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Reducing Gasoline Specific Consumption in Dual-Fuel Electricity Generation by Using Combustible Gas from Rice Husk Gasification

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Using air gasification process, rice husk is attractive to be converted into combustible gas mixture which contains mainly CO, H_2, and several hydrocarbon substances. The gas is possible for fueling gasoline engine generator to generate electricity in dual-fuel operation mode, while partially substitutes the gasoline consumption. Obviously, it will influence the generator's performance. This research reports the gasoline consumption savings in dual-fuel operation of electricity generation at different electricity loads. The gas flowrate was limited with the engine vibration level. A small scale air-blown downdraft gasifier converted rice husk at maximum capacity of 1 kg/h to the gas. A 1 kWe gasoline engine generator was used for this operation. At electricity load of 0.92 kVA in dual-fuel operation, the saving of gasoline (L/kVAh) attained 20.9% and the thermal system energy efficiency was about 11%. In this case, the producer gas flow rate was 1.84 L/s^{-1} and Specific Gasification Rate (SGR) was 81.53 kg/(m^2.h). The energy equivalent was 4.6 kg rice husk/L gasoline or 0.7 kg rice husk/kVAh.

Keywords: Gasification, Rice Husk, Dual-fuel Operation, Electricity Generation, Gasoline Consumption

Introduction

Development of renewable energy in Indonesia was listed in Presidential Decree No. 5/2006 on National Energy Policy. The contribution of renewable energy in the national primary energy mix in 2025 will account for 17% of total energy mix [1]. The National Energy Policy was revised in 2014, setting a target energy mix of new and renewable energy 23% for a total of 380 Mtoe by 2025 [2]. Meanwhile, the amount of biomass potential in Indonesia is estimated at 32,654 MW [2] causes the energy from biomass is one of the priorities to be developed and selected by goverment and private parties engaged in energy industry. The abundant of biomass in Indonesia such as rice husk, with total production in 2011 reached 10.52 million tons (increased approximately 3.1% annualy) which is equivalent to about 5.24 million tons of coal can be utilized as renewable energy sources. This equates to an electrical power potential of around 4,481 MW [3]. The availabilities of rice husk in rice milling plant will ease the biomass collection and provision, furthermore it will reduce raw material cost. Rice production usually generates husk as much as 20% - 30% by weight of the dried paddy. The bulk density of rice husk is around 100 - 120 kg/m^3 with moisture content is approximately 10%-14% [4]. The typical chemical compositions of rice husk in terms of proximate and ultimate analysis [5] are shown in Table 1. The lower heating value of rice husk is about 14.35 MJ/kg [6]. According to chemical-elemental composition and heating value, rice husk is suitable as feedstock of biomass gasification process. Biomass gasification is an alternative technology for converting this solid phase energy sources into combustible-gaseous fuel (hereinafter referred to as producer gas). Typical chemical compositions of producer gas generated form air-blown gasifier (v/v) are CO 10% - 20%, H_2 9% - 20%, CH_4 1% - 8%, CO_2 10% - 20%, and N_2 40% - 55% [5]. The combustion heating value of producer gas is 4.0 - 6.5 MJ/Nm^3 in dry basis [5,6]. This is a potential gas as fuel in internal combustion engine to substitute partially conventional fuel consumption in electricity generation by dual-fuel operation. The gas may contain impurities (tars

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Table 1—Proximate and ultimate analysis of rice husk

Proximate analysis (w/w – dry basis)	
Volatile matter	60.3
Fixed carbon	17.0
Ash	22.7
Ultimate analysis (w/w – dry ash free basis)	
C	46.7
H	6.2
O	46.4
N	0.4
S	0.3

and particulates) and has high temperature. High-quality producer gas with almost tar-free, dust-free, and high heating value can be fed to internal combustion engine directly, and this gas should be cooled down to increase the energy density before feeding [8]. Therefore, gas cleaning and cooling system are required before injection into internal combustion engine. Gas cleaning and cooling system consists of cyclones, water scrubbers, and filters [7]. Dual-fuel operation is possible operating mode for an internal combustion engine such as diesel engine or gasoline engine to reduce operating cost and emissions without reducing engine performance significantly.

