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Development and evaluation of updraft biomass gasifier for thermal application

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ABSTRACT

Energy input for technological, industrial, social and economical development of a nation. Gasification means the transformation of solid fuels into combustible gases in presence of an oxygen carrier (air, O_2, H_2O, CO_2) at high temperatures. The gasification process occurs at temperatures between 600-1000 °C and decomposes the complex hydrocarbons of wood. The gasification process, with high temperature, produces ash and char, tars, methane, charcoal and other hydrocarbons. Well-designed updraft gasifier is simplest type of gasifier. A biomass up draft gasifier was specially developed to meet the heat requirements of Indian kitchens as well as industrial applications. The physical properties and proximate analysis of maize cob and biomass briquettes was determined. The combustion zone temperature is vary in between 955 to 974.00 and 731 to 820,40 °C at four fuel consumption rate i.e. 4,6,8 and 10 kg/h using maize cob and biomass briquettes as a fuel in the system respectively. The up draft biomass gasifier efficiency is vary in between 68.06 to 75.63 per cent and 65.38 to 72.65 per cent at four fuel, consumption rate i.e. 4,6,8 and 10 kg/h using maize cob and biomass briquettes as a fuel in the system respectively.

Introduction

One of the most important challenges that the world has been continuing to meet in the 21st century is the ever increasing energy needs of its citizen. Along with the need to find a renewable long term energy source, there is a need to find a more environmental friendly energy source. One of the promising solutions for the future world energy problem is biomass crop residues, animal wastes, etc. Current biofuels are actually based on traditional food crops such as maize, rapeseed or sunflower. A wide range of energy and global green house gas budgets has been reported for them, although they are generally favourable compared with diesel (Hill *et. al.*, 2006).

Biomass is attracting great attention over the world as a source of renewable energy as well as an alternative to fossil fuels. Biomass resources supply over 14% of the world's energy needs (Demirbas and Demirbas, 2003; McKendry, 2002a). The attraction for biomass has been premised due to ease of its production, sustainable supply advantages, and environmental benefits. Several crops are being grown in energy crop farming as feed stocks for first generation biofuels. Biomass contributes a significant share of global primary energy consumption and its importance is likely to increase in future world energy scenarios (Vasudevan *et. al.*, 2005). Biomass can be converted into solid, liquid and gaseous fuel depending on their physical availability. Biomass can be considered as a carbon-neutral fuel, because plants and trees extract carbon-dioxide (CO_2) from the atmosphere and store it while they grew up and when this biomass is used in various application like home, industries for energy production then they release CO_2 to atmosphere and at the same time it is balanced by capturing CO_2 for the growth of plant and trees.

There are three methods to convert biomass material into a useful form of energy, viz. the direct combustion, the biological conversion and the thermochemical conversion (Zainal, 1996). Gasification means the transformation of solid fuels into combustible gases in presence of an oxygen carrier (air, O_2, H_2O, CO_2) at high temperatures. It is a process for converting carbonaceous materials to a combustible or synthetic gas like bio-methane or producer gas (Tavakoli *et. al.*, 2009). Bio-methane can be used like any other fuel, such as natural gas, which is not renewable (Leland *et.al.*, 2001). The gasification process occurs at temperatures between 600-1000 ºC and decomposes the complex hydrocarbons of wood (Rezaiyan and Cheremisinoff, 2005). The gasification process, with high temperature, produces ash and char, tars, methane, charcoal and other hydrocarbons. The corrosive ash elements such as chloride and potassium are removed, allowing clean gas production from otherwise problematic fuels. Conversion of solid biomass into combustible gas has all the advantages associated with using gaseous and liquid fuels. Such advantages include clean combustion, compact burning equipment, high thermal efficiency and a good degree of control. Well designed updraft gasifier is simplest type of gasifier. The air comes in at the bottom and produced producer (syngas) leaves from the top of the gasifier. Near the grate at the bottom combustion reaction occurs, above that reduction reaction occurs. In the upper part of the gasifier heating and pyrolysis of the feedstock occurs as a result of heat transfer by forced convention and radiation from the lower zones. Tars and volatile produce produced during the reaction will leave along with the producer at the top of the gasifier. The major advantages of this type of gasifier are its simplicity, high charcoal burn out and internal heat exchange

