GASIFICATION OF BIOMASS AS ALTERNATIVE ENERGY CONVERSION FOR RURAL AREA

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Abstract: Depletion of conventional fuel such as oil fuel and coal became concern not only in Indonesia but also worldwide. Different types of alternative energy sources have been utilized for substitution of conventional source of energy. Biomass gasification, one of many alternative energy conversion systems, have been developed to overcome a depletion of conventional fuel. Biomass gasification is thermo-chemical process of converting biomass to producer gas.
Quality of producer gas is affected by performance of gasifier which is affected by operating parameters during gasification process. The aim of this research is to study experimentally an effect of operating parameters on gasification of waste of biomass in a 20 kWe downdraft gasifier
The result shows that percentage of combustible gas increases with increasing producer gas flow rate. Increasing composition of combustible gas in producer gas is directly proportional with increasing calorific value of producer gas. Calorific value of producer gas is also affected by biomass type and continuity of gasification process in a gasifier.
Keywords: gasification, biomass, conversion, producer gas, performance

1. Introduction

The depletion of fossil fuels became a serious problem for last several years. Efforts have been done for solving the problem. Many researchers have investigated various sources of renewable energy and developed the energy conversion system for those sources. One of feasible energy conversion system is biomass gasification. Biomass gasification is a thermo-chemical process of converting solid biomass into combustible gas called producer gas by means of partial oxidation carried out in reactor called gasifier (Khisore, 2008). Biomass gasification occurs through a sequence of complex thermo-chemical reactions. In first stage, partial combustion of biomass producing gases and char occurs along with generation of heat. This heat is utilized in the drying of biomass to evaporate its moisture as well as for pyrolysis to bring out the volatile matter and for further reduction to generate producer gas. This gas consists of a mixture of combustible gases such as Carbon monoxide (CO), Hydrogen (H_2), and traces of Methane (CH_4) and other hydrocarbons. Normally, air is used as gasifying agent; however, the used of oxygen can produces higher caloric value gas but is not usually done due to the cost implication. Compared than solid biomass, producer gas has advantages: gases are easy to clean, to transport and to burn efficiently with a low excess of air and little resulting pollution. Further, gases can be burned in an internal combustion engine and can be easily applied in combined cycles (Swaaij, 1981).

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Under high temperature, the biomass loses its moisture and is then subjected to pyrolisis resulting in its decomposition into char and volatile. The volatile products are a mixture of a large number of short chain hydrocarbons which may crack further to yield compounds such as Carbon monoxide, Hydrogen, Carbon dioxide, water vapor and tar. These pyrolytic yields react with oxygen in high temperature combustion zone where oxidation and reduction reactions yield producer gas (Kumar A, 2006).

The oxidation takes place at about 700-1400^{0}C. A heterogeneous reaction takes place in the oxidation zone between solid carbonized fuel and oxygen in the air producing carbon dioxide and releasing a substantial amount of heat. In the reduction zone of all types of gasifier, a number of high-temperature chemical reactions take place in absence of oxygen or under a reducing atmosphere. The principal reduction reactions occur in the reduction zone (Khisore, 2008) are bouduard reaction, water-gas reaction, shift reaction, and methane production reaction.

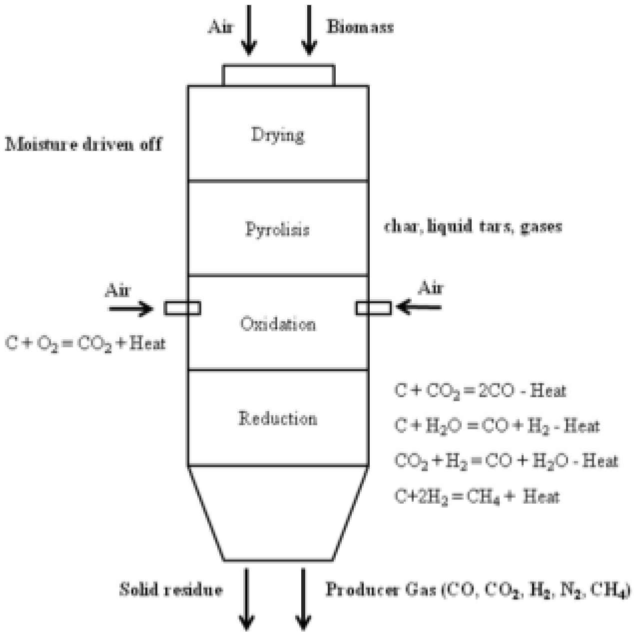

Figure 1. Typically reaction in downdraft gasifier

Several types of gasifier have been reported (Vyarawalla *et.al.*, 1984). They can be broadly categorized based on the direction of gas flow as updraft, downdraft and cross draft. Gasifier may also have either fixed or fluidized bed.

