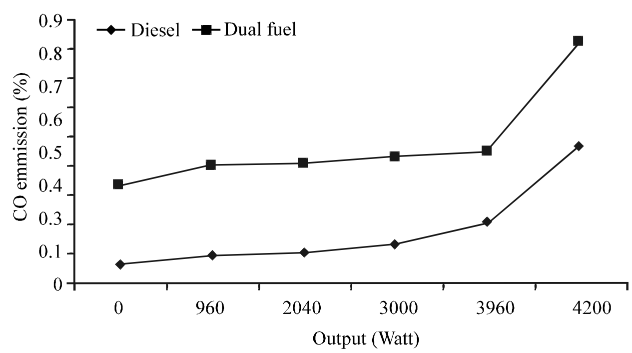

Fig. 7: CO emission of the engine at different load

CONCLUSIONS

In present study, the suction downdraft gasifier coupled to engine-generator is used for small medium electrification. The results of present investigation of using wood waste in this gasification can be summarized as follow:

- The moisture content of wood waste was always between 9.6 and 11.5%. It also presents the low ash content (0.22%) where ash content is a very important parameter affecting the composition and calorific value of the producer gas. The calorific value was found approximately 20.6 MJ kg^{-1}
- The maximum engine-generator efficiency set at the same load in diesel alone and dual fuel mode was 23.1 and 13.9%, respectively
- Diesel replacement rate under different load conditions is recorded varied between 29.8 and 53.4%
- NO_x emission per unit of electrical load in dual fuel mode is lower than diesel alone. The opposite trend has been observed in CO emission, which is high in dual fuel mode condition

All experiment runs on the gasifier-engine generator were conducted using a simple ejector system without many adjustments to the suction of the producer gas itself. It is expected that the efficiency of the overall system can be improved through more detailed study, including modification of the ejector system.

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