Chapter V

Flexible draft biomass gasifier for small thermal applications

This chapter discusses on development of a prototype of small thermal flexible gasifier for multi-fuel use. Gasification of wood, bamboo and dry stems of Ipomoea carnea has been carried out in the gasifier. The work presented in this chapter outlines the developmental efforts on design, fabrication, trials and preliminary experimental investigations performed on the gasifier for its performance evaluation. The simple and flexible design of the gasifier would open up possibilities for applications in different end-use requirements in low power level thermal applications such as in unorganised small and micro industries in the state.

5.1 Introduction:

There are a lot of small or micro level industries in Assam, which use biomass, primarily firewood, as fuel. These industries, mostly rural and traditional, are in the unorganised sector. Recently some commercial units such as road side restaurants (Dhaba) have opted for other biomass such as rice husk as fuel due to limited supply and ever rising price of fuelwood. However, the prevailing practice of conversion of biomass to energy has been the direct combustion in traditional devices with very low efficiency. Moreover, depending on the nature of end-use process the quality and quantity of heat requirement differs considerably. A convection based direct combustion device that use solid biomass is not only inefficient and polluting, but also has other limitations such as limited power control as per the requirement of the end-use unlike liquid or gaseous fuels. A properly designed biomass gasifier may provide better efficiency, low emission, and better power control. Gasifiers are not only efficient and clean devices for energy conversion, but it promotes the biomass users to a higher position in the energy ladder, because a gaseous fuel is more convenient to use than solid fuel in terms of combustion and power control.
5.2 Earlier works:

Earlier works on gasifier systems are available in open literatures. It has been revealed that research and development on biomass gasification has attained a certain level of maturity both in terms of fundamental research and technology development. Earlier works related to thermal gasifiers with low throughput have been investigated. In this section, an attempt is made to review some earlier works on fixed bed small thermal gasifiers with special focus on the Indian sub-continent and other Asian countries.

Shrinivasa and Mukunda (1983), probably in the dawn of biomass gasifier development research in India, conducted experimental and developmental studies on wood gas generators meant for running 5 hp diesel engines. A classical downdraft gasifier of forced draft type had been tested for about twelve months. Based on the critical design inputs obtained during the study, a prototype of gas generator was built. Their efforts, in fact, helped in the development of small range gasifiers, which were needed for rural applications in India. Jorapur and Rajvanshi, (1997) reported the use of indigenously available agricultural residues to generate producer gas as an attractive alternative in developing countries like India to meet the thermal energy demands of industries. A commercial scale gasifier of 1080 MJ/h (approximately 300 kW) was developed and field tested (in a metallurgical company) to gasify low-density biomass. The system was tested by retrofitting to a special ceramics baking LDO-fired furnace. The furnace was operated exclusively on the gasification system and the product quality was at par with, if not better than, that obtained during LDO-fired operation. Tripathi et al. (1999) reported a preliminary financial evaluation on biomass gasifier based institutional cooking in India. The unit cost of thermal energy for biomass gasifier-based institutional cooking systems was estimated and compared with that for LPG and coal-based institutional cooking options. The paper revealed that biomass gasifier based institutional cooking systems had been always financially more attractive than corresponding coal-based systems and even better than LPG based systems for capacities over 58 kWth. Bhattacharya et al. (2001.a) studied different designs of bigger stoves that could be used in institutional kitchen or certain traditional rural cottage industries using rice husk and saw dust briquettes. In the Gasifier Stove (fig. 5.1a), combustion was almost smokeless under certain conditions. Highest efficiency observed
was about 16% for sawdust briquettes. The gasifier stove which showed cleanest combustion in terms of smoke could be considered for food drying in a cabinet dryer. Bhattacharya et al. (2001.b) developed a natural cross-draft gasifier stove at the Asian Institute of Technology for institutional kitchens (fig. 5.1b). Design and experimental results of this stove using wood and rice husk briquette as fuels were presented. The stove operated with practically no smoke as reported. Another advantage of the stove was continuous operation by refilling fuel into the hopper at 1-2 hour intervals. Highest utilization efficiency of the gasifier stove as determined by water boiling test had been found to be about 27% for wood fuel.