But, the addition of producer gas to engine still possibly decreases power output [7] and increases engine vibration. Producer gas must fulfill several requirements for internal combustion engine application in order not to much reduce engine performance and engine service life, such as tar content should less than 100 mg/Nm^3, the maximum particulate content is 50 mg/Nm^3, and the temperature of producer gas is about 283 K above ambient temperature [9]. According to the equality of heat of combustion (energy equivalence), 1 liter of gasoline can be replaced by 7.9 Nm^3 producer gas or by 2.24 kg rice husk. This research studied the effects of producer gas injection into gasoline engine generator by dual-fuel operation on the generator performance, including the engine vibration and electricity output. Specific consumption of gasoline and rice husk were measured to calculate the gasoline savings and the energy equivalence between rice husk and gasoline.

Materials and methods

Rice husk from rice milling plant was used as main feedstock for gasification. Meanwhile, wood char and diesel oil were used as starting ignition materials in order to reach reaction temperature before feeding. The main generator engine fuel was gasoline (Premium class – RON 88) with heating value 34,496 kJ/L as a product of Pertamina. The appearence of gasifier unit coupled with engine generator is shown in Fig. 1, and the schematic process diagram is shown in Fig. 2 that consists of three main processes, i.e. conversion of biomass to producer gas in the gasifier, gas cleaning and cooling, and electricity generation

