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A GENERIC THERMODYNAMIC EQUILIBRIUM MODEL-BASED FRAMEWORK FOR BIOMASS GASIFICATION PROCESSES

Gan Gek Hian, Suriyati Saleh and Noor Asma Fazli Abdul Samad
Faculty of Chemical & Natural Resources Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak, Gambang, Pahang, Malaysia
E-Mail: asmafazli@ump.edu.my

ABSTRACT

In this paper a generic thermodynamic equilibrium model-based framework for biomass gasification processes has been developed. The designed framework contains a modelling for downdraft and fluidized bed gasifier. A biomass database has been developed as a supporting tools for this framework enabling this framework applicable to study a wide range of biomass gasification processes. Application of this framework has been highlighted based on two objectives. The first objective is to validate the thermodynamic equilibrium model for downdraft gasifier using wood and for fluidized bed gasifier using rice husk respectively. The predicted model shows a good agreement with literature data in terms of gas compositions produced indicating a reliable and valid model is achieved. Meanwhile the second objective of this study is to investigate the optimum parameters for downdraft and fluidized bed gasifiers using wood, rice husk, saw dust and empty fruit brunch. Based on this analysis, the optimum parameters obtained are at temperature 770 °C with moisture content of 0.2 and steam biomass ratio 1.32, where the hydrogen gas produced from wood, rice husk, sawdust and empty fruit bunch in downdraft gasifier is 16.38%, 17.02%, 15.11% and 50.12 % respectively, while in the fluidized bed gasifier is 38.75%, 50.12%, 73.24% and 71.77% respectively. The result of the performance analysis shows that the fluidized bed gasifier is more efficient than downdraft gasifier in term of hydrogen gas production.

Keywords: gasification, thermodynamic, equilibrium, biomass, hydrogen.

INTRODUCTION

Energy is an essential source for application in the domestic and industrial activities. However, the energy production and usage can lead to environmental, economic and social impacts. Increasing of global concern on the environmental issues and decreasing the dependence to the fossil fuels leads to the use of renewable energy (Galindo *et al.* 2014). Biomass is one of the most promising renewable energy sources due to its abundances, energy contents, and the low emissions of carbon dioxide to the atmosphere (Gao *et al.* 2008). Here, gasification is one of the ways to produce energy from the biomass. Typically, gasification is a thermo-chemical conversion technology or partial combustion process to convert biomass materials into energy through partial oxidation where solid fuel are transform into gas product (Bi and Liu, 2010). The main gas produced by gasification is the synthesis gas or syngas which is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide and nitrogen (Chen *et al.* 2007). The syngas can be directly used as a gaseous fuel and can be processed further to produce electricity and heat. Hydrogen is part of the syngas which is one of the clean energy sources and a potential alternative fuel. The combustion of hydrogen does not negatively affect the environment.

Technically, there are two groups of biomass gasification models to represent downdraft or fluidized bed gasification which are equilibrium approach and kinetic approach. The comparison between both types of the models show the most effective and applicable model is the equilibrium model due to its simplicity, behaviour and operation system (Garcia *et al.* 2009). Altafini *et al.* (2003) points to the researchers used the equilibrium model based on the minimization of Gibbs free energy

and equilibrium constant to analyse the gasification process and also to solve the optimization and non-linear equation problems based on the gasification process.

Biomass like wood, rice husk, sawdust and empty fruit bunch are important raw materials in the biomass gasification process. Wood had been used in many case studies as one of the main raw materials input during the gasification process. The experimental result for gas composition from wood gasification process is available in Zainal *et al.* (2001) is used as a base case study in this work to develop a thermodynamic equilibrium model for downdraft and fluidized bed gasifier. In addition, rice husk was successfully used as a biomass material in a downdraft biomass gasifier by works of Chowdhury *et al.* (1994) and Karmakar and Datta (2011) which the effects of reactor temperature, steam biomass ratio and carbon conversion were tested. Meanwhile, Miskam *et al.* (2009) studied on the characteristic of saw dust residues in cyclone gasifier. The result shows that the characteristic of saw dust from Malaysia's furniture industries is comparable with other types of biomass and making it a potential source of fuel for gasification. Gasification of biochar from empty fruit bunch (EFB) in fluidized bed reactor had been studied by Salleh *et al.* (2009) to determine the gas yield, overall carbon conversion, gas quality, and composition as a function of temperature. In their work, it also shown that the EFB has the potential to replace coal as a gasification agent in power plants. Although many literatures already performed the gasification using the wood, rice husk, saw dusk and empty fruit bunch but the important parameter is still poorly understood for improved performance so here the model is developed in order to study on these

important parameters such as temperature and moisture content.

