IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 42-48
www.iosrjournals.org

CFD Simulation of an Advanced Biomass Gasifier

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ABSTRACT: *Biomass is considered to be one of the most promising renewable energy sources in the future. Due to stringent policy on emission reduction, biomass has become a centre of attention worldwide as a source of green energy, e.g. motor fuel. This work has been carried out in order to perform computer simulation in an Advanced Biomass Gasification process developed at Gasification Lab, Centre for Energy Technology, University College of Engineering, Osmania University, Hyderabad. For an efficient and economically feasible we are converting biomass particles to a high quality synthesis gas. Computational fluid dynamics (CFD) has become a well known aiding tool in these regards as to characterize the conversion process, optimize the design, visualize the flow fields in the reacting flow environment, and to improve the operating efficiency as a whole. With this background, the commercial code Ansys-CFX has been used to perform CFD simulations of the Advanced Biomass Gasifier being developed at CET.*

Keywords: *Biomass Gasifier, CFD, Wood combustion, Temperature contours, Gas composition.*

I. INTRODUCTION

Wood gasification is a promising technology since renewable, environmental friendly and combination of heat and power (CHP) has many advantages especially on energy efficiency point of view. Under current development, the staged gasification is able to reduce tar concentration significantly [1, 2]. Another advantage of a biomass gasifier is the ability to control different zones of gasification carefully. The gasifica tion technology for different biomass feedstock has been investigated [3]. It is well known that biomass is not a single substance. Biomass consists of lignin, celluloses, hemicelluloses, etc. with different concentration of C, H, O, N, etc. Wood does not have single moisture content. In gasification, the present of moisture has advantages and disadvantages. Much energy has to be provided in order to evaporate the moisture. On the other hand, steam from moisture can increase char conversion rate via water gas reaction and produce CO and H2. Moisture also reacts with CO and produce CO2 and H2.

Biomass and waste are recognized to be the major potential sources for energy production. It is a renewable source of energy and has many advantages from an ecological point of view. Thermo chemical gasification is a process for converting solid fuels into gaseous form. The chemical energy of the solid fuel is converted into both the thermal and chemical energy of gas. The chemical energy contained within the gas is a function of its chemical composition. Thus the chemical composition of the product gas determines its quality as a fuel. High concentrations of combustible gases such as H2, CO and CH4 increase the combustion energy of the product gas. For electric power generation applications [4], the motive power from prime mover such as IC engine or gas turbine can be connected to an electric generator to produce electric energy.

II. LITERATURE REVIEW

In biomass gasification, the water gas shift reaction had to be taken into account at temperature above

973 K. At temperature 1123 K for pine wood when the ratio of steam/biomass is lower than 0.8 (with the same feeding of steam), H2 concentration was found to equal that of CO. At the highest temperature studied, i.e. 1173

K, the production of H2 was higher than the formation of CO [5]. Crnomarkovic N, et al. [6] investigated the wgsr and found that the most intensive decomposition of steam occurred in the temperature range from

600 to
1100 K. At temperature lower than 590 K, the production of H2 was hardly affected by steam injection.
According Franco C, et al. [5] at steam/biomass ratio 0.8, the increase of temperature led to higher gas yields and enhanced char reduction. In coal gasification, any increase in H2O/coal ratio below 1255 K would decrease the percentage of carbon gasified and thus the yield of produced gas and increase the O2 requirement.

Detail simulation of char reduction process in downdraft gasifier has been developed [7, 8]. In the reduction zone, there are many reactions that possible occur. Giltrap, et al. [7] developed a model for char reduction in downdraft biomass gasification based on steady state model. Meanwhile Babu BV, et al. [8] developed Giltrap's model that correspond to the exponentially varying char reactivity factor (CRF). They proposed four chemical reactions (R1 to R4) and the rate of reactions were obtained from Wang and Kinoshita.

The CFD simulation of reduction process based on Giltrap's model in a gasifier for low wood moisture content
has been developed successfully [9].

