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Research Article

Design and Development of Inverted Down Draft Gasifier for Cooking Purpose

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Abstract: Energy is a key input for technological, industrial, social and economical development of a nation. However, a large number of consumers in domestic, agricultural, commercial and industrial sectors are faced with a situation of energy availability that is characterized by inadequate quantity, poor quality, un-affordability, un-sustainability and negative environmental consequences. The challenge for the country is ensuring affordable-clean energy for all in a sustainable manner. In particular, the domestic sector relies heavily on traditional sources of energy, mainly for cooking, for which traditional stoves are often used. These stoves are usually thermally as well as environmentally inefficient and hence create drudgery and problems for the users. A wide variety of Chulha or biomass stoves are used in Indian kitchens and road side tea stalls and restaurants. These stoves emit smoke, ash and excessive heat creating uncomfortable and unhealthy environment for the user. Combustion rate is not well controlled. The efficiency of these stoves is quite less, generally not exceeding 18-22 %. A natural convection type inverted down draft gasifier has been developed at the College of Agricultural Engineering and Technology; Godhra for thermal purpose (cooking purpose).The inverted down draft gasifier consists of combustion chamber, gas wick, primary air inlet with control, grate, secondary holes for proper combustion of the producer gas and vessel support. The developed gasifier was tested with maize cobs and saw dust briquettes fuel. The experimental investigations show that the overall thermal efficiency of the gasifier using maize cobs with lid and without lid was 33.89 and 29.59 % respectively and in case of saw dust briquettes with lid and without lid was 40.53 and 38.68 % respectively. The maximum power output of the gasifier using maize cob with lid and without lid was 5.00 and 4.37 kW respectively where in the case of saw dust briquettes used in the gasifier with lid and without lid was 6.50 and 6.20 kW respectively. The major advantage of this type of gasifier was that all the energy available in the fuel was used and controlled the fuel consumption rate with the help of primary air inlet.
Keywords: Cook stove, inverted down draft gasifier, overall thermal efficiency, flame temperature, power input and output

INTRODUCTION

Biomass combustion provides basic energy requirements for cooking and heating of rural households in the developing countries. In general, biomass energy use in such cases is characterized by low energy efficiency and emissions of air pollutants [1].

In the past, traditional sources of energy such as fuelwood, charcoal, dung, etc. were the only sources of energy used for all types of applications. It is only during the last 250 years that fossil fuels such as coal, oil and gas and electricity have emerged as major sources of energy in most developed countries. However, nearly 75% of the world's population which lives in the developing countries continues to depend on the traditional sources of energy for most of their energy requirements [2]. Some Asian countries the traditional sources of energy accounted for about 60-90% of the total amount of energy consumed.

Indoor air pollution mediates the release of gases or particles into the air which are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emission from indoor sources and by not carrying indoor air pollutants out of the home. In our country air pollution studies particularly in rural households has so far been neglected. It is recently estimated that 82% of sulphur dioxide (SO_2), 38% of nitrogen dioxide (NO_2), 88% of volatile organic compounds and 96% particulate matter emissions in the country come from the household sector [3].

MATERIALS AND METHODS

Principles of down draft Gasification for cooking

Biomass gasification

When biomass burns without sufficient air it generates "producer gas" containing CO, CO_2, H_2, H_2O and CH_4. In convectional downdraft gasifier, starting from the top, passes down in gasifier, then in the well-defined drying, pyrolysis, combustion and reduction zones are created and both air and producer gas move downwards to the grate [4].

The "Inverted Downdraft Gasifier"

The "inverted down draft gasifier" stove. It operates using only natural convection. The rate of gas production and heating is controlled by the primary air supply to the gasifier. The stove can be stared and operated with indoors sufficient ventilation without no exhaust fans and it does not create odor of burning wood. The name comes from the fact that the fuel charge is lit "on the top", and forms a layer of charcoal there; the flaming pyrolysis zone is below that, the unburned fuel is on the bottom of the pile; and primary air or pyrolytic gasification enters of the bottom and moves up, forming gas in the flaming pyrolysis zone as shown in fig.1 [5]. The rate of gas production and heating is controlled by the primary air supply to the gasifier using butterfly valve (40mm valves). Both the parts of the stove were insulated using an "Insulite-7" to reduce the heat loss and to reduce the risk of burn injury. Thirty-four Numbers of holes (14.5 mm diameter) were drilled in the top part of the stove for supplying the secondary air for proper combustion. Major advantages of this type of gasifier was that all the heat available in the feedstock was used when its gas generation capacity was exhausted, the top half of the gasifier was removed and the vessel was placed over its lower half to utilize the heat of residual but still glowing charcoal.

We developed a "blue flame" gasifier using a "gas wick" to burn the gas in a very clean manner. The 25 mm thick insulation ring surrounding the vessel was used to reduce the dispersion of flame and stabilize it and to increase the heat absorption bi the vessel walls.

