Investigation of producer gas biomass gasification on reciprocated internal combustion engine

R F Naryanto 1,3, H Enomoto 1, VC Anh 1, K Fukadu 1, S Iwai 1, and R Noda 2

1 Mechanical Science and Engineering, Kanazawa University, Kakuma-machi, Kanazawa, Ishikawa 9201192 Japan
2 Environmental and Chemical Engineering Graduate School of Science and Technology Gunma University, 1-5-1, Tenjin-machi, Kiryu, Gunma 3760052 Japan
3 Department of Mechanical Engineering, Universitas Negeri Semarang, Sekaran, Gunung Pati, Semarang, Indonesia

E-mail: rizqi.fitri@stu.kanazawa-u.ac.jp or rizqi_fitri@mail.unnes.ac.id

Abstract. Biomass is sustainable and a source for renewable energy to overcome the limitation of fossil fuel. The research used woody pellet feedstock with 0.79 g/cm³ of bulk density and 6 mm diameter in the syngas production. Therefore, downdraft gasifier reactor with a stainless steel pipe 500 mm length and 120 mm inner diameter produced syngas as producer gas. Reciprocated Internal Combustion Engine (R-ICE) was used to drive the syngas production from biomass gasification process with 1800 rpm ± 20 rpm in constant engine speed. The Indication of Mean Effective Pressure (IMEP) and Excess Air Rate (EAR) were applied as the parameters for analyzing the system. Kawasaki FD750 with single cylinder was implemented to test the effect of syngas instability. Oxidizer and fuel for the engine were mixed in the venturi which typed Heinzmann, GM 50 to make homogenous fuel. The laminar flow meter type of Sokken, LFE-25B was adapted to measure the intake air flow rate, and the digital ignition system of Altronic, CD200D was used to control the ignition timing. In conclusion, the synthetic gas (syngas) as the main fuel will not be enough to replicate drive on R-ICE.

Keywords: Gasification process, wood pellet, synthetic gas, Reciprocated Internal Combustion Engine (R-ICE).

1. Introduction
Biomass is sustainable and a source for renewable energy to overcome the limitation of fossil fuel; the other side, the regulation for reducing CO₂ emission needs attention. Biomass solves this problem to fulfill the demand of electricity and synthetic gas [1]. Biomass gasification process operated with the production process of syngas using wood pellet as feedstock.

Gasification is a process to convert organic component from human life from animal, wood, or fruit into methane and flammable gas using partial oxidation at 500°C and more in the temperature [2]. The main production of the gasification system is producer gas or syngas, e.g. carbon monoxide (CO), methane (CH₄), hydrogen (H₂), carbon dioxide (CO₂), nitrogen (N₂). The resulted syngas will use to drive the engine to produce electricity and power.

In a small area or village, the source of electricity is not available. The small power plant which was operated using biomass with local wisdom can be implemented to overcome this case. For example, The Java island as the biggest rice production in Indonesia, the feedstock of the power
generation can use rice husk. On the other hand, the case for Sumatera island and Kalimantan island as the biggest production of palm oil in the world, all parts of palm oil tree can be used as the feedstock on power generation whereas Japanese country which has many trees, wood pellet or wood chips can be carried out for operating the biomass gasification [3]. Reciprocated Internal Combustion Engine (R-ICE) connected with a small biomass power plant could produce electricity (less than 2 MW) and more than 30% efficiency [4].

A part of a gasification reactor called reaction zone was in small condition with the reactor 500 mm length and 120 mm of inner diameter with downdraft gasifier type. With the small capacity feedstock, this condition influences the capacity production of syngas, and the effect on heat loss increased. The changes of fluctuation from engine speed and engine stop in the R-ICE are the matters of this experiment. In order to recognize the effect of the fluctuation on small R-ICE operation, small downdraft gasification reactor was proposed in this investigation.

In this research, engine speed was set up in constant at 1800 rpm and an average 20 rpm deviation. The investigated parameters were the Indication of Mean Effective Pressure (IMEP) accuracy and Air Excess Rate (AER). The component of composition on syngas, e.g. hydrogen (H₂), carbon monoxide (CO₂), and methane (CH₄) were examined in this experiment.

