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Performance Evaluation of Open Core Biomass Gasifier

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KEYWORDS : Open core gasifier, Silver-wood chips, performance

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ABSTRACT

An open core 10 kg h-1 capacity gasifier performance evaluation study was carried out. Flame temperature of gas was found to be 630oC. The overall efficiency was found to be 17.21% and the thermal output of the gasifier was worked out to be 11, 775 kCal h-1 and the power rating was worked out to be nearly 14 kW. The mass closure and energy closure were found to be 97 and 78% respectively.

More than 200 MT of agricultural residues are generated every year in the country. Even if a portion of these bio-resources are used for production of energy, 7 MT of petroleum fuels could be replaced. In addition to solid woody biomass, gasifier works well with loose biomass like rice husk, groundnut husk, silver wood chips, eucalyptus etc.

Agricultural residues like bagasse, groundnut shell, maize stalk, maize cobs, rice straw, rice husk, wheat straw etc are found that their calorific value varied from 15 to 20 MJ kg^{-1} (Pathak, 1984). The performance of natural draft gasifier burner system to replace the use of light fuel oil in ceramic product drying was reported by Patil *et al. (*2002). The open core, throat-less, down draft gasifier performance in terms of fuel consumption rate, calorific value of producer gas and gasification efficiency was reported by Bhoi *et al.* (2006).

MATERIALS AND METHODS

To assess the feed stock behaviour during thermo chemical conversion, proximate and ultimate compositions were determined. The proximate analysis was done to determine the fixed carbon, volatile matter and ash content of the material. ASTM standards D3172-73 (ASTM, 1977) through D3173-75 and modified procedure for volatiles were used (Sirisomboon, 1991).

The temperature profile of the gasifier was measured using chromel-alumel thermocouples at 4 different locations i.e. 20, 120, 320 and 720 mm from the grate. The digital temperature indicator was used to measure the temperature inside the gasifier. The flame temperature of the gas burning in the burner was measured using thermocouple with temperature indicator.

i. Water boiling and evaporation test

The water-boiling test was performed to estimate the time taken for boiling under fixed rate of charging of the fuel. The standard "water boiling and Evaporation Test" procedure was followed for determining the thermal efficiency of gasifier.

ii. Thermal capacity

The thermal capacity of gasifier was calculated as, using following formula

Thermal capacity, kW

$$= (F \times CV \times \eta) / (860 \times 100)$$

Where,

F= Quantity of fuel burnt, kg/h
CV= Calorific value of fuel, kCal/kg,
η= Gasifier efficiency

iii. Mass and energy balance

The mass balance was calculated for the best operating condition and closure was worked out to assess the gasifier performance.

Energy balance was arrived at by considering the energy content of the feedstock and energy in the output gas, char, ash along with heat loss from the gasifier reactor.

RESULTS AND DISCUSSION

i. Properties and Stoichiometric air requirement of feedstock

The properties, calorific value and Stoichiometric air requirements of feedstocks are presented in Table 1.

The bulk density was found maximum of 470 kg m^{-1} for Casuarina and minimum of 360 kg m^{-3} for Acacia. The fixed carbon content and volatile matter were maximum at 18 and 81% for silver wood chips followed by 17.85 and 80.25% for Casuarina and minimum of 15.9 and 67.85% for Acacia. Calorific value was found maximum for silver wood chips (17.81 MJ kg^{-1}) followed by Casurina (16.86 MJ kg^{-1}) and minimum of 15.53 MJ kg^{-1} for eucalyptus.

In the case of eucalyptus, stoichometeric air requirement was maximum of 6.2 kg/kg of fuel and minimum of 4.56 of Acacia. The total product of combustion of eucalyptus was found to be maximum of 7.287 kg/kg of fuel and minimum of 5.551 kg/kg of Silver wood chips.

ii. Performance evaluation of gasifier

Silverwood chips having more fixed carbon content of 18%. Hence, the gasifier was tested with silverwood chips for determining the performance. Parameters related to the gasifier *viz.*, the temperature at predetermined locations and flame temperature were taken.

The temperature profiles set up across the reactor in 10 kg trial with silver wood chips as feed material is shown in Figure 1.

Temperature gradually established up to a maximum of 923°C near the grate. Temperature as high as 550°C was reached in duration of 10 minutes near the grate and the gas temperature was 360°C (Figure 2). The temperature profile was found to fluctuate widely at different height. The flame temperature measured at the exit of burner was found to range from 360 to 603°C. Smoke temperature measured at the opening of chimney was found to be ranging from 136 to 156°C and it indicates that all the heat generated was utilized. Inlet air temperature was found to be in the range of 30.5 to 32.2°C.

iii. Calculation of overall efficiency of gasifier by water boiling experiment

To estimate the overall efficiency of the gasifier-burner system it is customary to carry out a water-boiling test as stipulated by BIS for thermally efficient wood burning stoves. The details of the calculations are furnished below.

