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CFD Simulation of Down Drought Biomass Gasifier

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Abstract- *Biomass is considered to be one of the most promising renewable energy sources in the present scenario. Due to stringent policy on emission reduction, biomass has become a centre of attention worldwide as a source of green energy. 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 present work has been carried out in order to perform CFD simulation in Biomass Gasification process, for this purpose a down draft biomass gasifier system is designed using empirical data and derived quantities in CATIA, changes made in the Model of reduction chamber with 30° inclination angle considering 4 number of nozzles. In this paper airflow analysis and temperature distribution across the chamber of gasification products has been analyzed by CFD method using ANSYS CFX 11.0 software.*

Key words- *Biomass, CFD, Gasification, CATIA, Airflow Analysis, Temperature Distribution, ANSYS CFX, etc.*

I. INTRODUCTION

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000°C. The reactor is called a gasifier. The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are (Figure No. 1) combustible gases like Carbon monoxide (CO), Hydrogen (H2) and traces of Methane and non useful products like tar and dust. The production of these gases is by reaction of water vapor and carbon dioxide through a glowing layer of charcoal.
Thus the key to gasifier design is to create conditions such that

- Biomass is reduced to charcoal and,
- Charcoal is converted at suitable temperature to produce CO and H_2.

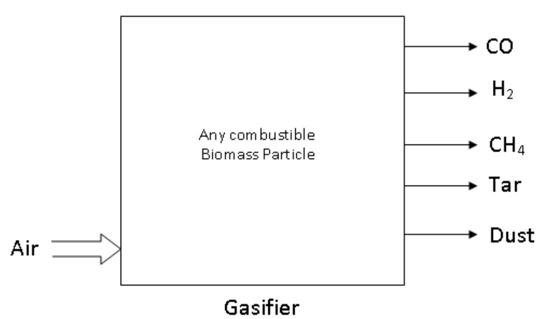


Figure No. 1: Production of Gasification

1.1 Types of Gasifiers

Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are three types of gasifiers.

- Downdraft gasifier,
- Updraft gasifier
- Cross draft gasifier.

1.1.1 Downdraft gasifier

Downdraft gasifier has air passing through the biomass from the tuyers in the downdraft direction. And the combustible gases come out from the bottom of the gasifier.

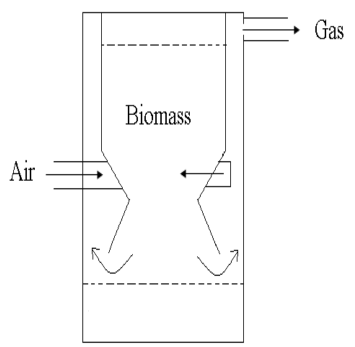


Figure No. 2: Down Draft Gasifier

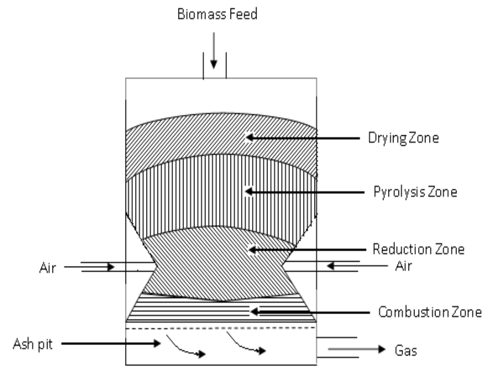


Figure No. 3: Various Zones in downdraft Gasifier

Process Zones

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are:

- Drying of fuel
- Pyrolysis – a process in which tar and other volatiles are driven off
- Combustion
- Reduction

Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place.

Figure No. 3 shows schematically a downdraft gasifier with different zones and their respective temperatures.

In the downdraft gasifiers there are two types:

- Single throat and,
- Double throat (Figure No. 4)

Single throat gasifiers are mainly used for stationary applications whereas double throat are for varying loads as well as automotive purposes.

