CFD Analysis of Biomass Gasification with Air as Medium

R. Saravana Sathiya Prabhahar, M. Prabu, P. Nagaraj, J.Thanikachalam

Abstract--- Rapid growth of industries, vehicle population and more sophisticated life of human beings leads to increase in energy consumption results in depleting conventional fuels and also causes serious threat to the environment. Due to stringent policy to reduce emission, biomass will play a key role across the world as a source of green energy. Gasification of biomass not only yields substantial amounts of hydrogen but also consumes the wastes which are produced from various sources. Gasification is a thermochemical technique which requires a medium, steam or air for conversion of biomass into useful products. Gasification is efficient only if it possess usable amount of fuel gases in its output. The implementation of gasification technology demands theoretical simulation which need to be validated with experimental analysis. Many researchers proposed different models for simulating gasification numerically. The present work reports the fluid dynamics simulation of gasification using species transport. CFD is a well characterized process, leads to design optimization, visualisation of fluid flow enhancing the efficiency of operation. Here CFD analysis is performed for different temperature (1023K, 1073K, 1123K) with air as the medium inlet to the reactor. Using advanced scheme, CFD predicts better. From the results obtained using CFD simulation, the various components of gaseous like H_2, CH_4, CO and CO_2 are calculated at different temperatures.

Keywords:

1. INTRODUCTION

Fossil fuels are depleted rapidly as most of the energy resources uses fossil fuels as medium, which causes environmental pollution. Thermochemical process is a form of conversion technique during which the biomass is converted into fuel with useful heating potential. P.C. Murugan et al. incorporated different zones of gasifier and performed simulation using CFD, conducted experiment in a 40 kW downdraft gasifier using rice husk as a source of biomass. It was reported that the key parameter to perform simulation is air to fuel ratio and its values are incorporated when the pyrolysis fraction variable are varied. Ratnakar Chodapaneedi et al. explained that when air to fuel ratio is higher, the pyrolysis fraction variable value used was least. S. Sivakumar et al. designed a down draft gasifier of capacity 100 kW and performed simulation using CFD. Qitai Eri et al explained the influence of temperature during gasification by simulation, while the quantity of steam with respect to biomass (SBR) did not affect the simulation results too much. P. Ranganathan et al. explained that the process of gasification and the pyrolysis products are variety of gases which are non-condensable, liquid and char. Here from all these studies energy sources depleting at an alarming rate pushes mankind to find some alternate source of energy, which is renewable and non-harmful to the environment. The selection should be based on the living being concern and the environmental concern because most of the fuel that are used were highly pollutant affecting the environment and they affect the human lives in some case. Gasification involves the conversion of fuels in the form of solid to gas by converting the chemical energy of solid fuel into useful gas. The chemical composition of the gas obtained depends on chemical energy that the biomass possess which determines the fuel quality. The combustible gases like H_2, carbon monoxide and methane present in higher concentration enhance the energy possessed by product gas on combustion. So hydrogen, one of the most prominent source of clean energy, which has a high heating value, no pollution due to burning, and is available in abundance from various sources. All the gasification processes are done with the materials that are thrown as waste and no use like rice husk, dried neem leaf etc. Here gasification of rice husk with air as the medium was done. Improper amounts of any of the operating parameters depict the operation of gasification useless. Finding the optimal parameters required for gasification is a tedious task. Gasification process is done using CFD and the finding are evaluated with the experimental values. One of the beneficial of CFD is, if the computational results are validated with the experimental results the remaining experiments can be simulated rather than experimental work, this normally reduces the work and cost as well. In CFD the fixture of raw materials like rice husk are made so the comparisons can be made effectively. Here by creating a CFD model of gasification using the species transport model for different operating temperatures and simulating the gasification reactions are executed. Material selection are selected as per the requirement, boundary condition is fixed based on the fixtures. This paper aims to study the effect of temperature on the concentration of syngas by making the biomass to react with air. Thus, the simulations provide a powerful theoretical basis for gasification.

