Design and Analysis Of Down Draft Biomass Gasifier using Computational Fluid Dynamics

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Abstract. *The gasification technology is now considered to be in an advanced stage of development. Hence there is huge expectation from the user industry for its application. The aim of this paper is focused on analysis of reduction chamber or zone for different changes in choke plate design. The choke plate itself is an integral part of reduction zone and thus analysis of reduction zone or choke plate is one and the same. For this purpose a 100 kW down draft biomass gasifier system is designed using empirical data and derived quantities. The changes made in choke plate include no. of nozzles, diameter of nozzle and nozzle inclination angle. In this paper airflow analysis, temperature distribution across the chamber and mass concentration of gasification products has been analyzed by CFD method using CFX 5.5.1 software.*

Keywords: CFD, Biomass, Gasification

1. Introduction

Gasification is a high temperature chemical process in which solid fuel is reacted with a limited supply of air or oxygen to completely convert all the carbonaceous material into a fuel gas. Thus thermo chemical characteristics of biomass play a major role in the selection of the gasification system design and performance [1].

The efficiency of the biomass gasifier depends on the design of choke plate, flow of air and combustion process. This work concentrates on the analysis of combustion chamber for different changes in the design of choke plate of down draught biomass gasifier. In order to do this work, a gasifier system connected to 150 HP diesel engine is taken for the design of choke plate.

2. Design Of Down Draft Biomass Gasifier

In downdraft gasifiers, (Co-current) the biomass feed and the gas stream moves in the same direction. The downdraft gasifiers can be of two types. Those having, throat type design (including choke plate) and those with open core design. Throat type gasifiers are used for biomass fuels with low ash and uniform size, while open core gasifiers can tolerate more variation in fuel properties like fuel moisture, size and ash content. Also smaller throat diameter means higher gas velocities at the oxidative and reduction zones. This reduces tars but increases dust loading. Large throat diameter causes an increase of tar in the gas stream due to by passing of the hot zone. Fuels with high ash content (e.g. rice husk -21.3% [1, 2]) create, problems by ash clogging and slogging at the combustion zone in downdraft gasifiers. The choke plates and throat type combustion regions used in downdraft gasifiers work well with lower coking tendency fuels (e.g. wood), but when high coking fuels (e.g. cotton stalk) are used they cause bridging in and above the pyrolysis zone [3, 4].

Design of gasifier essentially means obtaining the dimensions of the various components of it. Design of gasifier is largely empirical. Design of gasifier is carried out partly through computations and partly using empirical relations and using some experimental data. The principal design parameters are specific gasification rate (SGR), gas resistance time (GRT) and area of air nozzles. The derived parameters are diameter of hearth and throat , total length of combustion and reduction zone, air velocity, diameter of nozzles and number of nozzles etc

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2.1 Design Parameters

2.1.1 Equivalence ratio (ER)

ER is defined as the ratio of oxygen supplied per kg wood to the stoichiometric requirement. ER fixes the amount of air supplied for gasification. A value of 0.3 ER is the theoretical optimum [2]. As the ER value approaches 1.0 combustion reaction is predominant and as it tends to zero, pyrolysis is the major process. All the gasifier designs were based on the above mentioned optimum. For a given biomass consumption rate, the volumetric rate of air can be calculated from ER value [5].

2.1.2 Specific gasification rate (SGR)

SGR is the volumetric flow rate of gas per unit area based on throat diameter, the gas volume being measured at the standard conditions. The recommended SGR falls in the range of 0.3 to 1.0 [6].

2.1.3. Specific solid flow rate (SSR)

SSR is the mass flow of fuel measured at throat. It is a derived parameter since it can be obtained from SGR. As one kg of wood approximately gives 2.4 m^3 of gas, SSR can be related to SGR as SGR/2.4[6].

2.1.4 Gas reduction time (GRT)

It is defined as the average time spent by the gas phase in reaction zone. If 'V' is the total volume of reactor, 'ε' is the void fraction (volume of voids in the bed/total volume of reactor) and 'G' is the gas flow rate then

$$GRT = (V\varepsilon/G) * (273/T) * 360 \text{ sec}$$

Where T = average temperature inside the reactor. Much attention has not been paid to this parameter which controls the convention in chemical reactions. Recommended value is 0.5 sec[6].

2.1.5 Air blast velocity (V_b)

This is the linear velocity of air in the nozzle under standard conditions. The range of V_b proposed is 15 - 30 m/s. It is argued that the higher air blast velocities help in higher penetration of air in to the bed and also prevent formation of hot spots.

