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Comparative studies of gasification potential of agro-waste with wood and their characterization

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Abstract. In this work, an experimental study of the gasification on wood was carried out in downdraft type fixed bed Gasifier attached with 10 kW duel fuel diesel engine. The main objective of the study was to use wood as the biomass fuel for downdraft Gasifier and to evaluate the operating parameter of gasifier unit to predict its performance in terms of gas yield and cold gas efficiency. The influence of different biomass on fuel consumption rate, gas yield and cold gas efficiency was studied. Composition of producer gas was also detected for measuring the lower heating value of producer gas to select the feed stock so that optimum performance in the existing gasifier unit can be achieved. Under the experimental conditions, Lower heating value, of producer gas, cold gas efficiency and gas yields, using wood as a feed stock, are 4.85 MJ/m^3, 46.57% and 0.519 m^3/kg.

Keywords: gasification; syngas; biomass; agrowaste; filtration; design parameters; diesel blending

1. Introduction

Gasification is the one of the important biomass conversion technology with internal combustion engine which is used for electric power generation. Biomass gasification in gasifier is done with controlled amount of air. During gasification the amount of air supplied in such a way that fuel air ratio is below the stoichiometric fuel air ratio. Due to this a relatively small parts of biomass burns and heat generated to control a series of thermo chemical processes. This results in generation of mixture of gas as final product known as producer gas or syngas. Yang *et al*. (2004) concluded that use of biomass and solid municipal wastes energy, fixed bed gasification is the most common technology. During the biomass gasification process, this biomass undergoes different processes. In a first step, biomass is dried up. Then, due to increase of the temperature, pyrolysis occurs and the lignin and cellulose are decomposed into volatile molecules such as hydrocarbons, hydrogen, carbon monoxide and water. Finally, the remaining solid fraction, which is called char, is oxidized in the presence of excess oxygen is known as combustion. When combustion is done in presence of less oxygen than the stoichiometric, gasification of char is completed by the pyrolysis and oxidation gases. In this process chemical reduction of hydrogen, carbon dioxide and water done by char. The inorganic components in the biomass are non- volatile and remain in solid state as ash. However, at

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present, generating energy from biomass is expensive due to technological limits related to lower conversion efficiency (2005). Zainal *et al*. (2002) conducted experimental study on a downdraft gasifier use in wood chip and charcoal varied the equivalence ratio from 0.259 to 0.46. It is found that the calorific value increases with equivalence ratio and reaches a peak value of 0.388, for which the calorific value is reported to be 5.34 MJ/Nm^3. It is also observed that complete conversion of carbon to gaseous fuel has not taken place even for the optimum equivalence ratio. Dogur *et al*. (2002) carried out gasification studies using hazelnut shell as a biomass. Jayah *et al*. (2003) investigated the gasification of chips of rubber wood of varying moisture content (12.5-18.5 %) and chip size (3.3-5.5 cm) in an 80 kW downdraft throated gasifier, which was double walled with an air gap in between. Titiloye *et al*. (2006) carried out thermo chemical characterization of agricultural biomass wastes from West Africa to use of their as feed stock in thermo chemical conversion processes. It is found that rice straw has high ash content of 45.76 wt % compared to other. The level of nitrogen and sulphur in all the samples were very low. Rice husk was found to have the highest lignin contents while corn cob low lignin contents indicate a potential feedstock source for quality bio-oil production using thermo chemical process. Lalta Prasad *et al*. (2014) a combined kinetic investigation of the pyrolysis of the de-oiled cake at various heating rates along with gasification of pelletized biomass was carried out in the present work. It is found that the thermal decomposition of de-oiled cake occurs in three stages. Most of the material decomposed (w60%) in stage-II between 166℃ and 480℃ due to the decomposition of lignin at temperatures above 480℃. Kinetic tests on pyrolysis of Pongamia de-oiled cake were carried out using a thermo gravimetric analysis technique at the heating rate of 10, 15, 20, 30℃/min. The thermal decomposition of de-oiled cake occurs in three stages, in stage-I moisture evolution and devolatization occurs and in stage-II & III pyrolysis take place. The activation energies are obtained in the range of 68.8-177.9 kJ/mol and 41.3-161.8 kJ/mol by differential method and FWO methods respectively. Krushna Patil *et al*. (2011) designed a downdraft gasifier with unique biomass pyrolysis and tar cracking mechanism at Oklahoma State University. This design has an internal separate combustion section where turbulent, swirling high-temperature combustion flows are generated. It is found that maximum tar cracking temperatures were above 1100℃ and average volumetric concentration of major combustible components in the product gas were 22% CO and 11% H_2. Hot and cold gas efficiencies were 72% and 66%, respectively. Chao *et al*. (2012) carried out gasification of non-woody biomass like corn straw, in a downdraft fixed bed gasifier under atmospheric pressure, using air as an oxidizer. The effects of the operating conditions on gasification performance in terms of the temperature profiles of the gasifier, the composition distribution of the producer gas and the release of sulphur and chlorine compounds during gasification of corn straw were investigated. the gasification characteristics were evaluated in terms of low heating value (LHV), gas yield, gasification efficiency and tar concentration in the raw gas. According to the experimental results, operating conditions have great influence on the temperature profiles of the gasifier and the composition distribution of the product gas. During the gasification of non-woody biomass, the variations of the concentration of sulphur and chlorine compounds in gaseous and ash are not a monotonic tread under different operating conditions. Besides, over the ranges of the equivalence ratio(ER) examined, higher or lower ER both degraded the quality of gas and gasification efficiency. If ER is regarded as a function of the combustible species, the optimum value of ER is 0.28-0.32, and the optimal LHV of 5.39 MJ/Nm^3, gas yield of 2.86 Nm^3/kg, gasification efficiency of 73.61% and tar concentration of 4617 mg/Nm^3 is obtained at different ER.