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leading to low temperature of exit gas and high equipment efficiency. This gasifier can work with several kind of feedstock ranging from Coal to Biomass. Major drawbacks result from the possibility of "channeling" in the equipment, which can lead to oxygen break-through and dangerous, explosive situations and the necessity to install automatic moving grate. Inlet of coal can be decided based on the type of gasification process selected to be used in this gasifier. However, the smallest biomass up draft gasifier designed so far and available to the user is too large for the kitchen and for applications needing around up to 10 kg of biomass per hour. A biomass up draft gasifier was specially developed to meet the heat requirements of Indian kitchens as well as industrial applications.

Methodology

Physical properties and proximate analysis of different biomass: Available biomass namely maize cob and biomass briquettes considered for combustion-gasification material. The physical properties (i.e. size, bulk and true density) and proximate analysis (i.e. moisture content, volatile matter, ash content & fixed carbon) properties were determined using ASAE [2] and ASTM [3] standard for maize cob and biomass briquettes as fuel used in updraft gasifier. The calorific value of biomass could be measured using advance bomb calorimeter.

Performance evaluation of Updraft gasifier

Updraft Gasifier:

The up draft gasifier is designed at Department of Renewable Energy Engineering, College of Agricultural Engineering & Technology (CAET), Anand Agricultural University, Godhra. The gasifier with single stage of chamber namely, gasifier-gasification chamber. This part is made of a mild steel sheet. It is a batch feeding gasifier system, biomass feeding port is placed on the top of the gasifier chamber to feed the biomass into the gasifier, and it has a fit clamped and isolated cover.Air is supplied with control valve to the gasification chamber at almost atmospheric pressure. Flow of air is passing through a bottom of the grate to provide a good mixing with the gases from the gasifier chamber. An incomplete combustion in the gasification chamber creates a very hot zone which pushes the gases upward and creates a stack effect which creates a vacuum pressure in the gasifier chamber and pulls the air through a controlled air intake in the down side and in to the gasifier chamber to complete the gasification process. The schematic diagram of the experimental setup of the biomass updraft gasifier is shown in Figure 1.

Assuming the gasifier is producing a thermal power of 4-10 kW, and assuming that the efficiency of the gasifier is about 70%, the energy content for wood (12% moisture content), *Cv* 4000 kcal/kg = 16748 MJ/kg, so we can calculate the biomass fuel consumption using Eq. 1:

$$Q' = m_w \times Cv \quad (1)$$

Maize cob and biomass briquettes, mass flow rate will be around m_w = 4-10 kg/hr.

To calculate theoretically the mass flow rate of the producer gas out of the gasification chamber, for heating value per normal cubic meter of about *Cp*= 900- 1000 kcal/kg, from the power balance equation (Eq. 2):

$$Q = m_g \times C_p \quad (2)$$

Fuel Consumption Rate (FCR)

This is the amount of maize cobs and biomass briquettes fuel used in operating the gasifier divided by the operating time. This is computed using the formula,

$$FCR(kg/h) = \left(\frac{\text{Weight of Maize cob or biomass briquettes Fuel Used (kg)}}{\text{Operating Time (h)}} \right)$$

Specific Gasification Rate (SGR)

This is the amount of maize cob and biomass briquettes fuel used per unit time per unit area of the reactor. This is computed using the formula

$$SGR(kg/m^2h) = \left(\frac{\text{Weight of Maize cob or biomass briquettes Fuel Used (kg)}}{\text{Reactor area (m}^2\text{) x Operating Time (hr)}} \right)$$

Reactor diameter

This refers to the size of the reactor in terms of the diameter of the cross-section of the cylinder where biomass briquettes are being burned. This is a function of the amount of the fuel consumed per unit time (FCR) to the specific gasification rate (SGR) of maize cob and biomass briquettes, which is in the range of 110 to 210 kg/m^2-hr or 56 to 130 as revealed by the results of several test on biomass briquettes gasifier. As shown below, the reactor diameter can be computed using the formula,

$$D = \left(\frac{1.27 \times \text{Fuel Consumption Rate (kg/hr)}}{\text{Specific Gasification Rat (kg/m}^2\text{ - hr)}} \right)$$