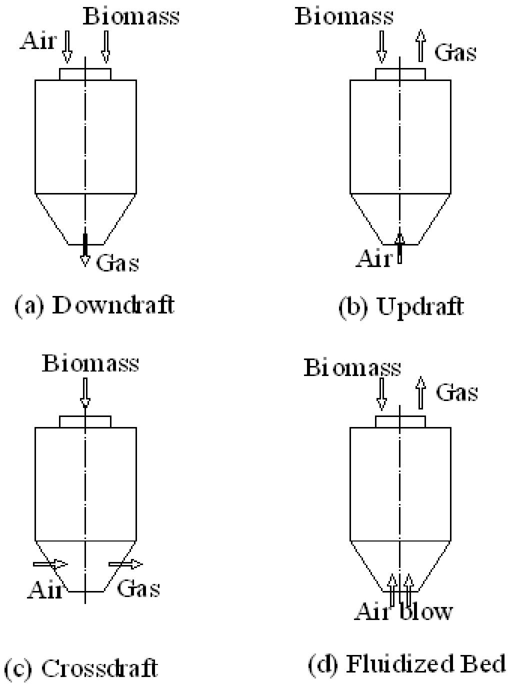

Figure 2. Types of Gasifier

Operating parameter on producer gas has been investigated by many researchers. An effect of biomass sources and particles size on producer gas has been reported by Kumar. A hard wood typically gives a higher caloric value of producer gas than softwood. Hardwood and ordinary wood shows marginally better gasifier power output as compared to softwood. The percentages of Carbon monoxide, Hydrogen, and calorific value of the gas decrease with initial increasing in particle size. Dogru *et al.* investigated hazelnut shells gasification in downdraft gasifier. The quality of product gas is to be dependent on smooth flow of the biomass in the reactor. Flow characteristics of biomass in the gasifier reactor play an important rule for optimum operation of gasifier. Composition of combustible gas CO, H_2, and H_4 was found to be dependent on gas flow rate. Increase in gas flow rate results in increasing CO, H_2, and CH_4 composition, hence higher calorific value of producer gas at higher gas flow rate (Singh, *et al*., 2006)

Producer gas composition is also affected by equivalence ratio of biomass gasification. Calorific value of producer gas is defined from the composition of producer gas. Typically for effective gasification, equivalence ratio should be in the range of 0.2-0.4 (Kaupp & Goss, 1981). Meanwhile, Zainal *et al*. have investigated a furniture wood and chip wood gasification in a downdraft gasifier. They obtained an optimum producer gas composition from those biomass is at equivalence ratio of 0.268 - 0.430.

sIn this work, gasification of Pongamia *pinnata* shells in downdraft wood gasifier is studied. The aim of the work is to investigate an effect of operating parameters on performance of gasifier, in term of composition and calorific value of producer gas.

Figure 3. Pongamia fruits and its shells

Typically properties of Pongamia shells compared with ordinary wood as reported on previous work by Sonkar *et al*, 2007, are in the limit of essential properties of biomass for gasifier.

Table 1. Proximate analysis of Pongamia shell (Sonkar *et al*. 2007)

Entity	Pongamia Shell (%)
Ash	4.09
Volatile matter	66.99
Fixed Carbon	18.95

Table 2. Ultimate analysis of Pongamia shell (Sonkar *et al*. 2007)

Entity	Pongamia Shell (%)
Ash	4.09
Carbon	44.3
Hydrogen	7.45
Nitrogen	1.73
Sulphur	0.3
Oxygen	42.13

2. Methodology

Gasifier used in this experimental work was originally wood downdraft gasifier which capacity of 20 kWe. An original 16 cm diameter of conical grate has been replaced with conical grate which diameter of 15 cm for encountering the blocking in grates section of gasifier reactor.

Typically in downdraft gasifier, biomass is fed from top of the reactor. Air enters the gasifier in the oxidation zone through air nozzles (tuyer) by means of suction blower. Remains gasified biomass flow through the grate region at the bottom of gasifier. Producer gas flows in the recirculation duct from the bottom of reactor and exits at the top of reactor. Producer gas is cooled by spray water in two stage cooling unit. Further, gas is cleaned in the coarse sand and fine sand filter from dust and fine particle present in producer gas.

