Modeling Of Rice Husks Gasification In A Fluidized Bed Reactor

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Abstract

Gasification of biomass has increasingly become a promising alternative to direct combustion. The paper presents a study where rice husks were gasified in a fluidized bed using air to determine gas yield and composition as a function of equivalence ratio. Mathematical modeling of the gasification process is based on the computational fluid dynamics (CFD) technique where the conservative transport equations were modeled in a fluidized reactor coupled with the kinetic equations for gasification and combustion of rice husks.

The model results compared well with published experimental data, therefore indicating that the model can be a useful tool for the prediction of performance variables of fluidized bed reactor for rice husks gasification process.

Key Words: biomass, gasification, hydrodynamics, kinetics, fluidization, rice husks, modeling.

1. Introduction

The environmental concerns towards the use of fossil fuels increasingly drive interest in the biomass gasification process as biomass is a potential source of renewable energy. However, biomass is not presently competitive with fossil fuels. Fossil fuel contributes to the major portion of world's total energy consumption. According to the As mentioned by Xiong *et al* [3], the World Energy Assessment Report, says that 80% of the world's primary energy consumption is contributed by fossil fuel while 14% by renewable sources (out of which biomass contributes 9.5%). This implies that future sustainable energy scenario requires a combination of factors such as renewable resources and advanced energy technology. Traditionally, biomass is used as energy source of energy for cooking and heating particularly in the developing countries. Biomass gasification systems are of prime importance as modern technologies. Among all biomass conversion processes, gasification is one of the promising ones. This is particularly so because the energy efficiency in case of gasification is higher than that of combustion by David Ross [1] and Fryda [4].

The gasification process is defined as a thermo chemical conversion of carbonaceous material under reducing atmosphere to produce combustible gases frequently know as syngas which is a mixture mainly of CO and H2. In a gasifier reactor, the carbonaceous material undergoes gasification process at a controlled oxygen and temperature.

Fluidized beds reactors are widely used type gasifier reactor for biomass gasification as they offer a number of advantages such as high heat transfer rates, good temperature control and ability to handle a wide variation of feed materials. A fluidized bed is a packed bed through which fluid flows at such a high velocity that the bed is loosened and the particle-fluid mixture behaves as though it is a fluid. Thus, when a bed of

particles is fluidized, the entire bed can be transported like a fluid, if desired. Both gas and liquid flows can be used to fluidize a bed of particles.

2. Model Description

The 40 kg/hr rice husks gasifier reactor is shown in Figure 1 whose diameter and height are 0.3m and 5m, respectively. Air flows through a porous plate at the bottom of the reactor at a velocity of 0.5 m/s. Rice husks are injected at the sand bed which has been previously fluidized. Momentum is transferred from the bubbling bed to the rice husks biomass particle as well as from the formed bubbles inside the bed. For the design calculations, the physical properties of the rice husk and the inert material (sand) composing the bed were determined. The pertinent process data appear is shown in Table 1.

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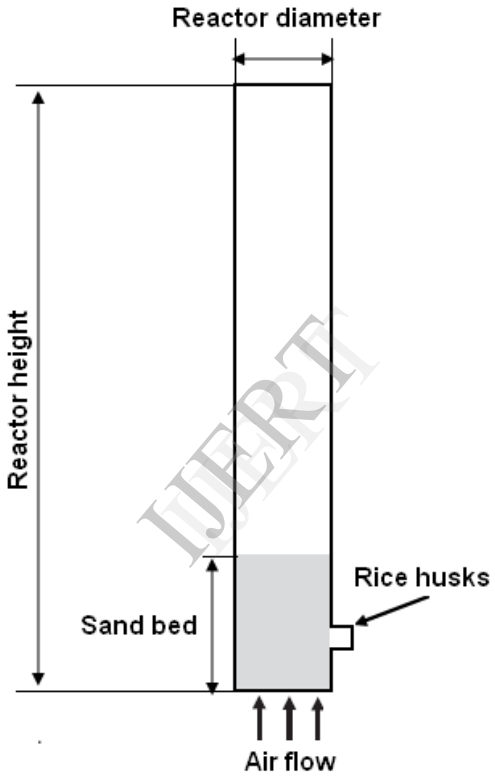