Height of the Reactor

This refers to the total distance from the top and the bottom end of the reactor. This determines how long would the stove be operated in one loading of fuel. Basically, it is a function of a number of variables such as the required time to operate the gasifier (T), the specific gasification rate (SGR), and the density of maize cob (rrh). As shown below, the height of the reactor can be computed using the formula

$$H = \left(\frac{\text{Specific gasification rate (kg/hr)} \times \text{Time required to maize cob \& biomass briquette (hr)}}{\text{Density of maize cob \& biomass briquette (kg/m}^3\text{)}} \right)$$

Amount of air needed for gasification-air flow rate (FCR)

This refers to the rate of flow of air needed for gasify the fuel. This is very important in determining the size of the fan or of the blower needed for the reactor in gasifying the fuel. This can be simply determined using the rate of consumption of the fuel (FCR) the stoichiometric air of the fuel (SA), density of air (ρ_a) and the recommended equivalent ratio (ε) for gasifying maize cobs and biomass briquettes fuel of 0.3 to 0.5. This obtained using the formula (Belonio, 2005).

$$AFR(m^3/h) = \left(\frac{\text{Equivalent Ratio } (\varepsilon) \times \text{Fuel Consumption Rate (kg/h)} \times \text{Stoichiometric Air of the Fuel (SA)}}{\text{Density of Air } (\rho_a)} \right)$$

Superficial air Velocity (V_s)

This refers to the speed of the air flow in the fuel bed. The velocity of air in the bed of the fuel will cause channel formation which may greatly affect gasification. The diameter of the reactor (D) and the Air flow rate (AFR) determine the superficial velocity of air in the gasifier. This is computed using the formula (Belonio, 2005).

$$V_s = \left(\frac{\text{Air Flow Rate}}{\text{Area of the Reactor}} \right)$$

Combustion zone Rate (CZR)

This is the time required for the combustion zone to move down the reactor. This is computed using the formula (Belonio, 2005).

$$CZR = \left(\frac{\text{Length of the reactor (m)}}{\text{Operating time (h)}} \right)$$

Heat Energy Input (QF)

This is the amount of heat energy available in the fuel. This is computed using the formula (Belonio, 2005).

$$QF = Weightoffu\,elused \times HeatingVal\,ueofFuel$$

Power Input of the biomass gasifier (PI)

This is the amount of energy supplied to the gasifier based on the amount of fuel consumed. This is computed using the formula (Belonio, 2005).

$$PI = FuelConsumptionRate\,(kg/h) \times HeatingVal\,ueofFuel$$

Power output of the biomass gasifier (PO)

This is the amount of energy released by the gasifier. This is computed using the formula (Belonio, 2005).

$$PO = FuelConsumptionRate\,(kg/h) \times HeatingVal\,ueofFuel$$

Biomass gasifier efficiency (η)

In order to determine the thermal performance of biomass gasifier, efficiency of biomass gasifier (η*)* is calculated from Eq. 4:

$$\eta = \left(\frac{\text{Quantity of producer gas produce} \times \text{Density of producer gas} \times \text{Heating value of the Producer gas}}{\text{Fuel consumption rate} \times \text{Calorific value of the fuel used}} \right) \times 100$$

Assume;

1 kg of biomass produced the 2.5 Nm^3/kg producer gas

Density of producer gas = 1.1 kg/Nm^3

Heating value of the producer gas = 900-1000 $kcal/Nm^3$

Results And Discussions

Physical and Proximate Analysis of Maize Cob Biomass and Biomass Briquettes

Table 1 shows the physical and proximate analysis of maize cob and biomass briquettes fuel used in up draft gasifier. The average length and diameter of the maize cobs and biomass briquettes is 35.24, 22.30 mm and 76.30, 65.42 mm respectively. The bulk density and true density were measured for maize cob and biomass briquettes to be 159.25 kg/m^3, 0.39 gm/cc and 595.70 kg/m^3, 0.79 gm/cc respectively. Proximate analysis in terms moisture content, fixed carbon, volatile matter and ash content is determined and results of this analysis are presented below. The values so obtained are nearly in the vicinity to that reported by other researchers (Anonymous (2005) and Vyas *et. al.* (2007)).

