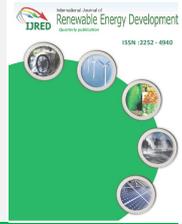




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Research Article

Performance Investigation of a Gasifier and Gas Engine System Operated on Municipal Solid Waste Briquettes

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ABSTRACT. Municipal solid waste (MSW) and charcoal can be used as a substitute fuel in a gas engine. In this work, performance of a downdraft gasifier and gas engine system operated on MSW briquette fuel was investigated. Experimental test was carried out on a 62 kW, four-cylinder, naturally aspirated engine coupled to a 20 kW dynamometer. The downdraft gasifier was used to generate producer gas from MSW briquettes and charcoal. The engine load was varied between 1.5-9.0 kW. Biomass consumption, producer gas production, cold gas efficiency, thermal efficiency of the gas engine, carbon monoxide (CO), hydrocarbon (HC) emissions and exhaust temperature were evaluated. The MSW briquette fuelled operation was compared against that with charcoal. It was found that, the use of MSW briquette led to lowering performance of the downdraft gasifier and gas engine system, in comparison with the use of charcoal. Maximum cold gas and thermal efficiencies obtained were 64.6% and 16% at 4.5 kW and 9 kW loading, respectively. The CO and HC emissions of the gas engine operated on MSW briquettes were higher than that on charcoal, while the exhaust temperatures were similar. ©2019. CBIOR-IJRED. All rights reserved

Keywords: biomass, gas engine, gasification, MSW, densified fuel, renewable energy

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1. Introduction

Management of municipal solid waste (MSW) or other solid wastes is one of the major challenges for Thailand (Tippayawong and Tippayawong, 2017). From the government survey, it was found that MSW generation rate was about less than 1 kg/capita/day. Consequently, there are more than 2400 MSW pits in the country (Chiemchaisri et al., 2007). At present, the reduction technology adopted to reduce MSW are direct burning and briquette fuel production. The burning of MSW focuses on reducing the volume of waste and that can be easily buried or stored, while the briquetting or densification method focuses on production of alternative fuels to replace fossil fuels in factories (Tippayawong et al., 2018; Piboon et al., 2017; Wongsiriamnuay and Tippayawong, 2015). However, the use of direct combustion to MSW has low efficiency, with average value between 15-25% (Department of Industrial Promotion, 2007), while the gasification technology can offer the average efficiency in a range of 60-75% (Homdoun et al., 2012; Punnarapong et al., 2017). The use of briquette fuel to generate the producer gas and operate on gas engines for electricity production is very

attractive. Importantly, this approach can help reduce imported energy from overseas.

The study about utilization of MSW briquette fuel for energy production can be described as follows. The main material for producing MSW briquettes was from wood chips, papers, plastics, textile waste or other combustible materials (Krizan et al., 2011; Shrestha et al., 2011). Normally, the MSW briquettes have an average density of 900-1200 kg/m³ (Prasityousil et al., 2013). Binders may be used in MSW briquettes to increase the bulk density, (Shyamalee et al., 2015; Bhoumick et al., 2016). The average heating value of MSW briquette fuel was in a range of 13.6-16.6 MJ/kg (Romallosa et al., 2016).

In actual implementation, most MSW briquette fuel will be used in industrial plants namely direct combustion system and gasification process. In direct combustion application, majority of the briquette fuel will be used to produce cement, steam and another thermal energy (Chatziaras et al., 2016), while gasification process will be used to produce the producer gas or syngas for electricity generation (Nasner et al., 2017). The thermal efficiency in the direct combustion process obtained was around 15-20% (Raju et al., 2014), while

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the gasification process can achieve between 60-70%, the calorific value of producer gas was between 4-6 MJ/Nm³ (Dzombo et al., 2013). The gas engine can be operated with producer gas well (Sridhar et al., 2001; Homdoun et al., 2014). The gas engine was adopted from a compression ignited engine and modified into a spark ignited engine at high compression ratio. Charcoal was used in gasification and calorific value of the producer gas was in a range of 4.64-5.00 MJ/Nm³. Nevertheless, the engine power was expected to decrease by more than 50% (Munoz et al., 1999). The cause of brake power reduction was due to the fact that the energy density of producer gas was low (Sridhar et al., 2001; Mustafi et al., 2006). However, the engine performance can be improved by modifications of existing engines, including changing the combustion chamber, increasing compression ratio and ignition timing adjustment (Homdoun et al., 2015). The emissions of producer gas engine were similar to original fuel. The CO and HC emissions from gas engines were slightly higher, but lower than standards when use at the optimum condition.

