Jurnal Teknologi

Full paper

A Simplified Model for Gasification of Oil Palm Empty Fruit Bunch Briquettes

Bemgba Bevan Nyakuma*, Olagoke Abimbola Oladokun, Anwar Johari, Arshad Ahmad, Tuan Amran Tuan Abdullah

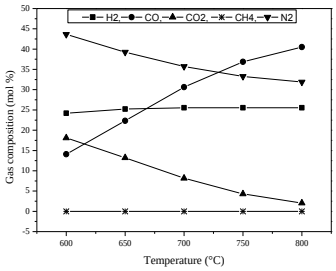
Institute of Hydrogen Economy, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author: bnbevan2@live.utm.my

Article history

Received :1 January 2014
Received in revised form :
15 February 2014
Accepted :18 March 2014

Graphical abstract



Abstract

This study is aimed at investigating the product gas yield and composition of EFB briquettes gasification using a simplified stoichiometric equilibrium model. Similar mathematical models have been successfully adopted by a number of research groups to investigate the thermochemical conversion of biomass species. Hence the effect of gasification temperature on the product gas yield and composition of EFB briquettes gasification using a simplified stoichiometric equilibrium model is presented in this study. The results indicate that the H_2 and CO content increased with increasing temperature from 600 to 800°C while the CO_2, N_2 and CH_4 content decreased. The H_2 content increased with increasing temperature, with peak production of 25.55 mol % at 750°C. The HHV (4.87 to 8.38 MJ/Nm3), CGE (27.72 to 47.71%) and CCE (25.42 to 41.54%) values increased with increasing temperature during gasification. Hence for a reacting system with known reaction mechanism, the model can be used to reasonably deduce the yield and composition of the gasification products.

Keywords: Stoichiometric; equilibrium; model; gasification; briquettes; temperature

1.0 INTRODUCTION

The transition from fossil fuels to renewable energy sources is necessitated by global issues such as climate change and environmental sustainability. The gasification of biomass resources is considered a promising route for the production of clean energy fuels for the future [1-3]. Hence, the valorization of oil palm waste in Malaysia can significantly influence the sustainability of future clean energy supplies around the globe.

Currently palm waste is utilized for agricultural, pharmaceutical uses, however it can also be converted into densified fuels or briquettes with enhanced properties for thermochemical conversion. The use of oil palm empty fruit (EFB) briquettes for thermochemical applications has been explored [4-5]. However, research on the yield and composition of EFB briquette gasification is significantly lacking.

This study is aimed at investigating the effect of gasification temperature on the product gas yield and composition of EFB briquettes using a simplified stoichiometric equilibrium model. Similar models have been successfully adopted to investigate the thermochemical conversion of biomass species in the past. Hence, the model can be used to determine the product yield and composition of a reacting system without considering hydrodynamics and reactor geometry [6-7].

2.0 MODEL THEORY AND DEVELOPMENT

The model considers only the chemical reactions and species involved during gasification. Considering C, H and O gasification can be represented by the relation;

$$CH_aO_bN_c + dH_2O + e(O_2 + 3.76N_2) \rightarrow n_1C + n_2H_2 + n_3CO + n_4H_2O + n_5CO_2 + n_6CH_4 + n_7N_2 \quad (1)$$

Where n_1 to n_7 are stoichiometric coefficients; *a, b, c* are the mole ratios from the ultimate analysis; *d* and *e* are input parameters for steam and air respectively. The major reactions of gasification can be expressed as;

$$C + CO_2 \rightarrow 2CO \quad (2)$$
$$C + H_2O \rightarrow CO + H_2 \quad (3)$$
$$C + 2H_2 \rightarrow CH_4 \quad (4)$$
$$CO + H_2O \rightarrow CO_2 + H_2 \quad (5)$$

The atomic balance for C, H, and O can be represented by Equations 6-9 and the total number of moles in the gas phase is given by Equation 10.