Experimental set up

The instrumented experimented set up was developed to evaluate the performance of the inverted down draft gasifier on terms of overall efficiency and rate of heat release with respect to time with and without insulation ring. The schematic diagram of the experimented set up and photographic view of the inverted down draft gasifier is shown in Fig.1 and 2.

Gasifier operation and measurements

The gasifier was filled of maize cob and saw dust briquettes. To start the test some small parts of maize cobs are places of the cob and saw dust briquettes. After 2-3 minutes a good quality of producer gas was generated. Whenever good quality of producer gas was generated, putting an Aluminium vessel filled at 1 inch height with 4 litre of water and time taken for rising the temperature of water at 96 °C. The performance of the gasifier was evaluated by measuring the following parameters

1) Heat loss through surface temperature(°C)
2) Water loss through water evaporation during the each test
3) Water temperature measured using a mercury thermometer. Chromel-Alumel (k type) thermpcouples and a digital multi-channel temperature indicator were used to measure the different zone temperature and flame temperature.

With the help of constant heat output method, to evaluate the overall thermal efficiency of the cook stove [6]. A known amount of water at ambient temperature is heated in an Aluminium vessel on the stove till it attains a temperature of 96 °C. At this point it is replaced by another Aluminium vessel with the same quantity of water of ambient temperature. The process is repeated till the completion of the combustion process. The overall thermal efficiency of the process is calculated at

$$\boldsymbol{\eta} = [(n \text{ x } M \text{ x } C_p \text{ x } (T_x\text{-}T_a))+(M_x \text{ x } Cp \text{ x } (Tb\text{-}T_a))+(M_2 * H_1)]/[W \text{ x } H_c]$$

Where,

M=Quantity of water in each pot (4 litre)
T_x= Water heating temperature (96 °C)
T_a=Ambient temperature (°C)
T_b=Highest temperature attained by the last pot (°C)
H_c=Calorific value of the fuel (kcal/kg)
W=Amount of fuel burnt (3 kg)
n=Number of times cold vessels have been placed on the fire
C_p=Specific heat of the water (1kcal/kg)
M_2=Amount of water evaporated (kg)
H_1=Latest heat of vaporisation (540.00 kcal/kg)

RESULT AND DISCUSSION

The proximate analysis of maize cob and saw dust briquettes fuel used in inverted down draft gasifier. The moisture content of the maize cob and saw dust briquettes fuel is 8.78 and 9.97 % 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 16.72, 82.18 and 1.09 percent and 15.96, 82.06 and 1.96 per cent respectively.

System performance

The system was extensively tested to evaluate gasifier performance through close monitoring of the system operation and suitable data collection. The performance parameter like known amount of water heated at particular temperature 96 ºC, flame temperature. Also calculate the overall thermal efficiency of the inverted down draft gasifier at particular temperature 96 ºC.

Variation of heat released with respect time

The variation heat released from maize cob and saw dust briquettes fuel used in the inverted down draft gasifier with time. Table 3 shows that the heat released from the fuel is a function of time. Water heating temperature of 96 ºC, the maximum heat released from the system using maize cob with lid and maximum time taken for heat released was 68.269 kcal/min and 44.30 min respectively for these much amount of heat released respectively as shown in Figure 3. In case system using without lid of the vessel the maximum heat released and maximum time taken for heat released was 54.511 kcal/min and 40.46 min respectively as shown in Figure 4. In case of saw dust briquettes using in gasifier the maximum heat released from the system using saw dust briquettes with lid and maximum time taken for heat released was 47.811 kcal/min and 51.00 min respectively for these much amount of heat released respectively as shown in Figure 5 where without lid using in the gasifier, the maximum heat released from the system using saw dust briquettes was 40.288 kcal/min and 38.35 min respectively as shown in Figure 6. The overall thermal efficiency increased with increase in the water heating temperature (96°C) (Table 2). The average overall thermal efficiency of the gasifier using maize cob and saw dust briquettes with lid were 28.70 and 28.59 % respectively. In case of the average overall thermal efficiency of the gasifier using maize cob and saw dust briquettes without lid were 28.48 and 28.65 % respectively.

Variation of flame temperature

Figure 7 to Figure 10 shows the variation of the flame temperature using the different gasifier fuel of the water boiling temperature (96 °C) used in the gasifier. Figure 7 and Figure 8 shows that the maximum flame temperature of the gasifier using maize cob with lid and without lid of the vessel was 742 °C and 665 °C respectively. Figure 9 and Figure 10 shows that the maximum flame temperature of the gasifier using saw dust briquettes with lid and without lid of the vessel was 710 °C and 733 °C respectively.