Dogra et al. (2002) reported the development of a pilot scale down-draft gasifier, which was used to investigate gasification potential of hazelnut shells. The gasifier delivered about 11 kW, of power by consuming feed in the range of 4.06 to 4.48 kg/h. The gasifier produced a good quality gas of gross calorific value of about 5 MJ/m³ at a volumetric flow rate of 8-9 Nm³/h. It was suggested that, in view of ease of operation, small-scale gasifiers can make an important contribution to the economy of rural areas where the residues of nut were abundant. Dasppa et al. (2003) in a paper addressed a low temperature and a high temperature industrial heat requirement being met using biomass gasification. The gasification system for these applications consisted of an open top down draft reburn reactor lined with ceramic. The low temperature application
system for drying marigold flowers consumed 500 kg/hr (@ 1.75 MW at 70% efficiency), which could replace diesel fuel in the range of 125-150 l/hr. The high temperature application is for a heat treatment furnace in the temperature range of 873-1200 K. A 300 kg/hr of biomass (@ 1 MW at 70% efficiency) gasifier could replace 2000 litres of diesel or LDO per day completely. The system operated over 140 h per week on a nearly nonstop mode over 4000 h of operation replacing fossil fuel completely. Dhingra et al. (2004) reported an effort on design, development and testing of gasifier based cottage basin system for silk¹ cocoon cooking in silk reeling industry. Field testing of gasifier based cottage oven had significantly improved efficiency in which 48.5% saving in fuel had been achieved along with better product quality. A vital part of their work was the technology development path chosen to achieve the desired goal, which was through a series of steps (refer to fig. 5.2). Their comment on intervention of technology, "... a majority of R & D or technology development projects generally assume that once a laboratory prototype is developed, commercialization automatically follows. This has never been the case.... till a commercial model is evolved", is a valuable point to be noted for any researcher in this field.

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¹ India ranks second in silk production in the world after China; Assam silk is famous for its unique quality and it is a prestigious and reputed traditional village industry in the country.
Belonio (2005) of Philippines successfully developed a number of low cost and environment friendly rice husk thermal gasifiers suitable for applications in rice producing developing countries. The operation of the stoves was based on inverted down draft or top lit updraft (TLUD) principle. These devices were suitable for supplying thermal energy from cooking to process heat in different small industrial applications. Details of the gasifier stoves are given in BioEnergy Lists site (http://www.bioenergylists.org). Raman et al. (2005) reported the development of a producer gas based system for steel hardening. The system consists of a batch type up-draft gasifier along with a burner and furnace. A local industry engaged in steel hardening was involved in the development process. Results have shown that the system offers better efficiency, process controllability and environmental acceptability. The producer gas system furnace attained a uniform temperature of 900°C within 30 minutes. One batch load of 20 kg steel takes 2 hours for hardening by consuming 15 kg of biomass (@ 25 kW at 70% efficiency). The system accepts wide variety of dry biomass like wood/woody agricultural residues (Ipomoea) and woody saw mill waste as feedstock. Jain et al. (2006) published a paper on design parameters for a rice husk throatless gasifier. It was found that the reactor diameter was the most critical parameter for a throatless gasifier. Five open core throatless batch fed rice husk gasifier reactors having internal diameters of 15.2, 20.3, 24.4, 30.3 & 34.3 cm had been designed, fabricated and tested. It was found that for each reactor the gasifier performance was the best at a specific gasification rate of around 200 kg/hr-m². Under the best operating conditions, the equivalence ratio was found 0.40 and the gasification efficiency was around 65%. These parameters could be used for designing rice husk operated throatless gasifiers in the capacity range of 3 kW to 30 kW. Chopra and Jain (2007) elaborately presented a review on the status of fixed bed gasification systems for biomass. Biomass gasifiers were developed primarily as fixed bed (<10MWth) and fluidized beds (>15MWth). The paper has concluded that fixed bed gasifiers were the most practical option for production of low calorific value producer gas for use in small-scale power generation or thermal applications. Saravanakumar et al. (2007a) reported on development and experimental investigations of a bottom lit updraft fixed bed gasifier suitable to work with long stick woody biomass as the feed materials. A 10 kW thermal output power gasifier for long stick wood was designed and constructed. The air/fuel ratio shows operation in a combustion mode at start up, a gasification mode
for the middle part of the run and a charcoal gasification mode at the end of the run. The rate of feed was found between 9 and 10 kg/h. It is may be mentioned here that the output power corresponding to the fuel consumption rate was considerably low which implies low efficiency of conversion in comparison to gasifiers using wood chips as feed stock. However they claimed the gasifier efficiency about 73%. Their attempt was to reduce the efforts and energy for wood chip preparation in a typical gasifier. In an another paper the same authors, Saravanakumar et al. (2007b), reported developmental efforts on a thermal gasifier in a top lit up-draft (T-LUD) mode using long stick wood with length 68 cm and diameter 6 cm. Experimental investigation and modelling study was carried out. Wood with 25% moisture content was used to run the gasifier with forced draft primary air supply to obtain 9–10 kW of thermal energy. The feed rate was between 9 and 10 kg/h. The gasifier was operated continuously for 5 hours. It is probably among the very few attempts in which a T-LUD has been used to generate gas other than in small stoves. The results of the experiments have revealed that the T-LUD gasifier would be more suitable for long stick wood as feed when compared to conventional updraft gasifier.