Therefore the objective of this work is to develop a thermodynamic equilibrium model-based framework for a wide range of biomass gasification processes. The application of the framework is highlighted first to validate the thermodynamic equilibrium model using rice husk and wood as a biomass and subsequently the performance of downdraft and fluidized bed biomass gasification using wood, rice husk, empty fruit bunch and sawdust are investigated and analyzed. The sensitivity analysis by varying the gasification temperature, moisture content and steam biomass ratio for downdraft and fluidized bed gasification also taking into consideration in this performance analysis. Lastly, the performance comparison of downdraft and fluidized bed biomass gasification has been implemented and discussed in the next section.

METHODOLOGY

An overview of the different steps to be taken for performance analysis of a downdraft and fluidized bed biomass gasification is shown in Figure-1. It consists of the 5 main steps. The first step is the problem definition where the overall objective is defined. The main objective which can be applied using this framework may includes to investigate and analyse the performance of downdraft/fluidized bed biomass gasification using thermodynamic equilibrium model, to optimize the important parameters in term of gasifier temperature, moisture content, steam biomass ratio and carbon conversion for downdraft and fluidized bed gasification or to compare the performance of downdraft and fluidized bed biomass gasification under nominal operating condition and optimal condition.

In step 2, process and product specifications are specified by the user before the performance analysis is implemented. The specification is required to give information for the system that needs to be analyzed based on the desired product or analysis data needed. In terms of the process specification, the user needs to specify process to use either downdraft or fluidized bed gasifier or using both type of gasifier in order to study the performance of the gasifier. Next the selection of the biomass that will be used for the gasification process. For this selection, a database for biomass has been developed. An example of the developed biomass database is shown in Figure-2. Generally, approximately around 90 biomasses have been collected and arranged in this database. The ultimate and proximate analysis for each biomasses listed in the database are available in th database which has been collected from various literatures.
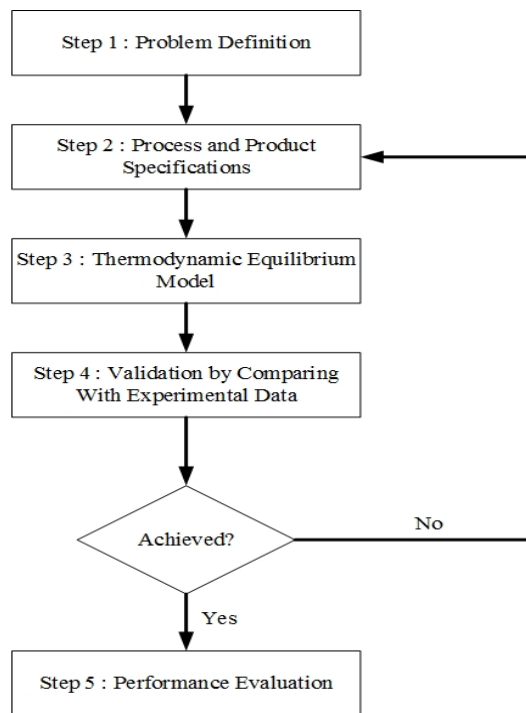

Figure-1. Thermodynamic equilibrium model-based framework for biomass gasification processes.