From the literature review, the operation of MSW briquette fuel in gasifier-engine setup was quite limited. Thus, the objective of this research was to investigate the use of MSW briquette fuel in a downdraft gasifier to generate a fuel gas and subsequently fed to a gas engine. Performance of the gasifier and gas engine system was evaluated in terms of biomass fuel consumption, producer gas production, cold gas efficiency, thermal efficiency of the gas engine, exhaust emissions and temperature.

2. Materials and Methods

2.1 Gasifier and gas engine

Figure 1 shows the overall view of the engine test rig. It consisted of a gasification reactor and a spark ignited engine adapted to operate on producer gas from MSW gasification. The gasifier system consisted of a downdraft gasifier, a gas cooler and a gas conditioning unit including a cyclone, a venturi and packed bed scrubber, biomass and paper filters. Reduction of temperature and removal of tar and particulate were done by closed-loop water recirculation, with the detail shown in Table 1. Specification of the gasifier used may be found in our previous work (Homdoun et al., 2012).

Table. 1
 Specifications of the gasifier fuelled with biomass

Parameters	Specification
Gasifier type	Downdraft
Gasifier capacity	MSW briquette: 100-110 kg Charcoal: 35-45 kg
Feed system	Batch feeding
Cooling system	Water
Cleaning system	Cyclone, Venturi and pack bed scrubber, Fabric and paper filters
Biomass size	25-50 cm
Producer gas temperature	45-55 °C