Calculations

Overall Thermal efficiency of the system was calculated as follows

Initial mass of water taken=30kg
Mass of vessel, lid and stirrer =3kg
Calorific value of biomass=4061 kCal/kg
Kerosence consumed=0.2kg
Kerosence calorific value =9122 kCal/kg
Duration of trial =1h
Initial temperature of water =25.5°C,
Final temperature of water =99.5°C;
Final mass of water =19.8 kg
Mass of water evaporated=10.2 kg
Mass of fuel consumed=10 kg
Specific heat of Al =0.21 kCal/kg k
Specific heat of water =1 kCal/kg
Latent heat of water =540 kCal/kg
Sensible heat of water = 2220 kCal
Sensible heat of vessel =46.62 kCal
Latent heat of water =5508 kCal
Heat utilized= Sensible heat of water+ Sensible heat of vessel + Latent heat of water

Heat utilized = 7774.62 kCal
Heat produced= Heat produced by kerosence + Heat produced by fuel

Heat produced by kerosence =4561 kCal
Heat produced wood chips=40610 kCal
Heat produced =45171 kCal **Overall Thermal efficiency** (η) =

(Heat Utilized/Heat Produced)x 100

= (7774.62/45171) x 100 = 17.21%

iv. Thermal Capacity of the gasifier

The thermal capacity of the gasifier is a measurement of the total useful energy produced during one hour by fuel sample. It was calculated as follows:

Assumed the efficiency of burner is 60%, then the efficiency of the gasifier (η) = 17.21/0.60 = 28.68% = 29% (approx)

Thermal capacity = 13.69 kW.

Thermal output of the gasifier =11,775 kCal/h

The overall efficiency was found to be 17.21% (by water boiling test) and the output of the gasifier was worked out to be 11, 775 kCal h^{-1} (thermal) and the power rating was worked out to be nearly 14 kW.

v. Mass and energy balance

A material and energy balance was calculated in order to track the material flow and its energy value through input and output.

a. Mass balance

Feeding rate = 10 kg h^1

Air consumption = air flow rate, $m^3\ h^{-1}$ x density of air, kg m^{-3}

The air flow rate corresponding to maximum heat output (η=0.3) was selected for calculation

= 12.67 x 1.293 = 16.38 kg h^{-1}

Total mass input = 10+16.38 = 26.38 kg/h

Mass output

G- Gas output = 22 $m^3\ h^{-1}$
η_{g-} Density of producer gas = 1.16 kg m^{-3}
Gas output = 22 x 1.16 = 25.52 kg h^{-1}
Total char output = 1.4 kg
Time of operation = 2.5 h
Char output = 1.4 kg
Total ash output = 0.2 kg
Time of operation= 2.5 h
Ash output = 0.08 kg h^{-1}
Total mass output = 25.52 kg h^{-1}

Mass closure, % = $\frac{Mass\ output Mass\ output}{Mass\ input\ \ Mass\ input}$ **x 100**

= $\frac{25.52\ 25.52}{26.38\ 26.38}$ x 100 = 97%

This mass closure does not take into account the tar and water produced during gasification as no measurement method was available to observe them. This is the reason for not getting 100% closure.

b. Energy balance

An energy balance equates the energy entering and leaving the gasifier. Energy balance was calculated as per procedure adopted by Coovattanachai (1989).

Energy input

The energy input (Q_i) to the gasifier is obtained by multiplying the heating value of feedstock by the feeding rate.

Energy input (Q_i) = F x CV

Where,

F- Feed rate= 10 kg h^{-1}
CV- Calorific value of feed= 17 MJ kg^{-1}
Energy input = 10 x 17 = 170 MJ h^{-1}

Energy output

The energy output (Q_o) consists of several components as outlined below:

(i) Gas energy output (Q_g) = G x CV

where,

G- Gas production rate = 22 $m^3\ h^{-1}$
CV – Gas calorific value = 4.4 MJ m^{-3}
Gas energy output = 96.8 MJ h^{-1}

(ii) Sensible heat in gas

= G x η_g x $C_{p\ gas}$ x dt_{gas}
where,

$\eta_{g\ -}$ Density of producer gas = 1.16 kg m^{-3}
$C_{p\ gas}$ – specific heat of gas = 1.41 x 10^{-3} MJ $kg^{-1}\ {}^oC^{-1}$
dt_{gas}- gas temperature difference with ambient, °C
Gas temperature= 585°C Ambient temperature = 30°C
Sensible heat in gas= 16.14 MJ h^{-1}

(iii) Energy output in char

= W_c x H_c
where,

W_c – Weight of char produced = 0.62 kg h^{-1}

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H_c - Heating value of char = 29.31 MJ kg^{-1}

