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Ipomoea Carnea As Fuelwood Substitute in Domestic Cooking through Gasification in A Fixed Bed Gasifier

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ABSTRACT

This paper investigates on potentiality of a noxious weed Ipomoea carnea as an alternative biomass to substitute fuelwood in domestic cooking applications. The weed has created a lot of problem due to its invasive nature; as a biomass it is considered as low grade fuel to be used in traditional combustion based devices. The objective of the work is to derive energy from woody stems of Ipomoea through gasification process. A gasifier based stove is developed and experiments are performed to study its performance using Ipomoea and compared with fuelwood. Results of experiments are analysed and presented. Thermal efficiencies of the stove have been found to be 28% and 26% respectively for fuel wood and Ipomoea. The flame temperature obtained for both the fuels is above 700 °C. The stove delivered power in the range of 2.8 kW to 3.3 kW which is sufficient for domestic cooking for a standard family. It has been revealed that the weed could be used to substitute fuelwood in cooking through gasification process in an appropriate device.

KEYWORDS : Biomass, Ipomoea carnea, gasification, gasifier stove.

1. Introduction:

Fuel wood is the primary energy source in domestic cooking in many developing countries because it is easily available either at free of cost or at a price much lower than other commercial fuels such as coal, LPG, kerosene etc. As a renewable energy source it is carbon neutral if sustainably used. But the demand of fuel wood has been increasing gradually, particularly in Asian developing countries, despite the use of other commercial liquid and gaseous fuels (Demirbas et al., 2009). On the other hand the traditional direct combustion based devices being in use for converting biomass to energy are very inefficient (10-12% efficiency) that cause wastage of fuel. Another associated problem in the traditional conversion method is the high level of indoor air pollution (IAP) in which women and children are highly affected as they spend maximum time within the house (Mac Carty et al., 2008). The WHO (World Health Organisation) estimates that more than 1.5 million people prematurely die each year due to exposure to the smoke and other air pollutants from burning solid fuels (IEA, 2007). A World Bank document (World Bank, 2011) on India reports that despite large national level subsidies on liquid and gaseous fuels nearly 700 million Indians still burn biomass as the primary energy source for cooking in inefficient cook stoves. It has been reported that in developing countries 730 million tonnes of biomass are burned in a year, which accounts for the emission of one billion tonnes of carbon dioxide into the atmosphere (Raman et al., 2013). Drudgery and loss of man days in collection of fuel is also a problem for the biomass users. Intervention of better technology would likely to address these problems. A biomass cook stove with higher efficiency could reduce fuel wood consumption as a whole. However, acceptability of other locally available biomass in cooking by the biomass users would reduce excessive pressure on fuel wood demand.

Among different thermo-chemical conversion processes gasification has got some merits which could be used in small scale to produce energy efficiently. Biomass gasification is a thermo-chemical conversion method in which inhomogeneous solid biomass could be converted to a homogeneous gaseous fuel by controlled burning (sub-stoichiometric supply of air) of the solid biomass in a reactor called gasifier. A biomass gasifier coupled with a combustion chamber could convert solid biomass into gaseous fuel allowing better and clean combustion. Efforts on development of gasifier based stove with improved efficiency and reduced emission have been made by a number of earlier workers (Reed T.B., 2000; Anderson P.S. et al., 2007; Panwar, N.L., 2009). Jetter and Kariher studied different biomass as cooking fuel in different cook stoves (Jetter and Kariher, 2009). However, few efforts have been reported on utilization of a noxious weed Ipomoea carnea as cooking fuel. This weed grows very fast in agricultural lands, small rivers, cannels and in road sides in many parts of developing countries such as in India. The invasion of this weed has created serious threat to the farmers who are interestingly the biomass users. Most of the earlier research works on this weed were attempted on effective eradication (Bhuyan M. et al., 2008; Haase R., 1999) and its potentiality as cooking fuel to substitute fuelwood has been mostly overlooked. Even the biomass users do not prefer it as fuel because of fast burning rate, low heating value and toxic emission in direct combustion. The present work is an effort to utilize woody stems of Ipomoea carnea as cooking fuel in a gasifier based combustion system rather than direct burning in traditional devices. The expected outcomes are conversion of the solid biomass to gaseous fuel, clean combustion, better conversion efficiency and improved emission. With these objectives an experimental study has been taken up.