Fig. 1—An appearence of gasifier unit coupled with engine generator

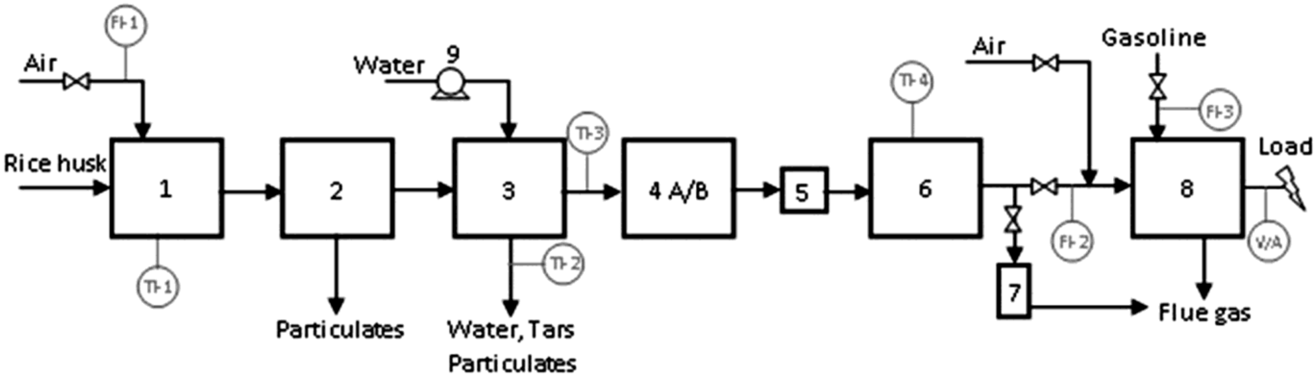

Fig. 2—Schematic process diagram

by dual-fuel operation. In this researh, an air-blown downdraft gasifier with throat (1) was used to conduct gasification process. Throat diameter was 0.10 m and angle of the cone was 45°. Four pipes with 0.5 inch in diameter were placed at the throat to introduce air into oxydation zone. Gasifier was equipped with type of K-thermocouple to monitor reduction zone temperature (TI-1). This small scale gasifier is capable to gasify up to 1 kg rice husk/hour. The flow-rate of air as gasifying medium was controlled by a globe valve and measured using installed orificemeter (FI-1). The generated producer gas was then passed the Cyclone (2) to separate paticulates from gas. Hot raw producer gas was then cleaned and cooled in Water Scrubber (3) by contacting with sprayed water directly. The flow-rate of water as cooling medium was controlled by bypass system on the discharge of a 0.125 kW Water Pump (9) to achieve the producer gas temperature to around 313 K (measured by thermometer TI-3 and TI-4). Particulates and condensable tars should be mostly removed in this step. Further, the remaining particulates and condensed tars should be removed in filters (4 A/B) which were used wood char and cloth as adsorbent bed. Vortex blower of 0.35 kW (5) sucked air into gasifier and transported gas from gasifier by negative pressure action, and a gas holder (6) will stabilized producer gas flow-rate before injecting into the engine. Beside of low temperature, quality of the producer gas was tested visually by the color and stability of the flames at burner (7), and tested instrumentally by Gas Chromatography (GC) apparatus for chemical composition analysis. Good quality of producer gas should then be injected into engine through an air duct, and the flow rate was measured by orificemeter (FI-2). This research applied four different electricity loads generated by a gasoline engine generator (8) with maximum power output 1 kW_e. The flow rate of gasoline was then controlled by a valve and measured volumetrically by scaled glass tube apparatus (FI-3). Electricity output in terms of kVA was measured by means of Volt-Amperemeter. In each experiment, some data such as reduction zone temperature, final producer gas temperature, air flow rate, rice husk consumption (kg/h), producer gas consumption (L/h), gasoline consumption (L/h), and electricity output (kVA) were collected. These data were then used to calculate the specific gasification rate (SGR) which indicates the rate of gasification per throat area ($kg/(m^2.h)$), the specific gasoline consumption (L/kVAh), percentage of spesific gasoline consumption savings based on L/kVAh, the specific rice husk consumption (kg/kVAh), and energy equivalence between rice husk and gasoline (kg/L).

Results and Discussion

Gasification process

The size of rice husk gives the small bed porosity which create higher pressure drop in the gasifier [10], but the available power of blower overcomed this pressure drop and sucked air into gasifier. The average rice husk feed into gasifier was 2.5 kg for 2.5 hours operation, and the average amount of solid residue including ash and biomass char was 0.9 kg, rice husk consumption rate was then 0.64 kg/h. The gasifier throat area is 0.00785 m2, the calculated specific gasification rate (SGR) was 81.53 kg/(m2.h). Meanwhile, the temperature of reduction zone in gasifier during operation were in the range of 973 - 1,100 K, which were in accordance with the theoretical temperature of reduction zone between 800 - 1300 K [7]. Chemical composition (v/v) of producer gas as a result of gasification experiment were CO 20.6%, H_2 0.4%, CH_4 0.6%, and CO_2 4.4%. Results show that the quality of producer gas was not yet approached the typical gas composition of air-blown biomass gasification [11]. Refers to Centeno, *et al.* [7], the range of CO, H_2, CH_4, CO_2, and N_2 content were 18.4% - 22.1%, 12.5% - 18.3%, 0.9% - 1.4%, 8.5% - 11.4%, and 50.7% - 59.2% respectively. However, the orange flame in the burner was relatively stable at 10 - 15 cm length. Orange flame was caused by the uncondensable tars content in producer gas in the forms of C_2 and higher hydrocarbons that were not detected by GC apparatus. Proper setting of air flow-rate as gasifying agent that produces high reactor temperature generated gas with higher CO content, thereby improving the calorific value of gas. Refers to Sharma [12], at certain producer gas flow rate the higher reaction temperature leads to better thermochemical conversion of biomass into combustibles gas. Thus, improving gasification efficiency in terms of energy efficiency and power output. Concentration of H_2 and CO in producer gas depend on moisture content in biomass (attains maximum at 28%-30% w/w), equivalence ratio (attains maximum at ER around 0.3), and reaction temperature (attains maximum at 1073-1173 K) [13].

Furthermore, the increase in the calorific value of producer gas can also be done by using O_2 and CO_2 or H_2O as gasifying agent. The mixture of gasifying agent with high CO_2 concentration and higher reactor temperature will increase CO concentration in the producer gas [14]. Therefore, flue gas containing CO_2 which was generated from generator engine could possibly be used as gasifying agent. Particulates and condensed tars in producer gas were mostly removed in cyclone and water scrubber, and the rest were collected in filters. Contaminants in clean producer gas in terms of particulate and condensed tars were certainly low enough which was indicated by the relatively clean filters condition after usage. The temperature of producer gas in the holder was observed about 313 K which was suitable for fueling the gasoline-engine generator.