The moisture content of the maize cob and biomass briquettes fuel is 12.30 and 10.23 % respectively. The other proximate compositions are given in moisture free basis. It can be seen from the Table 1 that the fixed carbon, volatile matter and ash content were found for maize cob and saw dust briquettes to be 16.42, 81.25 and 2.33 percent and 6.89, 79.80 and 13.31 per cent, respectively.

Table 1 Physical properties and Proximate analysis of maize cob biomass and biomass briquettes

Sr. No.	Property of biomass	Types of fuel	
		Maize cob	Biomass Briquettes
1	Length, (mm)	35.24	76.30
2	Diameter, (mm)	22.30	65.42
3	Bulk Density, kg/m^3	159.25	595.70
4	True Density, gm/cm^3	0.39	0.79
5	Moisture content, (%,w.b.)	12.30	10.23
6	Volatile Matter (, % d.b.)	81.25	79.80
7	Ash Content (%, d.b.)	2.33	13.31
8	Fixed Carbon (%, d.b.)	16.42	6.89
9	Calorific Value, kcal/kg	3636.00	3785.00

Performance evaluation of up draft biomass gasifier for thermal application

The updraft biomass gasifier

The up draft biomass gasifier is the gasifier at Department of Renewable Energy Engineering, College of Agricultural Engineering & Technology (CAET), Anand Agricultural University, Godhra. The up draft biomass gasifier has been developed considering the shredded maize cob (i.e. after collecting the seed from the maize), biomass briquettes and wood (*Prosopis Juliflora* and mixed wood) as feed material used in gasifier.

Table 2 shows the result on diameter of reactor, height of reactor fuel consumption, specific gasification rate, volume of reactor designed and developed for experimentation. Accordingly, the developed biomass combustor system is described in earlier section.

Table 2 Parameter of biomass updraft biomass gasifier for different biomass

Sr. No.	Design Parameters	Maize Cob and biomass briquettes
1	Diameter of reactor, (m)	0.400
2	Height of reactor, (m)	1.032
3	Area required, (m^2)	0.1256
4	Volume of reactor, (m^3)	0.1296
5	Fuel consumption, (kg/h)	1.00 - 10.00
6	Specific Gasification rate, (kg/m^2h)	40 to 210

System Performance

The system was extensively tested to evaluate up draft biomass gasifier performance through close monitoring of the system operation and suitable data collection. The performance parameter like known amount of fuel consumption rate, different gasifier zone temperature and power input and power output of the gasifier. Also calculate the overall biomass gasifier efficiency for thermal application.

Variation of different gasifier zone temperature at different fuel consumption rate using maize cobs

The variation of different gasifier zone temperature of up draft biomass gasifier system at different fuel consumption rate with time.

Table 3 shows that the variation of different zone temperature from the fuel is a function of time and types of fuel. The average combustion zone temperature is varying in between 955 to 974 ºC at four fuel consumption rate i.e. 4, 6, 8 and 10 different kg/h using maize cob as a fuel in the system. The maximum and minimum combustion zone temperature, 974 ºC and 955.4 ºC is observed in case of 10 kg/h fuel consumption rate and 4 kg/h fuel consumption in the system respectively. These is because of the fuel consumption is high in 10 kg/h and minimum in case of 4 kg/h fuel consumption rate as shown in Figure 2 and Figure 5.

Table 3 Variation of different zone temperature at different fuel consumption rate using maize cob

Fuel consumption rate (kg/h)	Average Different Zone Temperature (ºC)			
	Combustion	Reduction	Pyrolysis	Drying
4.0	955.40	826.80	623.50	262.10
6.0	965.00	523.80	632.00	393.20
8.0	969.00	938.40	536.80	289.50
10.0	974.00	611.80	397.30	290.00

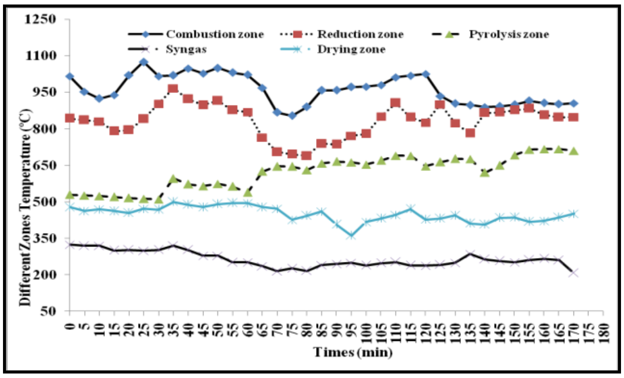

Figure 2 Variation of different zone temperature at 4 kg/h fuel consumption rate using maize cob