2. Materials and methods

2.1 Gasifier system

The gasifier system is an inverted down draft gasifier with integrated combustor [fig.1]. The system comprises of a cylindrical reactor core of mild steel with an external insulating cladding and a tapered combustion chamber with air holes for secondary air supply to be mixed with the product gas before combustion.

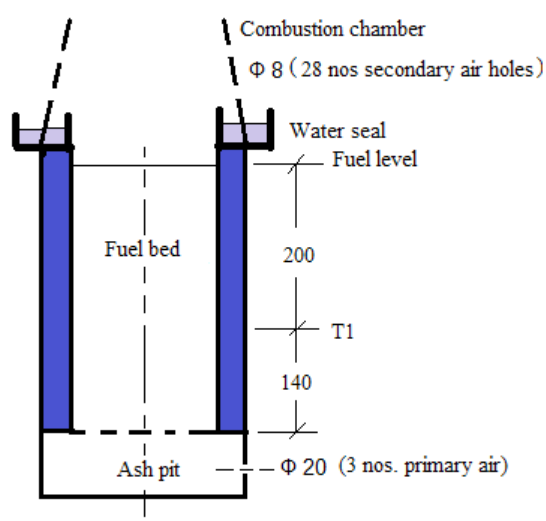


Fig. 1 Schematic diagram of the gasifier based combustion system or gasifier stove (Reactor core diameter 10

cm and stove external diameter 15 cm)

In such a gasifier a packed bed of dry biomass (solid fuel) is burnt at the top and controlled quantity of air is supplied in the upward direction that causes partial combustion of the biomass [fig.2].

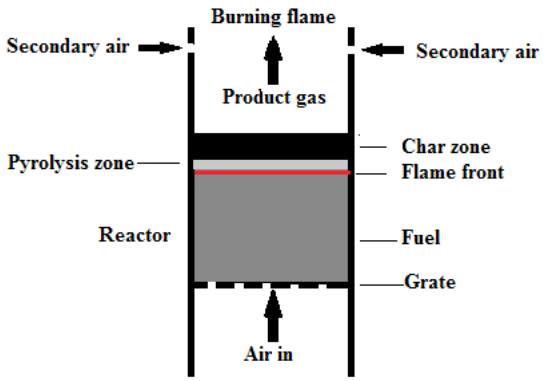


Fig.2 Packed bed Inverted down-draft gasifier

The rise in temperature devolatizes the biomass to give off pyrolytic gases and a flame front is established in the bed which propagates towards the grate leaving behind a hot char zone at the top. A complex thermo-chemical reaction takes place to produce a combustible gas. The gas so produced passes through the hot char zone allowing the tar (heavy hydrocarbon) to be cracked to give a relatively clean fuel gas. The product gases passing through the hot char zone react with the hot chars giving off relatively a clean energy rich gas. These gases coming out of the bed typically contains 16% CO, 12% H_2, 3% CH_4, 12% H_2O (as gas), some higher hydrocarbons (5-6%) and remaining being N_2 (Varunkumar et al., 2011) .The gases when allowed to mix with the secondary air supplied directly to the combustion chamber burns with a brilliant flame if the air fuel mixture is proper. The present configuration may be considered suitable for a standard family of 4-5 persons to cook a single meal.

2.2 Biomass feed

Fuelwood and Ipomoea carnea were selected in the study. Both wood and woody stems of Ipomoea were chopped manually into 2-4 cm sizes (Fig.3) and were dried in open air for three weeks. The bulk density of the dry fuel samples were determined by measuring the weight of each fuel sample in a laboratory beaker of known volume. The other thermo-chemical properties were determined by standard laboratory test methods. The physical and thermo-chemical properties of the fuels are presented in table 1.

