RESEARCH ARTICLE

International Journal of Science, Technology and Society
Vol 2, No. 1&2 (2016) : 01-06

Experimental Investigation of Horizontal Gasifier

R N Singh*, J B Balwanshi, V K Aharwal, and S P Singh

School of Energy and Environmental Studies, Devi Ahilya Vishwavidyalaya, Takshashila Campus, Khandwa Road, Indore, Madhya Pradesh, India

Publication Info

Article history:
Received : 26.06.2016
Accepted : 26.10.2016
DOI: 10.18091/ijsts.v2i1-2.7535

Key words:
Horizontal gasifier, Biomass,Thermal Zone, Tar, Suspended Particulate Matter.

Corresponding author:
R N Singh

Email:
rnsingh.seema@gmail.com

ABSTRACT

Vertically fixed-bed updraft gasification systems are well established, however, due to vertical orientation, the thermal zones of the gasifier are fixed, i.e. the residence time in a vertical gasifier is fixed, which sometimes creates clinkers of biomass materials having higher ash content and are responsible for discontinuation of gasification process. Considering the above problem, it was thought to move the zones (All the gasifiers has four zone named as drying, pyrolysis, reduction and combustion). Their positions are changing as per the temperature of the gasifier rather than moving the biomass. In order to overcome the limitations of a vertically fixed-bed updraft gasifier, a batch type 10 kW_{th} capacity horizontally fixed-bed updraft gasifier concept was introduced.The system was designed, developed and successfully tested to prove that the concept was viable. The horizontally fixed-bed configuration of gasifier resulted in an increased particle residence time as compared to a vertical fixed-bed system, in which gravitational forces create lower residence time. Additionally, it enhances particle to metal surface contact which results in enhanced heat transfer to the particle, thus increasing fuel conversion efficiency. A horizontal gasifier produces less tar and particulate matter compared to a vertical updraft gasifier.

1. INTRODUCTION

Among the different renewable energy technologies, biomass gasification is a promising technology for biomass and waste thermo-chemical conversion. Gasification has the advantage of low environmental impact, high effective conversion and reduced global CO_2 emissions (Devi *et al.,* 2003).

It has also been confirmed by a number of researchers that energy efficiency of gasification is higher than that of combustion (Zhang *et al.,* 2010). Gasification is a process in which carbonaceous feedstock (biomass) is heated in a closed chamber (gasifier) with a controlled amount of oxygen supply to produce a raw gas with components of CO, H_2, H_2S, CH_4, CO_2 and N_2 which could be converted into syngas (H_2 & CO) (Hindsgaul *et al.,* 2000). Most of the gasifiers used in the fields are vertically oriented.

The design of a vertical gasifier is simple with few moving parts and provides ease of control. This design results in high on-line availability, with an exception of time required to "clean out" the ash system. The gasifier operates at slightly lower pressure, which provides two benefits –

1) The fuel feed system does not have to overcome a significant pressure differential, which results in a basic, dependable feeding system.

2) Any leakage is due to ambient air entering into the controlled process conditions and not leakage of combustible Syngas out into the atmosphere, thus maintaining safe operating conditions (DST, Project Report, 2015).

However, despite these benefits, these units must go off-line for maintenance of the ash beds much more frequently. Additionally, waste fuels that are introduced in vertical systems must be limited to light weight homogeneous feed stocks or the materials will drop too rapidly through the gasification zone. Beyond the efficiency losses, this creates ash removal issues and disposal problems due to un-burnt carbon in the ash. Moreover in the existing vertically fixed-bed gasifier the thermal zones are fixed, i.e. the residence time in a vertical gasifier is fixed (based on the travel time driven by gravity as the fuel "falls" through the unit), which may sometimes lead to clinker formation for biomasses having higher ash content and are responsible for discontinuation of gasification process. Considering the above problems, it was planned to move the zones of the gasifier instead of the biomass. This may solve several problems encountered with the existing vertically fixed-bed gasifiers. It may provide more fuel flexibility and control. The control may be provided using a mechanical system or manual system that moves the fuel through different zones in the gasifier. This allows the gasifier operation to be tuned to deliver the residence time in the gasification zone based on specific fuel chemistry (Balwanshi *et al.,* 2015).