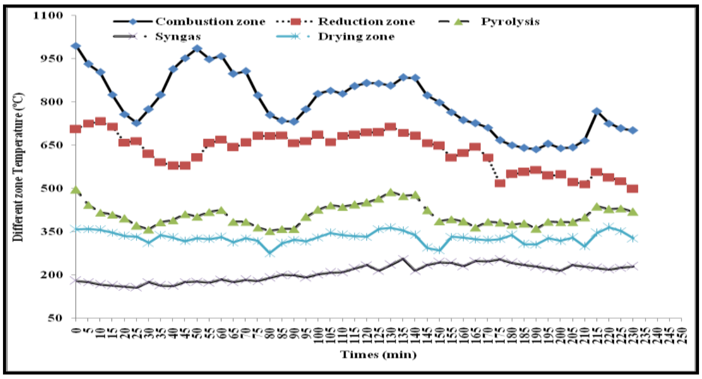

Figure 3 Variation of different zone temperature at 6 kg/h fuel consumption rate using maize cob

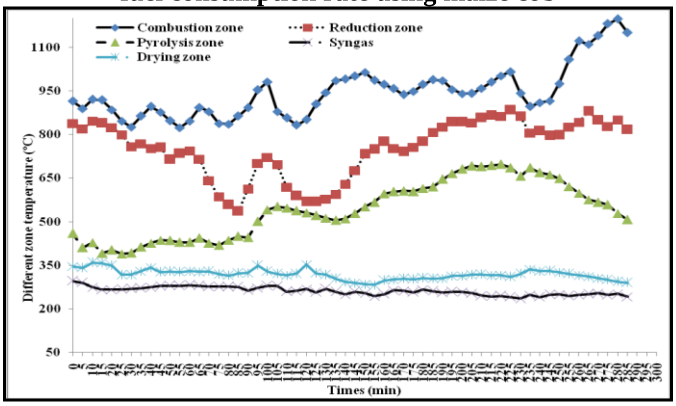

Figure 4 Variation of different zone temperature at 8 kg/h fuel consumption rate using maize cob

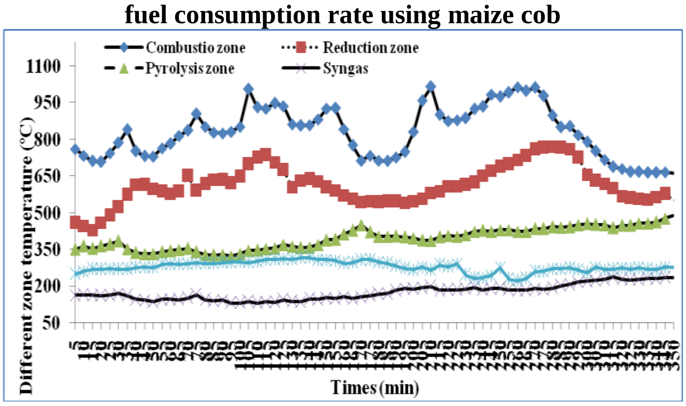

Figure 5 Variation of different zone temperature at 10 kg/h fuel consumption rate using maize cob

Variation of different gasifier zone temperature at different fuel consumption rate using biomass briquettes

The variation of different gasifier zone temperature of up draft biomass gasifier system at different fuel consumption rate with time. Table 4 shows that the variation of different zone temperature from the fuel is a function of time and types of fuel.

The average combustion zone temperature is varying in between 731.60 to 820.40 ºC at four fuel consumption rate i.e. 4,6, 8 and 10 kg/h using maize cob as a fuel in the system. The maximum and minimum combustion zone temperature, 820.40 ºC and 731.60 ºC is observed in case of 4 kg/h fuel consumption rate and 10 kg/h fuel consumption in the system respectively. These is because of the fuel consumption is high in 4 kg/h and minimum in case of 10 kg/h fuel consumption rate as shown in Figure 6 to Figure 9.