Dual-fuel operation

Four different electricity loads were generated from the engine generator in dual-fuel operation mode. Those data were compared with single-fuel operation mode. The gasoline engine intake manifold was modified for dual-fuel operation by installing a tee connection for mixing combustion air and producer gas before entering the engine combustion chamber. Producer gas flow-rate, combustion air flow-rate, and gasoline flow-rate were controlled by certain globe valves (see Fig. 2). These flow-rate adjusment was to maintain the level of engine vibration which was observed visually. Certain electricity equipments were installed to consume the electricity load and served to vary electricity loads. At 0.92 kVA electricity load, the volumetric flow-rate of producer gas was measured at about 1.84 L/s. Based on specific gasoline consumption (L/kVAh) for single-fuel operation, the engine consumed high amount of gasoline which was about 0.732 L/kVAh at this electricity load compared to the theoretical spesific gasoline consumption based on its heating value which is about 0.104 L/kWh. This high gasoline consumption possibly caused by inappropriate engine intake manifold modification. The increase of electricity load caused the rise of temperature in the combustion chamber which improved fuel atomization and evaporation, and so were the better mixing between fuel and air. This phenomenon caused the combustion process more effective and affect on low spesific gasoline consumption as shown in Fig.3. Second order polynomial regression was then applied to specific gasoline consumption data to predicted the specific gasoline consumption saving at various electricity loads. Percentages of spesific gasoline consumption saving at various electricity loads are also shown in Fig. 3. The highest percentage of gasoline consumption savings was 20.9% based on L/kVAh at electricity load 0.92 kVA. The low gasoline savings is associated with the low heating value of producer gas, that just only one third of typical heating value of producer gas which was generated from air-blown downdraft biomass gasifier. The inappropriate arragement for mixing of producer gas and combustion air caused incomplete combustion and high gasoline consumption. Ventury-type design which is consisted of a properly designed ventury in the air intake coupled with valves can be used to mix producer gas and air for further

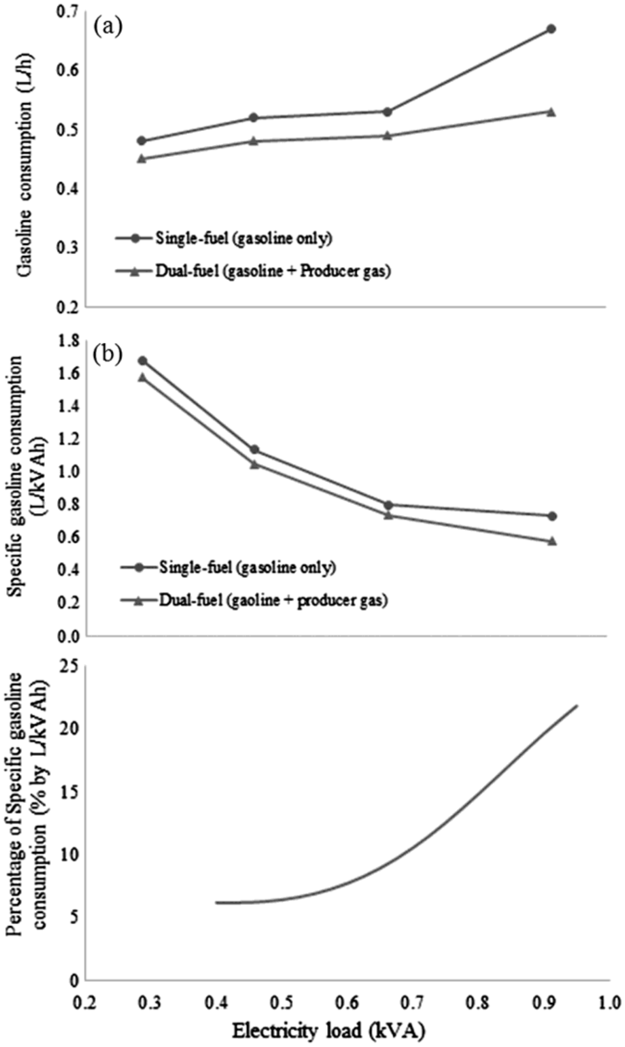

Fig. 3—(a) Gasoline consumption (L/h), (b) Spesific gasoline consumption (L/kVAh), and (c) Percentage of spesific gasoline consumption (% by L/kVAh) in dual-fuel operation mode