2. MATERIALS AND METHODS

2. 1 Experimental investigation of horizontal updraft gasifier

After a critical study of available literature, it was decided to design a 10 kW_{th} horizontally fixed-bed gasifier. For fixing out the dimensions of the gasifier, the output energy and input energy available in the biomass was considered. From literature 10 kW_{th} is equivalent to 8598.452 kCal which is approximately 8600 kCal. Mostly sun dried biomass is used for gasification, which have about 12- 15% moisture. Maintaining moisture content of about 12- 15% is also required for gasification process. Therefore, considering the energy content of dried biomass as 4000 $kCalkg^{-1}$ and moisture content of 15%, energy content of biomass= 4000 x (100 -15)/100=3400 $kCalkg^{-1}$. Thus the quantity of biomass required to produce 8600 kCal energy=8600/3400 = 2.53 kg. This is the theoretically calculated quantity of biomass required; however thermal efficiency of gasifier is generally taken as 70% as or more than that (Elango and Chung, 2012), (Duttaa *et al.,* 2014) depending upon the design of gasifier and operating conditions. Here for calculation purposes efficiency of gasifier is taken as 70%. Therefore, actual quantity of biomass required to produce 8600 kCal energy = 2.53/0.7= 3.61 kg.

According to Kaupp and Goss, 1984, for agriculture residues, the specific gasification rate should be between 100 - 250 $kgh^{-1}m^{-2}$, and as suggested by Jain and Goss, 2000 (Jain and Goss, 2000)specific gasification Rate (SGR) = (Weight of dry biomass, kgh^{-1})/ (Cross sectional area of reactor, m^2). Therefore cross- sectional area of reactor, m^2 = 3.61/100= 0.0361 m^2, which will give the diameter of the reactor as 0.21m. In general, density of the fire wood may be taken as 256 kgm^{-3}(Iyer *et al.,*1997), which gives the volume of the reactor required to accommodate this mass of biomass= 3.61/256 = 0.014 m^3. Hence the length of the reactor=0.39 m ≈ 0.40 m. Again, most of the researchers (Jayah *et al.,* 2003; Lamarche *et al.,* 2013; Simanjuntak and Zainal 2015), have found that for effective gasification, diameter to length ratio of the reactor should be about 1:2. More over space is also required to accommodate the grate and plenum chamber for oxidizing any medium i.e. air and for inner side insulation of the reactor. Hence, it was decided to fabricate the reactor with dimensions 0.5m diameter and 1.0 m length. It would also provide space for optimization of the reactor dimensions.

2.2 Experimental Setup and Measurement

The experimental setup consists of a 10 kW_{th} capacity horizontally fixed-bed updraft gasifier (Insulated from inside), producer gas piping, flow measuring device (orifice plate) and burner for flaring of gas (Figure1). Furniture Industry waste *Tactona grandis* fire wood blocks (30x 30 mm to 60x60mm, diagonal length) were used for producer gas generation. The characteristics of biomass (moisture content, ash content, volatile matter, fixed carbon, calorific value) were carried out as per the ASTM standards (American Society for Testing of Materials (ASTM). For estimation of zones and producer gas temperature K type thermocouples along multichannel indicator were used, however for sampling of tar in the raw producer gas, known volumes of sampling bottles (500ml) were used. Fuel consumption of biomass was measured by topping method; however for quantifying the amount of producer gas a calibrated orifice plate was used. After collecting the tar sample from raw gas it was placed in an incubator (maintaining a constant temperature of 5°C) overnight. Later, the sampling bottle was taken out from the incubator and gas was released from the bottle. The tar deposited on the inner surfaces of bottle was washed with acetone. The washed material was drained on to pre-weighed cotton