Variation of power output of the gasifier

The variation of power input and power output of the gasifier in terms of kW from maize cob and saw dust briquettes fuel used in the inverted down draft gasifier using with lid and without lid of the vessel. Table 4 shows that the power output of the gasifier in terms of kW is a function of calorific value of the biomass used in the system. The power output in terms of kW at water heating temperature of 96 ºC, the maximum power output with lid in both case using maize cob and saw dust briquettes 5.00 and 6.50 kW respectively. In case of without lid of the vessel using in both case, the output of the in terms of kW is 4.37 and 6.20 kW. The power output is higher in case of saw dust briquettes because of the higher calorific value of the saw dust briquettes.

Table 1. Proximate analysis of maize cob biomass and sawdust briquettes

Sr. No	Fuel	Moisture content, %(w.b)	Fixed carbon, %	Volatile matter, %	Ash content,%	Lower Calorific value, kcal/kg
1	Maize cob	9.93	16.72	82.18	1.09	4106.00
2	Sawdust briquettes.	9.97	15.96	82.06	1.96	4453.00

Table 2. Parameter of Inverted Downdraft Gasifier obtained for different biomass

Sr. No.	**Design Parameters**	**Maize Cob**	**Saw Dust Briquettes**
1	Fuel consumption	3.00 kg/h	5.26 kg/h
2	Volume of reactor	0.0109 cubic meter	0.0108 cubic meter
3	Area required	0.0248 square meter	0.0245 square meter
4	Diameter of reactor	0.1781 meter	0.1770 meter
5	Height of reactor	0.4411 meter	0.4409 meter

Table 3. Variation of heat released with time and overall thermal efficiency of the system

Types of fuel	Water boiling temperature (°C)	Treatments	Time taken for maximum heat released (min)	Maximum amount of heat released (kcal/min)	Efficiency of the gasifier (%)	R^2 Value
Maize cob	96	With Lid	44.30	68.269	33.89	0.937
	96	Without lid	40.46	54.511	29.59	0.937
Saw Dust Briquettes	96	With Lid	51.00	47.811	40.53	0.927
	96	Without lid	38.35	40.288	38.68	0.921

Table 4. Variation of power input and power output of the gasifier in terms of kW using different biomass and different conditions of the vessel

Types of fuel	Water boiling temperature (°C)	Treatments	Power Input (kW)	Efficiency of the gasifier (%)	Power output (kW)
Maize cob	96	With Lid	14.78	33.89	5.00
	96	Without lid	14.78	29.59	4.37
Saw Dust Briquettes	96	With Lid	16.03	40.53	6.50
	96	Without lid	16.03	38.68	6.20