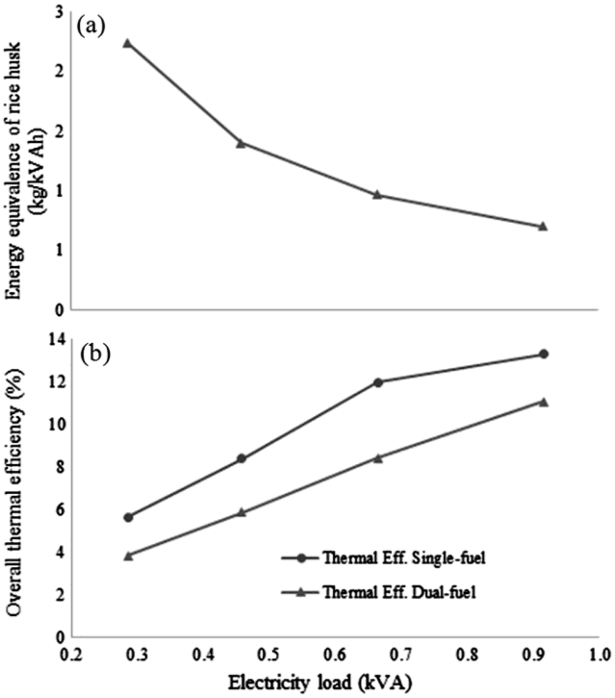

Fig. 4—(a) Energy equivalence of rice husk and (b) Overall thermal efficiency of system at various electricity loads

experiment. Furthermore, the high engine efficiency could possibly achieved by a complete close-loop control of the engine operation to maintain engine speed across the entire load range, control the fuel injection, and maintaining an optimum fuel-air equivalence ratio by using electronic control unit (ECU) [15,16,17]. At the highest electricity load, the energy equivalence between rice husk and gasoline was observed at 4.6 kg rice husk/L gasoline or 0.7 kg rice husk/kVAh as shown in Fig. 4. This value seems too high compared with the heating value ratio between gasoline and rice husk which is 2.24 kg/L. The overall system thermal efficiency was estimated by dividing the energy output measured by volt-amperemeter with total energy content of consumed fuel (rice husk and gasoline) and external energy to operate gasification unit (pump and blower) as parasitic loads. The results are shown in Fig. 4 by assuming a cos φ value is 1. The overall thermal efficiency in dual-fuel operation are lower than single-fuel operation. At 0.92 kVA electricity load, the overall thermal efficiency for dual-fuel operation is 11% compared with 13.3% for single-fuel operation.

Conclusions

A small scale biomass gasification unit with 1 kg/h of capacity was tested and coupled with 1 kW_e gasoline engine generator to generate electricity while reducing gasoline consumption. The gasifier unit operated at the proper reduction zone temperature 973-1100 K, but generated low quality of producer gas which was indicated by the orange flame in the burner. Gas cleaning and cooling system showed a good performance operation and provided appropriate producer gas temperature for engine generator which was observed around 313 K. In this study, the calculated specific gasification rate was 81.53 kg rice husk per square meter of throath area and per hour operation time. In both operation modes, the gasoline consumption was reduced with increasing the electricity load. Dual-fuel operation mode showed that the higher electricity load the higher percentage of specific gasoline consumption saving. The highest percentage of gasoline consumption savings was 20.9% based on L/kVAh at 0.92 kVA electricity load and 1.84 L/s producer gas injection flow-rate. But, this system reduced overall thermal efficiency compared to single-fuel operation by 1.8-3.6%. In this study, the energy equivalence between rice husk and gasoline was observed at 4.6 kg rice husk/L gasoline or 0.7 kg rice husk/kVAh.

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