Table 1: Physical and thermo-chemical properties of different biomass

Properties	Fuel wood	Ipomoea
Bulk density (kg m^{-3})	174	160
Moisture content(% wt)	9.5	9.1
Volatile matter (% db)	80.3	64
Fixed carbon (% db)	17.6	25.9
Ash content (% db)	2.2	2.1
Heat value (MJ kg^{-1})	16.6	13.2



(a) **(b)**

Fig.3 (a, b): Two fuel samples: a) Fuelwood, b) Ipomoea dry chips

2.3 Experimental:

The experimental set up is shown in figure 4. A measured quantity of fuel (0.5 kg each) was packed in the reactor core. A few drops of kerosene were sprinkled over the top and was burnt with a match stick. As soon as the flame established in the combustion chamber an aluminium vessel with lid filled with 5 litres of water was placed over the combustion chamber on a support. The gap of 12 cm was maintained between the top of the combustion chamber and the base of the water vessel. The water in the pot was periodically stirred and the rise in temperature of water was measured using an alcohol thermometer. The stove was run till the flame extinguished. The residue was immediately transferred to an air tight metal container of known weight and the net weight of the residue was measured. The gross weight of the aluminium vessel was also measured immediately by using a digital balance of 30 kg capacity having resolution of 1 gm. The differential weight of water filled pot before and at the end of the experiment gave the quantity of water evaporated. The differential weight of fresh biomass and residue was the amount of fuel used during the experiment.

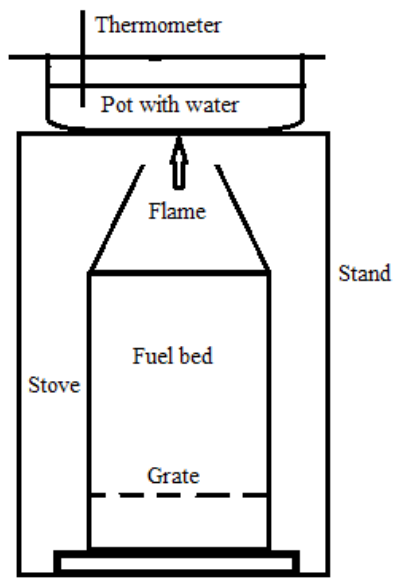


Fig.4 Schematic of experimental set-up for water boiling test

The thermal efficiency of the system was calculated by using the following relation:

$$\eta = \frac{Heat\ utilised}{Heat\ supplied}$$

$$\eta = \frac{[m_{wi}\, c_{pw}\, (T_b - T_c) + m_{we}\, L_w]}{m_f C_f}$$

Where is initial mass of water (kg), is specific heat of water (kJ $kg^{-1}K$), is the mass of water evaporated (kg), is the latent heat of vaporization of water at 373 K and 10^5 P_a (kJ kg^{-1}), is the net mass of fuel consumed (kg), is the calorific value of fuel (kJ kg^{-1}), is the temperature of water at boiling point (K) and is the temperature of cold water.

3. Results and discussions

3.1 General observations

The time taken to establish the flame in the combustion chamber was 3-4 minutes for both fuelwood and Ipomoea. The visible flame quality was almost same for both the fuels which was golden yellowish in colour and almost free from soot or smoke. The operational period of the device was 42 minutes for fuelwood and 40 minutes for Ipomoea. The stove operation was very consistent throughout the period which indicated near constant power level for each individual fuel. There was no need to attend the fire during the operation unlike the traditional biomass burning mud stoves. It took 23 minutes and 32 minutes for fuelwood and Ipomoea respectively to bring 5 litres of water into boiling point.





(a) (b)

Fig.5 (a) Gasifier stove in operation; (b) Combustion chamber

3.2 Power level

Table 1 shows the energy and power of the stove for the two fuels. The range of power level of the stove for two individual biomass indicates sufficiency to cook a meal of an average family of four or five. However, if one needs to extend the operational period, increase in the reactor height may be suggested.

Table 2 Energy and Power of the stove

Fuel	Qty. (kg)	C_f (MJ/kg)	Energy (MJ)	Time(min)	Power(kW)
F1	0.5	16.6	8.2	42	3.3
F2	0.5	13.2	6.6	40	2.8

F1: Fuelwood; F2: Ipomoea; $\dot{m}_f$: Fuel consumption rate; Cf: Calorific value

3.3 Specific fuel consumption (SFC)

SFC is a strong indicator of stove performance than the simple measurement of efficiency. It is the quantity of fuel consumed to boil and evaporate water in a specified time. In the present study specific fuel consumption of Ipomoea is higher than fuelwood though efficiencies are quite comparable. It may be because of Ipomoea's low heating value.