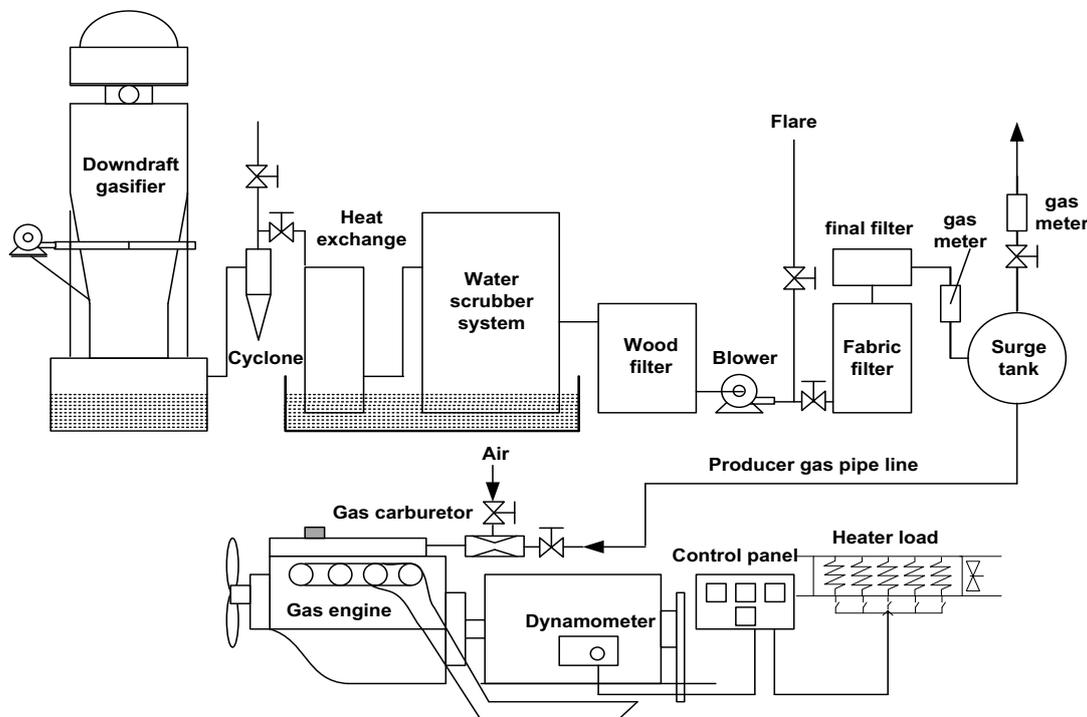


Figure 1. Schematic diagram of the experimental setup

The engine used in this work was a 62 kW (82 hp), naturally aspirated gas engine. It was a four-stroke, four-cylinder engine with a bore × stroke of 83 × 73.7 mm, and a compression ratio of 8.8:1. The engine was coupled to a 20 kW alternator to generate 200–240V electricity at 60

Hz. The gas mixer used was similar to a carburettor. The velocity of producer gas flow through a venturi will draws air into the main flow and they were mixed before entering the cylinder. Specifications of the gas engine are given in Table 2.

Table. 2
Specifications of the gas engine fuelled with producer gas

Parameters	Specification
Type	SI, 4-stroke/cylinders, gas carburetor
Engine rating (kW)	61.4 (82 HP)
Bore (mm)	83
Stroke (mm)	73.7
Displacement (CC)	1595
Compression ratio	8.8 : 1
Advance timing	30° BTDC
Alternator rating (kW)	20
Rated output	20 kW @ 1500 rpm
Loading device	Electrical heater

2.2 MSW briquette fuel

The production of MSW briquette fuel was based on densification of the mixture between paper, plastic and biomass at a mass ratio of 1:1:1, with binding agent made from cassava starch and lime. Figure 2 shows the resulting MSW briquettes as well as its components (paper, plastic and biomass).



Figure 2. MSW briquette fuel from paper, plastic and biomass

The density of MSW briquette fuel was about 902 kg/m³ on average, and 2-4% moisture content. Diameter of the briquette fuel was 5 cm on average and cut into 2.5-5.0 cm prior to feeding in the downdraft gasifier. The size of the charcoal used was about 2.5x2.5x2.5 to 5x5x5 cm³, in accord with the FAO (FAO, 1986), while the density and moisture content were found to be 250-300 kg/m³ and 7%, respectively. Analysis of both fuels were conducted based on ASTM C373-88 and ASTM D 2016-74 standards. The lower heating value of the MSW briquette fuel and charcoal were about 26,000 kJ/kg and 28,500 kJ/kg, respectively.

2.3 Test procedures and data analysis

The test conditions were as follows: ambient pressure was 0.92 kPa; density of air was 1.1 kg/m³ and the ambient temperature during the testing period was 310 ± 3K. A load bank was connected to test the engine generator set. Measurements on current, voltage,

frequency and fuel consumption were carried out. The static pressures were monitored using water tube manometers. The temperature of the producer gas from both fuels after reduction zone was about 500-600°C. The hot producer gas was allowed to pass through the cooler where its temperature was reduced to room condition. The cooled and moist gas was then passed through the filters to remove tar and other particulate matter.

A gas analyzer from Agilant 6890 gas chromatography was used to measure the mole fractions of CO, H₂, CH₄, CO₂ and N₂ in the producer gas. Average composition of fuel gas from gasification of the MSW briquette fuel was found to be CO = 8.35 ± 2%, H₂ = 10.23 ± 2%, CH₄ = 3.52 ± 0.5%, CO₂ = 17.7 ± 2% and the rest N₂, while for the charcoal, CO = 30.86 ± 2%, H₂ = 8.2 ± 2%, CH₄ = 0.32 ± 0.5%, CO₂ = 4.68 ± 2%. The biomass and producer gas consumption were measured at varying engine loads between 1.5 – 9.0 kW. The producer gas and air flow rates were measured using gas flow meters. Afterwards, biomass consumption, producer gas production, cold gas efficiency, thermal efficiency of the gas engine, CO, HC emissions and exhaust temperature were evaluated. The cold gas efficiency and brake thermal efficiency of the gas engine were evaluated using the following equations. The cold gas efficiency of downdraft gasifier was given by (Murakami et al., 2013)

$$\eta_g = \frac{m_g \times CV_g}{m_b \times LHV_b}$$

Where m_g is producer gas flow rate (m³/s), CV_g is the calorific value of producer gas, (MJ/Nm³). m_b is biomass consumption rate (kg/s) and LHV_b is the lower heating value of the producer gas, (MJ/Nm³).

