

## **ANALYSIS OF BIOMASS BASED DOWNDRAFT GASIFIER USING EQUILIBRIUM MODEL**

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### **ABSTRACT**

Development of non-conventional energy is an important activity all over the world. Among the non-conventional energy sources, biomass is the most promising one. During the past decade, substantial research has been performed on different biomass gasification systems, employing different gasifier configuration (e.g., fixed bed, and fluidized bed, or other), different oxidants (air, oxygen, steam), and different modes of heating (direct or indirect). Downdraft biomass gasification is of particular interest in many applications because of its low tar and oil yields and low carry-over of char and ash into the product gas. Downdraft gasifiers find wide applications in both power generation and thermal energy applications. Since the experimental approach is expensive, computer simulations are used for the investigation. A mathematical model to study the performance of a gasifier is required to improve the design of the gasifier. In this connection a survey of the existing model in the literature was carried out. In the present work Mathematical model was developed to characterize the gasification performance of a typical biomass downdraft gasifier. The composition of producer gas has been determined. The effects of Moisture content in the wood and equivalence ratio in the gasification zone have been investigated. The predicted values compare reasonably well with experimental data.

**KEY WORDS:** Biomass, Equilibrium Modeling and Gasifiers.

### **INTRODUCTION**

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 the gas. The chemical energy contained within the gas is a function of its chemical composition. Thus the composition of the product gas determines its quality as a fuel. High concentrations of combustible gases such as H<sub>2</sub>, CO and CH<sub>4</sub> increase the combustion energy of the product gas[1]. During gasification, the organic material contained in the fuel is thermally released very rapidly leading to the formation of porous char, which primarily consists of carbon and ash. The char particles undergo further reactions with several gases to yield the desired gaseous products. Thus thermo chemical characteristics of biomass play a major role in the selection of the gasification system design and performance [2].

Biomass gasification allows the conversion of different biomass feedstock to a more convenient gaseous fuel that can then be used in conventional equipment (e.g., boilers, engines, and turbines) or advanced equipment (e.g., fuel cells) for the generation of heat and electricity. The conversion to a gaseous fuel provides a wider choice of technologies for heat and electricity generation for small- to large-scale applications. Furthermore, electricity generation from gaseous fuels is likely to be more efficient compared to the direct combustion of solid fuels. Efficiency is a particularly important issue for biomass systems because of the possible energy and cost implications of the production and transport of biomass fuels, which are generally characterized by a low energy density. The upgrading of biomass feedstock to gaseous fuels is also likely to lead to a cleaner conversion. In addition to the production of heat and electricity, the product gas could be used to produce transport fuels, such as synthetic diesel or hydrogen. The most significant properties of any biomass that are known to influence the gasification process are moisture content, size and shape, absolute and bulk density, chemical composition (i.e. proximate and ultimate analysis) and the higher heating value. Gasifier performance in terms of gas calorific value, gas composition, gas outlet temperature and gasification efficiency depend upon the nature of flow through the gasifier [3].

### **DOWN-DRAFT GASIFIERS (CO-CURRENT GASIFIERS)**

Downdraft gasification is a comparatively cheap method of gasification that can produce a product gas with very low tar content. Fig. 1 shows the major features of a downdraft gasifier. In the region nearest the air inlet, flaming Pyrolysis processes occur. Highly exothermic combustion reactions provide the energy to Pyrolyse (devolatilize) the solid fuel, and these two processes can occur nearly simultaneously. The temperature in the 'flaming Pyrolysis' region is sufficiently high to thermally 'crack' the Pyrolysis products into components of low molecular weight. Down-draft gasifiers have relatively low tar content and therefore usually are the preferred type for small scale power generation from biomass, having said this, it should also be realized that the tar from down-draft gasifiers is more stable than from up-draft gasifiers, which may still provide problems in tar removal. Moreover, proper operation asks for narrow specifications of both fuel size and moisture content (typically 20 Wt % db). Further, the classical downdraft gasifier with its typical throat cannot be scaled-up. Even with special designs, such as a rotating cone in the throat [4] to increase its efficiency, its maximum size, probably is limited to about 1 MWe.