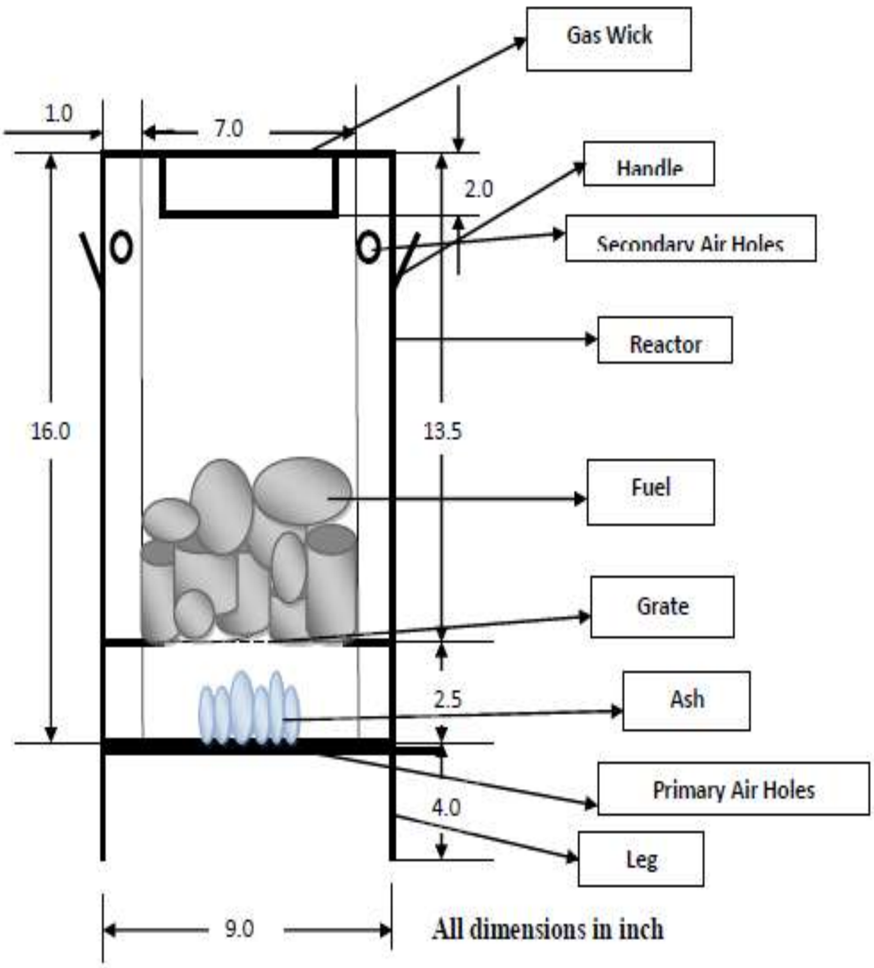

Fig-1: Schematic diagram of inverted down Draft Gasifier

Fig- 2: Photographic Views of the Inverted Down Draft Gasifier

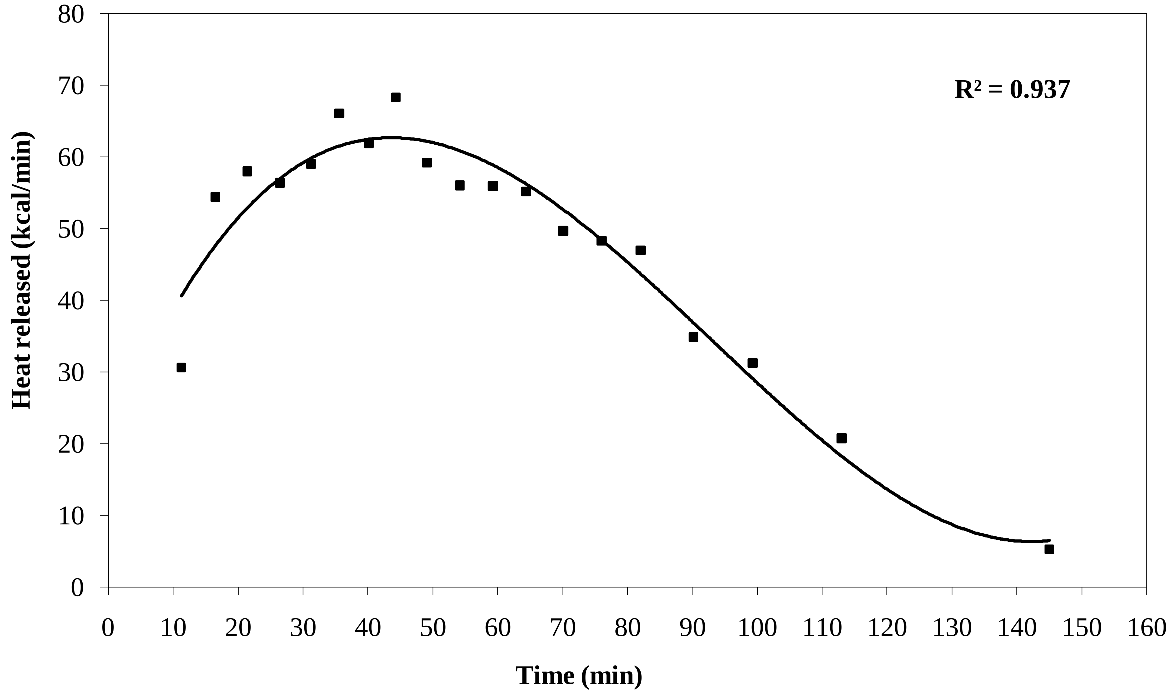

Fig- 3: Effect of time on heat released using maize cob with lid at 96 °C