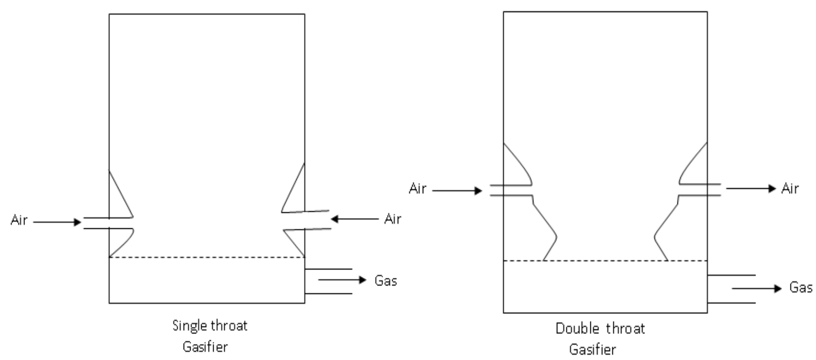


Figure No. 4: Single and Double Throat Gasifier

Advantages:

- Flexible adaptation of gas production to load
- Low sensitivity to charcoal dust and tar content of fuel

Disadvantages:

- Design tends to be tall
- Not feasible for very small particle size of fuel

II. LITERATURE SURVEY

Various models that have been reported for different gasifier configurations include:
(1) Unsteady one-dimensional model for stratified downdraft gasification [4],
(2) Transient single particle and fuel bed model for crosscurrent moving bed furnace [5].
(3) steady-state reduction zone model for downdraft gasification [3] and

(4) Steady state fluid flow and heat transfer model for open top throat-less downdraft gasification [7].

However, for throated close-top downdraft biomass gasifier, commonly known as an Imbert downdraft gasifier, a complete model including pyrolysis, combustion and reduction zones has not been reported in the literature. In a survey of gasifier manufacturers, it is reported that 75% of gasifiers offered commercially were downdraft, 20% were fluid beds (including circulation fluid beds), 2.5% were updraft, and 2.5% were of other types [11] [13]. Taking into account of the importance of downdraft biomass gasifier and its commercial applications, it is essential to have a complete model for such a configuration. In the present study, a transient one-dimensional model is developed for the throated close-top downdraft biomass gasifier. The model takes into account of the pyrolysis, secondary tar reactions, homogeneous gas reactions and heterogeneous combustion/gasification reactions. The developed model is divided into three parts according to three prevailing zones in the gasifier: (1) pyrolysis, (2) oxidation, and (3) reduction. The drying zone is indirectly incorporated in the developed model. The experimental data obtained in the earlier study [18] are used to validate the simulation results of the combined transport and kinetic model.

III. DESIGN OF FIXED BED DOWN DRAFT BIOMASS GASIFIER

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.

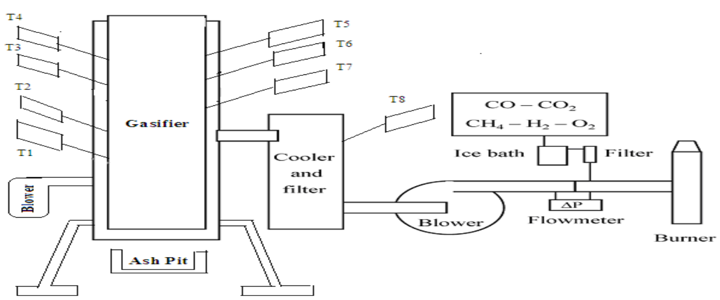


Figure No. 5: Experimental setup scheme

Figure No.5 setup of down draft biomass gasifier. Figure No.6 shows the schematic design of the down draught gasifier. Firing nozzle is used start the combustion process. Ash and gases will pass through the grate region. 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 Figure No.7.

Figure No. 6: Setup of down draft biomass gasifier

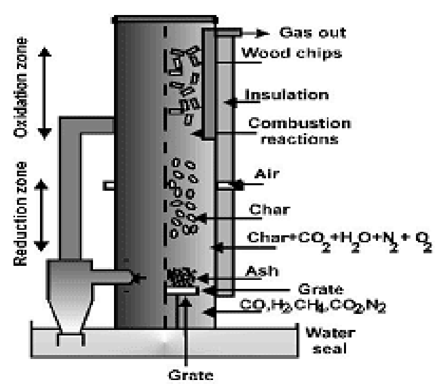


Figure No. 7: Schematic design of downdraft gasifier

The main components of the gaseous mixture leaving the combustion zone are carbon dioxide, water vapor, inert nitrogen, carbon monoxide, hydrogen and some amount of low molecular weight hydrocarbons such as methane, ethane, ethylene etc.