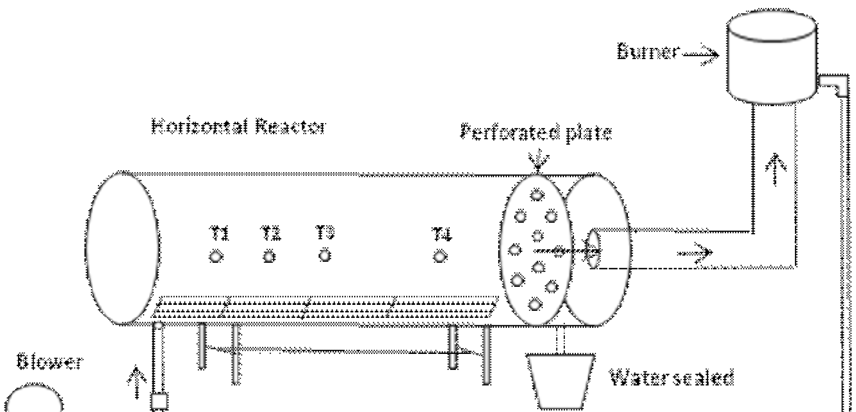

Fig.1. Schematic of the horizontally fixed-bed Updraft gasifier

placed inside the Petri dish. In order to ensure removal of tar completely from the sample bottle, it was washed two to three times. Acetone was allowed to evaporate using hot air oven, resulting in tar and pre-weighed cotton. Weight of cotton along with tar minus weight of cotton gave the amount of tar in the known volume of producer gas. Gasifier was operated as per the method suggested by Parikh and Arikkat, 1985 and Reed and Das, 1998.

3. RESULTS AND DISCUSSION

3.1 Performance evaluation of horizontally fixed-bed Updraft gasifier

A 10 kW_{th} horizontally fixed-bed updraft gasifier with dimension 0.5 m dia. and 1 m length was tested with a number of combinations such as - for gasification air supply was made tangential through a nozzle making an angle of 45° with the upper half circumferential portion of the gasifier reactor. On doing so, the gasifier produced gas for a period of 15-20 minutes. Later, the reactor was modified and air supply was made axial through a nozzle of 25 mm diameter. Even after this change no improvement was observed in the production of producer gas quality. It was observed that air was following the shortest route due to which pressure was not developed inside the reactor. To overcome this problem a perforated (2 mm diameter hole) metal sheet of 1 mm thickness was placed in front of the air inlet and another perforated (8 mm diameter hole) metal sheet of 4 mm was placed on the opposite side of the reactor. Even after these modifications no improvement was noticed. A trial run was performed by inserting a perforated pipe having dimensions of 50 mm × 850 mm with anaxial hole of 8 mm diameter throughout the centre of the reactor. Within 8-10 minutes, combustible gas was available at the burner; however the producer gas could not sustain for more than 20-25 minutes.

Finally it was decided to re-design and fabricate another reactor with dimensions of 0.32 m diameter, 1 m length and 5 mm thickness with a grate (13 mm) at the lower surface. Hopper arrangement was not provided in this reactor as the biomass feed was axial. To control the supply of air to reactor and to the burner, a blower (0.52 kW) with control valve arrangement was provided through a 38 mm diameter pipe. For uniform ignition of biomass five air vent pockets of 38 mm diameter were provided throughout the circumference of the reactor. A 63.5 mm diameter pipe was also provided for the collection of producer gas, which was mounted on the top centre line at the other end of reactor (Figure 2). A 0.31 m diameter perforated plate (8 mm dia. hole) was also inserted in the reactor before collection of the producer gas which ensured uniform flow of producer gas. To maintain the quality of biomass used in the gasifier, proximate analysis (ASTM, 1983) of biomass (*Tactona Grandis*) was carried out and the average results of five samples are tabulated in Table 1. Detailed performance of the gasifier is presented in Table 2.