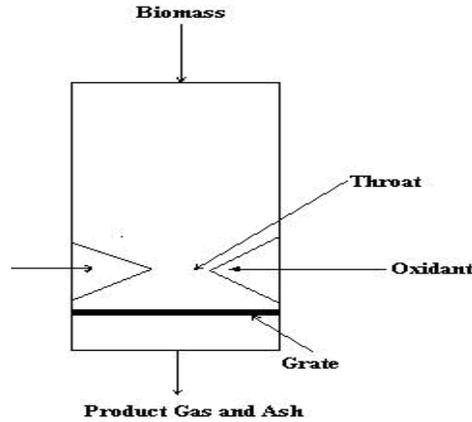


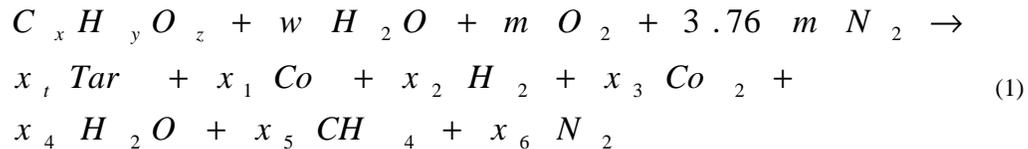
Fig. 1 Downdraft Gasifier

### EQUILIBRIUM MODEL FOR DOWNDRAFT BIOMASS GASIFIER

Calculations comprising the gasification proper are based on thermodynamics, mass and energy balances and process conditions, such as temperature, pressure, and the addition or subtraction of indirect heat. In all these calculations it is essential that the elemental composition and the temperature of the feed streams are known. For wood, both the proximate analysis (fixed carbon, volatile matter, moisture, ash) and the ultimate analysis (elemental, apart from ash) must be known. In gasification, use is made of a variety of reactions of which some are exothermic and some are endothermic. In virtually all cases the desired operating temperature is obtained by judiciously playing with the exothermic and endothermic reactions. The reaction of the fuel with oxygen is always complete and exothermic, whereas the reaction with steam or carbon dioxide is always endothermic and never complete because of thermodynamic limitations [4, 5].

The typical chemical formula of woody material, based on a single atom of carbon is  $CH_{1.44}O_{0.66}$

The global gasification reaction can be written as follows:



Where  $w$  is the amount of water per kmole of wood,  $m$ , the amount of oxygen per kmole of wood,  $x_1$  to  $x_5$ , the coefficients of constituents of the products. Let  $MC$  = Moisture content per mol of wood

$$mf = \frac{(12x + y + 16z) \times Mc}{18 [100 - Mc]} \quad (2)$$

For the known moisture content, the value of  $w$  becomes a constant and  $m$  can be found out from the airflow rate per kmol of wood.

$$m = s \times \Phi_c \quad (3)$$

From the global reactions, there are six unknowns  $x_1$  to  $x_6$ , and  $Tg$ , representing the five unknown species of the product and the temperature of the reaction. Therefore six equations are required, which can be obtained from the following balances.

$$\text{Carbon balance: } x = x_c + x_t + x_1 + x_3 + x_5 \quad (4)$$

$$\text{Hydrogen balance: } y + 2\omega = 1.03x_t + 2x_2 + 2x_4 + 4x_5 \quad (5)$$

$$\text{Oxygen balance: } z + \omega + 2m = 0.03x_t + x_1 + 2x_3 + x_4 \quad (6)$$

$$\text{Nitrogen balance: } 3.76 m = x_6 \quad (7)$$

The equilibrium constant for methane formation ( $K_1$ ) is

$$K_1 = \frac{P_{CH_4}}{(P_{H_2})^2} \rightarrow \text{for } 1_{atm} . pr ; K_1 = \frac{x_5}{(x_1)^2} \quad (8)$$

Similarly the Equilibrium constant for the shift reaction ( $K_2$ ) is

$$\text{For } CO + H_2O \Leftrightarrow CO_2 + H_2 ; K_2 = \frac{x_1 x_3}{x_2 x_4} \quad (9)$$