It is evident that research works on gasifiers have been persuaded in Asian countries for small-scale thermal applications with fuel specific designs in a certain mode of operation. The feasibility of fixed bed biomass gasifiers as an appropriate technology option in small thermal areas has been ascertained. Considering from users’ perspective as well as the manufacturers’, it would be imperative to say that a small gasifier system with flexible design would be a better technological option. However, the cost of the device should be within the reach of the potential users. A gasifier, which is simple in design, flexible in biomass selection, easy to operate and possesses operational flexibility for different end-use requirements would be a most appropriate proposition. Such attempts by earlier workers on gasifiers with multi-fuel option have been reported. However, there is no positive evidence of earlier attempt on a single gasifier, which would comply with most of the above mentioned criteria. Considering this view in mind, an attempt has been made to develop a flexible draft gasifier for multi-fuel use. The work has been organised in the following sequence to achieve the desired goal: a) to design and develop a small biomass gasifier with flexible design to operate in three different drafts, b) to perform trials on the new gasifier with at least two
different locally available woody biomass to ensure fuel flexibility, c) to perform preliminary experiments in order to study the performance of the gasifier.

5.3 Background:

The development started with fabrication of a small up-draft gasifier. The reactor consisted of a mild steel cylinder of 20 cm height and 15 cm diameter with a mild steel grate at the bottom. A mild steel pipe of 20 cm diameter and 90 cm height was welded over the reactor to be used as fuel hopper. The reactor had an external cladding with insulation made of a mixture of fire brick chips, fireclay and cement. The device was run successfully in a steady state operation with wood chips, of course, for a limited time (about 10-15 minutes). A few problems were encountered while the gasifier was tried to run in a continuous mode of operation. The problems detected were - bridging and ash-char accumulation over the grate. The bridging problem was overcome by using an inverted tapered cylindrical hopper; and the other problem was overcome by introducing primary air from radial direction of the reactor (a few holes were drilled in one side of the reactor) instead of bottom of the grate; in addition a comb type grate agitator was also incorporated as proposed earlier by Bhattacharya et al. (2001.b) in the AIT cook stove design. The result of these modifications was found quite satisfactory. Air was supplied with an electric blower (250 W) through an air control valve fitted to the inlet air pipe. Now the gasifier was successfully run for a prolonged period with small wood chips of 3-4 cm in size. The next step of the development was to go for detailed design to fix the dimensions of a gasifier for desired power level.