Fig. 1 Gasifier unit

2. Experimental setup and specification

Fig. 1 presents an appearance of a 10 kw fixed bed downdraft Gasifier built by URJA Pvt. Limited for test at “Centre For Energy And Resources Development” in department of Mechanical Engineering, IIT BHU. The Gasifier is used for the production of producer gas, from wood blocks and is coupled with a double cylinder internal combustion engine shown in Fig. 2. The Gasifier is made of carbon steel and its total height, considering the biomass feeding Hooper and the ash discharge system, is about 2.28 m. The internal and external diameters of the reactor are 70 cm and 72 cm respectively. A thermocouple is installed at outlet of the reactor to measure the temperature of producer gas.

The air is supply to the reactor by two nozzle, due to which partial combustion of biomass take place, heat is released to maintain the drying and pyrolysis process. The drying section is located in the Gasifier top part, where distillation process of lighter compounds of the biomass take place. The pyrolysis zone which is located just below the drying zone where organic compounds of the biomass volatilize and char is produced, which is gasified later in the process.

Producer gas leaves the reactor through the exit in its lower part. The grate supporting the fuel bed is moved to and fro at regular time intervals to discharge ashes. The particulate matters and tar in producer gas is separated in cyclone separator and venture respectively. After passing through the cyclone separator producer gas is directed into the filter section which consists of three chambers, rice husk, saw dust and cotton fabric respectively.

Gasifier is coupled to two cylinder diesel engine. The engine alternation includes arrangement of separate fuel measuring unit, which is shown in Fig. 4 and application of pipe of producer gas and air filter as shown in Fig. 2. For measuring the flow rate of the producer gas air box method is utilized as shown in Fig. 3

2.1 Gasifier unit

Table 1 Parts of gasifier

1) Hopper	17) Blower band
2) Hopper balance	18) Blower
3) Reactor first	19) Cyclone Separator
4) Firing nozzle	20) Cyclone drain pipe
5) Stair for feeding biomass	21) Catch pot
6) Reactor second	22) Fire valve
7) Grid	23) Chimney
8) Water seal	24) Gas testing point
9) Water Suction pump	25) Three way gas filter
10) Thermocouple	26) Dry filter using rice husk
11) Down draft	27) Dry filter using wood dust
12) Up draft or Pack Column	28) Cotton filter
13) Shower wash control valve	29) Manometer
14) Steam jet control valve	30) Moisture drain valve
15) Venturi	31) Producer gas outlet
16) Drain box	32) Tar collecting pot
16 A) Butterfly valve or Gas regulator	33) Water tank