In the reduction zone, the gaseous mixture passes through the hot porous charcoal bed resting above the grate. The reduction zone is often referred as gasification zone.

IV. DESIGN AND ANALYSIS USING CFD

CFD Analysis on "Fixed Bed Downdraft Biomass Gasifier" to analysis the temperature and air flow velocity of the producer gas.

Tools used:
CAD: CATIA
Preprocessor: ANSYS CFX 11.0
Solver: ANSYS CFX
Post Processor: ANSYS CFX

Steps followed during the execution of project:
Phase 1: (Initial Model)

- 3D Model generation
- Mesh generation
- Solution
- Post Processing

Phase 2: (Modified Model)

- 3D Model generation based on CFD results of Initial Model
- Mesh generation
- Solution
- Post Processing

4.1. Model of the chamber with Zero Nozzle Inclination Angle

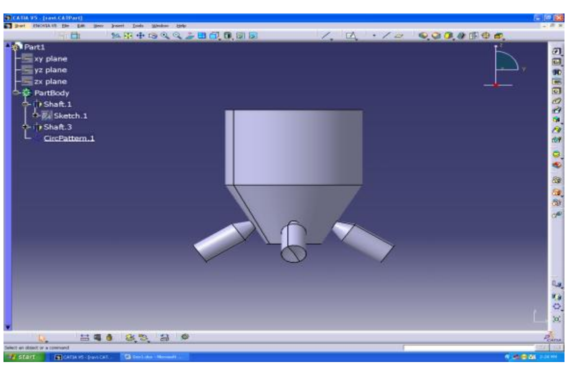
The nozzle inclination angle is the angle between the radial line connecting the nozzle with the center and the center line of nozzle and angle being measured in clockwise sense.

In the first case, 4 nodded tetrahedral elements are used to mesh the model. 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. The air flow has not reached the wall efficiently and the Gasification in this zone is poor. The temperature is maximum at the reduction zone and in the wall region it varies from 1220 K to 1349° K. The 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 [18].

4.2. Model of a reduction chamber with 30° inclination angle

The model is analyzed considering the wall of the reduction chamber. The model is shown in Figure No. 8; 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 chamber

Figure No. 8 Shows model of a reduction chamber with 30° inclination angle by considering four nozzles. It is modeled in CATIA and imported in to ANSYS CFX 11.0. Figure No. 9, Shows model with volume mesh with nodes 15081 and elements 76724.



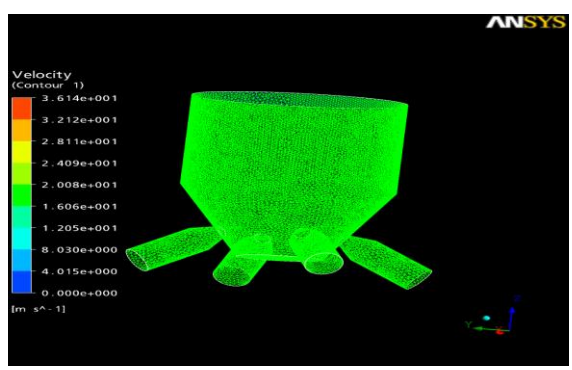
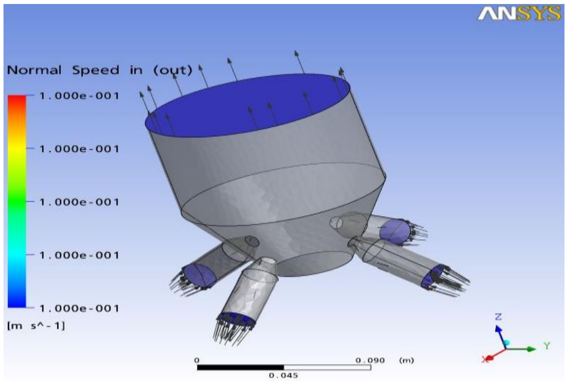