Therefore, the general equations for  $\ln K_1$  and  $\ln K_2$  is

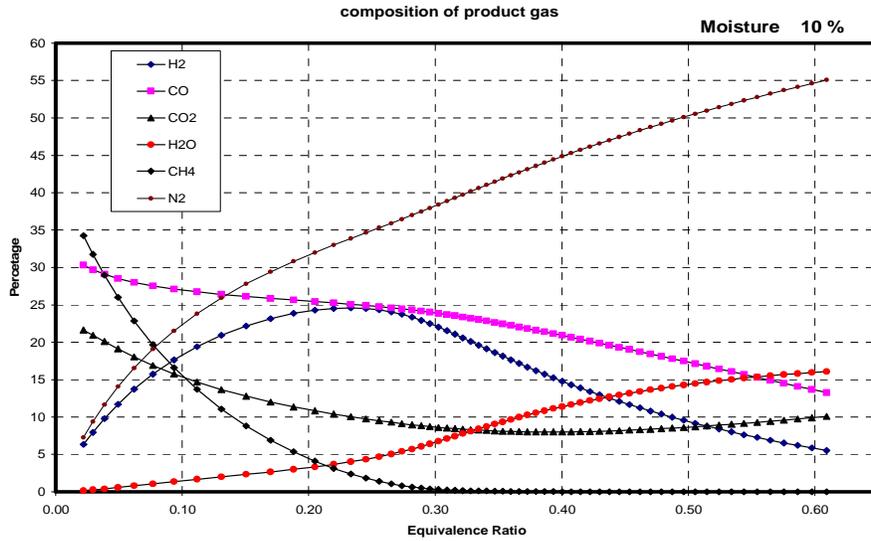
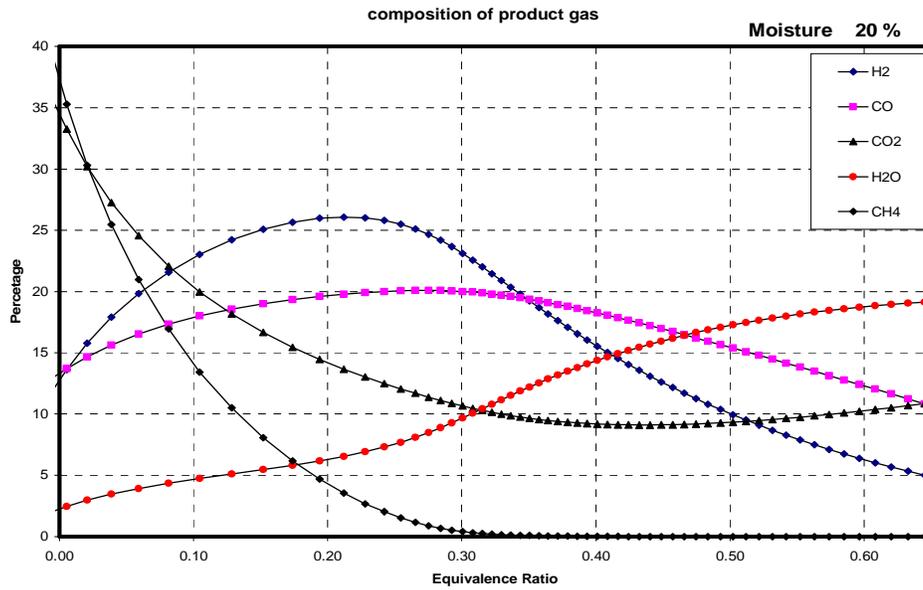


Figure 2 Gas composition with E.R for 10 % moisture content

$$\ln k_1 = \frac{7082.848}{T_g} - (6.567) \ln T_g + \frac{7.466 \times 10^{-3}}{2} \times T_g + \frac{-2.164 \times 10^{-6}}{6} \times T_g^2 + \frac{0.701 \times 10^{-5}}{2T_g^2} + 32.541 \quad (10)$$

$$\ln k_2 = \frac{5870.53}{T_g} + (1.86) \ln T_g + 2.7 \times 10^{-4} T_g + \frac{58200}{T_g^2} - 18.007 \quad (11)$$

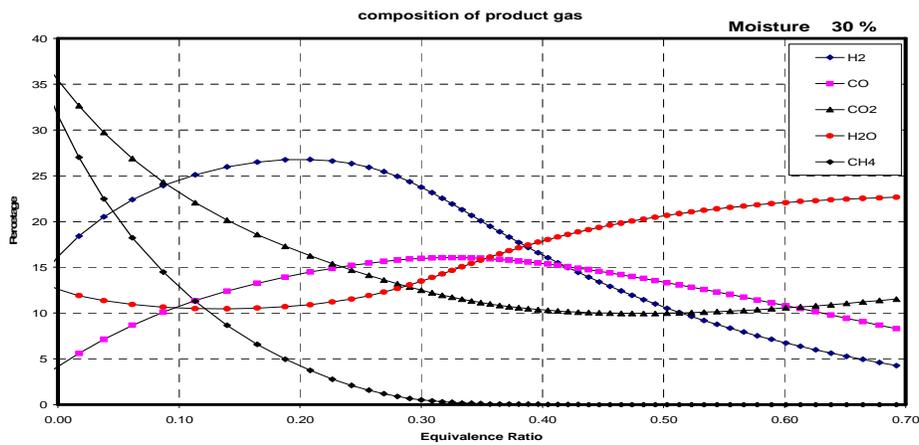
The equilibrium constants  $K_1, K_2$  for any temperature  $T$  can be obtained by substituting the temperature  $T_g$  into equations 10 and 11. Figures 2 –6 show the percentage of the components of the product gas against the equivalence ratio for different moisture content from 10 % to 50 %. In Figure 2 the percentage of  $N_2$  increases with increases in equivalence ratio. The percentage of  $H_2$  increases with the equivalence ratio up to 0.25 and reaches the maximum value of 24 % in product gas then decreases. The percentage of  $CO$  gradually decreases with increase of equivalence ratio and reaches the value of 25% in product gas at equivalence ratio of 0.25.