Figure 1: Fluidized bed gasifier reactor

Table 1: Major specifications for fluidized bed rice husks gasifier

Object	Parameter	Unit
Reactor	Height (m)	5.0
	Diameter (m)	0.3
	Wall material thickness (mm)	
Rice husks		
	Mass flow rate (kg/hr)	40
	Feed material density (kg/m^3)	389
	Porosity	0.64
	Particle size (μm)	856
	Thermal conductivity (W/m-K)	0.15
	Specific heat (kJ/kg-K)	2.5

Fluidization		
	Sand thermal conductivity (W/m-K)	0.25
	Sand density (kg/m^3)	2650
	Sand particle size (μm)	385
	Bed porosity	0.46
	Fluidization air velocity (m/s)	0.5
	Air temperature (C)	297
Proximate Analysis	Moisture (%wt)	9.3
	Volatile matter (%wt)	57.7
	Fixed carbon (%wt)	15.4
	Ash content (%wt)	17.6
	LHV (MJ/kg)	13.56
Ultimate Analysis		
	Carbon (%wt)	36.6
	Hydrogen (%wt)	5.83
	Oxygen (%wt)	36.65
	Nitrogen (%wt)	3.31

3. Computational Model

The computational modeling approach in this paper consists mainly of two parts, namely: the chemical kinetics of the gasification process and the hydrodynamics of the fluidized bed reactor.

3.1 Chemical Kinetics Model

It is widely reported in literature that the actual reaction scheme of biomass gasification is extremely complex because of the formation of over a hundred intermediate products. Because of this complexity, gasification process is generally simplified and modeled in single or multi-steps kinetics. The work presented in this paper follows multi-step kinetics (Figure 1) whose reaction rate is in Arrhenius form as shown in equation 1 which is frequently cited in literature.

$$\frac{dm}{dt} = -m * A * \exp\left(-\frac{E}{RT}\right) \qquad (1)$$

where A is the apparent frequency factor, E is the apparent activation energy, and *m* is the mass of reactant. E is activation energy at a temperature T. R is the universal gas constant.

The kinetic mechanism employed in our simulation of single particle biomass pyrolysis and gasification accounts for three parallel primary reactions with the possibility of a tar cracking reaction; that is, the biomass decomposes to gas, tar and char, and vapor tar decomposes to yield further gas as shown in Figure 2. Tar cracking reactions in the form of secondary reactions were adapted from Di Blasi [2].

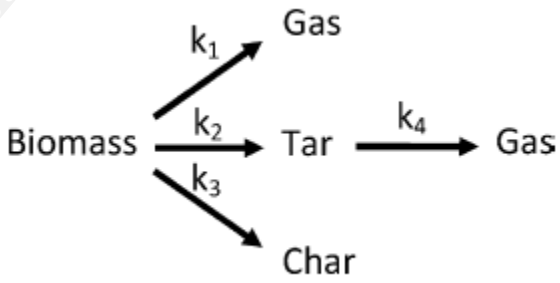

Figure 2: Schematic of biomass gasification and tar cracking [2].

3.2Conservative Governing Equations

The hydrodynamics of the fluidized bed gasifier was performed by solving the equations of motion of a multiphase system. An Eulerian model for the mass and momentum for the gaseous phase was applied, while the kinetic theory of granular flow was applied for the conservation of the solid's fluctuation energy. The governing equations are expressed in the following form Gidaspow [7].

3.2.1 Mass conservation

Eulerian–Eulerian continuum modeling is the most commonly used approach for fluidized bed simulations. The phases are able to interpenetrate and the accumulation of mass in each phase is balanced by the convective mass fluxes.