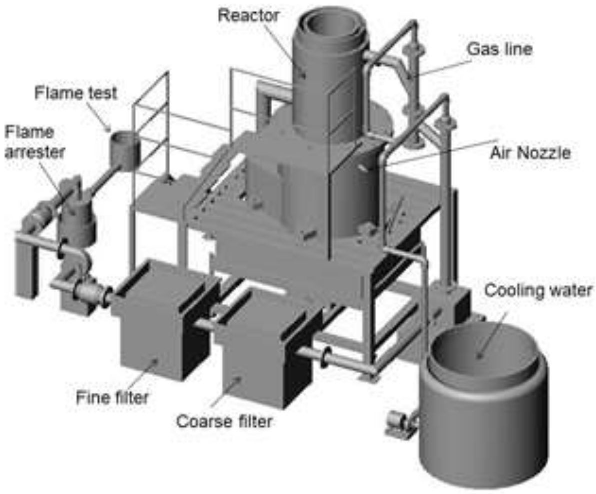

Figure 4. A 20 kWe downdraft gasifier

The main component of this 20 kWe downdraft gasifier system are reactor, gas circulation pipe, water tank, water pump, cooling water circulation pipe, suction blower, sand filter, flame arrester, flame test, and three air nozzles. U tube water manometers were provided for measurement of pressure at four strategic locations: at the exit of gasifier (P_1), at the exit of cooling unit (P_2), at the exit of coarse filter (P_3), and at the exit of fine filter (P_4), and at venturi meter (P_v)

Shells of Pongamia pinnata were loaded into the reactor from top. After partially opening a gas valve, suction blower and electric water pump are switched ON. To generate the flame inside a reactor, *Pongamia pinnata* shells in the reactor was initiated by holding the flame in a form of a blowtorch or wick near to an air nozzle. After 10-15 minutes generated producer gas in the burner was flared. Sample of producer gas is taken after 30 minutes of continuous operation of gasifier. Composition of producer gas was measured using NUCON Gas Chromatograph with Argon as gas carrier. Gas Chromatograph was calibrated using calibration gas which composition of 10.07% CO_2, 24.43% CO, 24.98% H_2, 35.55 N_2, and 4.97% CH_4. Composition of producer gas is determined using existing computer software by comparing the peaks area of calibration gas and gas sample.

This experimental work was run at one air nozzle opening and two air nozzle opening. Effect of producer gas flow rate and equivalence ratio on composition and calorific value of producer was studied. Producer gas flow rate is calculated by equation given in manual book of 20 kWe downdraft gasifier (Netpro, I.I.S_C,1999);

$$\dot{m}_g = 3.3\sqrt{\Delta h_v} \qquad (1)$$

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Δh_v is height difference of water in U-tube manometer at venturi meter.

Assuming chemical properties of biomass were Carbon, Hydrogen, Oxygen, and Nitrogen, equation of chemical reaction of Pongamia pinnata shells was (Sonkar *et al.*, 2007);

$$n(C_{3.69}H_{7.45}O_{2.63}N_{0.12}) + n\,\Phi\,(O_2+3.76N_2) \rightarrow x_1CO_2 + x_2CO + x_3H_2 + x_4N_2 + x_5CH_4 + x_6O_2 \quad (2)$$

The value of n and Φ are determined from Carbon and Nitrogen balance equations. Value of x_1, x_2, x_3, x_4, and x_5 is taken from composition of CO_2, CO, H_2, N_2, and CH_4 of producer gas that obtained from Gas Chromatograph measurement.

Carbon balance;

$$n = \frac{x_1 + x_2 + x_5}{x} \quad (3)$$

Nitrogen balance;

$$\Phi = \frac{x_4 - \left(\frac{1}{2} n \cdot k\right)}{3.76\,n} \quad (4)$$

Prior to calculate an equivalence ratio, it required to calculate theoretical and actual A/F ratio. Theoretical A/F ratio on the basis of 100 kg fuel:

$$(A/F)_{th} = \frac{4.76 \times \Phi \times MW_{air}}{100} \quad (5)$$

Meanwhile actual A/F ratio;

$$(A/F)_{act} = \frac{\dot{m}_a}{\dot{m}_s} \quad (6)$$

Actual air consumption rate;

$$\dot{m}_a = \rho \times \left(n \times \frac{\pi}{4} d_m^2\right) \times v \quad (7)$$

Where:

ρ = air density at 1 atm and 25^0C (1.18 kg/m^3)
n = number of nozzle opening
d_m = nozzle diameter (0.03 m)
v = air velocity (10 m/s)

Shells consumption rates;

$$\dot{m}_s = \frac{\rho_{bl} \times \left(\frac{\pi}{4} D^2 \times h\right)}{t} \quad (8)$$

