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DESIGN AND DEVELOPMENT OF DOWNDRAFT VENTURI TYPE GASIFIER

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ABSTRACT

The most promising future application of the thermo chemical gasification of biomass will require generating a quite clean gas and having trouble free operation of gasifier. These two facts necessitate an optimized design of gasifier. Commensurate with this the objective of present work is to develop a new Venturi type gasifier.

In the present gasifier to avoid the flow problem a special proking arrangement through the air nozzle kept in vertical. The proking arrangement centrally in all zones, so that proper mixing of biomass can be achieved. To measure the temperature at various positions in the gasifier, thermocouple probes were designed. These thermocouple were made of chromal-alumil having temperature range 0–1200 ^{0} C. The set up has facility for simultaneous measurement of temperature and gas composition investigations have been carried out with two biomass materials i.e. Peltophorum and babul wood. The different particle size considered were 10 mm*10mm (100 mm^2), 10mm*15mm (150 mm^2) and 15mm*15mm (225 mm^2).

It is observed that the flames for various wood sizes were obtained within short period of 3-6 minutes. Gas generation rate was nearer to design point in venturi type gasifier indicating the worthines of this gasifier. Further, from the experimental investigation, it is observed that small particle size offers better quality in terms of better gas calorific value and reduced tar. Higher temperatures achieved in venturi type gasifier are responsible for offering minimum tar levels. Thus it may be stated that present venturi type design may be adopted for obtaining consistent good quality gas for continuous operation.

Keywords: Design, Venturitype, Gasifier.

1. INTRODUCTION

Scanning through the published literature it is found that most of the published design approaches are based upon empirical rules for which practically no explanation is available. There is no unanimity regarding these design rules, so much so that it has been called as an art rather than science [1, 2]. However, there do exist some sincere efforts towards documentation of design rules for gasifiers based on simplified theoretical calculations and evaluation of existing gasifier designs. There is Evidence of Imbert design having been used most extesively [3]. The design recommendation regarding the no. of air nozzle and their orientation is mostly governed by the consideration of achieving a uniform temperature of oxidation zone. Several investigators [1,2,3,4,5] have recommended five radial nozzles where as Groenveld [6] has used a central single nozzle. Susanto has used two nozzles with provision for pyrolysis gas recirculation for minimization of the tar. Bhagwat [7] and Parikh [8] found introduction of a Swirl component beneficial in tar minimization. They have used three nozzles, air entry velocity varying from 3 to 9 m/s and the height from the throat as 100mm, which is in conformity of the findings of Nordenswan [4]. Prasad [9] worked on optimization of the several components in terms of the air entry velocity direction, which was varied from radial to tangential. He concluded that 45^0 to 60^0 to the radial direction give better results with reference to tar minimization and overall performance of the gasifier.

Venselaar [5] and Graf [10] have evaluated optimal nozzle configuration on the large no. of successful gasifier designs and presented these data in a very convenient form as a function of hearth/throat diameter. It is worth stating over here that presently, the design rules outlined by Venselaar [5] and Graf [10] forms the basis of down draft gasifier design.

Channiwala [11] found from his extensive research work that gasifier produces best gas at 45^o, best cold gas efficiencies at 60^0 and minimum tar levels between 60^0 and 75^0. Although in general orientation angle vary between 45^0 to 75^0, best compromise for all the combination is obtained at 60^0.

Based on the actual recording of axial temperature profile Channiwala and Parikh etc. al [12] have reported the pyrolysis zone length to be not exceeding 100 to 150 mm, the measurement being for wood gasifier of 15 to 20 kWe capacity. They also observed a marked difference in the pyrolysis zone length when operating on blower and engine mode and accordingly stated that the gasifier designs are not only biomass specific but also application specific.

The height of the oxidation zone decides the residence time of pyrolysis gases as well as pyrolysed biomass while passing this zone. The axial temperature obtained by channiwala [11] clearly indicated this dimension to be about 50 to 100 mm.

Reduction zone length is an extremely important design parameter to which the gasifier performance is highly sensitive. Channiwala [11] based on his extensive studies on temperature profile correlates this height with throat diameter

The conclusions based upon the research work of Channiwala [11] on flowability studies are given below and which is also a base for selecting the various designing parameters for the present work.