2.2.1 Design of hearth and nozzle

Assume the SGR to be 3000m^3/m^2-h

Area of hearth	Total gas rate / SGR = 260/3000 = 0.087 sq.m.
The hearth diameter	0.33 [m]

Total area of Nozzle orifices

Here the controlling parameters are air inlet velocity and number of nozzles. High velocities will produce narrow jets and Low velocities will not reach the central area. Both cases lead to formation of central dark zone meaning poor non-uniform combustion zone and inefficient tar cracking.[6,7]

General range for air inlet velocity is 6 m/s to 10 m/s
Number of nozzles to be used – generally ranges from 1 to 10.

The aim of the nozzle design is to have no cold/dark zones in the oxidation zone.

Assume velocity of air as	7 m/s
Total area of nozzle orifices	160/7 * 3600 = 0.00635

Co-efficient of discharge of air 0.60

Selection of either 3 or 6 nozzles seems suitable. In general 4 * 57, 5 * 52, 6 * 47 are recommended and for the present case 6 * 47 and 4 * 57 nozzles have been selected[6].

2.2.2 Sizing of Hopper / Hopper design

Main parameters to be designed are the diameter and the height of the hopper. The main considerations governing the diameter of the hopper are[8]:

- Storage requirements
- The hearth size (D_{hearth})
- Size of the biomass particle

A down draft gasifier is designed for hauling a 150 HP diesel engine. The engine is coupled to A.C. alternator having an output of 100 kW. For compression ignition engine about 75% diesel substitution is possible. Various designed parameters of the gasifiers are determined according to the recommendations given in the literature and based on the previous experience [6]. Finally the following important parameters and dimensions are chosen for this analysis.

Mass flow rate of wood	=	100 kg/hr
Gas output	=	260 nm^3/hr
Air requirement	=	16 kg/hr
Velocity of air	=	7 m/s
Diameter of hearth	=	0.33 m
Depth of reduction zone	=	0.46 m
Size of hopper	=	2.16 m
Diameter of hopper	=	0.93 m
No. of nozzles	=	6 or 4
Diameter of nozzle	=	0.047 m or 0.057 m

Fig. 1 shows the schematic design of the down draught gasifier. That is the diagram is drawn as a block diagram and its material thickness is not shown. Firing nozzle is used start the combustion process. Ash and gases will pass through the grate region [6]. Ash will be collected in the ash pit and producer gas will leave the gasifier through the gas outlet. A close up view of the combustion zone is shown in the Fig.2. The choke plate dimensions and combustion chamber dimensions are shown in the Fig. 3.

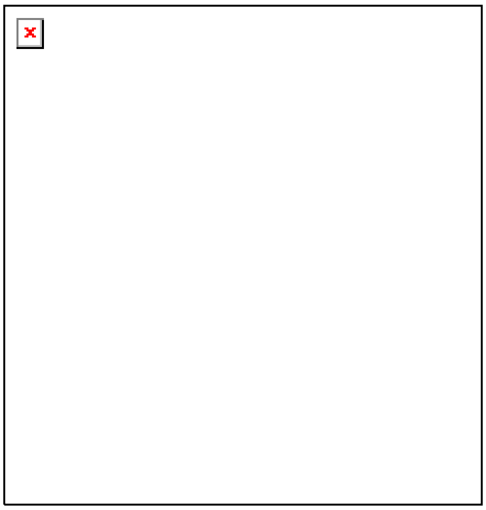
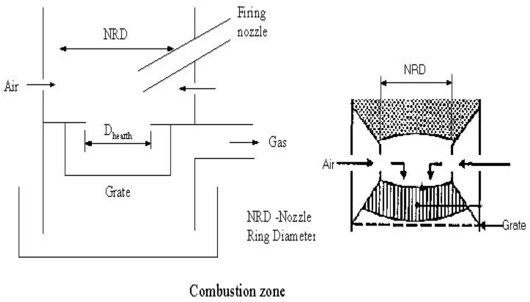


