EFFECT OF OPERATING PARAMETER ON THERMAL CONVERSION OF GASIFICATION OF *PONGAMIA PINNATA* SHELLS

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ABSTRACT

Typically, composition of producer gas from biomass gasification are combustible gas (CO, H_2, and CH_4), and noncombustible gas (CO_2 and N_2). A composition of combustible gas affects a calorific value of producer gas from biomass gasification. Composition of CO, H_2, CH_4, CO_2 and N_2 in producer gas is affected by producer gas flow rate and equivalence ratio. This experimental work aims to study an effect of producer gas flow rate and equivalence ratio on composition and calorific value of producer gas from gasification of Pongamia pinnata shells. Gasification of these shells is carried out in a 20 kWe downdraft wood gasifier. Original conical grate of gasifier reactor has been replaced with smaller diameter to encounter a blocking problem in grate section of reactor. Air flow rate into a gasifier reactor is controlled using different number of air nozzle opening. Globe valve is used to control producer gas flow rate. Sample of producer gas is measured using Gas Chromatograph for different flow rate and air nozzle opening. Calorific value of producer gas is calculated from percentage of combustible gas present in producer gas. Equivalence ratio is a ratio of air/biomass theoretical to ratio of air/biomass actual. Optimum calorific value of producer gas from Pongamia pinnata shells gasification is obtained at producer gas flow rate of 9.9 g/s and at equivalence ratio of 0.5.

Keywords: *producer gas, gasification, biomass, Pongamia pinnata, equivalence ratio*

INTISARI

Producer gas hasil dari gasifikasi biomassa umumnya terdiri dari gas mampu bakar CO, H_2,dan CH_4, serta gas yang tidak mampu bakar CO_2 dan N_2. Besar kecilnya kandungan gas mampu bakar mempengaruhi nilai kalor dari producer gas hasil gasifikasi. Komposisi gas pada producer gas dipengaruhi antara lain oleh laju aliran producer gas dan equivalence rationya. Penelitian ini bertujuan untuk mengetahui pengaruh laju aliran dan equivalence ratio terhadap komposisi gas dan nilai kalor dari producer gas hasil gasifikasi kulit kering buah Pongamia pinnata. Dalam penelitian ini dilakukan gasifikasi kulit Pongamia pinnata didalam tungku gasifikasi tipe downdraft dengan kapasitas 20 kWe. Conical grate yang asli diganti dengan conical grate berdiameter lebih kecil untuk mengatasi penyumbatan yang terjadi di daerah grate dari tungku gasifikasi. Laju udara ke dalam tungku gasifikasi diatur dengan penggunaan jumlah nozzle udara, serta laju producer gas diatur dengan globe valve. Sample dari producer gas diukur dengan menggunakan Gas Chromatograph untuk mengetahui komposisi gasnya untuk masing-masing penggunaan jumlah nozzle udara dan laju aliran producer gas. Dari komposisi producer gas dapat ditentukan nilai kalornya. Sedangkan equivalence ratio didapatkan dari perbandingan antara rasio udara/biomassa teoritis dengan rasio udara/biomassa aktual. Nilai kalor producer gas hasil gasifikasi kulit Pongamia pinnata optimum pada laju aliran udara 9.9 g/s dan equivalence ratio 0.5.

Kata Kunci: producer gas, gasifikasi, biomassa, Pongamia pinnata, equivalence ratio.

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INTRODUCTION

Fossil fuels as the main source of energy have been used worldwide for years. But, the depletion of fossil fuels became a serious problem for last several years. Efforts have been done for solving this 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 thermo-chemical process carried out in the reactor called gasifier. Sequence process of drying, pyrolysis, oxidation and reduction occur at different zone in the gasifier reactor. Product of gasification process is called producer gas which mainly contain of combustible gas (CO, H_2, and CH_4) and also non combustible gas (CO_2 and N_2). Typically biomass utilized for gasification is from agricultural waste, wood industry, as well as from domestic waste.

Waste of *Pongamia pinnata* shells has a potential as biomass source for reneable energy. From mass and energy distribution, it was obtained total energy of 45.36 GJ from 3.15 tons shells of *Pongamia pinnata* (Subbarao, 2007).