2.2 Electric power generation unit

Table 2 some part of engine

1) Producer gas input to generator	3) Diesel tank
2) Air filter	4) Alternator

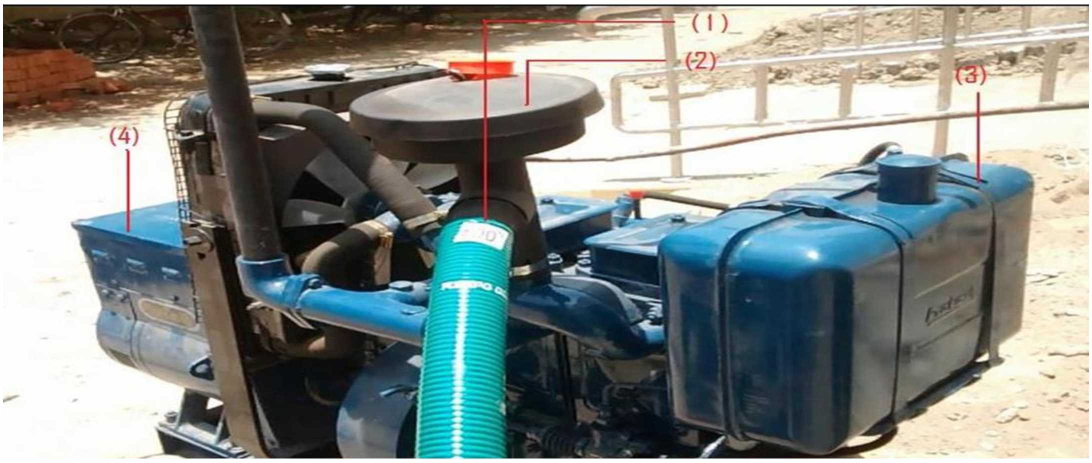

Fig. 2 Dual fuel engine

2.3 Gas flow measuring unit

Fig. 3 Air box

2.4 Fuel consumption finding unit

Table 3 Fuel consumption finding unit

1) Diesel tank	4) Burette pipe
2) Burette	5) Diesel tap
3) Diesel pipe	6) Burette tap

Fig. 4 Fuel feed setup

2.5 Material

In this experiment wood, mixture of cow dung, saw dust is used as feed stock for gasifier. Calorific value of these, biomass material is calculated with the help of bomb calorimeter. Cutting of wood is done by hand circular saw in lab and preparation of cow dunk as feed stock is completed.

2.6 Working principle

The experimental setup used in this work mainly utilizes wood biomass to produce syngas. In this wood is feed in reactor by Hooper. After this pump and blower have started respectively, and fire is setup in nozzle and atmospheric air flows in second reactor due to suction created by blower. Partial oxidation of wood is taking place for the formation of syngas thermocouple read the temperature of gas before entering in the pack column where gas is moving upward and tar is filtered by water flowing downward direction. Blower suck the gas after filtration of tar in venture and send it into cyclone separator where solid dust and ash practical thrown away due to centrifugal action .At catch point quality of gas is checked to burn the gas before entering into three way filter. After filtration in rice husk, saw dust and cotton cloth gas is sent to dual fuel diesel engine from which a generator is coupled to produce electric power. A pump and motor having power of 5 HP each consumed power for their operation in gasifier unit. Pump is used to recalculate water from water tank to remove tar and other impurity in syngas while motor is used to run the blower.

2.7 Measurement of fuel consumption

To measure fuel consumption there is a modification made in fuel supply system. For this a burette and tank arranging with control valve is used for measuring volume of diesel required at different loading condition in a specified time. Using electric bulb circuit and electric heater having different kilo-watt rating wire are used to vary the load on the generator. Calculating fuel consumption rate on different load using syngas with diesel is measured and compared with fuel consumption required when engine is operating without using of producer gas to calculate the saving of diesel. Also different temperature and pressure of syngas is measured by thermocouple and simple manometer to know the effect of this parameter on performance of engine.

2.8 Measurement of gas and air flow rate

Gas flow rate is measured by digital anemometer and air box method while air flow rate is measured by anemometer only. In air box method deflection fluid in manometer is measured to measure the velocity of gas flow after calculating density of gas by assuming ideal gas and diameter of throat, mass flow rate of gas is evaluated. Anemometer read velocity and temperature of gas directly and these values are used to determine the mass flow rate of air.