III. DESIGN AND METHODOLOGY

In this paper, the procedure for development of the physical model is explained. This chapter gives the information of the base or reference document for this paper. And it explains the CAD modeling procedures and different types of mesh Methodologies used for generation of the physical model. These designs are based on information found in the Gasification Lab, Centre for Energy Technology, College of Engineering, Osmania University.

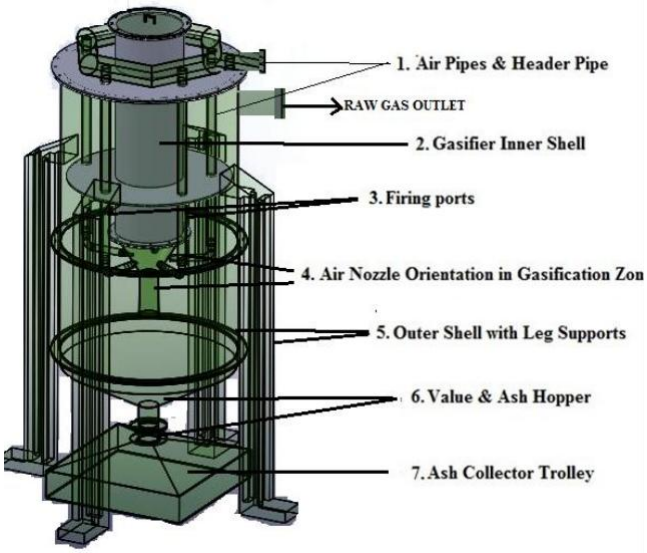


Figure 1 CAD model of advanced biomass gasifier

Table 1 Geometry Description

Components	Outer Diameter (mm)	Inner Diameter (mm)	Height (mm)
gasifier outer shell	1202	1092	2580
gasifier inner shell	460	454	2098

Table 2 Material properties of Down Draft Gasifier

Component	Material	Thickness (mm)	Density (Kg/m^3)
Inner Shell	SS 316	3	8000
Outer Shell	Mild Steel	5	7850
Nozzle	Mild Steel	3	7850
Insulation	Rock wool	100	--

For simulation of the gasifier, inner shell with air pipes assembly has been taken into consideration where the exact combustion and reactions occurs in the advanced biomass gasifier. The model for which analysis has been considered is shown in the figure 2. The air passes through pipes to the nozzle area where air gets mixed with fuel (wood) which is coming from the top as shown in figure 4.

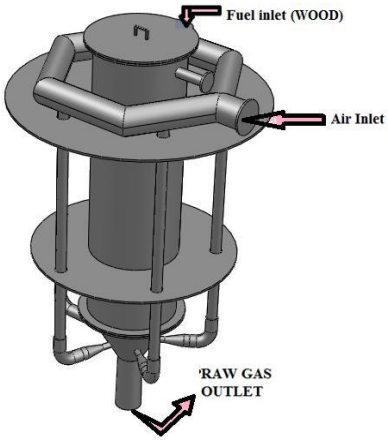


Figure 2 3D view of Gasifier Inner shell with nozzles

IV. MESHING AND BOUNDARY CONDITIONS

The geometry modeled as shown in figure 2 in Solid works, is exported to ICEM CFD software and meshing is generated. The unstructured triangular elements on surfaces and tetrahedral in flow domain are adopted in gasifier meshing as shown in Figure 3. The number of nodes are 31,823 and elements are 1, 73,993. The Figure 4 shows the air inlet and fuel inlet from top and raw gas outlet from the bottom. The air goes to the combustion area through the distributor pipe with nozzles. The boundary conditions are applied, fuel inlet, air inlet and outlet of gas for heat transfer models. The table 3 shows the physics report for the domain, the turbulence model used is K epsilon.