2. Materials and Methods
2.1 Feedstock
This experiment operated with wood pellet as fuel, which is easy to get and enough stock in availability. The applied combustion laboratory in Kanazawa University executed the experiment using a laboratory scale gasification system which used the bulk density of wood pellet was used 0.79 g/cm³ and 6 mm diameter. For the gasification process, thermochemical characteristic of feedstock is necessary to know for control operation condition. We developed a system for producing syngas using woody biomass gasification, which called a downdraft gasification generator. Then, we executed the syngas to drive the Reciprocated Internal Combustion Engine (R-ICE) and to generate electric power. The Ultimate Analysis (UA) involved a qualitative analysis of organic feedstock elements such as C, H, N, O, S. Then, the Proximate Analysis (PA) was used to acquire data for quantitative moisture, volatile matter, fixed carbon, and feedstock ash [5]. The UA and PA are based on Japan Industrial Standard (JIS). Table 1 shows the UA of wood pellet component and table 2 show of PA of wood pellet component.

### Table 1. Wood Pellet Components (Ultimate Analysis) [6,7]

| Ultimate analysis (wt%, dry basis) JIS M8813 |  |
|---------------------------------------------|---|
| C (dry, ash free)                           | 49.75 |
| H                                           | 6.40 |
| N                                           | 0.09 |
| S                                           | 0.09 |
| O (balance)                                 | 43.14 |
| Ash                                         | 0.53 |

### Table 2. Wood Pellet Components (Proximate Analysis) [6,7]

| Proximate analysis (wt%, dry basis) JIS M8812 |  |
|-----------------------------------------------|---|
| Ash                                           | 0.53 |
| Volatile Matter (dry base)                    | 81.82 |
| Fixed carbon                                 | 17.65 |
| Lower heating value (LHV) (MJ/kg-dry)         | 15.37 |
2.2 Gasifier System

The open top gasifier is a fixed bed downdraft gasifier in which the feedstock is together with the air at the reactor entry on top. Figure 1 shows a diagram of the downdraft gasifier system manufactured in this experiment. The reactor was made from a stainless steel tube with 500 mm of total length and 120 mm of inner diameter. The length of the gasifier reactor remained constant during operation on fixed bed gasifier.

The air which was functioned as oxidizer supplied to the reactor gasifier, Vair intake [L/min]. The air flow rate was set up to ± 1 L/min on the average rate. Moreover, other parts that were used were Soot Remover, Cooler, and Suction Pump. Gas Chromatography-Mass Spectrometry (GC-MS) (GL science, typed 490 micro GC) was functioned to separate, to identify and to quantify the component in syngas especially in the composition of hydrogen (H\(_2\)), oxygen (O\(_2\)), nitrogen (N\(_2\)), methane (CH\(_4\)), carbon monoxide (CO) and carbon dioxide (CO\(_2\)). The resulted syngas which was produced from the gasifier system will operate to drive the R-ICE.

![Figure 1. Diagram of Downdraft Gasifier System](image)

2.3 Reciprocated Internal Combustion Engine (R-ICE)

Single cylinder Kawasaki FD750 with the specification 78 mm in the bore, 78 mm in stroke, using V-twin, and water-cooled engine, single overhead valve, and using spark ignition was modified becoming small Reciprocated Internal Combustion Engine (R-ICE). This research applied the main principle of combustion, including three parts of fuel, oxidizer, and heat source. It has been applied that the premixed combustion system, air as oxidizer was mixed with fuel using Venture type mixer with the brand of Heinzmann GM 50. Hence, the oxidizer intake to the combustion chamber was measured by a laminar flow meter executing by Sokken, LFE-25B. Pent roof type of combustion chamber was chosen because have advantages in faster burn time of the air and fuel mixing. The major specification of the engine test is shown in table 3.

The experiment had identified that the Air Excess Rate (AER) was calculated from the intake air flow rate, and the gas fuel flow rate in the engine. So far, the precision of combusting timing was controlled by Altronic CD200D digital combusting system and was set up for 30° - After Top Dead Centre (ATDC). In order to reduce the temperature of the engine by avoiding overheat, the flow meter with the type TOFCO HF-GCT40-01-30-04 was used volume flow rate for cooling water.