(1) The quarter cylindrical shaped particles of 25 mm size emerge as the best flowing particle in the investigated range of D/d_p of 8 to 20.

(2) The ratio of throat diameter to particle size, D_{th} / d_p may be taken as 5 for free flow condition for the woody biomass material.

(3) The minimum value of the ratio of bed height to container diameter may be taken in the range of 1.3 to 1.7 for better flowability in the investigated D/d_p range.

(4) The radial air entry velocity of 7 m/s gives the better flowability of the material under the investigated test conditions.

(5) The nozzle height in the range of 50 to 100 mm may be selected for improved flowability.

(6) Nozzle orientation does not have any significant effect on the flowability of the material under the investigated range of test conditions.

Channiwala's [11] experimental investigation conclude the following regarding various other experimental results which are extremely important for the present design considerations.

(1) Biomass flow depends upon the shape and size of the particles. Quarter cylindrical particles are found to be better flowing particles.

(2) It was found that an SGR (Specific gasification rate) of 3000 ± 10 % $Nm^3/h\text{-}m^2$ gave the best performance.

(3) The axial temperature profiles recorded under different SGR's indicate that constituent processes of gasification take place within about 500 mm from the throat. This suggests that with continuous biomass feed, the hopper height could be limited to about 500 mm which in turn would resolve most of the flow related problems.

(5) Provision of a tangential velocity component to the air entry is beneficial from point of view of tar minimization. In the experimental research gasifier 60^0 orientations to the radial gave minimum tar without affecting the performance levels.

(6) Presence of water-seal influences the gas CV adversely but helps in considerable reduction of tar through reformation reactions. Results clearly indicate possibility of optimizing the water-seal design to minimize the performance impairment. The parameters to be optimized are the exposed water-surface area and the distance between the water-surface and grate.

The actual data generated in his study can be used in design and development of gasifiers, particularly in matching the sub-systems and also in deciding the design criterion of the gasifier unit.

Ratnadharia [13,14] developed a 3 zone kinetic free model modifying few assumptions of channiwala and obtained good assessment of theoretical predictions with experimental results. He used cobalt catalyzed wire mesh in reduction zone, used specific gas exit path and injected moisture in reduction zone and with these innovations he could really developed a tar free gasifier.

2. DESIGN OF DOWNDRAFT VENTURI TYPE GASIFIER

A 25 KW (Thermal) capacity Venturi type down draft woody biomass gasifier is designed as per existing design methodologies presented by various researchers as discussed earlier. Most of them however are taken from an extensive work of channiwala [11]. Further, the present gasifier is designed with a specific aim to obtain continuos flow of biomass and to avoid choking due to Venturi shape of the gasifier.

2.1 Design data:

Output = 25 KW (Thermal).

CV = 4800 kJ / Nm^3.

Qg = 18.75 Nm^3 / hr.

2.2 Design of throat

$A_{th} = Q_g / SGR$

SGR=3000 N m^3/h

Also $A_{th} = (\pi/4)D^2_{th}$

D_{th} = 90 mm, L_{th} = 50 mm

For better flowability:

$D_{th} / d_p = 6$

Limiting value of d_p = 16.00 mm. or less

2.3 Length of pyrolysis zone above throat:

Temperature profile of channiwala[11] indicates effective length to be less than 400 mm.

Let $D_s / d_p = 16$.

D_s = 290 mm.

Let $H / D_s = 1.5$

H = 432 mm

$\tan \theta = 100/ H$.

Take $\theta = 30^0$.

H = 173 mm.

Select: D_{th} = 100 mm

H =200 mm.

D_s=300 mm.

2.4 Reduction & Oxidation zone length:

Let us give 1 s as reduction time for gas & mean superficial velocity as 0.4 m/s.

L = 400 mm.

Now $H_N / D_{th} = 0.6$.

Air entry point is 60 mm above throat.

Throat length is D_{th} / 2 = 50 mm.

L_D = 400 –60 –50 =290 mm.
L_R / D_{th} =2
Selecting L_R = 200 mm.
tan θ = 50/ 200. **(4)**
θ =14.5^0.