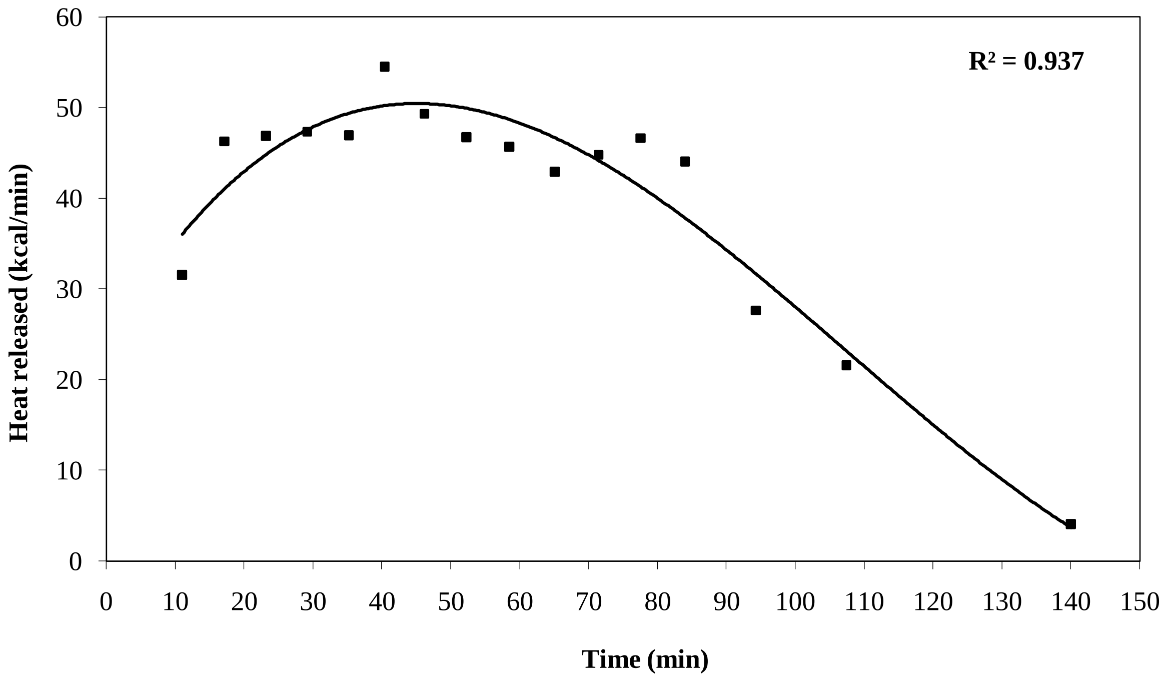

Fig-4: Effect of time on heat released using maize cob without lid at 96 °C

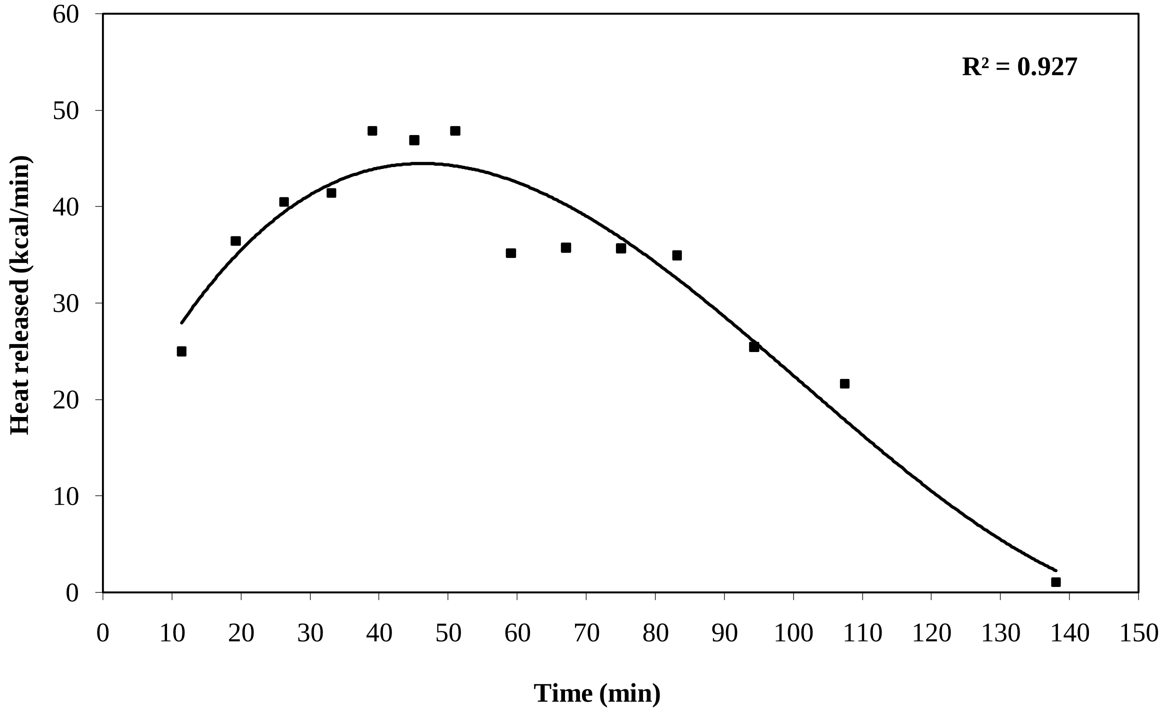

Fig- 5: Effect of time on heat released using saw dust briquettes with lid at 96 °C