The brake thermal efficiency of the gas engine can be calculated by the following relation (Heywood, 1989) which the equation can be used for another gas fuel (Haryanto et al., 2017),

$$BTE = \frac{P_b}{m_g \times CV_g} \times 100$$

Where P_b is brake power (kW).

3. Results and Discussion

3.1 Biomass consumption

Figure 3 shows the consumption of MSW briquette fuel and charcoal when operated on the downdraft gasifier. Consumption of both biomass feedstocks was increased with increasing engine load. The use of MSW briquette fuel in the gasifier appeared to be higher than charcoal. This was due to the fact that the MSW briquette fuel was deformed during the reaction and partially blocked the air flows, hindering the gasification reaction. Fraction of obtained combustible gases became smaller, hence smaller heating value of the gas. Maximum consumption of both fuels was obtained at 9 kW of engine loading. They were between 13-15 kg/h.

3.2 Producer gas generation

Figure 4 shows effect of engine loading on producer gas flow rate. The generation of producer gas was found

to increase with increasing engine load. The highest producer gas from MSW briquette fuel was obtained at 60 m³/h, while the producer gas from charcoal was only 40 m³/h occurring at higher engine load. The gas engine consumed the producer gas from MSW briquette fuel at higher amount than the charcoal, with average of 33% higher. Since the calorific value of the producer gas from MSW briquette was lower than that from charcoal, when the engine run at full load, the producer gas of MSW was consumed more.

3.3 Cold gas efficiency

Figure 5 shows the cold gas efficiency when using MSW briquette fuel and charcoal. The cold gas efficiency did not exhibit large variation with engine load. At high engine load, the cold gas efficiency was observed to decrease slightly. Maximum cold gas efficiency for charcoal was about 70%, while for the MSW briquette fuel, it was about 65%, occurring at 4.5 kW of engine load. Reduction in cold gas efficiency of MSW briquette fuel occurred when operated on plastics (Kungkajit et al., 2015). The use of charcoal to generate producer gas can provide higher cold gas efficiency than MSW briquette fuel. However, when compared with other downdraft gasifiers, the average cold gas efficiency was similar, in a range of 62-69% using agricultural waste (Chawdhurya et al., 2011).

3.4 Thermal efficiency

The thermal efficiency of the producer gas engine operated on MSW briquette fuel and charcoal are shown in Figure 6. Increase in engine load led to increase in thermal efficiency. The highest thermal efficiency occurred at 7.5 kW. Drop in the thermal efficiency was caused by incomplete combustion in the engine cylinder (Lekpradit et al., 2009). The use of producer gas from charcoal showed higher thermal efficiency than that from MSW briquette. This may be due to higher producer gas flow rates and lower calorific value of the producer gas. Maximum thermal efficiencies of the gas engine operated on MSW briquette fuel and charcoal were calculated to be 16 and 17.3%, respectively. Both were achieved at engine load of 7.5 kW.