2. DESCRIPTION OF MODEL

The reactor used for gasification is shown in Fig.1. The reactor has a cylindrical cross section of diameter 100 mm and the reaction zone heights are 180mm and 120mm

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tapered at an angle of 28°. On the top of the reactor there are medium inlet and outlet of 30mm diameter. The medium inlet is used to let the air inside the reactor and the outlet is used to send the gas out of the reactor. The normal inlet is set at the reactor bottom where the biomass is fed, the heat input is given by the furnace.

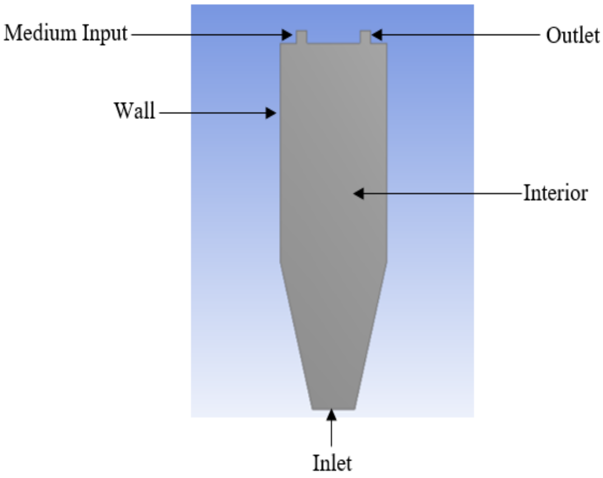
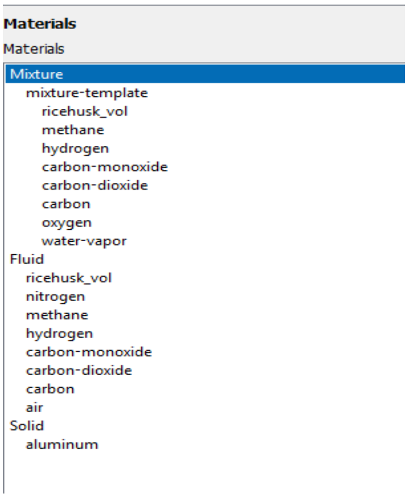


Fig. 1 Geometry model of gasifier

3. GOVERNING MATERIALS AND EQUATIONS USED IN SIMULATION

3.1 Material fixtures

Many researchers proved that the use of k-epsilon model yield results within acceptable range while performing similar simulation. Also, the power required for computation is less and the model is meek when compared to other models. Since, the species mixing is turbulence in nature, eddy dissipation model is chosen. Using chemical algorithm mass fractions for different gaseous components are calculated. Here the necessary materials are selected as per requirement as shown in the Fig. 2. The mass fraction of the mixtures are given by the CHNS/O analysis of Rice husk.



Materials

Materials

- Mixture
  - mixture-template
    - ricehusk_vol
    - methane
    - hydrogen
    - carbon-monoxide
    - carbon-dioxide
    - carbon
    - oxygen
    - water-vapor
- Fluid
  - ricehusk_vol
  - nitrogen
  - methane
  - hydrogen
  - carbon-monoxide
  - carbon-dioxide
  - carbon
  - air
- Solid
  - aluminum

Fig.2 Material fixtures

3.2 Continuity equation and Momentum conservation equation

The mechanics of fluids define continuity equation, as rate of mass entering the system will be equal to summation of mass leaving the system along with mass accumulation in the system. Each cells in the mesh is formulated by this equation. The differential form of continuity equation is as follows.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

Momentum like energy is always conserved. The momentum conservation equation is as follows.

$$\frac{\partial}{\partial t}(\rho\vec{v}) + \nabla\cdot(\rho\vec{v}\vec{v}) = -\nabla p + \nabla\cdot(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}$$