Figure No. 8: Model with wall of the Reduction chamber *Figure No. 9: Model with mesh*



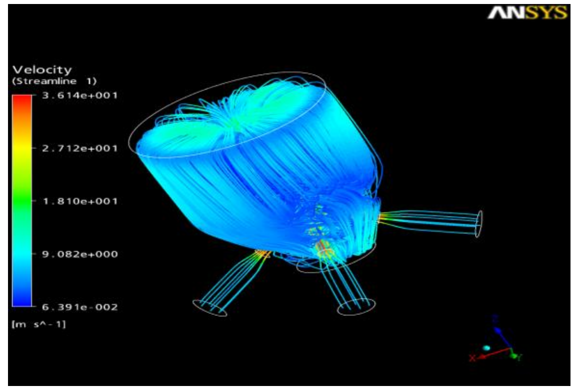
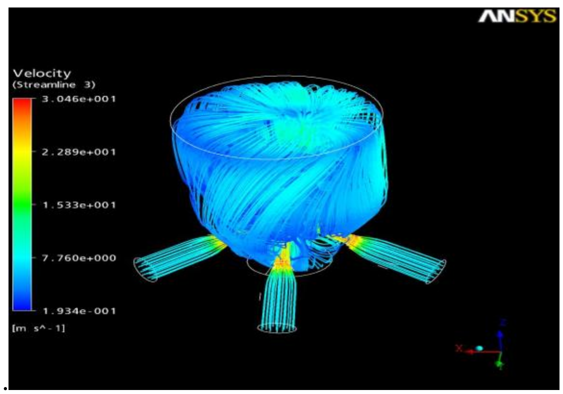


Figure No. 10: Boundary conditions *Figure No. 11: Stream lines across the Reduction chamber*

Figure No. 10, Shows boundary conditions of a reduction chamber with initial velocity and temperature V=6 m/s and T=298°K and outlet mass flow rate and temperature m˚=0.1 kg/s and T=523°K.



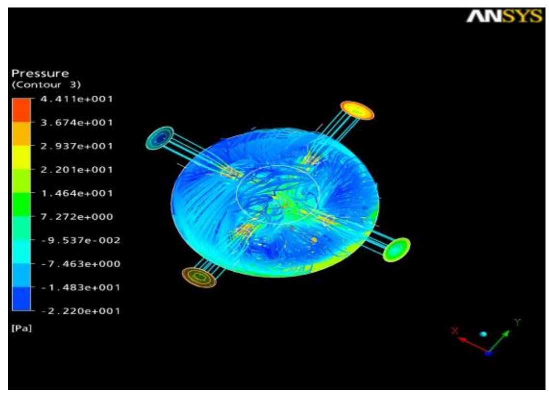
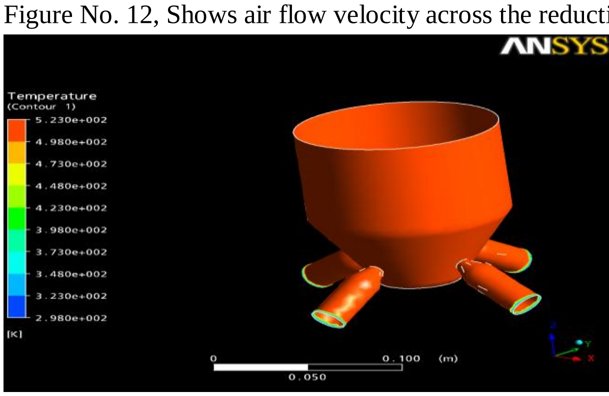


Figure No. 12: Air flow velocity across the Reduction chamber Top view and Bottom View

Figure No. 12, Shows air flow velocity across the reduction chamber with inlet velocity 6 m/s and outlet velocity 30 m/s.