$$C: n_1 + n_3 + n_5 + n_6 = 1 \quad (6)$$
$$H: 2n_2 + 2n_4 + 4n_6 = a + 2d \quad (7)$$

$$O: n_3 + n_4 + 2n_5 = b + d + 2e \quad (8)$$
$$N: n_7 = c + 7.5e \quad (9)$$
$$n_2 + n_3 + n_4 + n_5 + n_6 = n_g \quad (10)$$

Considering the gasifier pressure, P, the equilibrium constants for the reactions in Equations 2-4 can be represented by Equations 11-13;

$$K_{e1} = \frac{y_{CO}^2 P}{y_{CO2}} \quad (11)$$

$$K_{e2} = \frac{y_{CO} y_{H_2} P}{y_{H_2O}} \quad (12)$$

$$K_{e3} = \frac{y_{CH4}}{y_{H2}^2 P} \quad (13)$$

K_{e1}, K_{e2} and K_{e3} are the equilibrium constants for the Boudouard reaction, Water gas reaction and Methanation reactions respectively.

The mole fractions of the species CO, H_2, H_2O and CO_2 are represented by y_i in the relation in Equation 14;

$$y_{CO} = \frac{n_3}{n_g};\ y_{CO2} = \frac{n_5}{n_g};\ y_{H2} = \frac{n_2}{n_g};\ y_{H2O} = \frac{n_4}{n_g}\ y_{CH4} = \frac{n_6}{n_g} \quad (14)$$

Substituting Equation 14 into Equations 11-13, and combining with Equations 6-10 gives the set of non-linear equations in 15-22.

$$f_1 = n_1 + n_3 + n_5 + n_6 - 1 \quad (15)$$
$$f_2 = 2n_2 + 2n_4 + 4n_6 - (a + 2d) \quad (16)$$
$$f_3 = n_3 + n_4 + 2n_5 - (b + d + 2e) \quad (17)$$
$$f_4 = n_7 - (c + 7.52e) \quad (18)$$
$$f_5 = n_2 + n_3 + n_4 + n_5 + n_6 - n_g \quad (19)$$
$$f_6 = n_3^2 P - K_{e1} n_5 n_g \quad (20)$$
$$f_7 = n_2 n_3 P - K_{e2} n_4 n_g \quad (21)$$
$$f_8 = n_3^2 K_{e3} P - n_6 n_g \quad (22)$$

The solution to the non-linear equations gives the product gas yield and composition of the biomass feedstock. The equilibrium constants in Equations 20-22 are obtained from Equation 23.

$$K_e = exp\left(-\frac{\Delta G}{RT}\right) \quad (23)$$

Where G, R and T are the Gibbs free energy, universal gas constant and temperature, respectively. The required Gibbs free energy are estimated from Equation 24.

$$\Delta G_{f,T}^o = \Delta h_{298}^o - a'TIn(T) - b'T^2 - \left(\frac{c'}{2}\right)T^3 - \left(\frac{d'}{3}\right)T^4 + \left(\frac{e'}{2T}\right) + f' + g'T\ \left(\frac{kJ}{mol}\right) \quad (24)$$

Furthermore, the empirical relation can be obtained from Equation by [8] the value of the empirical coefficients are given in Table 1.

Table 1 Standard heat of formation, empirical coefficients for Equation 24 [8]

Product	Δh^o_{298}	a'	b'	c'	d'	e'	f'	g'
CO	-110.5	5.619×10^{-3}	-1.9×10^{-5}	6.383×10^{-9}	-1.846×10^{-12}	-4.891×10^{2}	0.868	-6.131×10^{-2}
CO_2	-393.5	-1.949×10^{-2}	3.122×10^{-5}	-2.448×10^{-8}	6.946×10^{-12}	-4.891×10^{2}	5.27	-0.1207
CH_4	-74.8	-4.62×10^{-2}	1.13×10^{-5}	1.319×10^{-8}	-6.647×10^{-12}	-4.891×10^{2}	14.11	0.2234
H_2O	-241.8	-8.95×10^{-3}	-3.672×10^{-6}	5.209×10^{-9}	-1.478×10^{-12}	0	2.868	-0.0172

3.0 RESULTS AND DISCUSSION

3.1 Ultimate Analysis

The ultimate analysis of the EFB briquette is presented in Table 2. By substituting the values of C, H, O, N, S, moisture content (steam) and equivalence ratio (ER) into the model, the yield and composition of EFB briquette gasification can be deduced.