Energy output in char = 18.76 MJ h^{-1}

iv) Sensible heat in char = $W_c \times C_{p\,char} \times dt_{char}$
where,

$C_{p\,char}$ - Specific heat of char = 0.312 x 4.1868 x 10^{-3}, MJ kg^{-1} $^oC^{-1}$

dt_{char} – char temperature difference with ambient, °C
Temperature of char = 400°C
Sensible heat in char = 0.309 MJ h^{-1}

(v) Sensible heat in ash = $W_a \times C_{p\,ash} \times dt_{ash}$
where,

W_a – weight of ash produced = 0.8 kg h^{-1}
$C_{p\,ash}$ - Specific heat of ash = 0.25 x 4.1868 x 10^{-3}, MJ kg^{-1} $^oC^{-1}$
dt_{ash} – ash temperature difference with ambient, °C
Temperature of ash = 400°C
Sensible heat in ash = 0.03 MJ h^{-1}

(vi)Energy output in tar and water are negligible
(vii) Heat losses from the gasifier by convection and radiation
The heat losses (Q_L) were calculated from the equation

$$Q_L = hA (T_r - T_a) + E_g \eta A_g (T_r^4 - T_a^4), \text{ MJ } h^{-1}$$
where,

h- convective heat transfer coefficient = 6.96 kCal m^{-2} h^{-1} $^oC^{-1}$ (Coovattannachi, 1989)
A_g - Surface area of the gasifier = $\pi d_i H_r$, m^2
d_i - Inner diameter of the reactor = 0.30 m
E_g – Emissivity of the gasifier = 0.049
η – Stefan- Boltzmann constant = 5.669 x 10^{-8} W m^{-2} K^{-4}
T_r - Average surface temperature of the reactor = 318 K
T_a - Ambient temperature = 303 K
Q_L = 102. 40 kCal h^{-1} = 0.428 MJ h^{-1}
Total energy output = 96.8 + 16.14 + 18.75 + 0.309 + 0.428 = 132.43 MJ h^{-1}

$$\text{Energy closure} = \frac{\text{Output energy Output energy}}{\text{Input enery Input enery}} \times 100$$

$$= \frac{132.43\ 132.43}{170\ \ 170} \times 100 = 77.9\ \% = 78\%$$

Thus the energy closure for the gasifier was found to be around 78% which was a little bit low because of loss of energy through chimney could not be measured due to lack of facility. The balance of 22% in energy closure was due to energy loss through chimney and other unaccounted losses.

CONCLUSION
The overall efficiency was found to be 17.21% and the thermal output of the gasifier was worked out to be 11, 775 kCal h^{-1} and the power rating was worked out to be nearly 14 kW. The mass closure and energy closure were found to be 97 and 78% respectively.

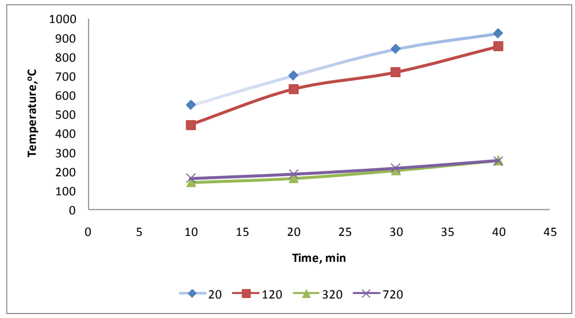

Figure 1. Reactor temperature distribution at different height from grate

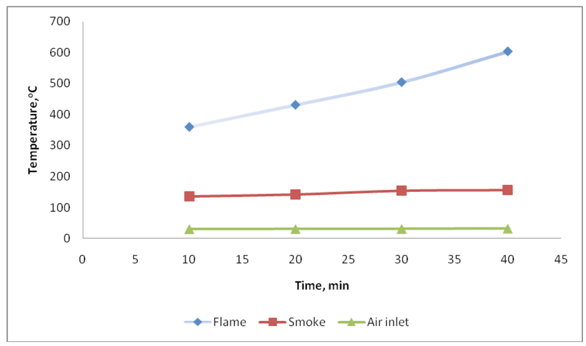

Figure 2. Flame, smoke and Air inlet temperature distribution

Table 1. Properties, Stoichometric air requirement and product of combustion of feedstocks

Biomass	Moisture content, % (w.b.)	Bulk density, kg/ m^3	True density, kg/m^3	Proximate composition, %			**Calorific value, MJ kg^{-1}**	Stoichometric air requirement, kg/ kg of fuel	Product of combustion/kg of fuel
				Fixed carbon	Volatile matter	Ash content			
Silver wood chip	8.3	428	842	18.00	81.00	1.00	17.81	5.81	6.740
Casuarina	7.01	470	780	17.85	76.01	2.63	16.86	6.06	7.012
Eucalyptus	8.79	365	710	16.72	80.25	0.78	15.53	6.20	7.287
Acacia	7.95	360	690	15.90	67.85	16.72	15.58	4.56	5.551

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