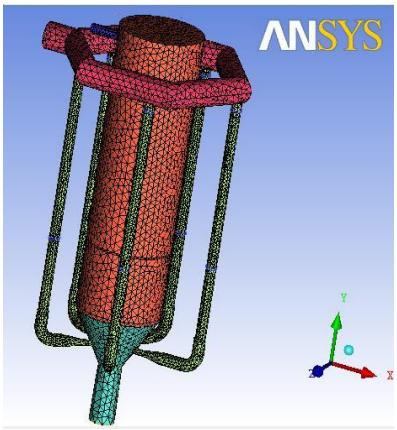


Figure 3 Meshed model

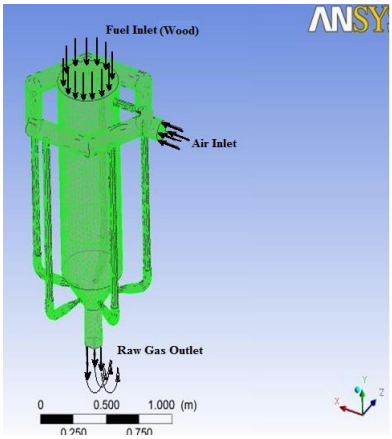


Figure 4 Defined Boundary Conditions

Table 3 Domain Physics for Gasifier
Table 4 Boundary Physics for air Inlet

Table 5 Boundary Physics for fuel Inlet

Domain – Gasifier	
Type	Fluid
Location	FUEL
Materials	
Gas Mixture HCN NO	
Fluid Definition	Material Library
Morphology	Continuous Fluid
HC Fuel	
Fluid Definition	Material Library
Morphology	Dispersed Particle Transport Solid
Particle Diameter Change	Mass Equivalent
Settings	
Buoyancy Model	Buoyant
Reference Pressure	1.0000e+00 [atm]
Combustion Model	Fluid Dependent
Heat Transfer Model	Fluid Dependent
Thermal Radiation Model	Fluid Dependent
Turbulence Model	k epsilon
Turbulent Wall Functions	Scalable

Table 6 Boundary Physics for Combustion Wall

Boundary – Wood Combustion Wall	
Type	WALL
Location	COMBUSTION_WALL
Settings	
Heat Transfer	Fixed Temperature
Fixed Temperature	8.0000e+02 [K]
Mass And Momentum	No Slip Wall
Thermal Radiation	Opaque
Diffuse Fraction	1.0000e+00
Emissivity	6.0000e-01
Wall Roughness	Smooth Wall
Fluid	HC Fuel
Particle Wall Interaction	Equation Dependent
Velocity	Restitution Coefficient
Parallel Coefficient of Restitution	1.0000e+00
Perpendicular Coefficient of Restitution	1.0000e+00

Boundaries	
Boundary - Air Inlet	
Type	INLET
Location	INLET_AIR
Settings	
Component	CO_2
Mass Fraction	0.0000e+00
Option	Mass Fraction
Component	Fuel Gas
Mass Fraction	0.0000e+00
Option	Mass Fraction
Component	H_2O
Mass Fraction	0.0000e+00
Option	Mass Fraction
Component	NO
Mass Fraction	0.0000e+00
Option	Mass Fraction
Component	O2
Mass Fraction	2.3200e-01
Option	Mass Fraction
Flow Direction	Normal to Boundary Condition
Flow Regime	Subsonic
Heat Transfer	Static Temperature
Static Temperature	5.7300e+02 [K]
Mass And Momentum	Mass Flow Rate
Mass Flow Rate	0.0680e+00 [kg s^-1]
Thermal Radiation	Local Temperature
Turbulence	Medium Intensity and Eddy Viscosity Ratio