Table 2 Ultimate analysis of EFB briquette

Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen
43.15	5.73	1.2	0.04	49.88

For gasification, the ER is between 0.2 and 0.3 [6]. However Mohammed *et al.*, [3] deduced the optimal ER of 0.25 for EFB gasification which is in agreement with Basu [6]. Hence ER = 0.25 was chosen for the simulations in this study.

3.2 Effect of Temperature on Producer Gas Composition

Temperature largely influences the product gas yield and composition of biomass gasification. In this study, the effect of temperature on product gas composition on EFB briquette gasification was investigated from 600 to 800°C and ER=0.25. The yield and product gas compostion is presented in Figure 1.

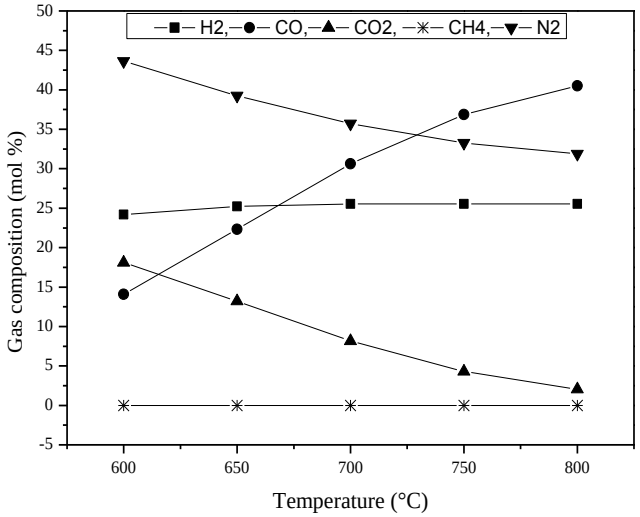


Figure 1 Effect of temperature on product gas composition

As can be observed in Figure 1, the H_2 and CO content increased while the CO_2, N_2 and CH_4 content decreased with

increasing temperature from 600 to 800°C. Furthermore, the increase in H_2 and CO content is due to the effect of increasing temperature on the endothermic reactions in Equations 2 and 3. The H_2 content increased from 24.19 mol % to 25.54 mol % with increasing temperature, with peak production of 25.55 mol % at 750°C. However, the most significant changes in product gas content was observed for CO (14.08 to 40.51 mol %) and CO_2 (18.12 to 2.06 mol %).

3.3 Effect of Temperature on Gasifier Performance

The parameters heating value (HHV), cold gas efficiency (CGE) and carbon conversion efficiency (CCE) serve as a measure of the efficiency of gasification and the gasifier performance. Mathematically the HHV, CGE and CCE can be calculated from Equations 25-27.

The heating value (HHV) of the producer gas is given by the relation;

$$HHV = [(H_2\% \, x \, 30.52) + (CO\% \, x \, 30.18) + (CH_4\% \, x \, 95)] \, x \, 4.1868 \left(\frac{MJ}{Nm^3}\right) \quad (25)$$

The cold gas efficiency (CGE) is given by the relation;

$$CGE = {}^{\alpha}/_{\mu} \, x \, 100 \, \% \quad (26)$$

Where α represents the heating value of the producer gas; μ is the heating value of the EFB briquettes.
The carbon conversion efficiency (CCE) is given by the relation;

$$CCE = {}^{\gamma}/_{\delta} \, x \, 100 \, \% \quad (27)$$

Where γ, represents the carbon content in CO, CO_2 and CH_4; while δ is the carbon content in EFB briquette

The effect of temperature on the heating value (HHV), cold gas efficiency (CGE) and carbon conversion efficiency (CCE) is presented in Table 3.