Where:

ρ_{bl} = bulk density of shell (146 Kg/m^3)
D = diameter of reactor (0.25 m)
h = depth of biomass in reactor (m)
t = time operation of gasifier (minute)

Hence equivalence ratio;

$$\Phi = \frac{(A/F)_{th}}{(A/F)_{act}} \qquad (9)$$

Calorific value of producer gas was calculated from composition of combustible gas in the producer gas obtained from Gas Chromatograph measurement. Calorific value of producer gas on basis of 100 kg fuel;

$$CV_g = \frac{(x_2 \cdot CV)_{CO} + (x_3 \cdot CV)_{H_2} + (x_5 \cdot CV)_{CH_4}}{100} \qquad (10)$$

Value of x_2, x_3, and x_5 were percentage of composition CO, H_2, and CH_4 respectively, since calorific value of CO, H_2, and CH_4 were taken from Iyer *et.al*, 2002 in table 3.

Table 3. Calorific Value of Compound (Iyer, et al,2002)

Compound	CV (MJ/m^3)
CO	12.71
H_2	12.78
CH_4	39.76

3. Results & Discussion

Figure 5 and Figure 6 show a composition of producer gas and calorific value at different gas flow rate.

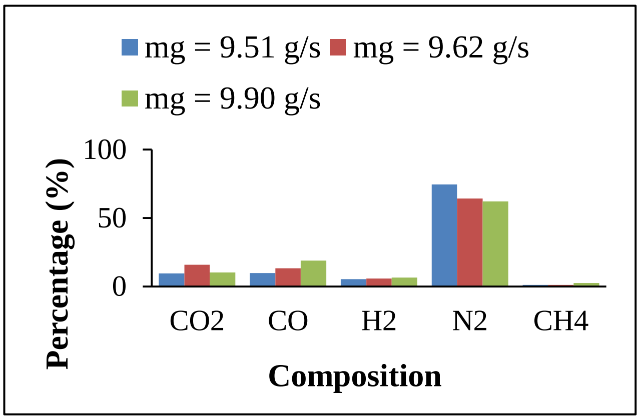

Figure 5. Composition of producer gas at different flow rate

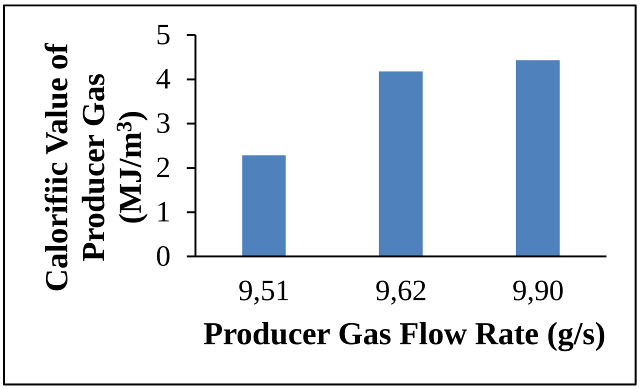

Figure 6. Calorific value of producer gas at different flow rate

Composition of combustible gas CO, H_2, and CH_4 was found to be optimum at gas flow rate of 9.90 g/s. Continuous operation of gasifier and smooth flow of shells in reactor was better at this gas flow rate. Increasing composition of producer gas was directly proportional with increasing calorific value of producer gas.

Figure 7 and Figure 8 show a composition and calorific value of producer gas respectively from *Pongamia pinnata* shells gasification at different equivalence ratio. Percentage of N_2 decreases as equivalence ratio increase. Better gasification occurs at higher equivalence ratio. Percentage of combustible gas CO, H_2, and CH_4 is higher at equivalence ratio of 0.5. Hence, calorific value was also higher at equivalence ratio of 0.5. Calorific value of producer gas depends on percentage of combustible gases CO, H_2, and CH_4.