2.5 OVERALL SHELL DESIGN:

DRYING ZONE SHELL
Diameter: 300 mm Length: 250 mm.
CONVERGENT SHELL
Upper Diameter: 300 mm
Lower Diameter: 100 mm Length: 250 mm.
THROAT
Diameter: 100 mm Length: 50 mm.
DIVERGENT SHELL
Upper Diameter: 200 mm
Lower Diameter: 100 mm Length: 200 mm.
LOWER SHELL
Diameter: 200 mm Length: 300 mm.
OVER ALL LENGTH OF SHELL= 250+250+50+200+300 =1050 mm
The material used is M. S. Sheet of 3-mm thickness. The details are given in Fig 1.

2.6 Special provisions:

(1) Design of Thermocouple Probe

To measure the temperature at various positions in the gasifier thermocouple probe were designed. The probe has been designed so as to increase its lifeline. For measuring the temperature of the different zones in the gasifier, we have used 16 thermocouples. For obtaining gas sample at various position in the gasifier copper tubes were placed in the thermocouple probe

Twin hole ceramic bids have been used as an insulator over Cromul-Alumil wire and thermocouple was prepared. This thermocouple has been placed. The thermocouple and ceramic bids were placed within an 8 mm diameter inconal tube which withstanding temperature up to 1200^o C and protects the thermocouple junction. The inconel tubes within the gasifier have been tapered so that the thermocouple does not come in direct contact with high temperature within the gasifier. These thermocouple were made of chromal-alumil having temperature range 0^oC –1200 ^{o}C.

(2) Proking arrangement in venturi type gasifier:

To avoid the flow problem a special proking arrangement through the air nozzle kept in vertical resting on hopper by means of M.S. bar 2 mm thick and 600 mm length. The proking arrangement is centrally in all zones, so that proper mixing of biomass can be achieved and it will ensure the continuous flow of biomass and avoid choking if any.

(3) Water Seal for continuous ash disposal and ease in maintenance.

(4) Provision of conical shape M.S. plate on elbow of 2" diameter for suction of gas below grate.

3. EXPERIMENTAL INVESTIGATION

Objectives of the experimental work include the following:

(i) Establishment of the validity and utility of the experimental setup designed and developed.
(ii) To carry out the parametric studies needed for design and performance optimization of gasifier system.

The set up has facility for measurement of zone temperature, pressure drops, flow rates, tar and gas sampling points. Total 16 calibrated k-type thermocouples are placed in various zones of venturi type gasifier. The performance trials were conducted with peltophorum (10mm*10mm cubical) babul wood (15mm R Quarter cylindrical) Table 1.Gives the elemental analysis and proximate analysis of the Peltophorum and babul wood.

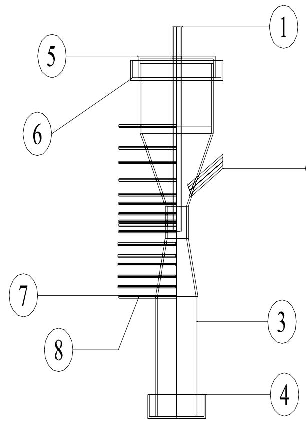

Fig 1. GASIFIER ASSEMBLY

8.	INCONAL TUBE	INCONAL	16
7.	THERMPCOUPLE	CHROMER-ALUMIL	16
6.	UPPER WATER SEAL	M.S.	1
5.	HOPPER	M.S.	1
4.	LOWER WATER SEAL	M.S.	1
3.	GASIFIER	M.S.	1
2.	FIRING NOZZLE	M.S.	1
1.	AIR NOZZLE	M.S.	1
No.	Part Name	Material	Quantity

The gas generation rate was varying and the exit gas quality, temp profile and the gas composition profile along the length of gasifier was measured using the special probe develop during the course of this work.