Table 4 Variation of different zone temperature at different fuel consumption rate using Biomass briquettes

Fuel consumption rate (kg/h)	Average Different Zone Temperature (ºC)			
	Combustion	Reduction	Pyrolysis	Drying
4.0	820.40	429.10	397.20	289.40
6.0	757.90	368.80	362.50	293.80
8.0	732.00	326.00	320.40	276.40
10.0	731.60	366.40	347.00	284.90

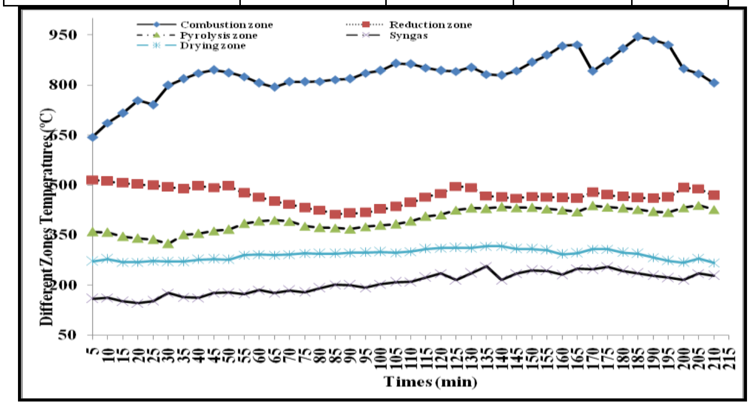

Figure 6 Variation of different zone temperature at 4 kg/h fuel consumption rate using Biomass briquettes

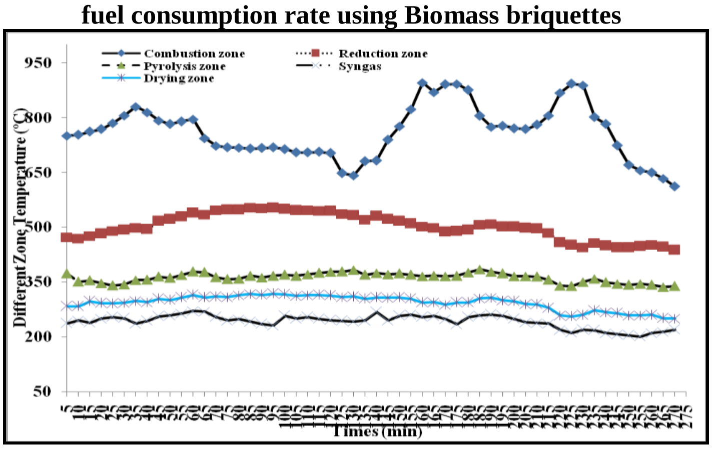

Figure 7 Variation of different zone temperature at 6 kg/h fuel consumption rate using Biomass briquettes

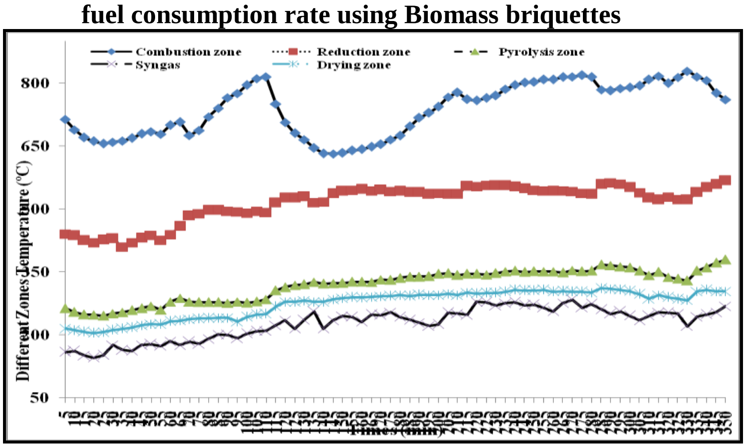

Figure 8 Variation of different zone temperature at 8 kg/h fuel consumption rate using Biomass briquettes