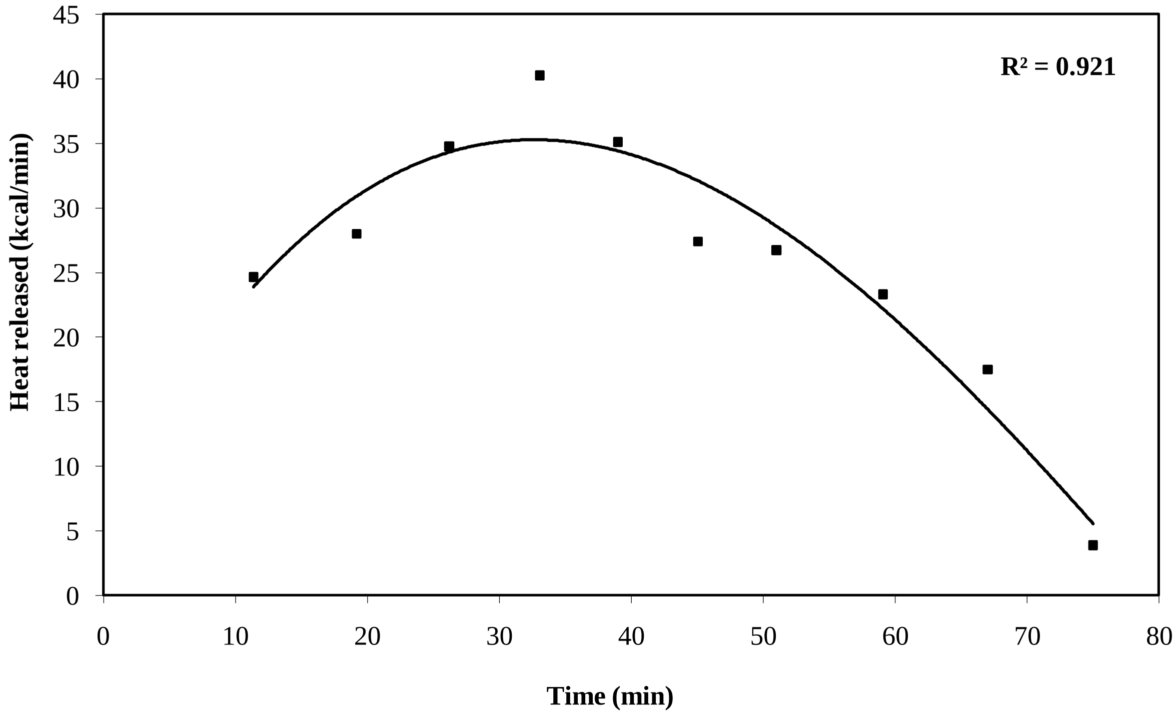

Fig- 6: Effect of time on heat released using saw dust briquettes without lid at 96 °C