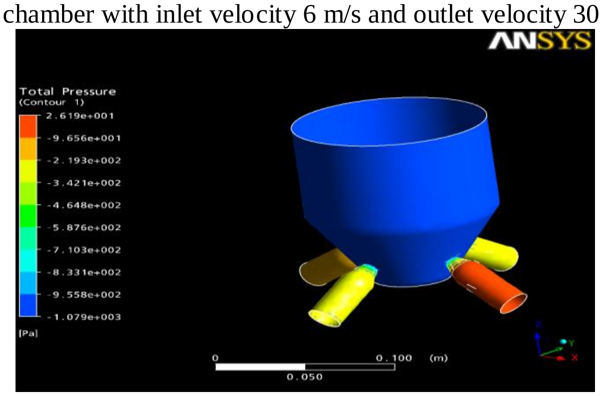


Figure No. 13: Temperature around the wall *Figure No. 14: Pressure around the wall*

Figure No. 13, Shows temperature contours around the reduction chamber wall with an inlet temperature 298^0 k and outlet temperature around 523^0 k.

Figure No. 14, Shows pressure contours around the reduction chamber with pressure 261 Pascal's. The temperature is maximum at the reduction zone and in the wall region it varies from1220 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 523° K.

V. RESULTS AND CONCLUSIONS

Table No.1: Readings of velocity in m/s and Reference line Z (m)

S.No	Velocity(m/s)	Reference line Z(m)
1	12.5	-0.04
2	6.4	-0.024
3	19.5	-0.008
4	21	0.01
5	20	0.025
6	17.9	0.042
7	17.9	0.059
8	16.5	0.075

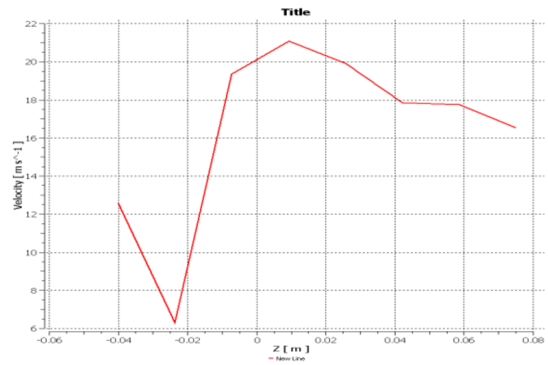


Figure No. 15: Velocity (m/s) Vs Reference line Z (m)

Table No.2: Readings of temperature (K) and Reference line Z (m)

S.No	Temperature(K)	Reference line Z(m)
1	322	-0.04
2	320	-0.025
3	320	-0.008
4	321	0.005
5	322.7	0.025
6	324.8	0.042
7	325	0.05
8	327.4	0.075

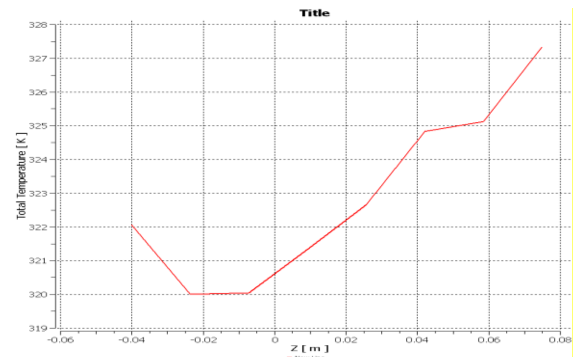


Figure No. 16: Temperature (K) Vs Reference line Z (m)

- The airflow rate is drastically reduced in the central region. When the inclination angle forms 0° 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.
- Air reaches all regions in the reduction zone efficiently when the nozzle inclination angle forms 30° with wall and the average air velocity ranges from 5 m/s to 7 m/s.
- The comparison of all the cases reveals that the choke plate design with 4 nozzles and 30° inclination angle is much better than the other designs considered in the work.
- Gasification is almost complete and the gasification takes place throughout the reduction chamber when the nozzle inclination angle forms 30° 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.
- The comparison of temperature distribution for all the models also indicates that the choke plate design with 4 nozzles and 30° inclination angle is better than the other models.
- However this 30° 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 0° to 30°.

VI. FUTURE SCOPE

- The future scope of the work, is the Approach of CFD analysis can be vary the inclination angle of the nozzle from 0^0 to 45^0. i.e. 10^0, 15^0 , etc.
- At the same time we change /increase the number of nozzles. i.e. 2, 4 and 6.
- Experimental results can be extracted in order to further validate the presented numerical results.

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