3. Performance study

3.1 Gas flow rate by air box

$$\upsilon_g = \sqrt{\frac{\nabla_p}{\rho_g g}} \tag{1}$$

$$\nabla p = \rho_w \times g \times h_w \tag{2}$$

Where:

ρ_w=density of water (1000 kg/m^3)
h_w= deflection of water in manometer
g= acceleration due to gravity (9.81m^2/s)

Table 4 Air box measurements

Biomass	h_w (mm)	υ_g (m/s)
Eucalyptus	2.5	1.573
Wood	2.6	1.622
Cow dunk	2.8	1.605

3.2 Density of producer gas

$$\rho_g = \frac{p}{TRg} \tag{3}$$

Where:

p= atmospheric pressure =101,325 N/m^2
R_g= gas constant for producer gas = 8314 J/kmol-K
T= temperature of producer gas outlet of filter (315K)

3.3 Gas flow rate

$$m_g=\rho_g \times \pi \times d^2 \times \upsilon_g \times 0.25 \text{ (kg/s)} \tag{4}$$

$$\rho_g = \frac{p}{R_g \times T_g} \tag{5}$$

d=diameter of air nozzle (3.81 cm)

Table 5 Mass flow rate of producer gas

Biomass	υ_g (m/s)	ρ_g (kg/m^3)	R_g (kj/kg-K)	m_g (kg/hr)	m_{g1} (kg/hr)
Eucalyptus	0.76	1.0096	0.3186	3.147	6.514
Wood	0.72	0.9882	0.3255	2.918	6.574
Cow dunk	0.78	1.086	0.2960	3.474	7.152

Table 6 Calorific values of constituents

Compound	*CV* (MJ/m^3)	Biomass	Q_{CV} (MJ/m^3)
CO_2	0	Eucalyptus	4.35
CO	12.71	Wood	4.85
H_2	12.78	Cow dunk	3.82
N_2	0		
CH_4	39.76		

3.4 Calorific value of producer gas

$$Q_{CV}=x_2CVCO+x_3CVH_2+x_5CVCH_4 \tag{6}$$

3.5 Calorific value of biomass fuel

In this experiment, calorific value of biomass is determined by using bomb calorimeter.

$$CV = \frac{m_w \times C_p \times \Delta T - 4.18 \times m_T - 0.335 \times m}{m_f} \quad \frac{kcal}{gm} \tag{7}$$

Where:

m_w=mass of water = 2 kg

C_p=specific heat capacity of water = $\frac{1kcal}{kg \times \circ C}$

ΔT=temperature rise of water in ℃

m_T=mass of thread in gm

m=mass of wire in gm

m_f=mass of fuel in gm

3.6 Dry gas yield

This is one of the important parameter, usually signifies the gasifier performance. It is defined as the volume of producer gas at standard condition, per kg mass of feed stock supplied to the system.

$$gas\ yield\ (\frac{m^3}{kg})\ (y) = \frac{gas\ flow\,rate(\upsilon) \times gas\ production\ time(t)}{mass\ input\ of\ feed\ stock\,(m_{fe})} \tag{8}$$

Table 7 calorific value of different biomass

Biomass	m_T	m	m_f	ΔT	*CV* (MJ/kg)
Wood	0.0210	0.016	1.135	2.4	17.33
Eucalyptus	0.0212	0.018	1.036	2	15.75
Cow dunk	0.0214	0.017	1.037	1.52	11.87
Rice husk	0.0211	0.015	1.03	1.48	11.63

Table 8 Gas yield of biomass

Biomass	υ_1 (m^3/hr)	υ_2 (m^3/hr)	t (hr)	m_{fe} (kg)	y_1 (m^3/kg)	y_2 (m^3/kg)
Eucalyptus	3.117	6.452	2	25	0.249	0.523
Wood	2.953	6.653	2.5	32	0.230	0.519
Cow dunk	3.199	6.586	1.5	20	0.239	0.494

Table 9 Cold gas efficiency (45% to 67%)