Boundary – fuel Inlet	
Type	INLET
Location	INLET_WOOD
Settings	
Component	H_2
Mass Fraction	1.2300e-01
Option	Mass Fraction
Component	N2
Mass Fraction	5.3200e-01
Option	Mass Fraction
Component	O_2
Mass Fraction	2.3200e-01
Option	Mass Fraction
Flow Direction	Normal to Boundary Condition
Flow Regime	Subsonic
Heat Transfer	Static Temperature
Static Temperature	3.4300e+02 [K]
Mass And Momentum	Mass Flow Rate
Mass Flow Rate	1.3240e-02 [kg s^-1]
Thermal Radiation	Local Temperature
Turbulence	Medium Intensity and Eddy Viscosity Ratio
Fluid	HC Fuel
Define Particle Data	T
Heat Transfer	Static Temperature
Static Temperature	3.4300e+02 [K]
Mass And Momentum	Zero Slip Velocity

Table 7 Boundary for Outlet

Boundary – Outlet	
Type	OUTLET
Location	OUTLET
Settings	
Flow Regime	Subsonic
Mass And Momentum	Average Static Pressure
Pressure Profile Blend	5.0000e-02
Relative Pressure	0.0000e+00 [Pa]
Pressure Averaging	Average Over Whole Outlet
Thermal Radiation	Local Temperature

V. EXPERIMENTAL CALCULATIONS (for Wood)

Gasification efficiency defined as:

Mass flow rate of Wood = 0.01324 kg/sec
Calorific value of the Wood = 4384 Kcal/kg
Volume flow rate of Gas = 2.5*0.01324

= 0.0331 m^3/sec

Calorific value of producer gas = 1388 Kcal/m^3

= 79.21 %

Air flow rate (FD) = 200 m^3/Hour
Pressure = 200mm water column
Mass flow rate = Air flow rate * Density
= 200 m3/Hour * 1.225 Kg/m3
= 245 Kg/Hour
= 0.06805 Kg/Sec
Capacity of Gasifier = 32 KW

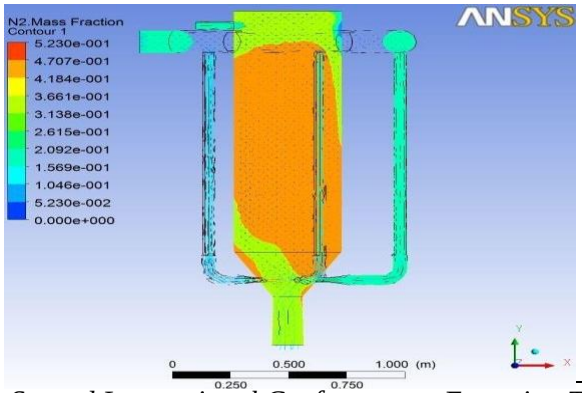
The Experimental composition of the gas obtained from wood gasification on volumetric basis is as follows:

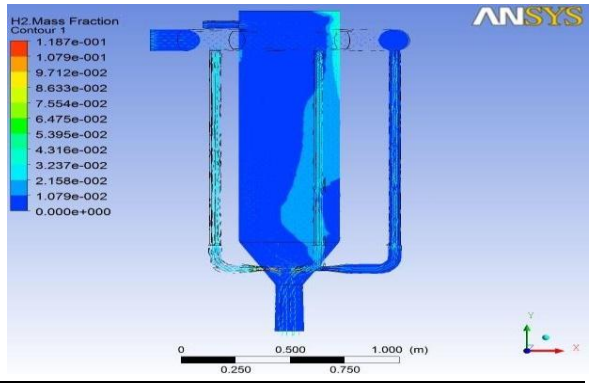
Table 8 Experimental composition of the components

COMPONENT	Exp. Data
Hydrogen	12.3
Methane	2.4
Water Vapour	4.1
Carbon Monoxide	17.8
Nitrogen	54
Carbon Dioxide	14.4

VI. RESULTS AND DISCUSSIONS

The data of typical composition of the components reported in Table 8 which is taken from gasification lab, Centre for Energy Technology is used to validate the simulation results. The initial moisture content fraction, air flow rate, temperature of the pyrolysis zone, and chemical composition of the biomass are required as an input data for the model to predict the composition of producer gas. The variation of mass fraction of producer gas components with time is predicted and compared with the experimental data. It is found that the model predicted mass fraction of nitrogen decreases first during the few initial minutes (5-10 min) of gasification. After that it increases and attains a steady value (after 10-15 min).