Fig.1 Schematic design of down draught gasifier



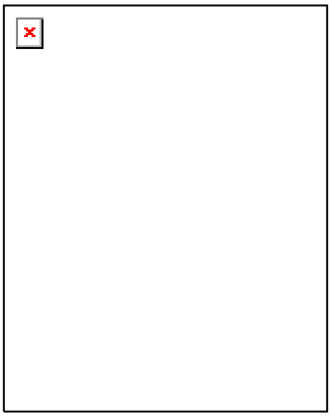


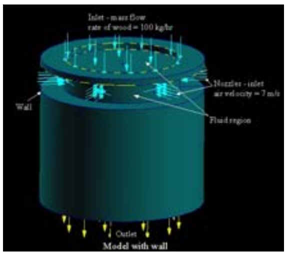
Fig.2 Close up view of Reduction zone

Fig.3 Choke plate and Reduction chamber

3. Flow And Temperature Analysis For Changes In Nozzle Inclination Angle

3.1 Case : 1 Model With The Wall And Zero Nozzle Inclination Angle

Now the model is analyzed considering the wall of the reduction chamber. The model is shown in Fig. 4 the effect of wall is neglected in the place of nozzles. Also the wall shown above the nozzle is not considered for the analysis. Thus the values in that region that we will get from the analysis are not true values. This portion of the wall is not considered for the analysis, because the combustion starts only from the region where the air enters into chamber and the flow is downwards



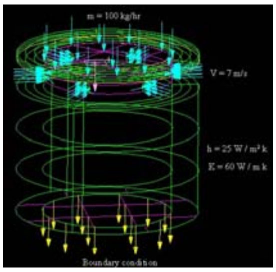
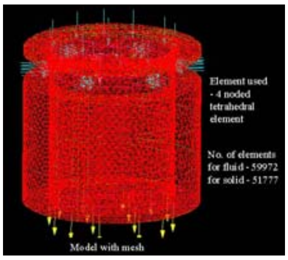


Fig. 4. Model with wall of the Reduction chamber

Fig. 5. Boundary condition



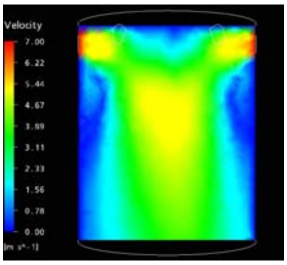


Fig. 6 Model with mesh.

Fig 7. Air flow across the Reduction chamber

The nozzle inclination angle for this model is zero. The nozzle inclination angle is the angle between the radial line connecting the nozzle with the center and the center line of nozzle and angle being measured in clockwise sense. The Fig 5 shows the boundary condition used for this model. In this model also 4 nodded tetrahedral element are used to mesh the model. Fig. 6 shows the meshing for this model.

3.1.1 Air flow analysis

Airflow analysis is same as that of the model without the wall, because the flow region is same and there is no property change as far as the flow analysis is concerned. Air flow is shown in Fig. 7 and as in the previous case here also the average air velocity inside the

Gasification chamber varies from 3 to 4 m/s. The air flow is not reaching the wall efficiently and the Gasification in this zone is poor

3.1.2 Temperature analysis

The temperature distribution throughout the wall is shown in the Fig.8 and temperature distribution across the Gasification chamber is shown in the Fig. 9.

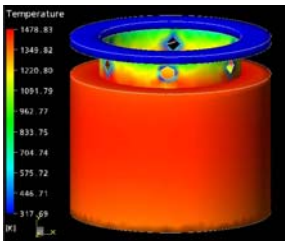


Fig. 8 Temperature around the wall

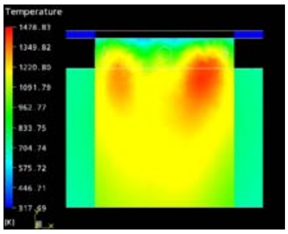


Fig. 9. Temperature across the Reduction chamber

The temperature is maximum at the reduction zone and in the wall region it varies from 1220° K to 1349° K. This maximum temperature of 1478° K is very well coincides with the theoretical maximum of 1200° C (1573° K). The temperature at the outlet where the producer gas leaves the gasification chamber is about 700° C.

3.1.3 Mass concentration

The mass concentration of CH_4, CO_2, N_2 , $H_2$and CO are shown in the Figures 10 to 14.The white color region is the wall of the combustion chamber. The approximate volumetric composition of producer gas at the outlet is