5.4 Design of the gasifier:

For simplicity of design, it was assumed that the device would run in updraft mode with dry pieces of solid biomass having average calorific value 18 MJ kg\(^{-1}\) as fuel to deliver thermal output of 15 kW\(_{th}\). It was also assumed that the device would run continuously for 45 minutes in a batch operation and the overall gasification efficiency would be within a reasonable limit of 60%. The third assumption was that the volume of residue was negligible in comparison to the volume of fresh biomass. The Empirical relations used by earlier researcher (Belonto, 2005; Panwar and Rathore, 2008) have been used in design calculations as presented below:
a) Energy input to the gasifier (MJ hr$^{-1}$):
\[
E_i = \frac{P_o}{\eta_g}
\]
\[
E_i = \frac{0.015 \times 3600}{60} \text{ MJ hr}^{-1} = 90 \text{ MJ hr}^{-1}
\]
b) Fuel consumption rate (FCR):
\[
m_f = \frac{E_i}{C_f},
\]
\[
m_f = \frac{90}{18} \text{ kg hr}^{-1} = 5 \text{ kg hr}^{-1}
\]
c) Specific gasification rate ($S_g$):
\[
S_g = \frac{\dot{m}_f}{A_r}
\]
Here, $S_g = 204 \text{ kg hr}^{-1} \text{ m}^2$ (taken from earlier explorative work)
d) Reactor diameter ($D_r$):
\[
D_r = (1.27 \frac{\dot{m}_f}{S_g})^{0.5}
\]
\[
D_r = (1.27 \times 5/204)^{0.5} \text{ m} = 0.1769 \text{ m}, (-0.20 \text{ m for the gasifier})
e) Reactor volume ($V_r$):
Considering height to diameter ratio of the reactor 1.25, the height of the reactor is 0.25 m and accordingly volume of the cylindrical reactor is 0.0079 m$^3$.
f) Hopper volume ($V_h$):
Hopper volume is obtained by subtracting the reactor volume from the total volume of fuel
Total volume of fuel,
\[
V_f = \frac{T \times \dot{m}_f}{\rho_b} = \frac{(0.75 \times 5)}{242} \text{ m}^3 = 0.015 \text{ m}^3
\]
\[
V_h = V_f - V_r = (0.015 - 0.0079)\text{m}^3 = 0.0071 \text{ m}^3
\]
g) Hopper height ($H_h$):
The hopper is a taper cylinder with base diameter equal to the diameter of the reactor core and the radius at the top is 0.15 cm
\[
H_h = \left[3 \times V_h\right]/\left[\pi (r_1^2 + r_2 r_2 + r_2^2)\right]
\]
\[
H_h = [3 \times 0.0071]/[(\pi(0.1^2 + 0.1 \times 0.075 + 0.075^2)] \text{ m} = 0.70 \text{ m}
\]
5.5 Fabrication of the gasifier:

A local steel fabrication unit was involved in the fabrication of the gasifier under full supervision. The intention was to make the device with minimum manufacturing facilities – an underlying objective of the work. The reactor core was fabricated with 2 mm thick fresh mild steel sheet by bending and welding into a cylinder with 38 (thirty eight) numbers of 10 mm diameter drilled holes in diametrically opposite sides. The reactor was insulated with castable refractory material (*Bhatti cement*) purchased locally and enclosed by an octagonal exterior cladding of 20 cm side and 40 cm height made of 2 mm thick M.S. sheet [Fig. 5.3a,b]. The lower part of the cladding served as the ash pit. A circular grate of 25 mm equal spacing was fitted at the bottom of the reactor to support the fuel bed and to allow the ash to fall down. The ash-pit was provided with an air tight door. A comb type agitator was provided with a handle to remove accumulated ash. The tapered hopper, insulated and enclosed by a regular cylinder of 1.5 mm mild steel sheet, was fitted with bolts and nuts at the top of the reactor. The necessary provisions were made for primary air supply and product gas outlet for cross draft. Control valves were fitted for regulating air and gas flow. The annular space at the hopper top was used as water seal. The water seal cover supports a flare pipe for up-draft and inverted down draft or TLUD operation [fig.5.4 (a, b)].

![Fig.5.3 (a, b): (a) Reactor core (Material: M.S. Sheet, 14 Gauges. Dimensions: Height= 25 cm, Diameter= 20 cm, Number of holes= 38/side, Diameter of each hole= 10 mm); (b) Reactor with exterior cladding without insulation, figure shows reactor exterior cladding, inlet airflow, cross-draft gas outlet, grate and grate agitator.](image-url)
5.6 Experimental:

This section presents the material and method used in the experimental investigation to evaluate the gasifier performance. Selection of feedstock, operational procedure and measurement issues are addressed.