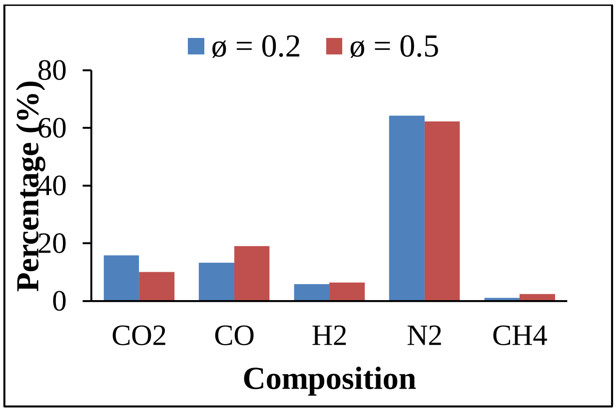

Figure 7. Composition of producer gas at different equivalence ratio

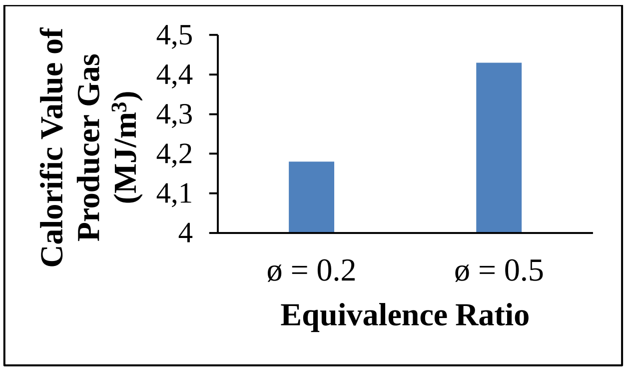

Figure 8. Calorific value of producer gas at different equivalence ratio

Figure 9 to 10 show a composition and calorific value of producer gas from wood chips and Pongamia's shells gasification. Gasification of wood chips shows better performance than gasification of Pongamia's shells. Calorific value of producer gas from wood chips is about 4. 48 MJ/m3, whereas producer gas from Pongamia's shells gasification is 3.13 MJ/m^3.

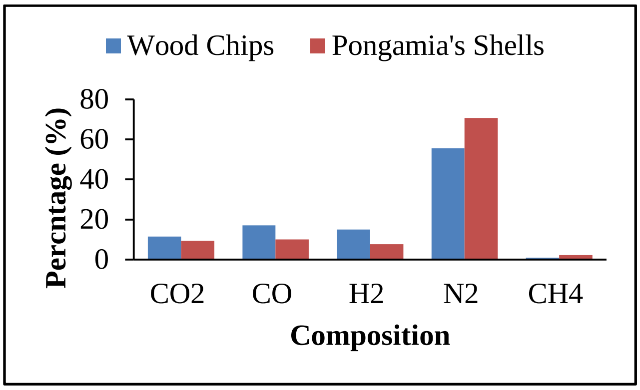

Figure 9. Composition of producer gas from wood chips and Pongamia's shells

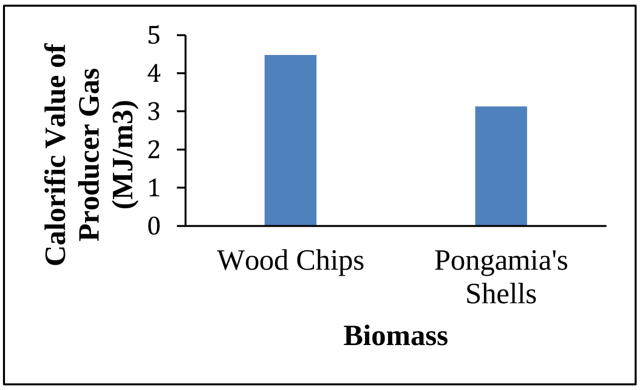

Figure 10. Calorific value of producer gas from wood chips and Pongamia's shells

4. Conclusion

Experimental work on operating parameter of gasification of *Pongamia pinnata* shells in a 20 kWe downdraft gasifier was carried out at different producer gas flow rate and at different equivalence ratio. Percentage of combustible gas (CO, H_2, and CH_4) increases with increasing producer gas flow rate. Calorific value of producer gas is found to be 4.43 MJ/m^3 at producer gas flow rate of 9.9 g/s. Percentage of combustible gas (CO, H_2, and CH_4) also increases with increasing equivalence ratio. Equivalence ratio $\Phi = 0.5$ is found to be an optimum equivalence ratio for the best performance of gasification of *Pongamia pinnata* shells. Typically wood chips gasification produces higher calorific value of producer gas compared to Pongamia's shells gasification.

5. Acknowledgment

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Nomenclature

A/F	Air Fual Ratio
CO	Carbon monoxide
CO_2	Carbon dioxide
CH_4	Methane
CV	Calorific Value (MJ/m^3)
D	Reactor diameter (m)
d	Nozzle diameter (m)
H_2	Hydrogen
kWe	Kilowatt Electricity
m_g	Gas mass flow rate (g/s)
N_2	Nitrogen
P	Pressure (N/m^2)

Greek letters

Φ	Equivalence ratio
ρ	Density (kg/m^3)

Subscripts

a	Air
act	Actual
g	Gas
th	Theoretical
s	Pongamia pinnata shells

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