Fig. 2. Horizontal gasifier in operation after insulation

To optimize the air - fuel ratio of the reactor, number of trial were taken at gasification air velocity 2.0 ms^{-1} to 3.6 ms^{-1}, however 2.5 ms^{-1} gasification air velocity was found optimum for fire wood (*Tactona grandis*) in a horizontally fixed-bed updraft gasifier. It was also noted that an increase in air velocity up to certain limits provided an increased oxidation of fuel and hence higher production of CO_2 and less production of combustible gases (CO, H_2 & CH_4).

To confirm whether the reactor zones were moving forward or not, a temperature profile of the reactor was taken. Temperatures were recorded at different locations {T_1, at 0.33 meter from air supply to reactor; T_2, at 0.46 meter from

Table 1. Proximate Analysis of fire wood biomass

Sr. No.	Biomass	Moisture content, %, wb	Volatile matter, % db	Ash content, % db	Fixed carbon, % db	Calorific Value, $kCalkg^{-1}$
1.	Tactona grandis (Sagaun)	5.76	77.77	0.81	21.42	4445.22

Calorific Value of *Tactona grandis* at 5.76% moisture content = 4223.84 $kCal/kg^{-1}$

Table 2. Performance of Horizontal gasifier

Sr. No.	Parameters	Values
1	Weight of Biomass	17 kg
2	Charcoal	1 kg
3	Starting time of gasifier	12:40 pm
4	Flaring of Producer gas	12:50 pm i.e. 10 min
5	Operating time of gasifier	18 hours (Cumulative)
6	Quantity of Tar and SPM in producer gas	52 gNm^{-3}
7	Fuel consumption rate of gasifier	6.1- 6.3 $kg^{-}h$
8	Flame temperature of producer gas	750-800ºC
9	Calorific value of Biomass	4482 $kCalkg^{-1}$
10	Calorific value of producer gas	1010 kCal Nm^{-3}
11	Generation rate of producer gas	2.72 -2.95 Nm^3 kg^{-1} of biomass

air supply to reactor; $T_{3,}$ at 0.58 meter from air supply to reactor, $T_{4,}$ at 0.89 meter from air supply to reactor} and at different intervals. Variations in the value of the temperatures at each zone {Updraft gasifier have four zone; from Top to bottom, drying Zone temperature ranges 30ºC -160ºC; pyrolysis Zone temperature ranges 200ºC -800ºC; Reduction Zone temperature ranges 900ºC -400ºC and finally Combustion Zone temperature ranges 850ºC -1200ºC clearly indicated that zones were moving as its following the same trends, discussed by Kaupp and Goss, 1984 and Read and Das, 1988 and hence the concept was proved (Figure 3).

The average value of (seven samples) fuel consumption rate and producer gas generation rate obtained during different trial are tabulated in Table 3. The average calorific value of producer gas (Table 4) was considered for estimating the thermal efficiency of horizontal gasifier. A critical review of contents in Table 3&4 and Figure 3 reveals that though the developed gasifier is behaving as per the expected concept i.e. zones of reactor are moving horizontally, still sustainability of combustible gas could not be maintained for longer durations throughout the experiment.