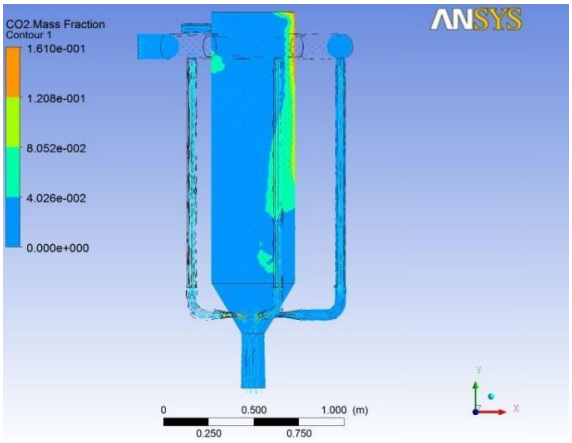


Figure 7. Mass Fraction of Carbon Dioxide

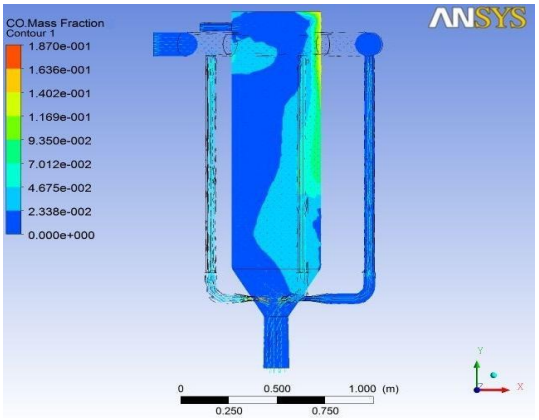


Figure 8. Mass Fraction of Carbon Monoxide

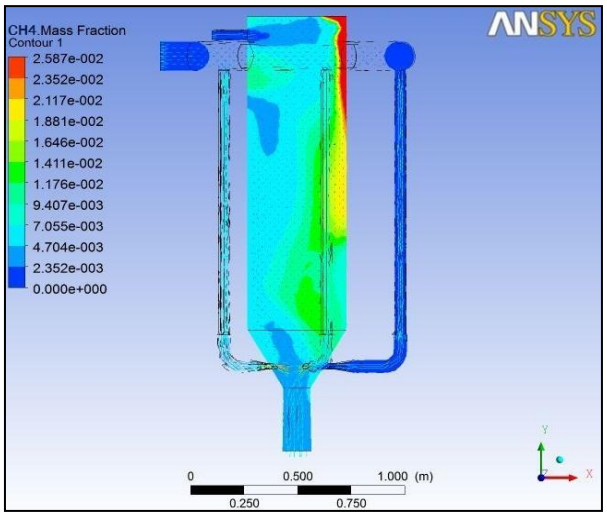


Figure 9. Mass Fraction of Methane

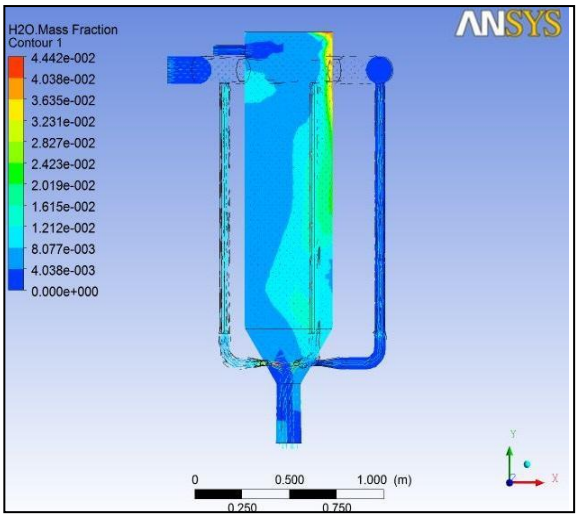
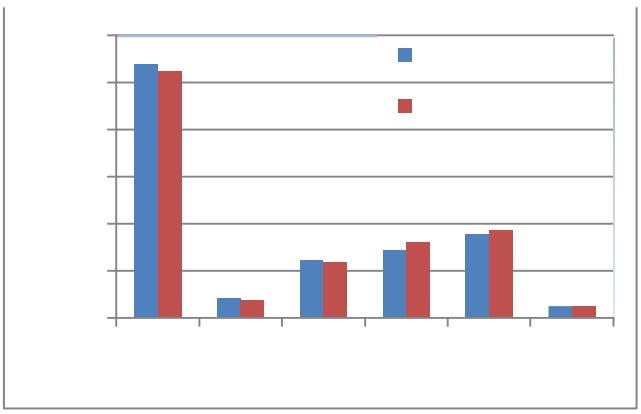


Figure 10. Mass Fraction of Water Vapour

Figures 5 to 10 shows the mass fraction of Nitrogen, Hydrogen, Carbon Dioxide, Carbon Monoxide, Methane and Water Vapour obtained in CFD. However, validation of predicted results is essential to get confidence in the prediction procedure. Validation of the predicted results is done by making qualitative comparison with the data available in the Gasification lab, Centre for Energy Technology, Osmania University, Hyderabad. Table 9 shows the comparison of model predicted mass fractions of producer gas components with those found experimentally in CET for an air-fuel ratio of 1.67.

Table 9 Comparison of CFD values of Gas Compositions with the Experimental Data

COMPONENT	Exp. Data	CFD
N_2	54	52.3
H_2O	4.1	3.8
H_2	12.3	11.8
CO_2	14.4	16.1
CO	17.8	18.7
CH_4	2.4	2.58



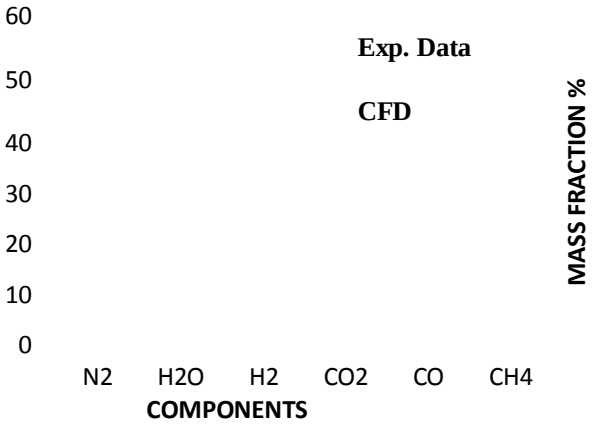


Figure 11. Column chart comparison of CFD values with

Experimental Data of Gas compositions

The amount of CO and H2 increases, while that of CO2, CH4, and N2 decreases across the length of the reduction zone. N2 content remains same as it is an inert gas, but its composition decreases as the content of other components change across the length. Figure 11 shows the comparison of CFD values of gas compositions with the Experimental data in column chart.

VII. CONCLUSIONS

The model discussed here predicts the composition of producer gas and temperature profiles across the length of the reduction zone. Char reactivity factor and the pyrolysis fraction variable are the key parameter in modeling of downdraft gasifier and it directly represents the reactivity of char in the reduction zone. Based on the results obtained and the discussions carried out in the earlier section, the following conclusions are drawn:

- It is found that air to fuel ratio is one of the key parameter in the simulation. And its effect can be incorporated by varying the value of pyrolysis fraction variable.
- For higher value of air to fuel ratio, the lower value of pyrolysis fraction variable has to be used.
- Model simulation with fp = 0.2 predicts better compared to the simulated results of the fp = 0.25

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