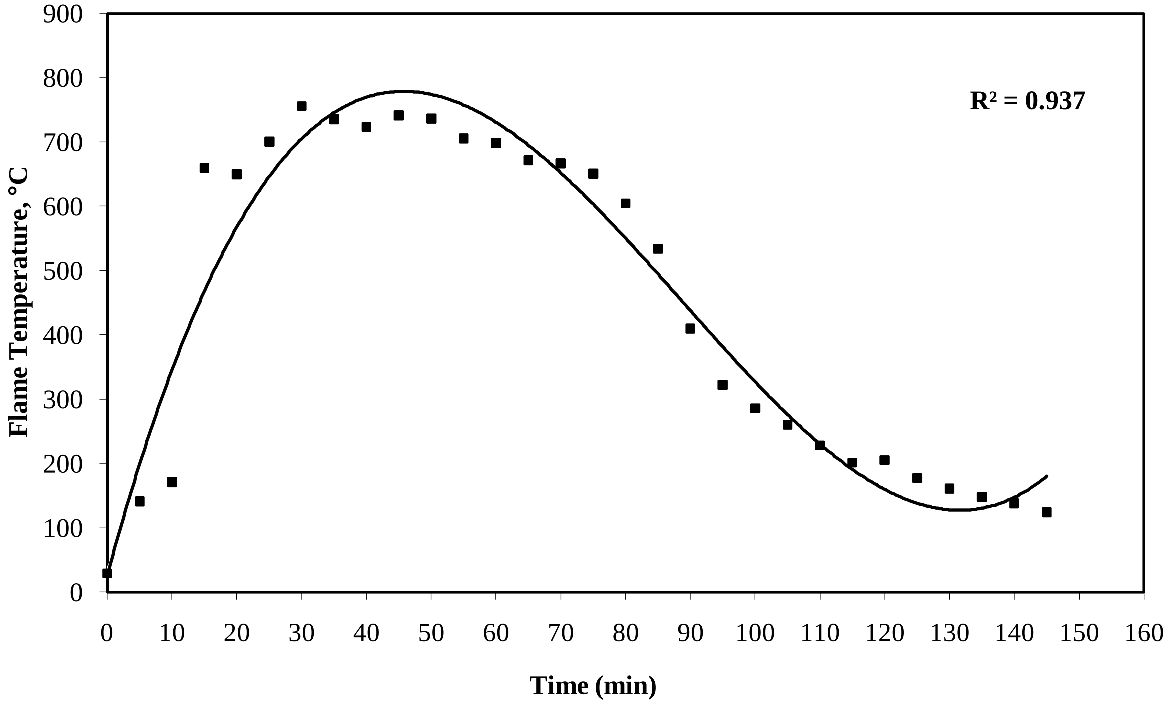

Fig- 7: Variation of flame temperature using maize cob with lid at 96 °C

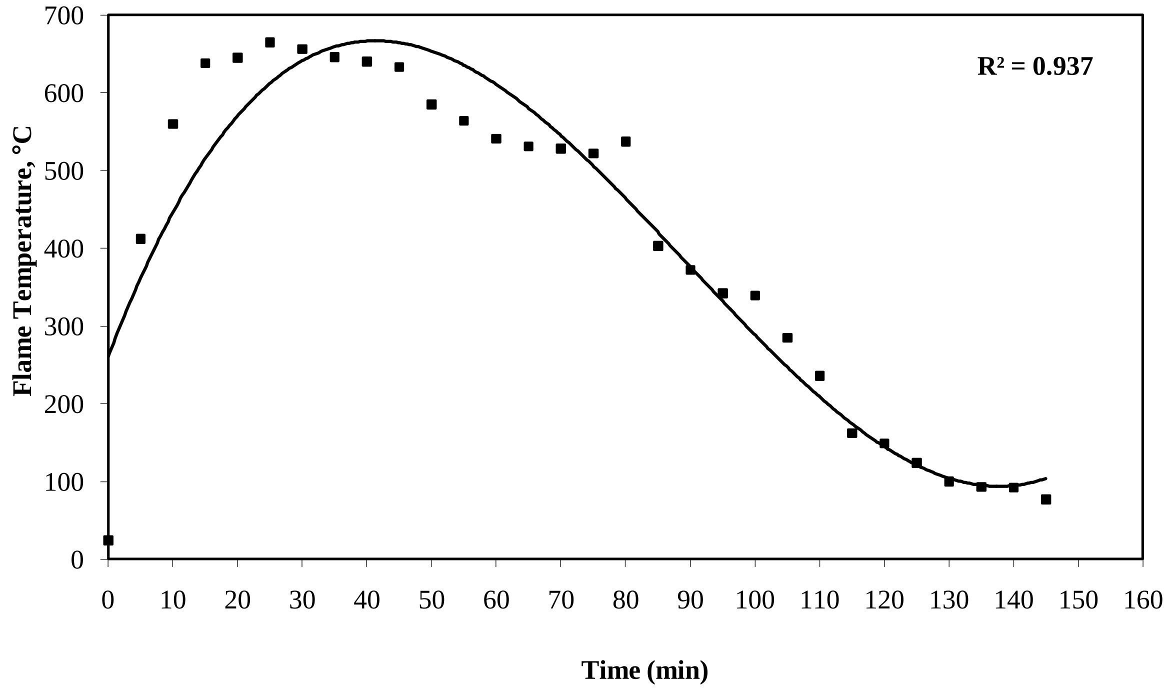

Fig-8: Variation of flame temperature using maize cob without lid at 96 °C

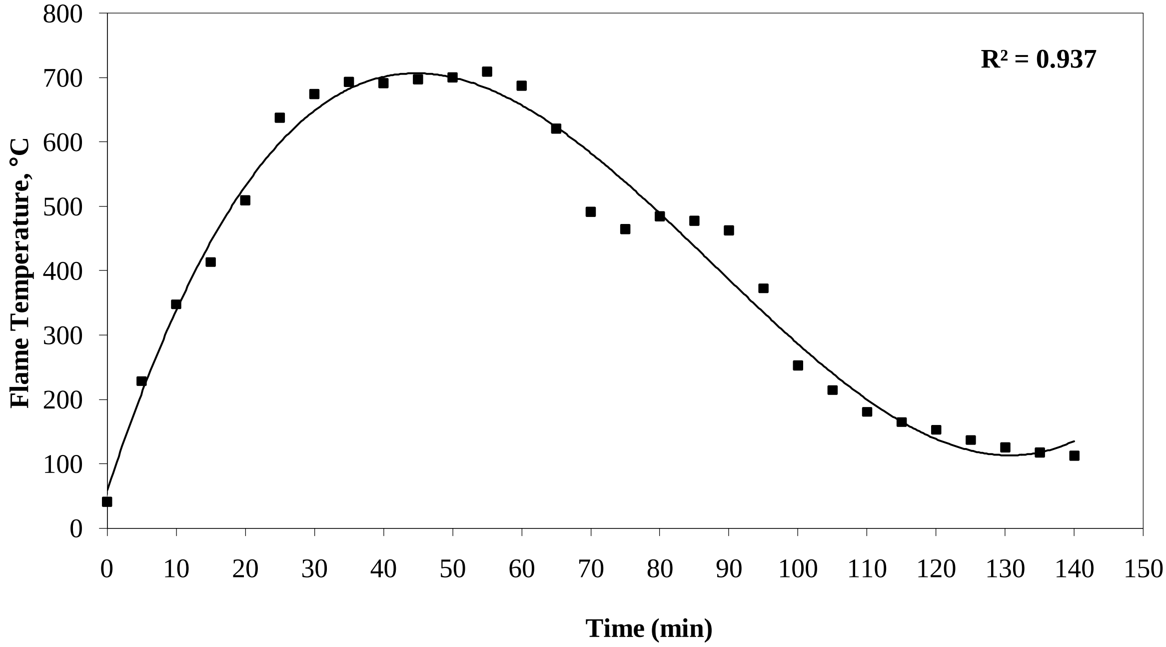

Fig-9: Variation of flame temperature using Saw dust briquettes with lid at 96 °C