The R-ICE load was measured with an eddy current type dynamometer on brand Tokyo meter, EWS-150-L. This type implemented 150 Nm in maximum torque, 0.5%-F.S. in torque accuracy and 1 rpm in engine speed accuracy. Another measurement of the pressure on the cylinder combustion chamber, a piezo type pressure sensor Kistler 6118CF type was used and combined with charge amplifier 5018A type production by Kistler. Finally, the data of pressure in the cylinder amounted on average one of 150 continuous cycles.
Table 3. Engine Specification

| Parameter                          | Kawasaki FD750 |
|-----------------------------------|----------------|
| Bore (mm)                         | 78.0           |
| Stroke (mm)                       | 78.0           |
| Combustion chamber volume (mL)    | 49.0           |
| Piston displacement (mL)          | 372.7          |
| Cylinder number                   | 1              |
| Compression ratio                 | 8.6            |
| Combustion chamber                | Pent roof type |

3. Results and Discussion
3.1 COV- Indication of Mean Effective Pressure (IMEP) and Combustible Rate

The process of biomass gasification will occur in the gasifier and will drive on R-ICE had been conducted using various types of gas, such as city gas, mixing between city gas and syngas, syngas, and mixing between syngas and hydrogen. The current experiment found that Indication of Mean Effective Pressure (IMEP) parameter has a relation with the combustible rate. The IMEP is an average quantity relating to the operation of the R-ICE and measuring on an engine’s capacity and necessary to estimate the indication of torque in R-ICE and contribute an important report of mechanical efficiency [8]. Also, since the torque is divided by the engine capacity, the IMEP parameter can be used to compare the internal combustion engine of different displacement. IMEP calculated from in-cylinder pressure over compression and expansion portion of an engine cycle in 360° in a four-stroke or 180° in a two-stroke.

![Graph of Combustible Rate vs COV-IMEP](image)

**Figure 2.** Graph of Combustible Rate vs COV-IMEP

The Coefficient of Variation for the Indicated Mean Effective Pressure (COV-IMEP), which is standard variable for combustion stability in spark-ignition engine, The COV-IMEP is varied experimentally either by changing the air-excess ratio, in the reciprocated engine. The product of syngas has a composition in flammable gas. They are H₂, CH₄ and CO. The effect of producer gas composition in flammable gas such as H₂, CH₄ and CO is shown in Figure 2. That the trend of combustible rate versus COV-IMEP for the CH₄ gas the combustible increased while combustible rate increased, besides that for inclined H₂ gas and CO gas the effect of combustible rate is declined, and for 13A (city gas) the increased COV-IMEP, the combustible rate of 13A (city gas) remained constant.
The result in the figure shows that the highest combustible rate was achieved on 13A (city gas) because of the calculated pressure was the highest.

Different fuels need a different amount of air to create expected air-gas mixtures that can be burned in an engine. Thus, the calorific value of an air-gas mixture, the flammability limits, and the flame speed of combustible rate, are the next important parameters to consider [9].

In this study, the first point of interest in evaluating the validity of the producer gas fuel as a suitable fuel for R-ICE engine was to obtain stable combustion at a given intake air to fuel ratio. Once stable combustion was achieved, the fuel flow was changed (and the ignition timing was adjusted) therefore varying the mixture equivalence ratio to determine an affective lean operating limit.

Figure 3 reveals that there has been a gradually increased on combustible rate, while the Pmax was increased too for CH\(_4\). In addition, for inclined H\(_2\) gas and CO gas, the effect of Pmax were declined, and for 13A (city gas) the increased Pmax, the combustible rate of 13A (city gas) remained constant. This matter was caused by heaviness of molecular weight for CH\(_4\) heavier than another gas compound.

3.2 *Burn Duration*

The percentage of Burn Duration for 0-10% achieved the highest rate for city gas with increasing on Maximum In-Cylinder Pressure; this condition occurs because of the increasing of pressure. While the Burn Duration for 10-90% was likely to increase for city gas and reached the highest value, this statement is described in Figure 4 and Figure 5. It can be caused by the flammability of city gas was higher than the other gas.
3.3 Air Excess Rate (AER)