Figure 1. *Pongamia pinnata* shells

Feasibility of gasification of *Pongamia pinnata* shells has been investtigated in a 20 kWe downdraft gasifier by Sonkar, *et a*l, and Susastriawan. The gasifier is originally wood gasifier. It was found that blocking of gasified shells in the grate section of reactor is a major problem. Sonkar *et al*. have also carried out proximate analysis and ultimate analysis of *Pongamia pinnata* shells.

Table 1. Proximate analysis

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

Source: (Sonkar *et al*. 2007)

Table 2. Ultimate analysis

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

Source: (Sonkar *et al*. 2007)

Effect of 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. The 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, 1984). 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.

EXPERIMENTAL WORK

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

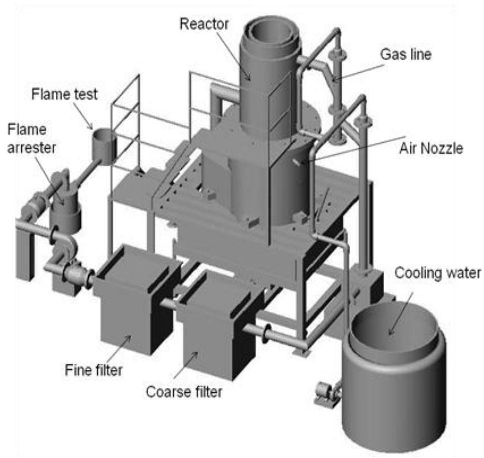

Figure 2. A 20 kWe downdraft gasifier

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)

The reactor was basically made of two shells, bottom shell being rolled from mild steel and has an inner lining of insulation using high temperature ceramic. The top shell was double walled stainless steel shell having an annular space through which hot gas was passed and allows heat transfer to the biomass chips. The re-circulating duct was the passage linking the bottom reactor with the top shell. The outer wall of the reactor was covered with low density alumina silicate and stainless steel sheet to reduce heat loss. The bottom of reactor dipped in reactor water seal to prevent the air entry. There was a conical grate mechanism provided at the bottom of the reactor with lever attached for grate shaking. A function of this conical grate is to hold biomass charge.

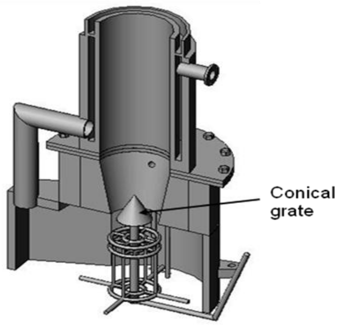

Figure 3. Gasifier reactor and conical grate

Coolers were made up of two sections. The first was a counter current spray whereas the second was a co-current spray. The spray was developed from impinging jet, which mixes with the gas and cools the gas to the ambient temperature and in this process some contaminants were removed from the gas. For cooling purpose, the existing water tank was replaced with larger capacity. And a pipe from tank to electric motor was also replaced with larger diameter.

Filter was comprised of two filters, coarse sand filter and fine sand filter. The coarse sand filter was a four-tier filter with total filtering area of approximately 1.8 m^2 to contain 1-2 mm sized sand particles forming a bed of 85-90 mm thickness. The fine filter was also a four-tier filter providing a filtering area of 5.40 m^2 for holding 200-600 μm sized sand particles of 85-90 mm thick.

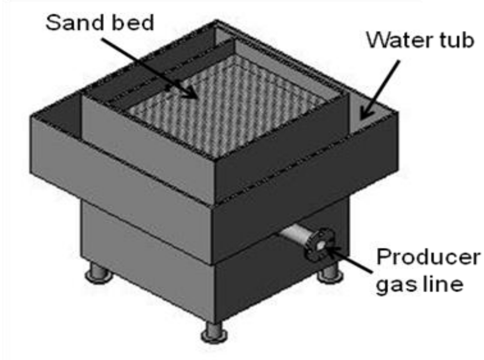

Figure 4. Four-tier sand filter

A producer gas from the exit of the suction blower was bubbled through a container before entering the burner. Bubbler was provided as a safety device to prevent flame flash backs from the burner end in the event of air leaking into the system.