No	Type of biomass	C	H	N	O	S	Ash	Volatile Matter
1	Forest biomass	40.54	5.25	0.44	53.74	0.03	3.75	
2	Cotton stalk	45.20	6.30	1.20	47.00	0.30	3.10	73.00
3	Corn stalk	42.70	6.20	1.20	49.60	0.30	8.30	70.20
4	Rape straw	44.90	6.60	0.80	47.50	0.20	6.30	74.30
5	Wheat straw	40.40	6.00	0.60	52.70	0.30	12.90	68.50
6	Rice straw	37.50	5.90	0.90	55.60	0.10	7.70	82.10
7	Tobacco stem	36.10	4.90	2.90	55.30	0.80	21.70	68.50
8	Pine	51.00	6.00	0.10	42.90	0.00	0.20	70.40
9	Poplar	41.40	5.30	0.30	52.70	0.30	1.30	79.70
10	Bamboo	48.40	6.10	0.30	44.90	0.00	0.70	72.80
11	Rice husk	48.60	5.50	0.50	44.90	0.50	16.80	60.40
12	Peanut shell	60.50	7.10	1.90	28.60	1.90	1.50	56.60
13	Corncob waste	42.00	6.70	1.50	49.80	0.00	1.50	68.50
14	Cassava rhizome	49.20	6.70	1.00	42.99	0.11	5.00	76.00
15	Palm shell	47.60	5.38	0.66	41.38	0.04	3.60	72.70
16	Palm fiber	46.64	5.66	1.73	39.46	0.10	6.60	73.70
17	Palm kernel	41.47	5.77	3.00	43.49	0.03	3.20	80.30
18	Shell	53.78	7.20	0.00	36.30	0.51	2.21	73.74
19	Fiber	50.27	7.07	0.42	36.28	0.63	5.33	75.99
20	EFB	48.79	7.33	0.00	40.18	0.68	3.02	79.67
21	Palm kernel shell	46.53	5.99	0.91	46.46	0.11	2.82	74.60
22	Palm fiber	43.78	5.88	1.45	48.76	0.13	6.03	74.59
23	EFB[a]	45.81	5.74	0.43	47.54	0.48	3.95	72.83
24	EFB[b]	45.00	5.60	0.37	48.57	0.46	4.14	72.97
25	PMF[a]	47.62	5.26	0.57	45.63	0.44	5.11	75.48
26	PMF[b]	47.88	5.74	0.63	45.34	0.41	4.98	75.28
27	PKS[a]	50.18	5.54	0.49	43.35	0.42	2.16	73.81
28	PKS[b]	49.27	5.46	0.42	44.64	0.38	2.48	73.67
29	Pine Sawdust	48.62	5.79	2.39	43.20	0.00	0.37	81.03
30	Sawdust	48.98	4.89	0.32	36.01	0.18	3.30	74.30
31	Oil Palm fiber	51.94	4.75	2.43	40.88	0.00	7.03	72.46
32	Eucalyptus	50.77	5.13	0.00	44.10	0.00	0.00	81.07
33	Palm kernel shell	50.62	6.02	0.37	42.15	0.00	0.84	70.50
34	EFB	45.53	5.46	0.45	43.40	0.04	5.12	
35	Mesocarp fiber	46.92	5.89	1.12	42.66	0.09	3.32	
36	Kernel shell	46.68	5.86	1.01	42.01	42.01	4.38	
37	Palm kernel shell	46.53	5.85	0.89	42.32	4.41	4.29	84.86
38	Reed canary grass	48.60	6.80	0.30	37.30	7.00	5.50	82.50
39	Wheat straw	47.30	6.80	0.80	37.70	7.40	6.30	76.40
40	Willow	49.90	6.50	0.20	39.90	3.50	1.70	87.60
41	Banyan	46.2	6.08	0.08	46.53	1.11	1.11	77.57
42	Beech	47.20	6.00	0.40	45.20	1.20	0.30	84.20

Figure-2. Example of biomass database available in the developed database for biomass gasification processes.

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Meanwhile, the main product in this model is hydrogen gas composition and efficiency of the gasifier. Therefore the user needs to select the composition and the efficiency of that needs to be achieved in this gasification process. The operating conditions of the gasifier may consists of the gasifier temperatures, steam biomass ratio, moisture content and gas composition. The range of temperature that can be selected is between 250°C-1000°C for both gasifiers. Meanwhile, the moisture content chosen in the result part is between 0% and 40%. It should be noted that the moisture content higher than this range will not be suitable for the gasification process. In addition the steam biomass ratio is also specified to analyze how the performance or amount of hydrogen product changes if the ratio of compound or feedstock reacted with the steam change. However the steam biomass ratio is available only for fluidized bed gasifier. The required specifications needed for this analysis is summarized in Table-1.

Table-1. Process and product specifications.

Process and Product Specifications	Selection
Type of Gasifier	a) Downdraft gasifier b) Fluidized bed gasifier
Biomass	Select biomass in the database as shown in Figure-2.
Temperature	Range of 250°C-1000°C
Moisture Content (MC)	Range of (0% -40%)
Steam Biomass Ratio	Range of 0.6-1.7 (for fluidized bed gasifier only)
Reactant	a) Air b) Steam
Product	a) Hydrogen gas composition b) Efficiency

In step 3, the thermodynamic equilibrium model is used to represent the gasification process as shown in Table-2. Two main general reactions that might occur to the feedstock during the gasification process based on the reactant used either using air or steam. The reaction occurs in the downdraft gasifier is using air as reactant and the reaction occurs in the fluidized bed gasifier is employing steam as reactant for gasification. The chemical formula of the selected biomass is determined from the data of ultimate analysis. In the ultimate analysis, the composition in mass fraction of element in the materials which includes the composition of carbon, hydrogen, nitrogen, sulphur and oxygen are given as shown in Figure-2. This information is then used to calculate the chemical formula using Equations (1) - (2). For example, the calculation of general biomass chemical formula $C_nH_aO_b$ is determined by assuming that n equal to 1.0 while unknown a and b is calculated as below:

$$a = \frac{\text{mass fraction}(H) \times \text{molecular weight}(C)}{\text{mass fraction}(C) \times \text{molecular weight}(H)} \quad (1)$$

$$b = \frac{\text{mass fraction}(O) \times \text{molecular weight}(C)}{\text{mass fraction}(C) \times \text{molecular weight}(O)} \quad (2)$$