5.6.1 Selection of feed stock

Two types of biomass have been selected as feed - wood chips and dry chips of *Ipomoea* of 2-4 cm size. Both of these feedstock bear similar physical and chemical properties as they were taken from the same samples used in the experiments of the gasifier stove. Therefore, the same values of calorific value have been used in the present experimental study. Accordingly, the calorific value of wood and *Ipomoea* have been taken as 17.1 MJ/kg and 13.2 MJ/kg respectively.

5.6.2 Trials and testing

Several trials were performed to fix the operational procedure on the gasifier for different modes of gasification. At this stage attention was focused on fuel feeding, start-up procedure, flaring of the combustible gas and flame control, possibility of gas leakage and shut down procedure of the gasifier.
Initially the gasifier was run in up-draft mode with dry wood chips. Fuel was loaded over the top leaving about 10 cm space at the top of the hopper. The water seal cover was placed properly. Fuel was burnt using a flaring torch below the grate. As the fuel caught fire, the blower was started and the ash-pit door was tightly closed. A few minutes later, streams of dense smoke of creamy white colour was observed which was flared with a flame. The air and gas valve was regulated to adjust the flame height and a stable flame was established. The gasifier was run for nearly two hours of continuous operation with intermediate feeding in between. The gasifier was then tested with dry chips of *Ipomoea carnea* and the fuel responded very well with adequate gas production confirmed by the brilliant flame in the flaring pipe. Next, with the same fuel types, the device was operated in the cross-draft mode. The procedure of start up was same as in up-draft. In this operation the gas outlet valve in cross draft flare pipe remained open. The gas outlet pipe has diameter twice the diameter of the inlet air pipe. Finally, in TLUD operation the hopper with exterior insulation cladding was used to serve as reactor. Fuel was burnt at the top of the bed by sprinkling a few drops of kerosene and introducing a flaming match stick. The water seal cover was placed and the blower was turned on keeping the valve in the flare pipe open. A few minutes later burnable gas evolved and it was flared. To shut down the gasifier the blower was turned off and the valves were closed.

The volumetric air flow rate was derived by measuring the velocity in the suction port of the blower with a digital anemometer (Agronic model-4822). The vane type probe of the anemometer intercepted the incoming air at right angle using a suitable hose. The fuel consumption (in up draft and cross draft operation) was measured by compensating the fuel consumed in a certain period of time with fresh feed of measured quantity. In case of the inverted down draft operation, which allows only batch feeding, the fuel consumption \( m_f \) was measured by using the relation \( m_f = (m_{fl} - m_{c, ch})/t_{dr} \), where \( m_{fl} \), \( m_c \) represent initial mass of fuel and the mass of residue (char) and \( t_o \) represents time of gasifier flaming mode operation. A digital calibrated balance of 10 kg range of 1 gm resolution was used to measure the weight of fuel and residue. Time was recorded with a digital stop watch. On shut down, the residue was removed from the ash pit with care, collected in a metal container and subsequently measured.
5.7 Results and discussions:

5.7.1 Visual observations

The brilliant steady flame in the flaring pipe without any smoke in all three operational modes confirmed sufficiency and consistency in gas production [fig. 5.5 (a-c)]. The maximum flame height was observed in up-draft operation, which was about 1 meter (refer to figure 5.5a) high. It was quite noticeable from the visible quality of the gas that T-LUD produced the most clean gas among the three processes (refer to figure 5.6). The system handled all three biomass samples without any problem such as bridging, ash accumulation etc. Wood chips and *Ipomoea* dry chips demonstrated similar flaring which indicated the potentiality of low grade biomass to be used for energy supply through gasification in order to reduce pressure on fuelwood.