Biomass	LHV_{Gas}	V_{Gas}	LHV_{Fuel}	m_{Fuel}	Ή
Eucalyptus	4.35	6.452	15.75	4	44.55
Wood	4.85	6.653	17.33	4	46.54
Cow dunk	3.82	6.586	11.87	6	35.32

3.7 Cold gas efficiency

It is defined as the ratio of total energy in producer gas and total energy supply by fuel.

$$\text{Efficiency } (\acute{\eta}) = \frac{LHV_{Gas} \times V_{Gas}}{LHV_{Fuel} \times m_{Fuel}} \tag{9}$$

Where:

LHV_{Gas} = lower heating value of syngas (MJ/m^3)
V_{Gas}= volume flow rate of syngas (m^3/hr)
LHV_{Fuel}= lower heating value of biomass (MJ/kg)
m_{Fuel}= mass flow rate of fuel (kg/hr)

3.8 Calculation for electric generator

Density of diesel (ρ) = 850 kg/m^3 or 0.00085 kg/ml
Volume of diesel =V (ml)
Time to consume 5 ml diesel = t (sec)

$$\text{Mass of diesel used in } T \text{ sec} = \frac{\rho \times V \times 3600}{t} \text{ kg/hr} \tag{10}$$

Diesel used without syngas = m_1 kg/hr
Diesel used with syngas = m_2 kg/hr
Load on generator =P (kW)
Average specific fuel consumption without syngas = m_3 kg/kW-hr
Average specific fuel consumption with syngas = m_4 kg/kW-hr
Temperature of syngas read by thermocouple =T (℃)

Table 10 Specific fuel consumption

Load	1 kW	2 kW	3 kW	4 kW	5 kW
s.f.c_1	0.7383	0.4068	0.2951	0.2490	0.2190
s.f.c_2	0.3670	0.1965	0.1421	0.1254	0.1052

Table 11 At half throat opening

Load	1 kW	2 kW	3 kW	4 kW	5 kW
s.f.c_1	0.7383	0.4068	0.2951	0.2490	0.2190
s.f.c_3	0.6188	0.1777	0.1261	0.1303	0.1382
Temperature(℃)	30-34	39-43	49-50	53	53

4. Results and discussion

The aim of the present experiment was to find out the performance of the Gasifier system in terms of gasifier efficiency, calorific value of producer gas, gas yield, fuel consumption rate and effect of temperature on specific fuel consumption is observed.

4.1 Fuel consumption

From Table 1 it is observed that as time increases consumption of diesel (m_2) decreases due to formation of high quality syngas .this shows that quality of gas increases as time increases Up to 2 Kw load s.f.c_2 decrease more rapidly as compare to s.f.c_1 (Fig. 6) .It's show that producer gas used with diesel having more influence to produce power Up to 2 kW load and beyond 3.5 kW load s.f.c_3 is less compare to s.f.c_2 so to run the Gasifier unit at half throat valve opening in this load range is economical (Fig. 6) .this is due to half opening of valve the amount of tar going to engine is less.

4.2 Effect of gas temperature

Decrement in s.f.c_3 with increase in temperature as shown in Fig. 7. This result shows that temperature of the producer gas played a great role on the producer gas composition. The lower heating value (LHV) of the gas increases as reduction temperature increases. A gas of high H_2 and CO concentration is obtained.