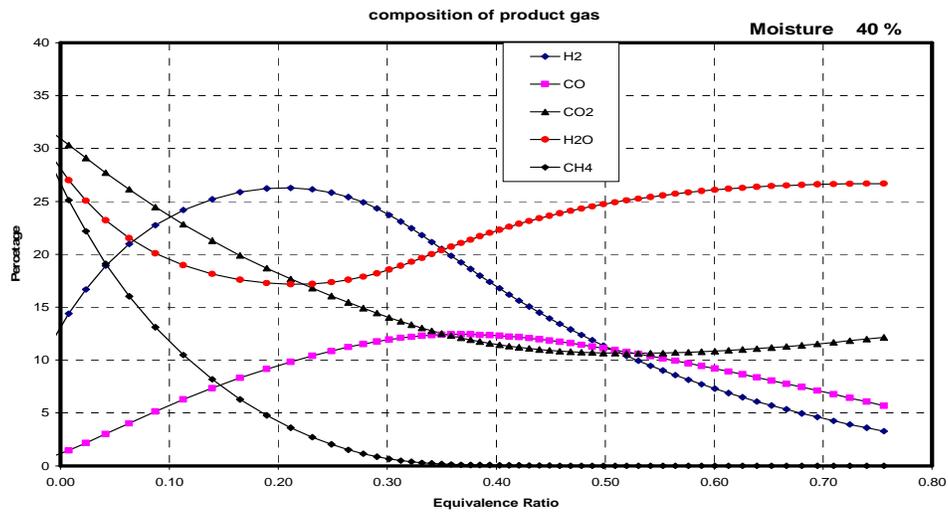
**Figure 3 Gas Composition with E.R for 20 % Moisture Content**

In Figure 3 the percentage of H<sub>2</sub> increases with the equivalence ratio up to 0.2 and reaches the maximum value of 26 % in product gas then decreases. The percentage of CO gradually increases with increase of equivalence ratio and reaches the value of 20% in product gas at equivalence ratio of 0.25 then decreases.

In Figure 4 the percentage of H<sub>2</sub> increases up to the equivalence ratio of 0.2 then decreases and reaches the value of 26 % in product gas at equivalence ratio of 0.25. The percentage of CO gradually increases up to the equivalence ratio of 0.3 then decreases and reaches the value of 16 % in product gas at equivalence ratio of 0.25.