![Gasifier flame in (a) up-draft, (b) TLUD, (c) cross-draft operation](image)

Fig.5.5 (a-c): Gasifier flame in (a) up-draft, (b) TLUD, (c) cross-draft operation
(Notice the invisible gas coming out from the flare tube before combustion in TLUD operation which indicates very clean gas production with minimum tar content)

5.7.2 Start-up time

Start-up time is the time required to generate combustible gas. The start up time ranged from 4 minutes to 8 minutes. More start-up time was needed for T-LUD mode. The relatively longer period in the T-LUD operation was probably due to the time necessary to produce the high temperature char layer at the top of the fuel bed necessary
to support the gasification process. In general, relatively short start-up time to generate combustible gas might be considered as an advantage of the system.

| Performance of the flexible draft gasifier for two selected biomass as fuel |
|--------------------------------------------------|---|---|---|---|
|                     | Up-draft | Cross-draft | T-LUD |
|                     | Wood     | Ipomoea    | Wood  | Ipomoea | Wood  | Ipomoea |
| Heating Value (MJ kg⁻¹) | 17.1 13.2 | 17.1 13.2 | 17.1 13.2 |
| FCR (kg hr⁻¹)          | 6.71 6.41 | 9.11 8.6  | 5.1 4.77 |
| SGR (kg hr⁻¹ m⁻²)      | 214 204  | 290 274  | 162 152 |
| Air flow (Nm³ hr⁻¹)    | 8.16 7.8  | 10.95 10.52 | 6.40 6.1 |
| Air/fuel               | 1.22 1.21 | 1.20 1.22 | 1.25 1.26 |
| ER*                   | 0.24 0.23 | 0.23 0.24 | 0.24 0.24 |
| SV (cm s⁻¹)            | 7.2 6.8  | 9.6 9.3  | 5.6 5.4 |
| Energy input (MJ hr⁻¹) | 115 85 | 156 114 | 87 63 |
| Power output** kW      | 17.6 13 | 24 17.4 | 13.3 9.6 |
| Char %                 | 11 12 | 13 12 | 9 10 |

Considering stoichiometric air for combustion of biomass 5.2 (Varunkumar, 2012). **Assuming 55% conversion efficiency only. FCR- Fuel consumption rate; SGR- Specific gasification rate; A/F-Air to fuel ratio; ER-Equivalence ratio; SV- Superficial velocity.

5.7.3 Fuel consumption

The fuel consumption rate was maximum in cross-draft and minimum in the T-LUD operation. Based on the fuel consumption rate the energy input to the gasifier was estimated. The fuel consumption rate is indicative of the relative power output from the gasifier in different draft mode. A significant outcome of the design is the capability of the gasifier to deliver variable power output for the same type of fuel as per the end-use requirements if gasification efficiency in all operational modes is considered nearly in the same level.
5.7.4 Air to fuel ratio

The air supply velocity through the hose at each run in a particular draft was measured. Then the average volumetric flow was determined. Considering ambient temperature equal to 20 °C and the density of dry air 1.20 kg m⁻³, the air-fuel ratio during the runs of the gasifier were found in the range from 1.20 to 1.26, which indicated a nominal variation for different drafts. The almost constant air-fuel ratio is a characteristic of gasification process as the higher amount of heat release due to oxidation is compensated by high consumption of char in the endothermic reduction process. Of course, the air flow rate changes to a higher value towards the end of each run (batch operation), which is an indication of end of pyrolytic gasification and the process approaching towards charcoal gasification and ultimately ends with combustion for a very short period (Sarvakumar et al. 2007b).

5.7.5 Specific gasification rate

The specific gasification rate (SGR) is an important characteristic of a gasifier, which is the amount of fuel consumed per unit operating time per unit cross-sectional area of the reactor for a particular feed stock. The SGR can be considered as the basis for comparison of different gasifiers and it is independent of the size or reactor area of the gasifier. The highest and lowest SGR of the present gasifier has been found 152 and 290 for cross-draft and TLUD operation respectively. It has been observed that the variation of SGR for the two selected biomass in a particular mode is not so significant. However, the SGR in a selected mode of operation may depend on physical and thermo-chemical properties of the biomass and its burn rate. Moisture content, volatile matter, density and bulk density of the feed stock also influence the SGR. A higher value of SGR indicates a higher value of power delivered from the device.