Gas Phase

$$\frac{\partial(\varepsilon_g \rho_g)}{\partial t} + \nabla \cdot (\varepsilon_g \rho_g v_g) = 0 \qquad (2)$$

Solid Phase

$$\frac{\partial(\varepsilon_s \rho_s)}{\partial t} + \nabla \cdot (\varepsilon_s \rho_s v_s) = 0 \qquad (3)$$

3.2.2 Momentum conservation

In gas–solid fluidized beds the sum of forces consists of the viscous force $\nabla \cdot \bar{\tau}_s$, the solids pressure force ∇p_s , the body force $\varepsilon_s \rho_s g$ the static pressure force $\varepsilon_s . \nabla p_s$ and the inter-phase force $K_{gs}(u_g - u_s)$ for the coupling of gas and solid momentum equations by drag forces [7].

Gas Phase

$$\frac{\partial(\varepsilon_g \rho_g v_g)}{\partial t} + \nabla \cdot (\varepsilon_g \rho_g v_g v_g) = -\varepsilon_g \cdot \nabla p + \nabla \cdot \bar{\tau}_g + \varepsilon_g \rho_g g + K_{gs}(u_g - u_s) \qquad (4)$$

Solid Phase

$$\frac{\partial(\varepsilon_s \rho_s v_s)}{\partial t} + \nabla \cdot (\varepsilon_s \rho_s v_g v_s) = -\varepsilon_s \cdot \nabla p - \nabla p_s + \nabla \cdot \bar{\tau}_s + \varepsilon_s \rho_s g + K_{gs}(u_g - u_s) \qquad (5)$$

where the solid-phase stress tensor $\bar{\tau}$ is given by

$$\bar{\tau} = \varepsilon_s \mu_s (\nabla u_s + \nabla u_s^T) + \varepsilon_s (\lambda_s - \frac{2}{3}\mu_s) \nabla . u_s \bar{I}_s \qquad (6)$$

and $\bar{I}$ is a unit vector. The bulk viscosity λ_s is based kinetic theory of granular flows.

The Gidaspow [7] inter-phase exchange coefficient is given as follows:

$$K_{gs} = \frac{3}{4} C_d \frac{\varepsilon_s \varepsilon_g \rho_g |u_s - u_g|}{d_s} (\varepsilon_g)^{-2.65} \quad \text{for } \varepsilon_g > 0.8 \qquad (7)$$

$$K_{gs} = 150 \frac{\varepsilon_s^2 \mu_g}{\varepsilon_g d_s^2} + 1.75 \frac{\varepsilon_s \rho_g |u_s - u_g|}{d_s} \quad \text{for } \varepsilon_g \le 0.8 \qquad (8)$$

3.2.3 Conservation of Energy

To describe the conservation of energy in Eulerian multiphase model, a separate enthalpy equation can be written for each phase:

Gas Phase

$$\frac{\partial}{\partial t}(\alpha_g \rho_g h_g) + \nabla \cdot (\alpha_g \rho_g u_g h_g) = -\alpha_g \frac{dp_g}{dt} + \bar{\tau}_g . \nabla u_g - \nabla \cdot q_g + Q_{gs} + \dot{m}_{gs} h_{gs} + S_q \qquad (9)$$

where, the last three terms are respectively heat conduction, energy transfer with heat transfer and energy source and h_g is the specific enthalpy of the gas phase, q_g is the heat flux, S_g is a source term that includes sources of enthalpy (e.g., due to chemical reaction or radiation), Q_{gs} is the intensity of heat exchange between the gas and solid phases, and h_{gs} is the inter-phase enthalpy (e.g., the enthalpy of the vapor at the temperature of the droplets, in the case of evaporation). Note that solid phase energy conservation equation is similar to equation (9) above, thus not shown. The fluidized bed heat transfer was based on the work reported by Gunn [8]

3.3 Computational Procedure

The governing partial differential equations for conservative of mass, momentum and energy are discritized and iteratively solved by FLUENT 12 software [6]. Initial conditions are required for the static bed void fraction in the reactor volume, and the bed temperature. The boundary conditions are those of the mass fluxes of the gases and solids at the flow boundary. Each inflow boundary is fully specified by the mass flow rate, void fraction, mass fractions of the gas and solids species and the boundary temperature. The reactor outlet was modeled as pressure outlet boundary.

