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Design and techno economic evaluation of biomass gasifier for community cooking

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ABSTRACT : This paper deals with design of community gasifier cookstove. The stove works on natural cross draft mode with two pots for community cooking. Gasifier stove fabricated at Department of Renewable Energy Sources, CTAE, Udaipur has a capacity of 18.78 kWh. The biomass-fired gasifier stove consisted of four main parts *i.e.* fuel chamber, reaction chamber, primary air inlet and combustion chamber. The diameter of gasifier reactor was 30 cm and 56 cm in height. Area for primary and secondary air requirement was 109.67 cm^2 and 69.33 cm^2, respectively. The stove was insulated by refractory castable cement with thickness 18cm to minimize heat losses. The cost benefit ratio was found to be 1.27 with a payback period of 6.7 months. The design criteria and techno economic evaluation of biomass gasifier for community cooking presented in this paper.

KEY WORDS : Biomass gasifier, Gasifier, Cooking stove

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Community cooking normally refers to cooking of food for a group of about 25 or more persons in hostels, schools, community centers, hotels, rural/semi urban restaurants and road side dhabas, places of worship, residential monasteries, ashrams, caterers, suppliers of mid-day meals for schools etc. Community cooking is done using a coal-based traditional oven/furnace (bhatti) and direct burning of wood in ovens. Recently the use of LPG-based burners has also become a common practice in India. It is obvious that the use of a biomass gasifier based system for community cooking may provide an overall efficiency of about 40 per cent as compared to 8 to 20 per cent from traditional oven/furnace, etc. Biomass gasifier-based community cooking systems are available in the thermal rating of 17.5 to 291kW.

In this case a biomass fuel is first converted to producer gas using a suitable gasifier; the producer gas is next burned to produce energy for cooking. The main advantage of a producer gas fired stove is that it produces no smoke during cooking. These stoves differ from domestic units in being used in community and commercial environments, where multiple meals for a much larger number of people are prepared with a greater frequency daily.

The use of the community stove will be for much longer time at a stretch as compared to the domestic stoves which have much shorter cooking cycles. Fuel uses for community cook stove are big logs, small twigs and processed fuel (briquettes or chopped wood). Stove may be forced draught or natural draught based; they may be fixed or portable etc.

METHODOLOGY

The present study on cross draft gasifier operated cook stove was carried out to design the community sized biomass based gasifier cook stove. The initial design conditions and assumptions made for the design of cross draft gasifier system are listed in Table A.

Design of cross draft gasifier:

The following design parameters were considered for the design of the cross draft gasifier with two pots for community cooking.

Heat required for community cooking, Q_n:

Cooking of food for 100 people

Total requirement of rice = 150 g/ person × 100 =15 kg

Total requirement of vegetable = 80 g/person×100 =8 kg

Energy needed

The amount of energy needed to cook food can be calculated using the formula:

Table A : Initial design conditions and assumption for design of gasifier system

Design parameters	:	Particulars
Type of gasifier	:	Cross draft
Type of fuel	:	Biomass wood
Calorific value of fuel, H_{Vf}	:	15.49 MJ kg^{-1} (3700 kcal/kg)
Bulk density of fuel, ρ_{rh}	:	370 kg m^{-3}
Gasification efficiency, n_g	:	65%
Specific gasification rate, S_{GR}	:	90 kg $m^{-2}h^{-1}$
Equivalent ration, ε	:	0.3
Stachiomatric air fuel ratio, S_A	:	5.9 kg of air kg^{-1} of biomass
Heat transfer coefficient of insulating material, h_c	:	15 $Wm^{-2}K^{-1}$ (refractory castable cement)
Cooking of food	:	For 100 people