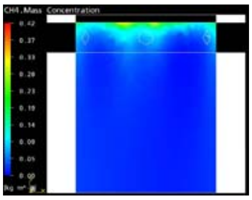


Fig. 10 CH_4 mass concentration

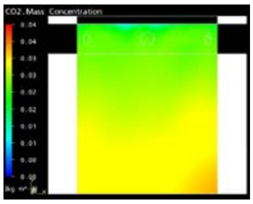


Fig. 11 CO_2 mass concentration

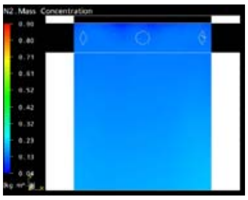


Fig. 12 N_2 mass concentration

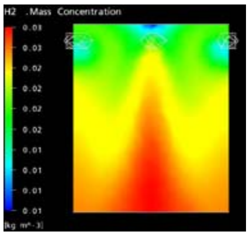


Fig. 13 H_2 mass concentration

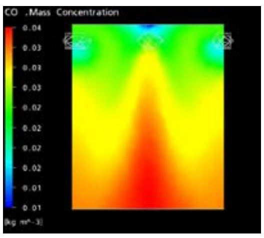


Fig. 14 CO mass concentration

H_2	-	16.1%
CO	-	19.72 %
CH_4	-	1.04 %
CO_2	-	10.94 %
N_2	-	52.2 %

3.3 Case 3: Model with 30° Inclination Angle

In this case the nozzle inclination angle used is 30° and all other conditions are same. The top view of the model is shown in figure 15 and the boundary condition is shown in Fig 16. In this case also overall heat transfer coefficient (U=24 W/m^2 k) is used to represent the wall condition. Meshing for this model is same as the one shown in Fig 4.

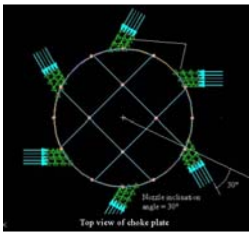


Fig. 15 Top view of the model

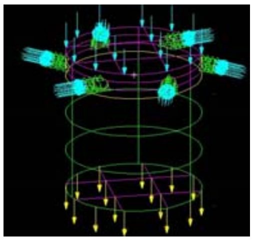


Fig.16 Boundary condition

3.3.1 Air flow analysis

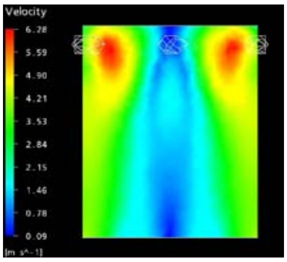


Fig. 17 Air flow across the Reduction chamber

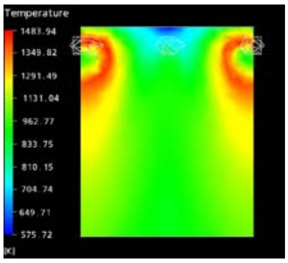


Fig. 18 Temperature across the Reduction chamber

Increasing the nozzle inclination angle to 30°, drastically reduces the air flow in the central region of reduction chamber and it is shown in the Fig 17. The air velocity ranges from 0.75 m/s to 1.5 m/s in the central region. In this model air reaches the wall side effectively and its velocity ranges from 3 m/s to 6 m/s whereas in the model with zero inclination angle air reaches the central region effectively. Thus suitable angle between 0° to 30° has to be selected to get the optimum distribution of air velocity.

3.3.2 Temperature analysis

The temperature distribution across the combustion chamber for this model is shown in the Fig. 18. The gasification is effective only at the narrow region near the wall and it is poor at the central region. Thus increasing the nozzle inclination angle to 30° is not to achieve complete gasification.

4. Results and Conclusion

Air reaches all regions in the reduction zone efficiently when the nozzle inclination angle forms 15° with wall and the average air velocity ranges from 3.5 m/s to 5 m/s. but the airflow rate is Drastically reduced in the central region. When the inclination angle forms 30° with wall and the air velocity ranges from 0.75 m/s to 1.5 m/s in the central region and from 3 m/s to 6 m/s near the wall. The comparison of all the cases reveals that the choke plate design with 6 nozzles and 15° inclination angle is much better than the other designs considered in this work. Gasification is almost complete and the gasification takes place throughout the reduction chamber when the nozzle inclination angle forms 15° with wall and the maximum temperature produced is 1483° K. The gasification is effective only at the narrow region near the wall and it is poor at the central region when the inclination angle forms 30° with wall. Thus the comparison of temperature distribution for all the models also indicates that the choke plate design with 6 nozzles and 15° inclination angle is better than the other models.

However this 15° inclination angle may not be the optimum and the optimum angle may lie between 10° to 25°. This has been arrived from the fact that for zero inclination angle the gasification and air flow is more at the central region and that for the 30° inclination angle it is near the wall of reduction chamber. In order to get the optimum inclination angle, we have to carry out the analysis for the choke plate designs with nozzle inclination angles ranging from 10° to 25°.The percentage volumetric composition of CH_4 and CO_2 are very well agree with the theoretical prediction for all the cases. The percentage volumetric composition of N_2 is higher than the theoretical prediction. This may be due to the poor gasification of biomass in the reduction chamber.

5.References

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