5.7.6 Superficial velocity (SV)

Superficial velocity is the velocity of air through the empty section of the gasifier. It is a crucial parameter of a gasifier operation. The SV of a gasifier is the most important measure of its performance, controlling gas production rate, gas energy content, fuel consumption rate, power output, and char and tar production rate (Reed et al., 1999). It is independent of gasifier size, and so permits comparison of gasifiers of
very different dimensions. The values of SV of the gasifier for different drafts have shown large variation with maximum value at cross-draft (~10 cm/s) and minimum at TLUD (~6 cm/s). Comparison of these values with other gasifier is difficult owing to unique design of the present device. However, the quantity of ash-char residue is an indication of adequate level of this velocity. A high SV causes very fast pyrolysis, producing less than 10% char-ash at 1050°C and hot gases at 1200-1400°C in the flaming pyrolysis zone and these gases then react with the remaining char to yield tars typically less than 1000 ppm, 5-7% char-ash and producer gas (Saravanakumar et al., 2007b)

5.7.7 Equivalence ratio (ER)

The equivalence ratio (ER, the amount of air added relative to the amount of air required for stoichiometric combustion) is another important parameter to characterize gasifier operation. Depending on ER, a thermo-chemical fuel conversion process may be classified as pyrolysis (ER = 0), gasification (ER=0.25-0.50) or combustion (ER ≥ 1). Desrosiers used ER values for dry- and ash-free biomass fuel of typical composition to calculate the gas phase compositions, temperatures and energy distribution curves at varying equivalence ratios (Prins, 2005). In the present gasifier, the ERs have been found almost at the same levels (0.23 to 0.24), which were deduced considering stoichiometric value of air-fuel ratio for pure combustion at 5.2 for biomass (Varunkumar, 2012). This is an indication of sufficiency of condition needed to obtain perfect gasification in the present gasifier.

5.7.8 Char conversion

The primary objective of gasification is to reduce maximum char for maximum amount of gas production. The char produced after each batch of operation was measured to find the percentage of char conversion and for all the three feed stocks and the values were found near 9-13 %. The cross draft produced maximum char-ash residue. The reason may be short length of the reactor diameter for which residence time of the gas for char conversion is reduced. Nevertheless this low amount of char indicated conversion of biomass to sufficient combustible gases satisfying the intended objective of gasification process.
5.7.9 Tar formation

The tar content of the produced gas depends on the mode of operation with minimum in T-LUD and maximum in updraft. Since the gas would be combusted in this small gasifier in an external burner with minimum carrying distance, therefore, tar treatment would require minimum intervention. In this regard dry filters such as rice husk char or cotton filters could be incorporated in the gas outlet of the system.

5.7.10 Safety in operation

Leakage of gas from the gasifier may cause health hazards as producer gas contains carbon monoxide (CO), a poisonous gas. Two possibilities of gas leakage were identified - one from the joints of the gasifier and the other during flaring. All the joints and the ash pit door were checked with a flame torch to ensure gas leakage and the result was found quite satisfactory. Any incomplete combustion of the gas could be avoided with proper burner design, preferably a pre-mixed burner, with near stoichiometric supply of secondary air for complete combustion and efficient transfer of heat at higher temperature. However the outer surface temperature of the gasifier was still high which needs further reduction. A protective cladding would prevent the chances of burning injuries.

5.8 Summary:

A small flexible gasifier has been designed and tested. Preliminary experimental results have indicated the viability of the device for low power thermal use with dry and woody biomass. The gasifier, which permits operational flexibility in three different modes, would provide solutions to avoid complicacy in design and manufacturing of different gasifiers needed for various end-uses. The simple device could be locally fabricated with minimum manufacturing facilities and thereby high cost on procuring commercial gasifiers (in absence of external financial support) could be avoided by the marginal buyers belong to the unorganised sector. The study has revealed the potential application of Ipomoea carnea as gasifier feed in the study area to replace fuelwood. Moreover, the inherent benefits in terms of better working environment, reduction in health cost, promotion to higher level in the energy ladder, better quality of product and overall economic benefits could be easily understood.