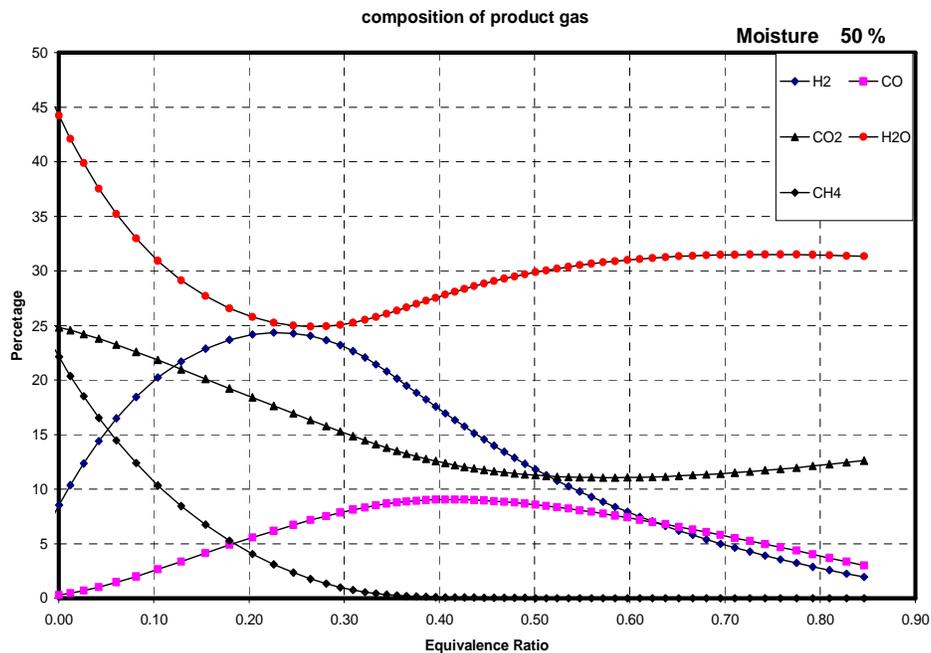


**Figure 4 Gas Compositions with E.R for 30 % Moisture Content**



**Figure 5 Gas Compositions with E.R for 40 % Moisture Content**

In Figure 5 the percentage of  $H_2$  increases up to the equivalence ratio of 0.2 then decreases and reaches the value of 26 % in product gas at equivalence ratio of 0.25. The percentage of CO gradually increases up to the equivalence ratio of 0.35 then decreases and reaches the value of 12 % in product gas at equivalence ratio of 0.25.



**Figure 6 Gas Compositions with E.R for 50 % Moisture Content**

The Figure 6 shows that the calorific value of the product gas is high with moisture content of 10 % and equivalence ratio 0.2 is high as compared to equivalence ratio of 0.25 and 0.3 with higher moisture

content of 20 %,30%,40%.but with less equivalence ratio of 0.2 the gasification was not completing and the equivalence ratio is increasing the calorific value goes on decreasing. Hence the equivalence ratio of 0.25 is taken optimum operating parameter for to satisfy both wood gasification and product gas with higher calorific value.

### VALIDATION OF EQUILIBRIUM MODEL

The composition of the product gas from wood are similar to those reported by other researchers (Hai 1992, Hollingdale 1983, Walawender et al 1985, Zainal et al 2002, Jayah et al 2003).The average gas compositions is 1.69% O<sub>2</sub>, 43.62% N<sub>2</sub>,14.05% H<sub>2</sub>, 24.04% CO,14.66% CO<sub>2</sub>, 2.02% CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub> detected as traces in most of the runs with a concentrations of 0.01%. The formation of CH<sub>4</sub> is unstable as it dissociates into CO and H<sub>2</sub> in the reduction zone. Equilibrium model predictions are compared with the Experimental data reported by Jayah et al 2003[6] and Aluddin 1996. The composition of product gas is compared and shown in Figure 8 and this shows that compositions of all components found by equilibrium model are in good agreement with experimentally reported data.

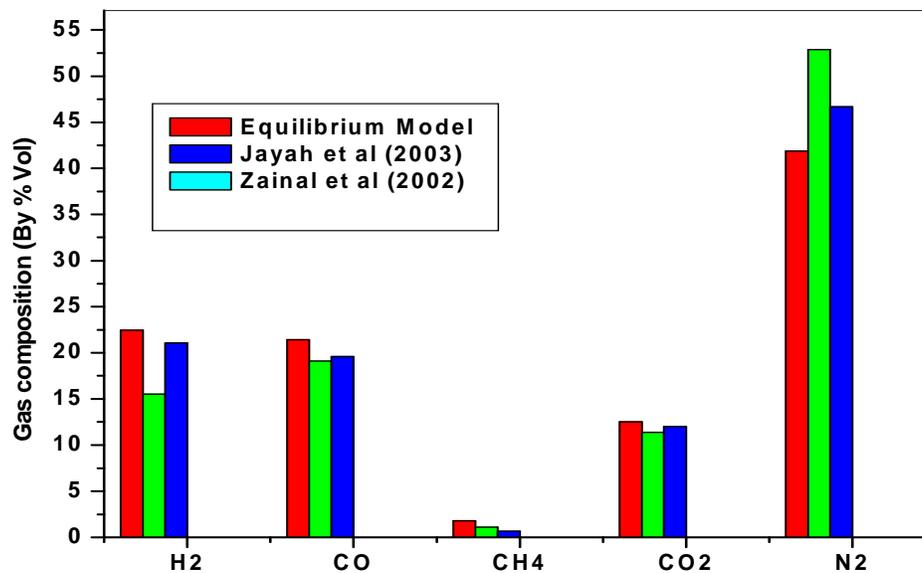


Figure 7. Comparison of Equilibrium Model Results with others

### CONCLUSIONS

Based on the simulation results of the Equilibrium model, it can be concluded that

- Equilibrium ratio of 0.25 with the moisture content of 10 % gives the higher percentage of CO and H<sub>2</sub> in product gas with higher heating value as compare to the moisture content of 20 %,30%,40%.
- CH<sub>4</sub> and H<sub>2</sub>O varies uniformly for different moisture content and it variation not influencing the calorific value of the product gas as compared to CO and H<sub>2</sub>O

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