Table 1: Elemental and Proximate Analysis of Biomass

Bio Mass	Ultimate Analysis (Dry basis) % by Volume					Proximate % by weight	HHV (KJ/Kg)
	C	H	O	N	S	ASH	
*1	44.8	4.9	47.6	0.8	_	1.734	16480
*2	43.6	5.2	47.0	0.5	_	3.482	16536

* 1 Peltophorum *2 Babul wood

4. RESULTS AND DISCUSSION

4.1Effect of Gas Generation Rate (GGR):

The gas generation rate obtained for both type of wood corresponds to value ranging from 11.927 to

18.35 Nm^3/ hr. Fig 2. and Fig 3. Shows the effect of gas generation rate on gas CV and tar respectively.

4.1.1Effect of GGR on Gas Calorific Value:

Fig 2. Presents the effect of GGR on gas CV. Peltophorum wood as a biomass feed stock gas CV increasing with increasing GGR, maximum gas CV in the vicinity of 16.87 Nm^3/hr. thereafter starts to decrease. Drop in calorific value at higher flow rates can be explained on the basis of inadequacies of biomass flow inducing marginal burnout of the reduction bed. Also higher equivalence ratio drives the gasification reactions towards combustion reactions and hence the calorific value of gas will obviously reduce.

4.1.2 Effect of GGR on Gas Composition:

Table 2. Shows the Dry gas Composition for both biomass feedstocks. Levels of CO, H2 are obtained for peltophorum feedstocks are better than babul wood. It clearly reveals that the gas quality influence is also depends upon types of biomass and particle Shape and Size.

Table 2: Dry Gas composition

Sr No.	Bio mass/ Size	Dry Gas Composition (% By Volume)					GGR m^3/hr
		CO	CO_2	H_2	CH_4	N_2	
1	Pelto	26.69	13.33	23.34	1.77	34.67	16.86
2	Phoram	23.81	12.68	20.28	1.25	41.98	14.36
3	10*10 mm^2	17.49	12.49	21.16	0.36	48.50	17.38
4	Babul	13.59	13.51	22.39	0.39	50.12	16.86
5	wood	18.72	11.30	23.90	0.25	45.83	12.65
6	Avg	17.43	12.51	23.42	0.54	46.10	16.76
7	15mm	16.01	10.48	23.66	0.27	49.58	12.93
8	Dia	21.27	6.99	20.16	0.14	51.44	12.93

4.1.3 Effect of GGR on Tar Content:

Fig 3. Shows the effect of GGR on tar using peltophorum wood as a biomass feed. Maximum tar is obtained with low GGR and it starts to decrease with increasing GGR .The minimum tar level is obtained at GGR in the vicinity of 16.87 Nm^3/h. Thereafter it increasing with increasing GGR.

4.2 Temperature Analysis:

The temperature at different zone of down draft venturi type gasifier was measured with 15 thermocouples above grate and one below grate and one at the exit of gasifier. The temperature profile for both peltophoram and babul wood was obtained by recording temperature at an interval of 5min. The maximum temperature recorded for pelophoram wood was 1039 °C and for babul wood, it was 1026.54°C.

The temperature profile clearly identifies various zones of gasifier. It is interesting to note that the maximum temperature in this gasifier is observe to be in the throat region, which is slight below air nozzle opening, at the air nozzle opening volume of the material present is more than the volume of material present at the throat, hence more homogeneous oxidation zone is observed at the throat region. Fig 4. Shows the typical temperature profile along the length of the venturi type gasifier using peltophorum biomass as feedstock.

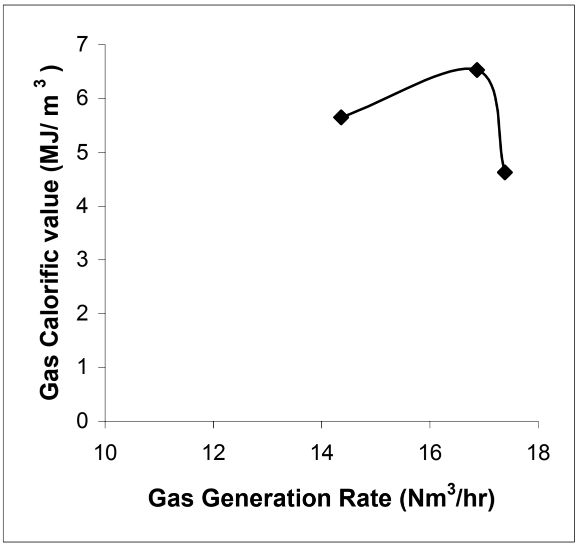

Fig 2. Effect of Gas Generation Rate on Gas Calorific Value.