3.4 Species transport

Species transport model represents continuity equation with some modification, by taking into consideration of the mass change in various species due to chemical reactions and mass influx due to the velocity of each involved in the species reaction. The differential representation of equation for transport of species is as follows

$$\frac{\partial}{\partial t}(\rho Y_C) + \nabla(\rho\vec{v}Y_C) = -\nabla.\vec{J_C} + R_C$$

$$\frac{\partial}{\partial t}(\rho Y_{H_2}) + \nabla(\rho\vec{v}Y_{H_2}) = -\nabla.\vec{J_{H_2}} + R_{H_2}$$

$$\frac{\partial}{\partial t}(\rho Y_{CO}) + \nabla(\rho\vec{v}Y_{CO}) = -\nabla.\vec{J_{CO}} + R_{CO}$$

$$\frac{\partial}{\partial t}(\rho Y_{O_2}) + \nabla(\rho\vec{v}Y_{O_2}) = -\nabla.\vec{J_{O_2}} + R_{O_2}$$

$$\frac{\partial}{\partial t}(\rho Y_{H_2O}) + \nabla(\rho\vec{v}Y_{H_2O}) = -\nabla.\vec{J_{H_2O}} + R_{H_2O}$$

$$\frac{\partial}{\partial t}(\rho Y_{N_2}) + \nabla(\rho\vec{v}Y_{N_2}) = -\nabla.\vec{J_{N_2}} + R_{N_2}$$

$$\frac{\partial}{\partial t}(\rho Y_{H_2O(l)}) + \nabla\left(\rho\vec{v}Y_{H_2O(l)}\right) = -\nabla.\vec{J_{H_2O(l)}} + R_{H_2O(l)}$$

$$\frac{\partial}{\partial t}(\rho Y_{CO_2}) + \nabla\left(\rho\vec{v}Y_{CO_2}\right) = -\nabla.\vec{J_{CO_2}} + R_{CO_2}$$

$$\frac{\partial}{\partial t}(\rho Y_{CH_4}) + \nabla\left(\rho\vec{v}Y_{CH_4}\right) = -\nabla.\vec{J_{CH_4}} + R_{CH_4}$$

Nomenclature

ρ is fluid density

J_c is the mass transfer due to diffusion of the species into other cells

v velocity vector

τ shear stress

t time

V is the velocity of the species

R_c is the rate of increase or decrease in the mass species.

u velocity vector

g acceleration due to gravity

3.5 Reaction values

Once after all the equations are evaluated then, the number of reactor needed to be fixed on the basis of the equation obtained including the raw material (rice husk) equation. Initially fix the rice husk composition, followed by the others. These are done for the chemical reaction involved inside the reactor.

3.6 Boundary conditions

By performing CHNS/O analysis of rice husk, the fraction of mass, rate of flow and the temperature of each species are obtained. The mass flow inlet is assigned for the inlet and the medium inlet for the reactor model. The boundary conditions are chosen in such a way that the outlet for gas is fixed as pressure-outlet and no slip adiabatic wall for the gasifier wall in the reactor model.

3.7 Grid independency

The grid independency is used to check whether the domains are divided into 25,000 coarse cells, and the CO, CO_2, CH_4 and H_2 compositions are analysed after the solution reaches convergence. Further the cells are improved in number and made fine, then the compositions are studied. From this, it is identified that these values are the optimum for cell numbers for this analysis

4. Results and Discussions

From the numerical simulation, the temperature of the gas, heating value, equivalence ratio and its composition are observed. Particle tracking is employed to identify the composition of producer gas in various gasification zones with the geometric model.

4.1 CFD Modelling

4.1.1 Reactor with different inlet and wall temperature

The reactor is fed with inlet temperature of 1073K, 1123K, 1173K and maintained wall temperature of about 850K having the equivalence ratio equal to 0.2, 0.3. The yield of gaseous products for various temperature with two equivalence ratios are shown in the Fig. 3. There is an increases in hydrogen when temperature increases and there is a sudden drop in hydrogen due to reduction in moisture content.