3.4 Flame temperature

Between the two fuels fuelwood takes less time to establish a stable flame. It takes only 4 minutes to obtain a stable flame with fuel-wood, while with Ipomoea the time taken is 6 minutes. Similarly, the maximum flame temperature of 733°C is attained with fuel-wood in 18 minutes and with Ipomoea, it is 707 °C attained in 28 minutes. Fig. 8 shows the flame temperature with respect to time.

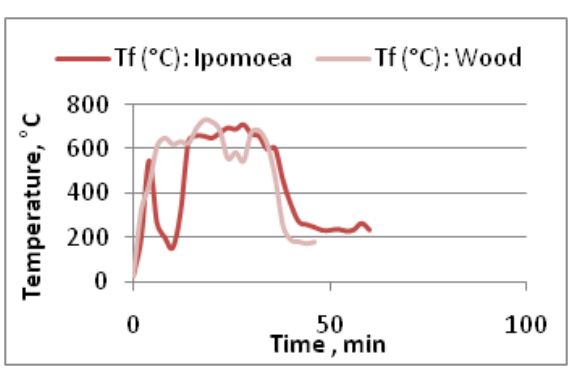


Fig.6 Temperature of flame vs. Time curve. (The sharp fall towards the end of the curve indicates completion of volatile release and gasification continues with the remaining char only).

The variation of flame temperature with time, as shown by Fig. 6, follows a definite pattern. Initially, it rises steeply to a temperature above 600 °C. Then the flame becomes stable and the flame temperature remains high; the temperature fluctuates within a range difference of about 150 °C. However, Ipomoea provides a slightly different pattern. Flame temperature of Ipomoea rises steeply from the initial temperature to 545°C within 4 minutes after which it drops steeply to 155 °C (it may be due to non-absorption of kerosene by Ipomoea chips immediately due to presence of berk) and then again rises. It attains the maximum value of 750 °C at 28th minute and after the 36th minute it starts declining.

The first phase (about 35 minutes) is dominated by devolatization and beyond that period there is a sharp fall of temperature; the gasification of char still continues and the radiant heat transfer from the hot char bed occurs simultaneously.

3.5 Thermal efficiency (η)

Table 4 shows the thermal efficiency of the stove. It has been found that efficiency of the stove is not too much influenced by the fuel used. However, Ipomoea has shown slightly lower efficiency.

Table 3 Thermal Efficiency under two different fuels

Fuel	Run	m_{we} (kg)	m_f (kg)	η %	Average η %
F1	1	0.395	0.456	29.1	28.3
	2	0.350	0.439	27.6	
	3	0.370	0.442	28.1	
F2	1	0.150	0.458	25.7	25.9
	2	0.165	0.467	25.9	
	3	0.165	0.462	26.1	

m_{wi} = 5 kg; C_{pw}= 4.2 kJ kg^{-1} k; L_w= 2258 kJ kg^{-1}; C_f (ref. Table 1); Tb = 365 K and Tc = 300 K.

Earlier design of natural draft gasifier reported thermal efficiency of their gasifier stove 26.5 % and maximum flame temperature 736 °C (Panwar, 2009). However, some forced draft stoves have reported more than 30 % conversion efficiency (Raman et al., 2013); these stoves require auxiliary power supply to run a fan for supplying air.

3.6 Specific gasification rate (SGR)

Specific gasification is also an important performance parameter of a gasifier based device. It is the quantity of fuel gasified per unit time per unit cross-sectional area of the reactor. For the present reactor core diameter of 0.11 m the SGR of the gasifier are 85.95 kg m^{-2} hr^{-1}, and 63.66 kg m^{-2} hr^{-1} for wood, and Ipomoea respectively.

3.7 Residual char

The corresponding values for residual char-ash were 6.1 % and 5.2 % respectively for wood and Ipomoea. This indicates high value of char conversion to energy at relatively higher conversion efficiency leading to saving in fuel.

4. Conclusion

Gasification opens up the option to use low grade biomass Ipomoea carnea as substitute of fuelwood. The performance of the cook stove is satisfactory for both the fuels. Moreover the system efficiency of conversion is much higher than direct combustion of fuelwood in traditional conversion devices.

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