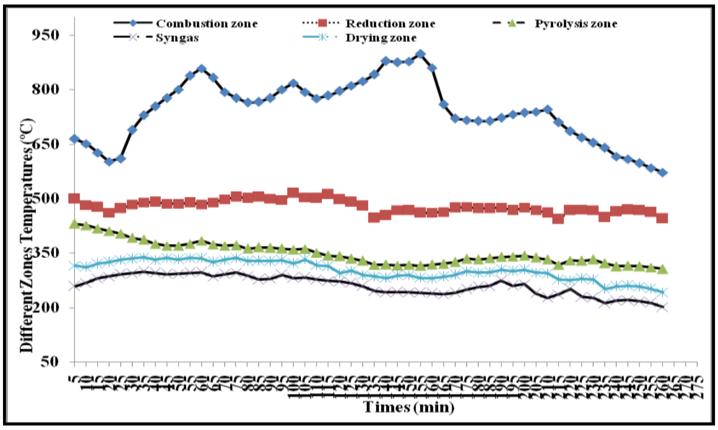

Figure 9 Variation of different zone temperature at 10 kg/h fuel consumption rate using Biomass briquettes

Power Input and Output of the gasifier

The performance result of the up draft biomass gasifier for the two carbon containing i.e. maize cobs and biomass briquettes considered is summarized in Table 5.

Table 5 Summery of the experimental and performance of the updraft gasifier with different fuel

Sr. No.	Parameters	Units	Maize cobs consumption rate (kg/h)			
			4.0	**6.0**	**8.0**	**10.0**
1	Power Input	kcal	14544	21816	29088	36360
2	Power output	Kcal	10180.8	15271.2	20361.6	25452
3	Thermal Efficiency	%	70.00			
4	Gasifier Efficiency	%	68.06 to 75.63			
			Biomass Briquettes consumption rate (kg/h)			
1	Power Input	kcal	15140.0	22710.0	30280.0	37850.0
2	Power output	Kcal	10598.0	15897.0	21196.0	26495.0
3	Thermal Efficiency	%	70.00			
4	Gasifier Efficiency	%	65.38 to 72.65			

Conclusions:

Well designed updraft gasifier is tested with the two types of biomass and major advantages of this type of gasifier are its simplicity, high charcoal burn out and internal heat exchange leading to low temperature of exit gas and high equipment efficiency. The smallest biomass up draft gasifier designed so far and available to the user is too large for the kitchen and for applications needing around up to 10 kg of biomass per hour. An updraft biomass gasifier was specially developed to meet the heat requirements of Indian kitchens as well as industrial applications. The following conclusions are :

1. The physical properties of maize cob in terms of length, diameter, bulk density and true density were found to be 35.24 mm, 22.30 mm, 159.25 kg/m^3 and 0.39 gm/cm^3 respectively. The proximate analysis of maize cob in terms of moisture content of the biomass was found 12.30 % (w.b). The fixed carbon, volatile matter and ash content were found to be 16.42, 81.25 and 2.33 percent respectively. The calorific value of maize cob was obtained as 3636.00 kcal/kg.
2. The physical properties of biomass briquettes in terms of length, diameter, bulk density and true density were found to be 76.30 mm, 65.42 mm, 595.70 kg/m^3 and 0.79 gm/cm^3 respectively. The proximate analysis of biomass briquettes in terms of moisture content of the biomass was found 10.23 % (w.b). The fixed carbon, volatile matter and ash content were found to be 6.89, 79.80 and 13.31 percent respectively. The calorific value of maize cob was obtained as 3785.00 kcal/kg.
3. Volume of reactor, area required, diameter of reactor and height of reactor were computed for maize cob and biomass briquettes used in the up draft biomass gasifier 0.1296 m^3 , 0.1256 m^2, 0.400 m, 1.032m respectively.
4. The combustion zone temperature is vary in between 955 to 974.00 and 731 to 820.40 ºC at four fuel consumption rate i.e. 4,6,8 and 10 kg/h using maize cob and biomass briquettes as a fuel in the system respectively.
5. The up draft biomass gasifier efficiency is vary in between 68.06 to 75.63 per cent and 65.38 to 72.65 per cent at four fuel consumption rate i.e. ,6,8 and 10 kg/h using maize cob and biomass briquettes as a fuel in the system respectively.

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