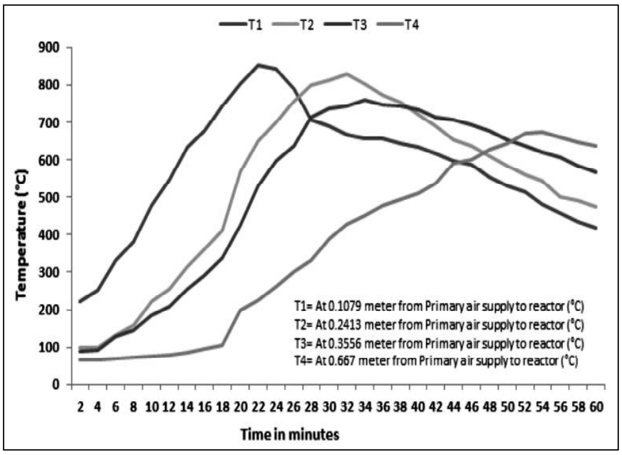

Fig. 3. Variations of gasifier Zone temperatures with time

In order to improve its performance, the whole reactor was insulated (inside 10-12 mm fire-cement insulator and outside Cera-wool blanket) to enhance the life of the reactor and to maintain desired reactor temperature. Again a trial runwas carried out after insulating the reactor which provided encouraging results as well as sustainable quantity of combustible gas could be maintained throughout the duration of experiment.

The gasifier was later on operated for a cumulative period of about 18 hours using*Tactona Grandis*. The composition of producer gas obtained is tabulated in Table 4. For estimating the energy content of producer gas; standard energy content of gases (obtained from Gas chromatograph) such as CO, H_2 and CH_4 were multiplied with their composition in producer gas and summation of all gases provided the energy content of producer gas. Though producer gas contains CO_2, N_2 and other inert gases, for estimation of energy content of producer gas only combustible components were considered (Table 4). The energy content of producer gas was also verified with the help of Junker gas calorimeter, which gave the direct energy content of producer gas. Tar and SPM content of producer gas obtained from horizontally fixed-bed updraft gasifier was compared with that obtained from vertically fixed-bed updraft gasifier available in the department. It was observed that a horizontal gasifier produced less tar and particulate matter compared to vertical updraft gasifier (Table 5). This may be due to horizontally fixed-bed configuration of gasifier, which might have increased the particle residence time when compared to a vertical fixed-bed gasifier.

Table 3. Biomass consumption and Producer gas generation

Sr. No	Biomass consumption rate, kg/hr	Producer gas generation, $Nm^3\ kg^{-1}$ of biomass	Producer gas generation rate, Nm^3h^{-1}	Thermal efficiency, ηth, %
1	6.1	2.902	17.70	68.3
2	6.3	2.722	17.15	64.1
3	6.1	2.993	18.25	70.5
4	6.2	2.677	16.60	63.1
5	6.3	2.722	17.14	64.1
6	6.1	2.721	16.60	64.1
7	6.2	2.945	18.26	69.4
				Average = 66.22

Table 4. Producer gas composition and its Energy content

Sr. No.	Producer gas Composition						Energy content of Producer gas, $kCalNm^{-3}$
	CO,%	H_2,%	CH_4, %	CO_2,%	N_2, %	O_2,%	
1	16.337	12.6	1.3	12.4581	54.3452	Balance	1036.357
2	18.037	12.2	0.83	12.0239	53.4592	Balance	1030.687
3	16.456	12.34	1.1	11.5651	58.289	Balance	1012.202
4	15.681	9.3	1.3	12.25	55.9025	Balance	911.7886
5	16.758	11.12	1.2	12.423	57.1146	Balance	993.028
6	16.12	12.1	1.1	12.1901	57.8572	Balance	994.1224
7	16.193	12.3	0.95	12.1035	55.8061	Balance	987.9512
				Average			**995.1625**

Table 5. Comparison of Tar and SPM in Horizontal Gasifier V/s Updraft gasifier

S. No.	Vertically fixed-bed Updraft gasifier	Horizontally fixed-bed Updraft gasifier
	Tar and SPM content, gNm^{-3}	Tar and SPM content, gNm^{-3}
1	90.73	85.09
2	85.13	74.85
3	88.21	66.73
4	78.95	64.18

4. CONCLUSION

A batch type 10 kW_{th} capacity horizontally fixed-bed updraft gasifier was designed, developed and successfully tested. Due to horizontally fixed-bed configuration of gasifier, there was an increased particle residence time as compared to a vertical fixed-bed system, wherein gravitational forces created lower residence time. Additionally, it also enhanced particle to metal surface contact resulting in promoted heat transfer to the particle, thus increasing fuel conversion efficiency. The horizontal gasifier produced less tar and particulate matter compared to a vertical updraft gasifier.