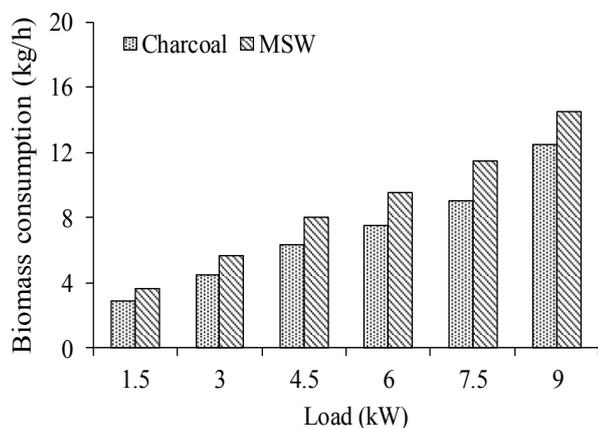


Figure 3. biomass consumption

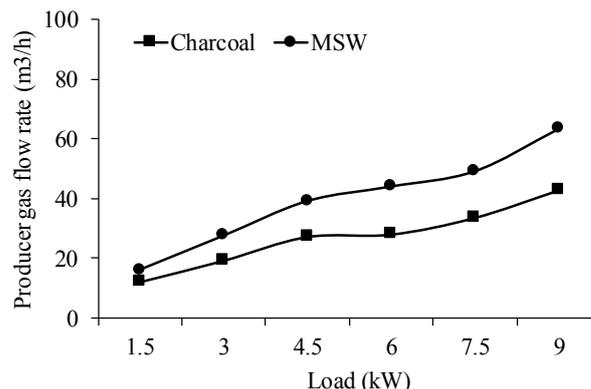


Figure 4. producer gas flow rate

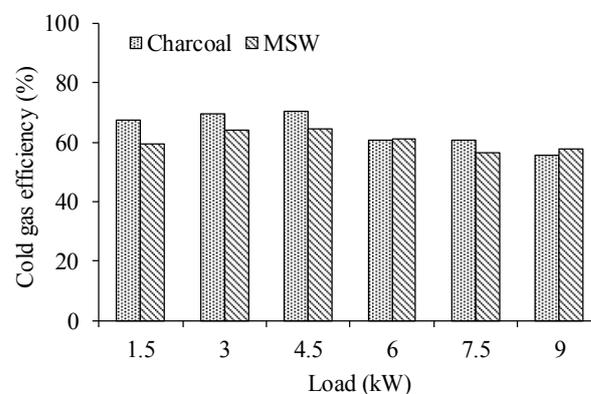


Figure 5. cold gas efficiency

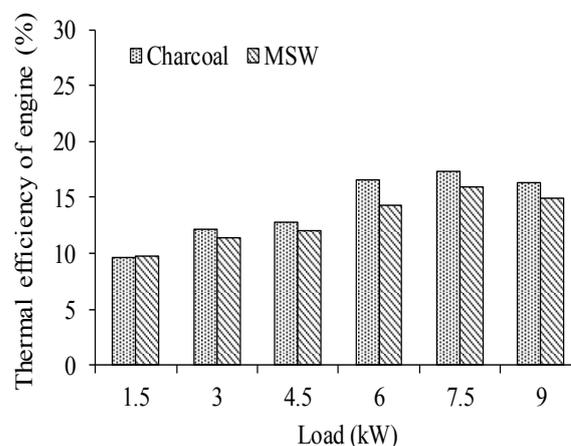


Figure 6. thermal efficiency of the gas engine

3.5 CO and HC emissions

High CO emission from the gas engine was due to incomplete combustion which in turn caused by rich air-fuel mixture ratio (Schirmer et al., 2017). Figure 7 shows the CO emission from the gas engine operated on producer gas from MSW briquette fuel and charcoal. Increasing engine load resulted in increased CO emission due to insufficient oxygen available for combustion (Homdoug et al., 2015). The CO emission from the use of MSW briquette fuel was higher than that from the use of

charcoal. The highest CO emission from MSW briquette occurred at maximum engine load. At low engine loads, the CO emission was found to be below Thailand pollution control regulations.