Table 3 Effect of temperature on gasifier performance

Temperature (°C)	Higher Heating Val (MJ/Nm^3)	Cold Gas Eff. (%)	Carbon Conv. Eff. (CCE, %)
600	4.87	27.72	25.43
650	6.04	34.39	30.52
700	7.13	40.59	35.56
750	7.93	45.11	39.35
800	8.38	47.71	41.54

The results indicate that the HHV, CGE and CCE increase with increasing temperature during gasification. This indicates the higher temperatures increase the overall efficiency of EFB briquette gasification. This can be attributed to the effect of higher temperatures on the thermal decomposition of the feedstock. The HHV values of EFB briquette gasification increased from 4 MJ/Nm^3 to 8 MJ/Nm^3 which is in good agreement for air gasification of biomass species [6]. Similar results have been reported in literature for biomass species [2-3].

In additon the results indicate that increasing gasification temperature by 30% from 600°C to 800°C results in ~ 72 % and 63% increase in cold gas efficiency (CGE) and carbon conversion efficiency (CCE) respectively. We can conclude that gasification temperature has a greater effect on CGE than CCE, hence future studies can optimize EFB gasification by focusing on other parameters such as ER, pressure and heating rate.

■4.0 CONCLUSION

The effect of gasification temperature on the product gas yield and composition of EFB briquettes was examined in this study. The results higher temperatures significantly influence the yield of the product gases H_2 and CO. In addition, we observed that gasification and gasifier performance is improved by increasing temperature. Furthermore, higher temperature increased cold gas efficiency (CGE) by a factor of 3 and carbon conversion efficiency (CCE) by a factor of 2. Hence we can conclude that the stoichiometric equilibrium model is robust, flexible and can be effectively used to predict the product gas yield and composition of EFB briquette gasification.

Acknowledgment

The authors acknowledge the financial support from the Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) GUP Grant (VOT No. 05H04).

References

[1] T. M. I. Mahlia, M. Z. Abdulmuin, T.M.I. Alamsyah, D. Mukhlishien. 2003. Dynamic Modelling and Simulation of a Palm Wastes Boiler. *Renewable Energy*. 28: 1235–1256.
[2] P. Lahijani, Z. A. Zainal. 2011. Gasification of Palm Empty Fruit Bunch in a Bubbling Fluidized Bed: A Performance and Agglomeration Study. *Bioresource Technology*. 102: 2068–2076.
[3] M. A. A Mohammed, A. Salmiaton, W. A. K. G. Wan Azlina, M. S. Mohammad Amran, A. Fakhru'l-Razi. 2011. Air Gasification of Empty Fruit Bunch for Hydrogen-Rich Gas Production in a Fluidized-bed Reactor. *Energy Conversion and Management*. 52: 555–1561.
[4] B. B. Nyakuma, A. Johari, A. Ahmad. 2012. Analysis of the Pyrolytic Fuel Properties of Empty Fruit Bunch Briquettes. *Journal of Applied Sciences*. 12(24): 2527–2533
[5] B. B. Nyakuma, A. Johari, A. Ahmad. 2013. Thermochemical Analysis of Palm Oil Wastes as fuel for Biomass Gasification. *Jurnal Teknologi*. 62(3).
[6] B. Basu. 2010. *Biomass Gasification and Pyrolysis: Practical Design and Theory*. Associated Press for Elsevier Inc., UK.
[7] X. T. Li, J. R. Grace, A. P. Watkinson, C. J. Lim, A. Ergüdenler A. 2001. Equilibrium Modeling of Gasification: A Free Energy Minimization Approach and Its Application to a Circulating Fluidized Bed Coal Gasifier. *Fuel*. 80(2): 195–207.
[8] R. F. Probstein, R. E. Hicks. 2006. *Synthetic Fuels*. Dover Publications.