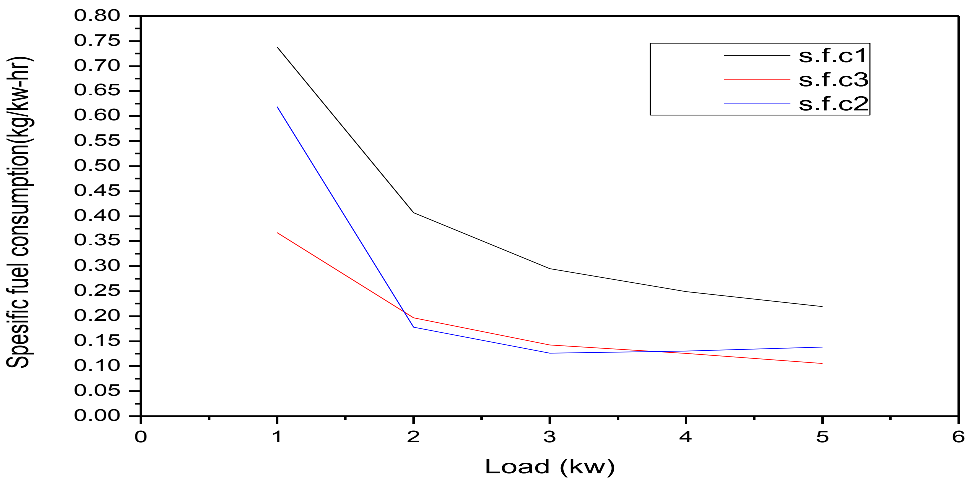

Fig. 5 Variation of sfc with load

Table 12 Parameter of producer gas

Biomass	Composition (Volume %)			Q_{CV} (MJ/m^3)	*CV* (MJ/kg)	y_2 (m^3/kg)	*Ή*
	H_2	CO	CH_4				
Eucalyptus	14.45	16.38	1.07	4.35	17.39	0.523	43.34
Wood	15.54	18.4	1.34	4.85	16.32	0.519	46.57
Cow dunk	11.36	15.45	1.03	3.82	11.87	0.494	35.32

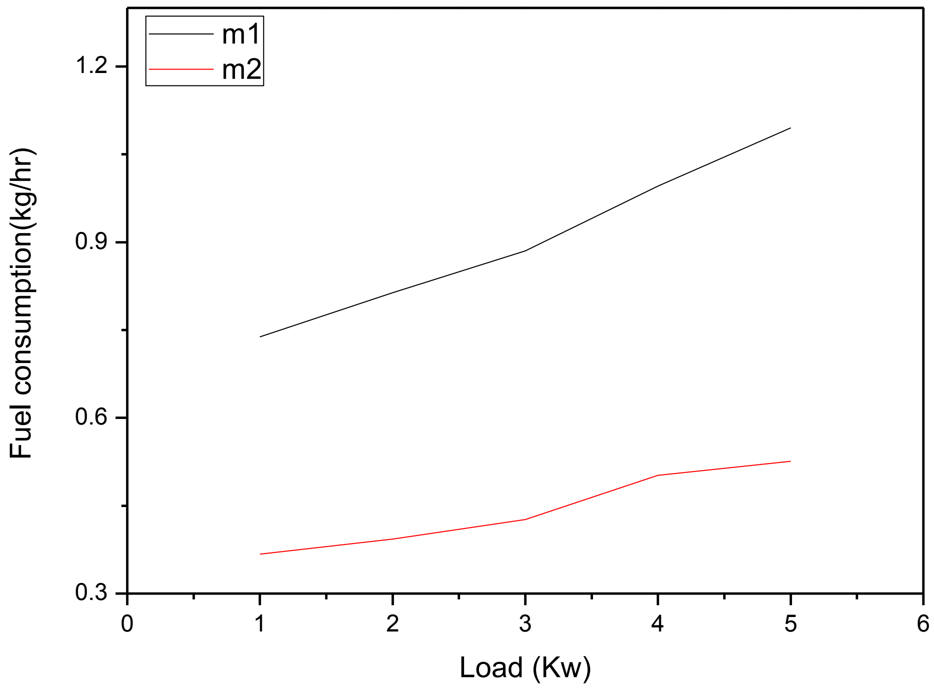

Fig. 6 Variation of fuel consumption with load

4.3 Calorific value

The variation of producer gas lower heating value for different biomass is given in Table 12. The highest lower heating value of 4.85 MJ/m^3 is observed for wood and least 3.82 MJ/m^3 for cow dunk. The results are in agreement with the published findings from other biomass downdraft gasification studies .The calorific value of other constituent like N_2 and O_2 are zero as listed in Table 6. Though CH_4 has higher calorific value (39.76 MJ/m^3), among other constituent of producer gas but have small contribution in determination of lower heating value of producer gas due to small volumetric percentage of CH_4.

The volumetric percentage of the constituent of major producer gas has been detected by the gas analyzer as shown in Table 12. These results are comparable with the results obtained from other biomass gasification studies. It was observed that at initial period of gasification concentration level of CO_2 high in producer gas. After some time about 1 hour, when Distribution of temperature in reactor become stable than concentration of CO level start increasing, and decrease the concentration level of CO_2.