4. Results and discussions

Figure 3 depict the temperature distribution in the gasifier reactor as the equivalence ratio is varied. It is clearly seen that highest reactor temperature is attained when the equivalence ratio is near 1, that is mostly combustion is taking place rather than gasification. On the other hand, the lowest temperature is observed at low equivalence ratio, that is the exothermic reactions are confined at bottom side of the reactor where limited air enters the reactor and quickly consumed.

The influence of equivalence ratio on the yield of syngas (CO and H2) is shown in Figures 4 and 5, respectively. The highest yield lies between the equivalence ratio 0.39 and 0.26, and that the syngas occupies nearly three quarters of the reactor volume. The uniform temperature distribution in the reactor due to fluidization favors gasification reactions to take place in large volume of the reactor.

Figure 6 depicts that the exit gas temperature decreases with decreasing the equivalence ratio. This was the expected trend which is due to the limited exothermic reactions at low equivalence ratios. On the other hand, Figure 7 provides validation of the CFD model with measured data [5] which compares fairly well.

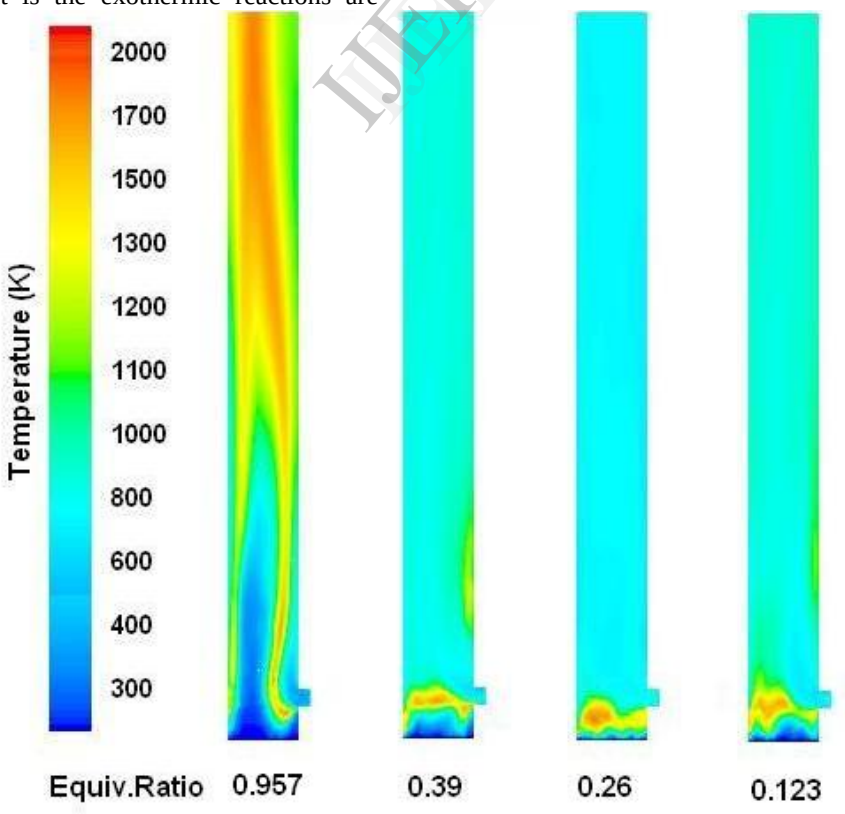

Figure 3: Temperature distribution in the gasifier with varying equivalent ratio

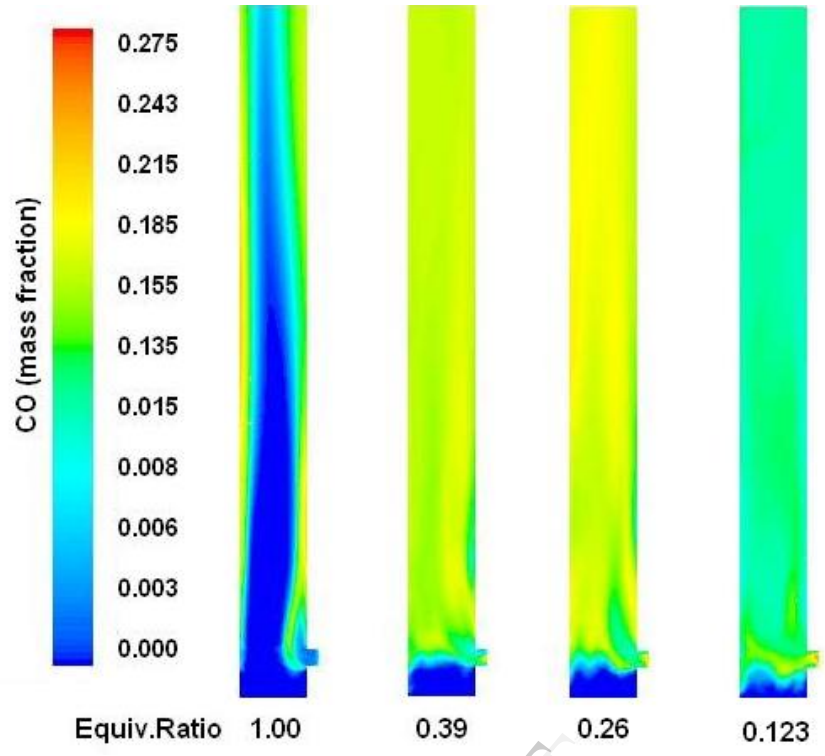

Figure 4: Distribution of CO concentration in gasifier with varying equivalent ratio

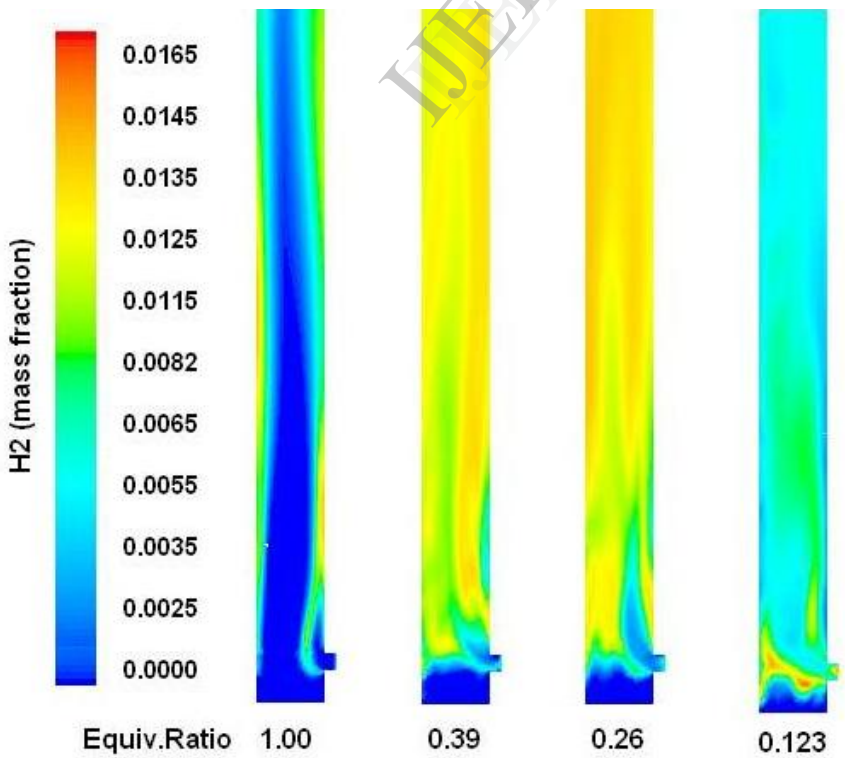

Figure 5: Distribution of H2 concentration in gasifier with varying equivalent ratio