Flame test/burner was provided to check the quality of the combustible gas. The gas was flared in the burner for a few minutes prior to change to the engine. Flame arrester in form of thin GI meshes was provided at the burner entry as a safety device.

Figure5. Producer gas flame

The cooled and cleaned gas was transferred to an engine using PVC pipe. The ability of venturi meter to regain much of original pressure head makes it especially useful in measuring the flow rate in systems which have low pressure differential or pressure head drive the fluid through the pipe.

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):

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

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):

$$n(C_{3.69}H_{7.45}O_{2.63}N_{0.12}) + n\ \Phi\ (O_2+3.76N_2) \rightarrow x_1CO_2 + x_2CO + x_3H_2 + x_4N_2 + x_5CH_4 + x_6O_2 \quad ... . \quad (3)$$

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;

$$n = \frac{x_1 + x_2 + x_5}{x} \quad \text{......................} \quad (4)$$

Nitrogen balance;

$$\phi = \frac{x_4 - \left(\frac{1}{2} n \cdot k\right)}{3.76n} \quad \text{.........} \quad (5)$$

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:

$$(A/F)_{th} = \frac{4.76 \times \phi \times MW_{air}}{100} \quad \text{....} \quad (6)$$

Meanwhile actual A/F ratio:

$$(A/F)_{act} = \frac{\dot{m}_a}{\dot{m}_s} \ldots \quad \text{....} \quad (7)$$

Actual air consumption rate:

$$\dot{m}_a = \rho \times \left(n \times \frac{\pi}{4} d_m^2\right) \times v \quad \text{....} \quad (8)$$

Where:
ρ = air density at 1 atm and 25^{0}C (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:

$$\dot{m}_s = \frac{\rho_{bl} \times \left(\frac{\pi}{4} D^2 \times h\right)}{t} \quad \text{.........} \quad (9)$$

Where:
ρ_{bl} = bulk density of shell (146 Kg/m^3)
D = diameter of reactor (0.25 m)
h = height of empty space of reactor at interval time (m)
t = time operation of gasifier (minute)

Hence equivalence ratio:

$$\phi = \frac{(A/F)_{th}}{(A/F)_{act}} \quad \text{..........} \quad (10)$$

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

$$CV_g = \frac{(x_2 \cdot CV)_{CO} + (x_3 \cdot CV)_{H_2} + (x_5 \cdot CV)_{CH_4}}{100} \quad \text{..} \quad (11)$$

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 2.

Table 3. Calorific Value of Compound

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

Source: Iyer, *et al*. 2002

RESULT AND DISCUSSION

Flow rate of Producer Gas, Figure 4 and Figure 5 show composition of producer gas and calorific value at different gas flow rate.

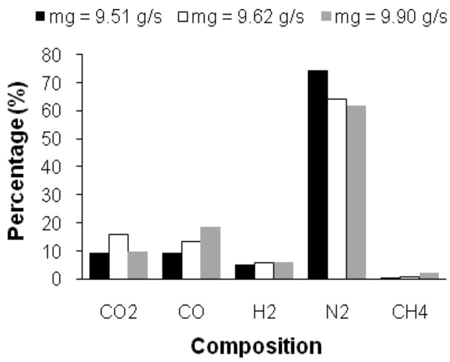

Figure 4. Composition of producer gas at different flow rate

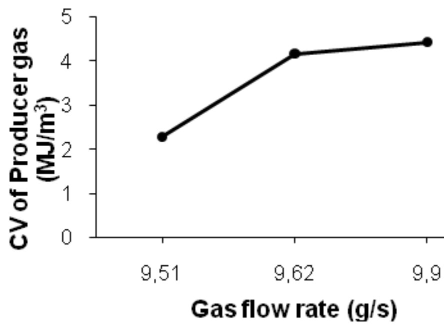

Figure 5. Calorific value of producer gas at different flow rate

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 in calorific value of producer gas.

Equivalence Ratio, Figure 6 and Figure 7 show composition and calorific value of producer gas respectively from *Pongamia pinnata* shells gasification at different equivalent ratio.