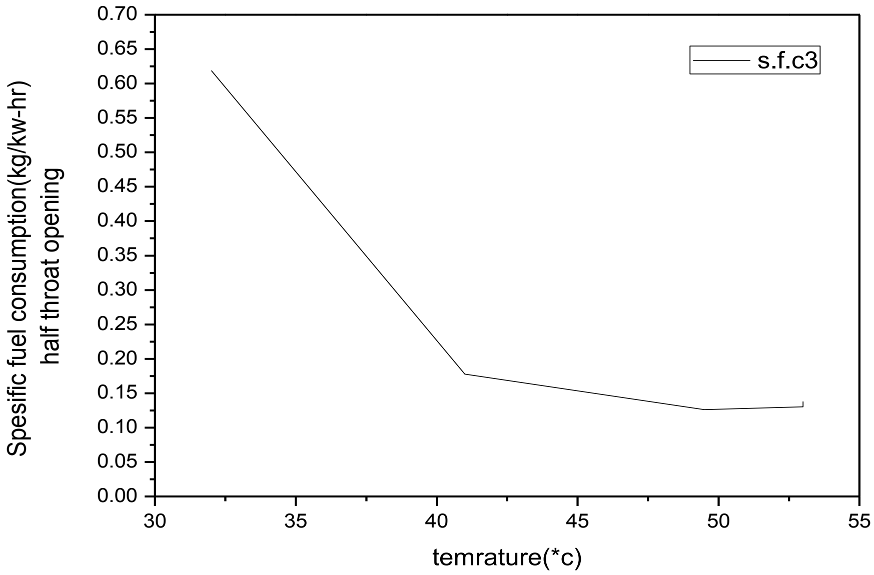

Fig. 7 Variation of sfc with temperature

4.4 The dry gas yield

The dry gas yield for different biomass is listed in Table 12. It is maximum for eucalyptus wood (0.523 m^3/kg) and minimum for cow dung (0.494 m^3/kg). In present experimental work, actual mass input of feed stock was taken to evaluate gas yield. Cow dunk has least value of dry gas yield as reduction of practical size results increase in density of the fuel and due to this, an increasing mass input Ryu *et al*. (2006).

4.5 Gas efficiency

The variation of gas efficiency for different biomass is given in Table 12. Wood has higher efficiency (46.57%). This is due to large value of its lower heating value and also has high volume flow rate as shown in Table 15. The results are in agreement with Cold gas efficiency (45% to 67%) obtained in studies of gasification in downdraft gasifier Patil *et al*. (2011).

5. Conclusions

The effect of different biomass on the performance of gasifier was experimentally investigated in 10kw downdraft gasifier. The major conclusions established from the experimental study are as follows:

(1) The highest lower heating value of 4.85 MJ/m^3 is observed for wood and least 3.82 MJ/m^3 for cow dunk. Though CH_4 has higher calorific value (39.76 MJ/m^3), among other constituent of producer gas but have small contribution in determination of lower heating value of producer gas due to small volumetric percentage of CH_4.

(2) It was observed that at initial period of gasification concentration level of CO_2 high in

producer gas. After some time about 1 hour, when Distribution of temperature in reactor become stable than concentration of CO level start increasing, and decrease the concentration level of $CO_{2.}$

(3) For cow dung, dry gas yield is least due to increase in solid mass input, as particle size decrease, density increases.

(4) Wood has higher efficiency (46.57%). This is due to large value of, it's lower heating value and also has high volume flow rate.

(5) Results obtained from experiment show that operating parameter of wood are best suited for this gasifier unit.

(6) At low reduction zone temperature formation of tar is more which degrade quality of syngas and reduce concentration of H_2 and CO in syngas also lead the problem of starting the engine due to sticking action of piston and cylinder.

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CC

Nomenclature

HHV	Higher heating value
LHV	Lower heating value
MC	Moisture content
VCM	Volatile combustible matter
FC	Fixed carbon
∇p	Pressure difference
h_w	Deflection of water in manometer
ρ_w	Density of water
Q_{CV}	Calorific value of producer gas
CV	Calorific value of biomass
y	Dry gas yield
$\acute{\eta}$	Cold gas efficiency