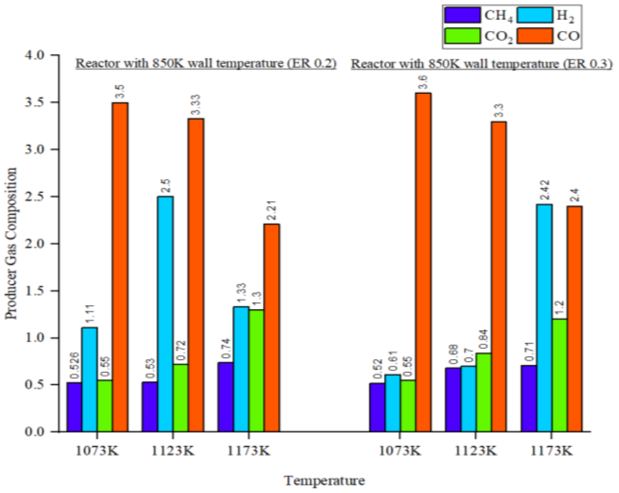


Fig. 3 Reactor with different inlet and wall temperature

4.1.2 Reactor with same inlet and wall temperature

Similar procedure is followed for this reactor but there is a change in temperature. The reactor is fed with inlet temperature and wall of 1073K,1123K,1173K throughout the process. The amount of gas produced inside the reactor for various temperature with two equivalence ratios are shown in the Fig. 4.

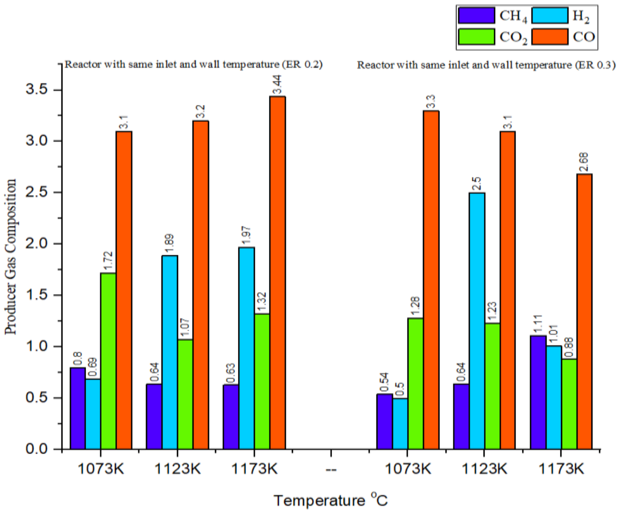


Fig. 4 Reactor with same inlet and wall temperature

4.2 Effect of ER on the gaseous constituents

Equivalence Ratio (ER) for the biomass is calculated based on air supplied and stoichiometric air required.

$$\text{E.R.} = \frac{\textit{Actual air supplied}}{\textit{Stoichiometric air required}}$$

Stoichiometric air required is calculated by the formula, M = [0.1153*C+0.3434*(H-O/8) + 0.0434S] kg/kg dry fuel

The composition of the gaseous products are obtained by both numerically as well as experimentally. The results revealed that, at an equivalence ratio about to 0.30, the quantity of CO, CO_2, CH_4 and H_2 are higher. Any change in the equivalence ratio (higher or lower) from this value resulted in reduction in the composition of combustible gas.

4.3. Effect of Temperature

The influence of temperature in pyrolysis reactions is very crucial. At lower temperature there is a chance for the reactions to be incomplete, and the yield of gases product is reduced. At higher temperature, excess combustion take place and there will be wastage of heat during the process of gasification. Hence, in this work, initially the wall temperature is kept constant (850K) whereas the inlet temperature is varied as 1073K,1123K and 1173K and variation in concentration of output gases were studied. Then wall temperature is increased and made equal to the inlet temperature and the results were graphically in Fig. 4.

5. CONCLUSION

The CFD analysis is performed using species transport model. Initially for a constant wall temperature of 850K and an ER of 0.2 with an inlet temperature of 1073K, the fraction of CH_4, H_2, CO_2 and CO were 0.526, 1.11, 0.55 and 3.5 respectively. There is an increases in hydrogen when temperature increased to 1123K and there is a sudden drop in hydrogen when the temperature is increased further to 1173K this is due to reduction in moisture content. When the ER is increased to 0.3, the concentration of H_2 is not improved, which are due to excess combustion of feed stock.

The simulation is repeated with different ER (0.2,0.3) keeping the wall and inlet temperature same. The maximum H_2 yield is obtained for an ER of 0.3 when the temperature is 1173K. This simulation results could be used as an input for experimental study in a gasifier.

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