Pot – 1, $Q_{n1} = (m_r C_{p(rice)} + m_w C_{P(W)})\Delta t + m_r \lambda_f$

$= (15\times0.44 + 30\times1)\ 72 + 15\times539.39 = 10726.05$ kcal

Pot – 2, $Q_{n2} = (m_v C_{p(veg)} + m_w C_{P(W)})\ \Delta t + m_v \lambda_f$

$= (8\times0.93+8\times1)\ 72 + 8\times539.39 = 5423.68$ kcal

$Q_n = Q_{n1} + Q_{n2} = 16149.73$ kcal

Energy input, FCR :

$$\mathbf{FCR = \frac{Qn}{(cv\ x\ ¦\ g)}}$$

$$\mathbf{FCR = \frac{16149.73}{(3700\ X\ 0.65)} = 6.71\ kg/hg}$$

Reactor diameter, D:

$$\mathbf{D = \sqrt{\frac{1.27\ FCR}{SGR}} = \sqrt{\frac{1.27\ X\ 6.71}{90}} = 0.301\ m = 30.1\ cm}$$

Height of the reactor, H:

Duty hour of gasifier cook stove is 2hours,

Then FCR = 6.71 × 2 = 13.42 kg

$$\mathbf{Fuel\ holding\ capacity = \frac{Fuel\ requirement}{Bulk\ density\ of\ fuel} = \frac{13.42}{320} = 0.0419\ m^3}$$

$$\mathbf{A = \frac{FCR}{SGR} = \frac{6.71}{90} = 0.0745\ m^2}$$

$$\mathbf{Height = \frac{Fuel\ holding\ capacity}{Area\ of\ grate} = \frac{0.0419\ m^3}{0.0745\ m^2} = 0.562\ m\ (56.2\ cm) \approx 56\ cm}$$

Stoichiometric air requirement for combustion:

Amount of air required theoretically for combustion of 1kg of fuel

$$\mathbf{= \frac{100}{23}\left[\frac{32}{12}\ x\ C + 8\left(H - \frac{O}{8}\right) + S\right]}$$

$$\mathbf{= \frac{100}{23}\left[\frac{32}{12}\ x\ 0.511 + 8\left(0.0515 - \frac{0.428}{8}\right) + 0.0068\right]}$$

= 5.9 kg

Amount of air needed for gasification, AFR:

$$\mathbf{AFR = \frac{£\ x\ FCR\ x\ SA}{°_a} = 9.69\ m^3/hr}$$

Area for primary air requirement, A_p:

$$\mathbf{A_p = \frac{AFR}{°_a\ x\ v} = \frac{9.69}{1.225\ x\ 0.2\ x\ 3600} = 109.86\ x\ 10^{-3}\ m^2 = 109.86\ cm^2}$$

Secondary air requirement:

The secondary air requirement for burning producer gas was calculated by assuming general composition of gas. Oxygen requirement for different combustion reaction was taken into consideration.

Producer gas composition:

H_2	= 14.1 %
CO	= 16.72 %
CH_4	= 1.04 %
CO_2	= 12.94 %
N_2	= 55.2 %

Combustion reaction:	Volume of O_2 needed (m^3)
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	0.0104 x 2 = 0.0208
$CO + 0.5\ O_2 \rightarrow CO_2$	0.1672 x 0.5 = 0.0836
$H_2 + 0.5\ O_2 \rightarrow H_2O$	0.141 x 0.5 = 0.0705
	0.1749

$$\mathbf{A_t = \left[0.1749\ x\left(\frac{100}{21}\right)\right] = 0.83\ m^3}$$

Thus,

Gas output from 1 kg of wood

(Theoretically) = 2.2 m^3

G_t = 6.7 x 2.2 = 14.74 m^3/hr

ARC = $G_t \times A_t$

$AR_q = 14.74 \times 0.83 = 12.23\ m^3/hr$

Area for secondary air requirement:

$$A_s = \frac{ARq}{\rho_a \times V} = \frac{12.23}{1.225 \times 0.2 \times 3600} = 69.33\ cm^2$$

Insulation thickness, R:

$$R = \frac{k}{h_c} = \frac{1.34}{15} = 0.09\ m = 9\ cm$$

Total thickness of insulation, $t_i = 2 \times R = 0.18\ m = 18\ cm$

Analyse the techno economical feasibility of developed system:

The economic viability of any system is calculated through economic analysis of the system. The attempt was made to evaluate economic viability of designed community gasifier stove. Economic analysis of the system was carried out by employing following indicators

– Net present worth
– Benefit-cost ratio
– Payback period

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussion have been summarized under following heads:

Table 1 : Technical specification of community sized gasifier stove

Developed cross draft Gasifier Stove specification	
Inner diameter of reactor	30 cm
Outer diameter of reactor	48 cm
Height of inner reactor	56 cm
FCR	6.71 kg/hr
Cross sectional area	706.5 cm^2
Area of primary air inlet	109.86 cm^2
Area of secondary air inlet	69.33 cm^2
Air flow rate	9.69 m^3/hr
Capacity	18.78 kWh (16149.73) kcal)

Design of gasifier cook stove:

Constructed stove:

The schematic diagram of biomass gasifier stove is shown Fig 1. The stove system comprises a gasifier stove, which includes the gas burner and a pot support to hold two pots. The biomass-fired gasifier stove consists of three main parts *i.e.* reaction chamber, primary air inlet and combustion chamber. Different parts of the stove could be attached together by bolts and nuts and welding mechanism. The biomass stove consists of well insulated cylindrical reactor, cast iron grate and adjustable air opening from bottom end. The reactor is a mild steel cylinder having inner diameter 30 cm, outer diameter 48 cm and height about 56 cm. in order to minimize heat losses critical insulation thickness of material from cement was held by mild steel anchors welded to the inner shell. Since the technology is adopted and using a standard material, in this case is not available most of the parts of the stove have been constructed using locally available material.

The stove works natural draft gasifier stove. Primary air enters into the reaction chamber at one side, flows across the fuel bed and out in to the gas burner. Producer gas is generated while the primary air passes through the hot fuel bed, and the gas leaves the reaction chamber at the other side.

System operation:

The procedures for starting and shutting down the reactor are described below:

Starting procedure:

Fuel is first loaded in the reactor and the lid is closed. Water is filled in the water seal. The fuel is then ignited from below the grate using a flame torch through the ash pit door. As the fuel gets ignited and the gasification preceded the flame developed well at the bottom portion of the fuel, the flame is visible in the combustion chamber and smoke disappears from the chimney. About five minutes later, the torch is removed and the ash pit door is closed. The ignition builds up slowly, and it takes about 20 minutes for the combustible gases (producer gas) to generate at the gas burner side. The gases are then ignited in the gas burner by showing a flame through the secondary air holes in the burner.

Once the gas gets ignited, the flow of gas is continuous and smooth. The stove can operate continuously for several hours, until the fuel in the fuel chamber is used up. Additional fuel can be loaded through the top of the fuel chamber to further extend its operation.

The ash scraper should be operated occasionally, to break up the ash accumulated inside the reactor. This will facilitate easy flow of fresh fuel from the hopper into the reactor.

Shutting down procedure:

For stopping the gasifier, feeding of the material into the reactor is stopped. The gas is then allowed to burn as long as it is obtained from left over material. The primary air entry into the gasifier reactor is switched off by closing the sliding door provided at the bottom of the primary air inlet. After the reactor is sufficiently cooled, its bottom ash door is opened and the ash is removed. The grate is cleaned again by scraper to make the gasifier cook stove ready for the next operation.

Analyse the techno economical feasibility of developed system:

The various economic indicators are presented in Table

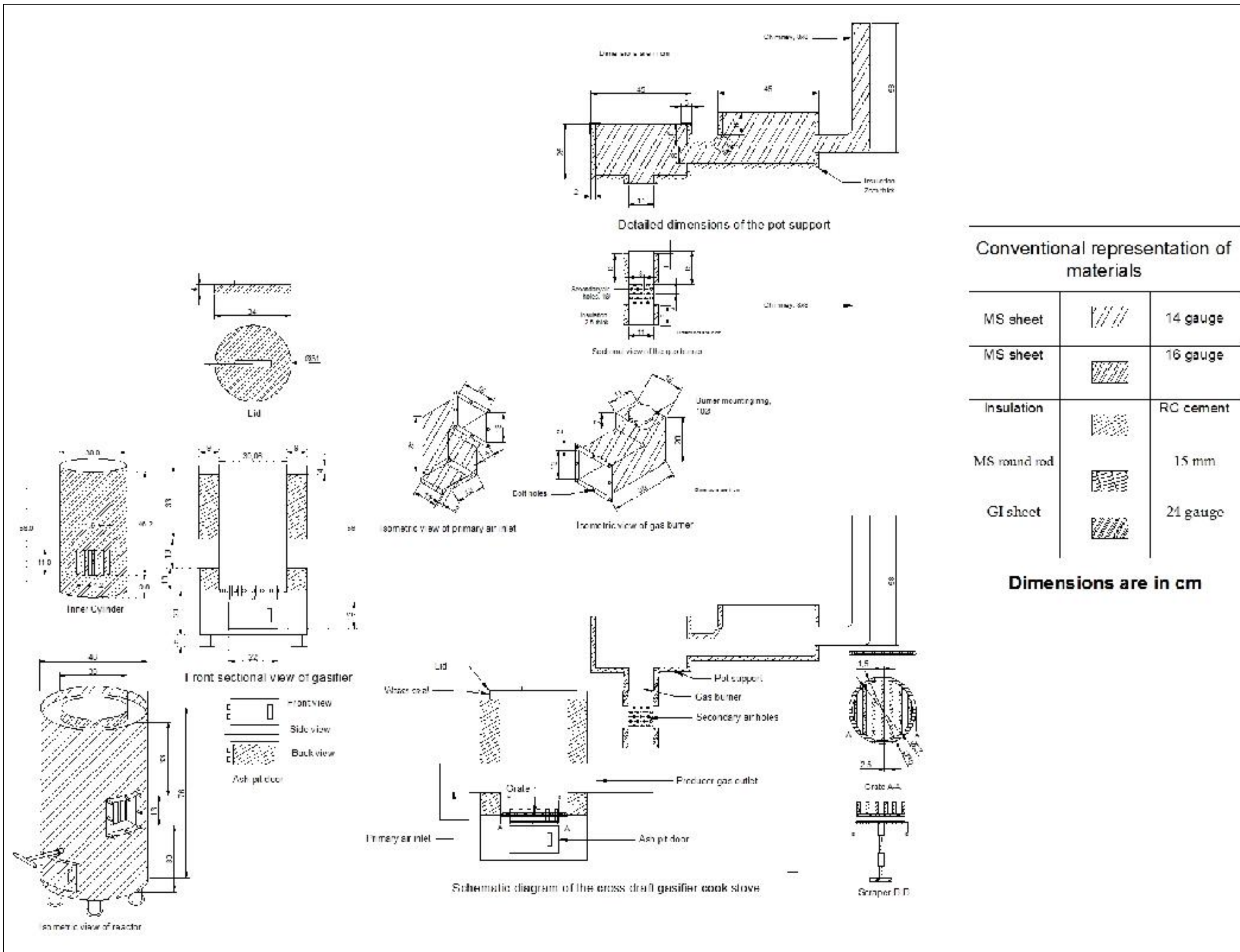

Fig. 1 : Cross draft Gasifier cook stove

Table 2 : Economic indicator for community gasifier cook stove		
Sr. No.	Economic indicator	Value
1.	Net present worth, Rs.	89927.52
2.	B : C ratio	1.27
3.	Payback period, months	6.7

Fig. 2 : Model and develop gasifier cook stove

2. The cost benefit ratio was found to be 1.27 with a payback period of 6.7 months. It can be inferred that the developed gasifier stove is technically as well as economically feasible. Similar investigationo were also made by Rathore *et al.* (2009) and Tripathi *et al.* (1999).

Conclusions:

The design of the community sized biomass based gasifier cook stove of 18.78 kWh capacity was suitable for cooking the food for above 25 member. The biomass stove consists of well insulated cylindrical reactor, MS grate and adjustable air opening from bottom end. In order to minimize heat losses critical insulation thickness of material from cement was held by mild steel anchors welded to the inner shell. This type community cook stove of has the potential to save fuel wood because it can be work on a great variety of non wood or waste wood fuels. The estimated cost of the system was

Rs. 9000/- with 6.7 months payback period and benefit cost ratio was found as 1.27. It can be inferred that the developed gasifier stove is technically as well as economically feasible.

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