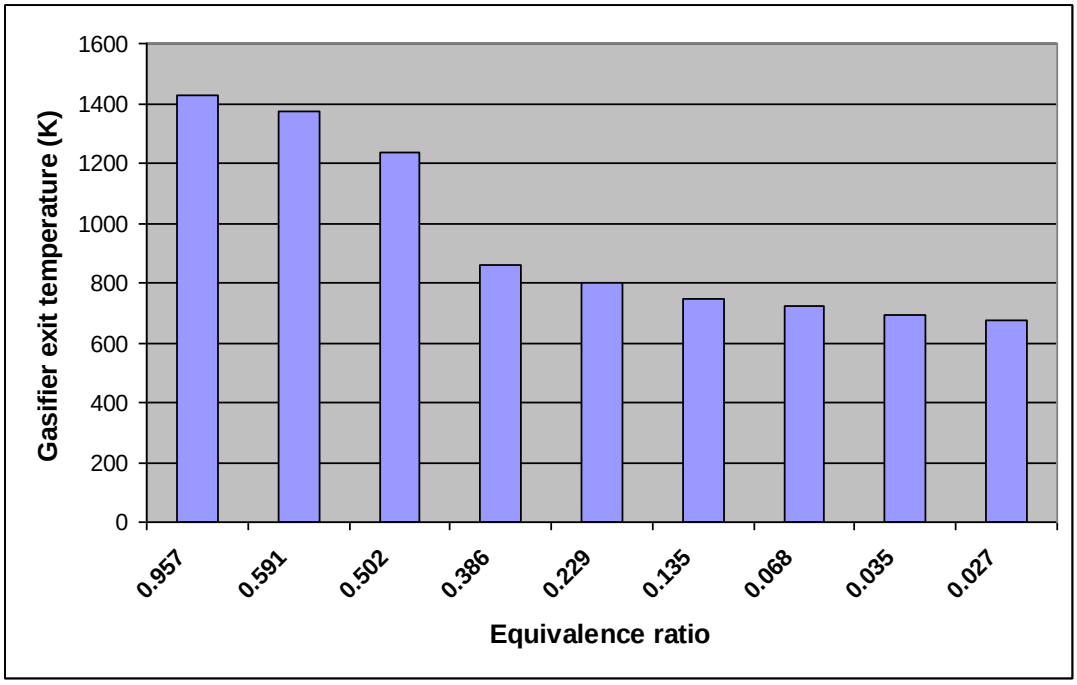

Figure 6: Gasifier exit temperature with varying equivalent ratio

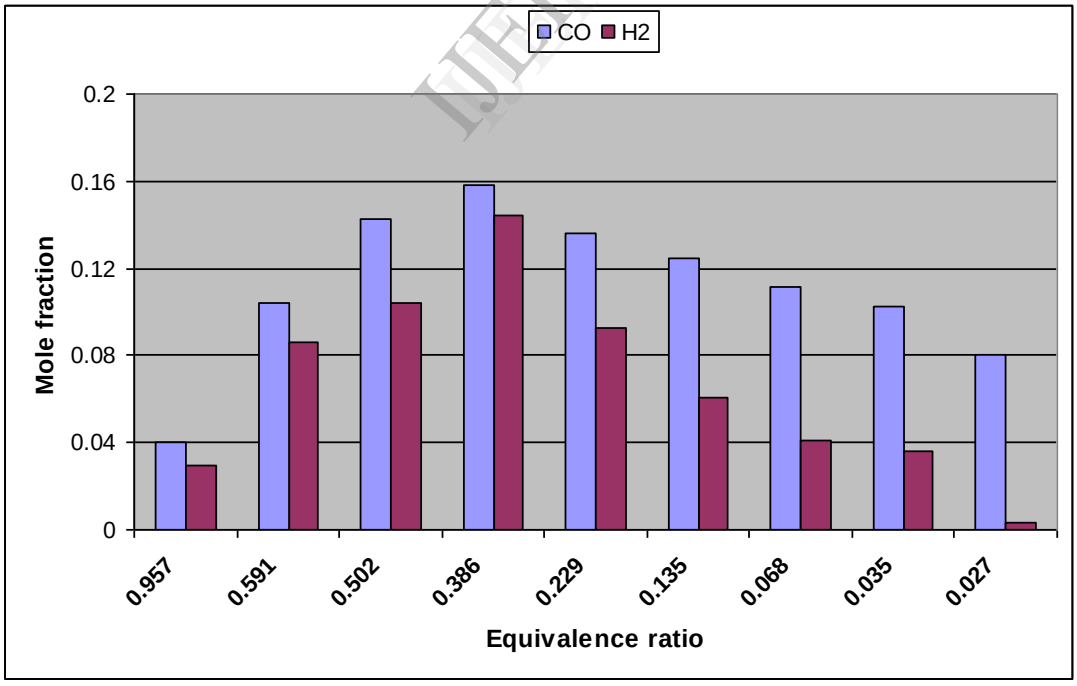

Figure 7: Gasifier exit concentration for CO and H2 with varying equivalent ratio

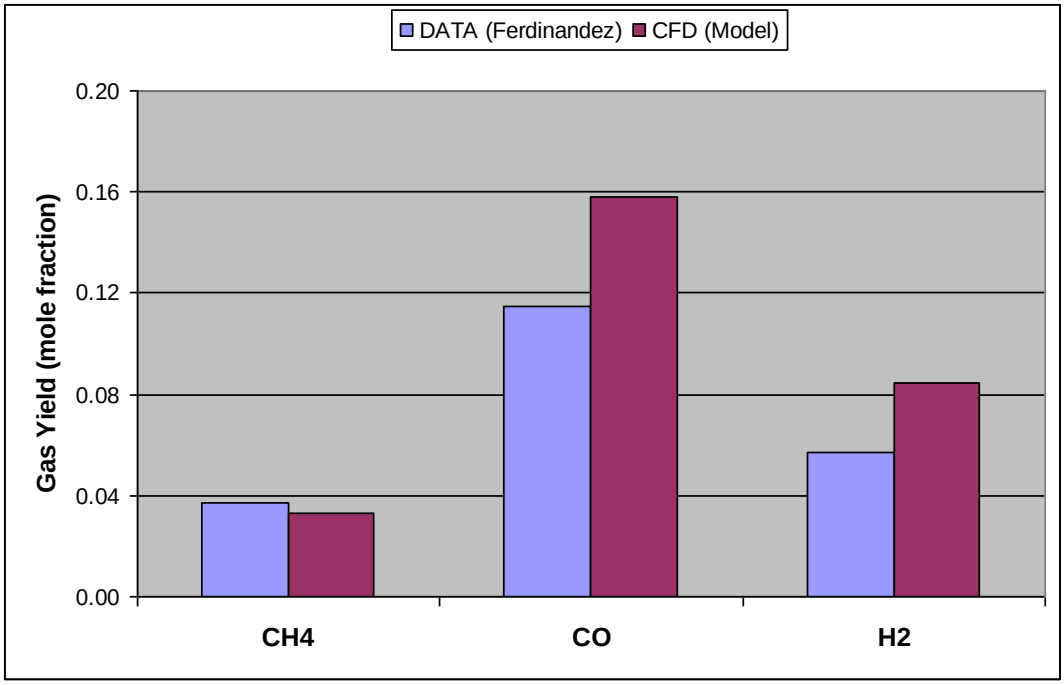

Figure 8: Model validation against measured data reported by Fernandez [5]

6. Conclusion

The simulation results of chemically reactive fluidized bed demonstrates that it is feasible to calculate the coupled effects of heavily-loaded gas-particles hydrodynamics, heat transfer and complicated gasification reactions. The comparison of results with published experimental data showed that the CFD model can be a useful tool when requiring a preliminary prediction of the performance variables values of pilot biomass fluidized bed gasifiers. That is, the successful results obtained stimulate the potential development of this clean technology for the value-added of agro-wastes by means of the use of the fluidized bed gasification technology. The current model can be a good guide for fluidized bed reactor design and troubleshoot, since it can predict the biomass particle motion and gasification reactions inside the reactor.

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