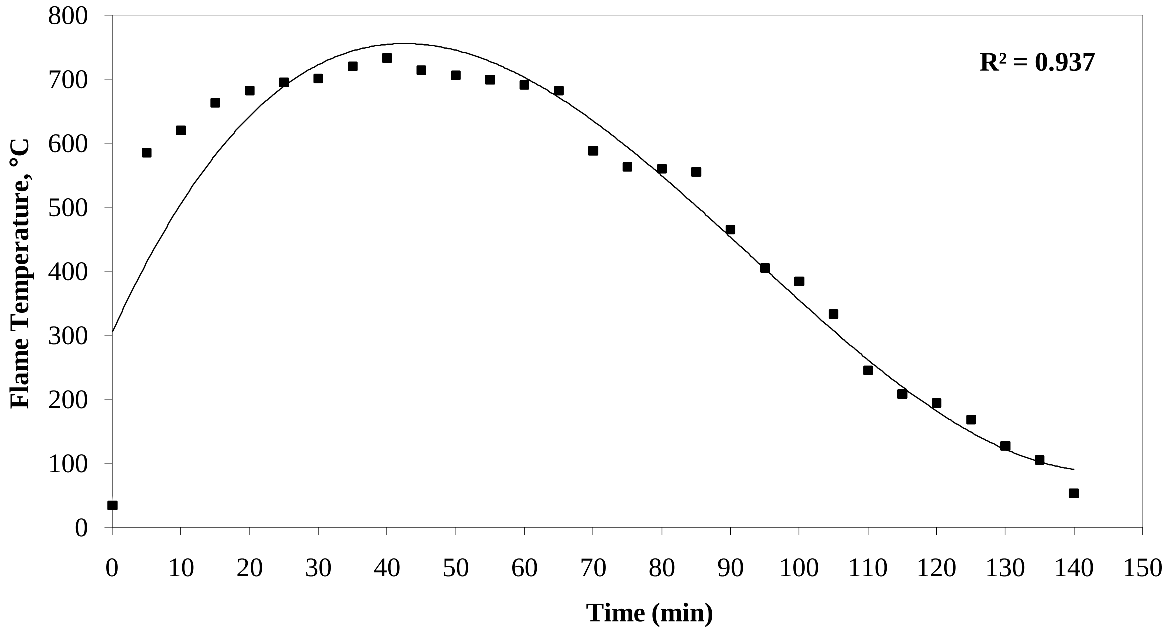

Fig-10: Variation of flame temperature using Saw dust briquettes without lid at 96 °C

CONCLUSIONS

The proximate analysis of maize cob biomass in terms of moisture content of the biomass was found 9.93 % (w.b). The fixed carbon, volatile matter and ash content were found to be 16.72, 82.18 and 1.09 percent respectively. The calorific value of maize cob biomass was obtained as 4106 kcal/kg.

The proximate analysis of saw dust briquettes biomass in terms of moisture content of the biomass was found 9.97 % (w.b). The fixed carbon, volatile matter and ash content were found to be 15.96, 82.06 and 1.96 percent respectively. The calorific value of saw dust briquettes biomass was obtained as 4453 kcal/kg.

An inverted down draft gasifier has been designed considering the maize cob and saw dust briquettes biomass as feed material.

Volume of reactor, area required, diameter of reactor and height of reactor were computed for maize cob and saw dust briquettes used in the inverted down draft gasifier 0.011 m^3 , 0.025 m^2, 0.178 m, 0.441 m respectively.

Volume of reactor, area required, diameter of reactor and height of reactor were computed for saw dust briquettes used in the inverted down draft gasifier 0.011 m^3 , 0.025 m^2, 0.1770 m, 0.4409 m respectively.

Constant temperature rise method for overall thermal efficiency of the gasifier using maize cob fuel with lid and without lid 33.89 and 29.59 percentage respectively.

Constant temperature rise method for overall thermal efficiency of the gasifier using saw dust briquettes fuel with lid and without lid 40.53 and 38.68 percentage respectively.

The maximum power output of the gasifier using maize cob with lid and without lid was 5.00 and 4.37 kW respectively

The maximum output in the case of saw dust briquettes used in the gasifier with lid and without lid was 6.50 and 6.20 kW respectively.

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