Figure 6 shows that when the condition of Air Excess Rate (AER) is less than 1, the condition is called rich, which means the composition of fuel is larger than air. This condition happens in the city gas. Meanwhile, the value of Air Excess Rate (AER) is more than 1, and the condition called lean, so the composition of fuel is smaller than air, which happens on syngas, mixing between syngas and H\textsubscript{2}, mixing between city gas and syngas, and syngas. The value of Air Excess Rate (AER) did not affect on the Indication of Mean Effective Pressure (IMEP) because the value of IMEP measurement varies from small to a large value.
Cylinder pressure information can be used to consider the work transfer from the gas to the piston. This is generally expressed as the indicated mean effective pressure (IMEP) and is a measure of the work output for the swept volume of the engine. The result is an essential parameter for definitive engine efficiency as it is independent of speed, number of cylinders, and displacement of the engine. The IMEP prediction is basically the enclosed area of the high-pressure part of the Pressure (P) – Volume (V) diagram and can be derived via integration [10]:

\[ IMEP = \int P \, dV \]

![Graph of Air Excess Rate vs IMEP](image)

**Figure 7.** Graph of Air Excess Rate vs IMEP

The compression ratio is the ratio of the volume of the cylinder and the combustion chamber when the piston is at the bottom dead center, and the volume of the combustion chamber when the piston is at the after top dead center. The Automotive engine can improve fuel efficiency and fuel economy by designing engines with high compression ratio. From Figure 7, we can see that the inclining value of compression ratio on engine FD750 with compression ratio (CR) 8.6 and the air excess rate (AER) became greater than 0.8, otherwise, the declining value of compression ratio on engine D905D with compression ratio (CR) 16.2 the Air Excess Rate (AER) and IMEP become lower than 0.8 so that the fuel composition is relatively reduce. It can be seen from the obtained result that the Air Excess Rate (AER) are greatly influence on the IMEP. Moreover, the decreasing of IMEP will affect the increasing Air Excess Rate (AER), because of the low Air Excess Rate, IMEP decreases almost linearly, than IMEP falls with non-linear behaviour.

4. Conclusion
In conclusion, the syngas which was produced from the gasifier and then driven to R-ICE has many gas compositions, which are carbon monoxide (CO), hydrogen (H₂), and Methane (CH₄). The gas of CO has an effect on the process of R-ICE than the gas of H₂ and CH₄. Therefore, those mixture gases will not be sufficient to do a simulation to drive in a small R-ICE operation with only syngas. The present contribution suggests the mixture of city gas and syngas as a producer gas to drive the R-ICE.
Acknowledgment
The author would like to thank to Minister of Finance, Indonesia Endowment Fund for Education (LPDP) and Ministry of Research, Technology and Higher Education (RISTEKDIKTI) for the support of Scholarship.

References
[1] James A M, Yuan W, Boyette M D and Wang D 2015 The effect of air flow rate and biomass type on the performance of an updraft biomass gasifier BioResources 10(2) 3615-3624
[2] Higman C and Burgt M V D 2003 Gasification (USA: Elsevier)
[3] Yoshioka T, Aruga K, Nitami T, Sakai H and Kobayashi H 2006 A case study on the cost and the fuel consumption of harvesting, transporting, and chipping chains for logging residues in japan Biomass & Bioenergy 30 342-348
[4] Beenackers A A C M 1999 Biomass gasification in moving bed a review of european technologies Renewable Energy 16 1180-1186
[5] Park SW, Lee SY, Jeong YO, Han GH and Seo YC 2018 Effect of oxygen enrichment in air oxidants on biomass gasification efficiency and the reduction of tar emissions Energies 11 1-13
[6] Naryanto R F, Enomoto H, Anh V C, Chunti C and Noda R 2019 Effect of tar formation on biomass downdraft gasification reactor of wood pellet with variation of moisture content Proc. 14th Biomass Science Conference (Hiroshima) vol 1 (Japan: The Japan Institute of Energy) p 39-40
[7] Naryanto R F, Enomoto H, Hieda N, Teraoka Y, Chunti C and Noda R 2019 The influence of wood pellet feedstock water content on tar component in biomass system using downdraft gasifier Journal of Japan Institute of Energy 98 124-127
[8] Omran R, Younes R, Champoussin J C and Outbib R 2011 New indicated mean effective pressure (IMEP) model for predicting cranksaft movement Energy Conversion and Management 52 3376-3382
[9] Przybyła G and Ziółkowski Ł 2008 Analysis of energy conversion process of SI engine fuelled with LCV gas Proceedings of the Ninth Asia-Pacific International Symposium on Combustion and Energy Utilization (Beijing) (China: World Publishing Corporation), p 113 – 118
[10] Martyr A J and Plint M A 2012 Engine Testing Chapter 15 The combustion process and combustion analysis (USA: Elsevier)