ACKNOWLEDGMENT

The authors wish to acknowledge the financial support received from Department of Science and Technology, India (DST/TSG/AF/2011/86, for the project entitled "Design and Development of Horizontal Gasifier for Biomass").

REFERENCES

American Society for Testing of Materials (ASTM), Annual book of ASTM standards. Philadelphia: ASTM 19103; 1983.

Balwanshi JB, Aharwal VK, Singh RN, Singh SP and Asha D (2015). A Novel Concept for Biomass Gasification, was presented as poster at, 4th Bhartiya Vigyan Sammelan (BVS) & Expo 2015, held at Kala Academy, Panaji-Goa on 5-8 February 2015.

Devi L, Ptasinski K J and Jansen FJJG (2003). A review of the primary measures for tar elimination in biomass gasification processes. *Biomass Bioenergy,* 2003, 24:125–40.

DST, Project Report, 2015. Design and Development of Horizontal Gasifier for Biomass Materials, (DST File No: DST/TSG/

AF/2011/86) Submitted by Centre of Energy Studies and Research Devi Ahilya Vishwavidyalaya, Indore.

Duttaa PP, Pandeya V, Dasa AR, Sena S and Baruahb DC (2014). Down Draft Gasification Modelling and Experimentation of Some Indigenous Biomass for Thermal Application. *Energy Procedia,* 54: 21 – 34.

Elango Balu and Chung JN (2012). System characteristics and performance evaluation of a trailer-scale downdraft gasifier with different feedstock. *Bioresource Technology,* 108: 264–273.

Hindsgaul, C, Schramm, J, Gratz, L, Henriksen, U and Bentzen Dall J (2000). Physical and chemical characterization of particles in producer gas from wood chips. *Bioresourse. Technol,* 2000, 73:147–155.

Iyer PVR, Rao TR, Grover, PD and Singh NP (1997) Biomass: Thermo-chemical Characterization, Published by Biomass Gasifier Action Research Centre, Biomass Conversion Laboratory, Chemical Engineering Department, I I T, New Delhi.

Jain Anil K and Goss John R (2000). Determination of reactor scaling factors for throatless rice. *Biomass and Bioenergy*; 18: 249-256.

Jayah TH, Aye Lu, Fuller RJ and Stewart DF (2003). Computer simulation of a downdraft wood gasifier for tea drying. *Biomass and Bioenergy*; 25: 459 – 469.

Kaupp Albrecht and Goss John R. (1984). Small Scale Gas Producer Engine System. Published by Friedr. Vieweg & Sohn Braunschweig/ Wiesbaden.

Lamarche Pierre, Tazerout Mohand, Gelix Franck, Köhler Stefanie, Mati Karim, Paviet Frédéric (2013). Modelling of an indirectly heated fixed bed pyrolysis reactor of wood: Transition from batch to continuous staged gasification. *Fuel*;106: 118–128.

Parikh PP and Arikkat P (1985). Scope and limitations of utilization of biomass- based producer gas in dual fuel operation of existing diesel engines. proc. of II[nd] International Producer gas Conference held at Bandung, Indonesia.

Reed TB and Das A (1998). Handbook of Biomass down draft gasifier engine system. IInd edition, Published by Solar Energy Research Institute, U.S. Dept. of Energy.

Simanjuntak JP and Zainal ZA (2015). Experimental study and characterization of a two-compartment cylindrical internally circulating fluidized bed gasifier. *Biomass and Bioenergy*, 77: 147-154.

Zhang Y, Kajitani S, Ashizawa M and Oki Y (2010). Tar destruction and coke formation during rapid Pyrolysis and gasification of biomass in a drop-tube furnace. *Fuel*, 2010, 89:302–309.