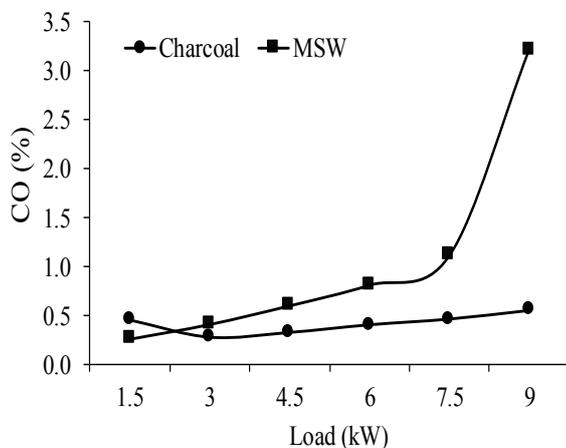


Figure 7. CO emission from the gas engine

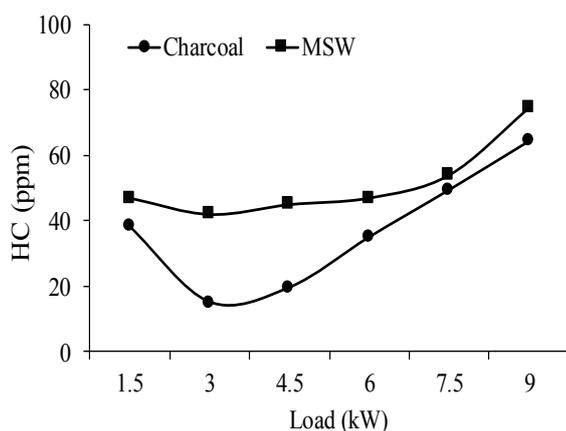


Figure 8. HC emission from the gas engine

Figure 8 shows the HC emission from the gas engine when using MSW briquette fuel and charcoal. Low HC emission occurred at 3.0-4.5 kW engine loading and tended to increase with increasing engine load. The HC emission from the gas engine using MSW briquette fuel was higher than that from charcoal. This was something to do with the temperature of cylinder of the gas engine may be slightly lower, caused by the lower calorific value of the producer gas, compared to charcoal operation (Ganesan, 2002). At the load between 1.5 to 3 kW, the gas engine appeared to have complete combustion. The cylinder of engine had high temperature, hence lower HC emission. The lower HC emission from the gas engine operated on MSW briquette fuel was between 42-45 ppm, while for charcoal, the HC emission was 15-19.5 ppm. It should be noted that the HC emission obtained was below Thailand standards, normally the HC emission of a spark ignition engine should be less than 200 ppm (Thailand Pollution Control Department, 2018).

3.6 Exhaust temperature

Figure 9 shows the exhaust temperature of the gas engine. Increasing engine load was found to lead to increase in exhaust temperature. Change in exhaust temperature of both fuels was similar. The exhaust temperature of the gas engine was decreased due to poor combustion in the engine cylinder (Ghazikhani et al., 2014). The exhaust temperature of the gas engine when using MSW briquette fuel and charcoal was in a range of 280 -350°C and 290 -350°C, respectively.

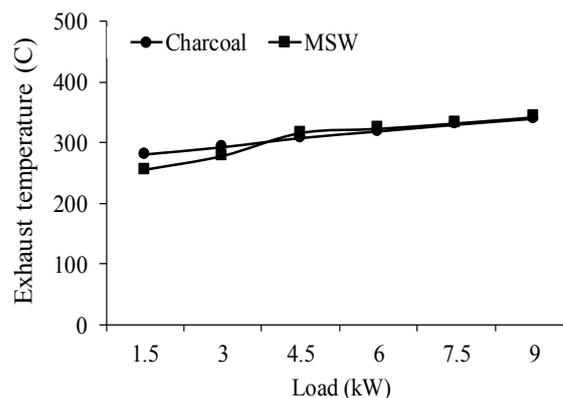


Figure 9. Exhaust temperature of the gas engine

4. Conclusions

The MSW briquette fuel may be used to power the gas engine via gasification process. The average cold gas efficiency from gasification of the MSW briquette fuel was about 65% at 45 kW of engine load. This was lower than that using charcoal by about 8%. The maximum thermal efficiency of the gas engine was 16% when using MSW briquette, while it was 17% for charcoal. The CO and HC emissions of the gas engine obtained were below the pollution control norms.

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