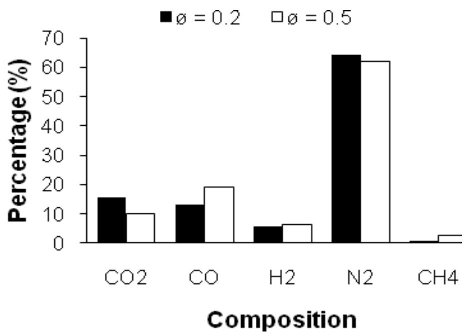

Figure 6. Composition of producer gas at different equivalence ratio

Percentage of N_2 decreases as equivalence ratio increase. Better gasify-cation occurs at higher equivalent ratio. Percentage of combustible gas CO, H_2, and CH_4 is higher at equivalence ratio of 0.5. Hence, calorific value was also hig-her at equivalence ratio of 0.5. From equation (11), calorific value of producer gas depends on percentage of combus-tible gas CO, H_2, and CH_4.

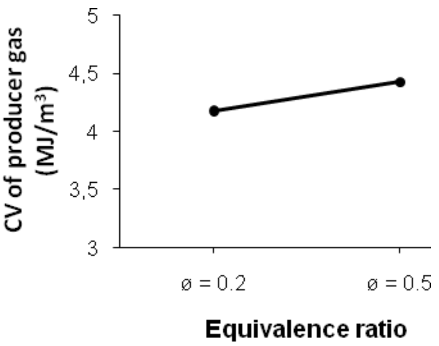

Figure 7. Calorific value of producer gas at different equivalence ratio

CONCLUSION

Experimental investigation 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 in producer gas flow rate. Calorific value of producer gas was 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 in equivalence ratio. Equivalence ratio ø = 0.5 is found to be an optimum equivalence ratio for the best performance of gasification of *Pongamia pinnata* shells.

REFERENCES

Dogru, M., Howarth, C.R., Akay, G., Keskinler, B., Malik, A.A., 2002, Gasification of hazelnut shells in a downdraft gasifier, Energy, Vol. 27, pp. 415-427.

Iyer P.V.R., Rao T.R., Grover P.D., 2002, Biomass-Thermo Chemical Cha-racteristic, Chemical Enginering Department, IIT Delhi, 3rd Edition.

Kaupp, A. and Goss, J.R. 1981, State-of-the-art for Small Scale (to 50 kW) Gas Producer Engine Systems, Bioresources for Energy Timber Management Research, USDA, Forest Service.

Kumar, A., 2006, Simulation of A Bio-mass Gasifier-Engine System, PhD thesis, `Mechanical Engi-neering Department IIT Delhi, New Delhi.

Netpro I.I.Sc., 1999, Dasag Solid Bio-mass Gasifier-Operation & Main-tenance Manual (20 kWe)', Net-pro Renewable Energy (I) Ltd. Bangalore.

Singh, R.N., Jena, U., Patel, J.B., Shar-ma, A.M., 2006, Feasibility Study of Cashew Nut Shells as An Open Core Gasifier Feedstock, Renewable energy, Vol. 23, pp. 481-487

Sonkar, A., Garg, A. and Gupta, P., 2007, Generation of Producer Gas From Pongamia Shells and Integration of Downdraft Gasifier, Producer Gas Engine and Oil Expeller, BTech Thesis, Depart-ment of Mechanical Engineering, IIT Delhi, New Delhi.

Subbarao, P.M.V.S., 2007, Sustainable Fuel Technologies using Non-edible oil Seed Collections, Seminar Presentation, Department of Mechanical Engineering, IIT Delhi, New Delhi.

Susastriawan, A.A.P., 2009, Development of Technologies for Complete Utilization of Waste of Oil Seed Collection, M.Tech Thesis, Department of Mechanical Engineering, IIT Delhi, New Delhi

Zainal, Z.A., Rifau, A, Quadir, G.A., and Seetharamu, K.N., 2002, Experimental Investigation of a Downdraft Biomass Gasifier, Biomass & Bioenergi Vol, 23, pp.283-289