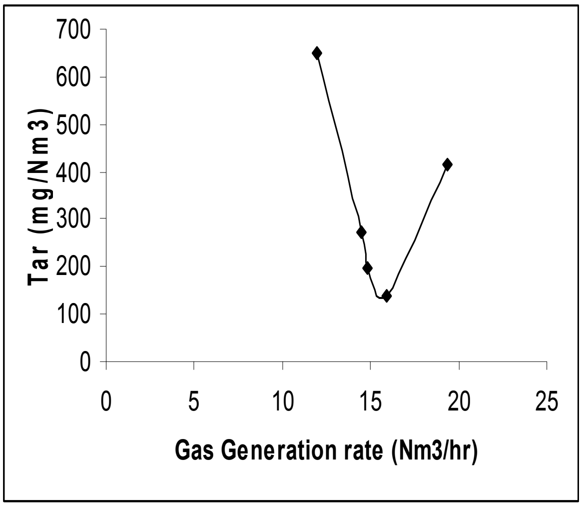

Fig 3. Effect of Gas Generation Rate on Tar level

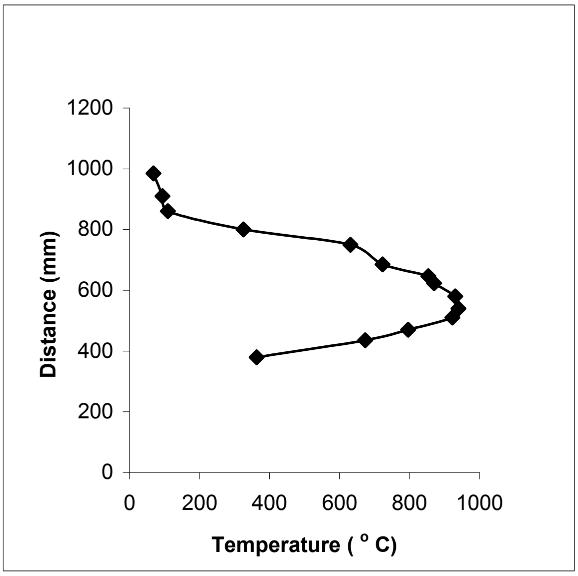

Fig 4. Temperature Profile above the grate level

5. CONCLUSIONS

Based on the experimental work carried out on venturi type gasifier the following conclusions may be derived.

1. In this gasifier, it is observed that small particle size offers better gas quality in terms of higher gas calorific value and reduced tar content which is basically due to availability of high reaction area with reduced particle size.
2. The higher gas generation rate result in deterioration in gas quality irrespective of the gasifer type and feedstocks, due to gasifier operation away from solid carbon conversion boundary.
3. The higher gas generation rates are possible to be achieved with the venturi type gasifier due to reduced flow resistance of venturi shape. The design point gas generation rate could be achieved with venturi type gasifier.
4. The tar content in venturi type design is less due to higher temperature level achieved in venturi type gasifier.
5. It is observed that the optimum gas quality and minimum tar have been achieved at GGR in the vicinity of 16.87 Nm^3/hr.

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8. NOMENCLATURE

Symbol	Meaning	Unit
CV	Calorific value	kJ/Nm^3
Qg	Gas generation rate	Nm^3/hr
HHV	High Heating Value of Fuel on Dry Basis	kJ/kg
GGR	Gas Generation Rate	Nm^3/hr
SGR	Specific Gas Generation	Nm^3/hr
D_s	Rate	mm
D_{th}	Diameter of the shell (mm)	mm
Dp	Throat diameter	mm
H	Particle diameter	mm
H_N	Height of shell	mm
L_R	Height of Nozzle	mm
L_D	Reduction Zone length	mm
θ	Divergent section length	
A_{th}	Divergent, convergent Angle	mm^2
	Area of throat Section	