In order to determine the gas compositions, the following steps need to be taken as follows:

a) The value of w is obtained based on the specified moisture content

$$w = \frac{24MC}{18(1-MC)} \quad (3)$$

b) Calculate ΔA, ΔB, ΔC and ΔD based on heat capacities for every chemical species.
c) Obtain the values of Gibbs of formation ($\Delta G°$) and heat of formation ($\Delta H°$) at 25 ^{0}C.
d) By using values obtained in a) and b), compute variables J and I by solving Equations (11)-(12) simultaneously.
e) Determine the equilibrium constants k_1 and k_2 using Equation (10) based on values obtained in a)-d).
f) The stoichiometries of x_1 (hydrogen), x_2 (carbon monoxide), x_3 (carbon dioxide), x_4 (water) and x_5 (methane) are obtained by solving Equations (5)-(9) in Table-2 simultaneously using Newton Raphson method.
g) The composition of the gas produced during the reactions is calculated based on the mole balance by assuming the amount of the biomass material used. After the value of mole for biomass material inlet is specified, the mole balance using the stoichiometry calculated from previous step is used to determine the composition of each component in the reactions.

The data for heat capacities, heat of formation and Gibbs of formation can be obtained from Robert and Don (1984). The fourth step is the validation process where the comparison is implemented between the simulation results using thermodynamic equilibrium model and the experimental result from the literature. In this work, the experimental data used in this validation stage are obtained from Zainal *et al.* (2001) for downdraft gasifier and Karmakar and Datta (2011) for fluidized bed gasifier. For this model validation, the root mean square is also calculated using Equation (4):

$$RMS = \sqrt{\frac{\sum (X_e - X_p)^2}{N}} \quad (4)$$

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Table-2. General thermodynamic equilibrium model for gasification processes.

Downdraft Gasifier	Fluidized Bed Gasifier	Eqs.
$CH_aO_b + wH_2O + mO_2 + 3.76mN_2 = x_1H_2 + x_2CO$ $+ x_3CO_2 + x_4H_2O + x_5CH_4 + 3.76mN_2$	$CH_aO_b + wH_2O + mH_2O = x_1H_2 + x_2CO + x_3CO_2$ $+ x_4H_2O + x_5CH_4$	(4)
Carbon balance: $x_2 + x_3 + x_5 - 1 = 0$	Carbon balance: $x_2 + x_3 + x_5 - 1 = 0$	(5)
Hydrogen balance: $2x_1 + 2x_4 + 4x_5 - a - 2w = 0$	Hydrogen balance: $2x_1 + 2x_4 + 4x_5 - a - 2w - 2m = 0$	(6)
Oxygen balance: $x_2 + 2x_3 + x_4 - w - 2m - b = 0$	Oxygen balance: $x_2 + 2x_3 + x_4 - w - m - b = 0$	(7)
Equilibrium constant: $k_1 = \dfrac{x_5}{(x_1)^2}$		(8)
Equilibrium constant: $k_2 = \dfrac{x_1 x_3}{x_2 x_4}$		(9)
$\ln k = -\dfrac{J}{RT} + \Delta A \ln T + \dfrac{\Delta B.T}{2} + \dfrac{\Delta C T^2}{6} + \dfrac{\Delta D}{2T^2} + I$		(10)
$\dfrac{\Delta H°}{R} = \dfrac{J}{R} + \Delta AT + \dfrac{\Delta B T^2}{2} + \dfrac{\Delta C.T^3}{3} - \dfrac{\Delta D}{T}$		(11)
$\Delta G° = J - RT\left[\Delta A \ln T + \dfrac{\Delta B T}{2} + \dfrac{\Delta C T^2}{6} - \dfrac{\Delta D}{2T^2} + I\right]$		(12)
Data on heat capacity: $\Delta A = A_{CH_4} - A_C - 2A_{H_2}$ $\Delta B = B_{CH_4} - B_C - 2B_{H_2}$ $\Delta C = C_{CH_4} - C_C - 2C_{H_2}$ $\Delta D = D_{CH_4} - D_C - 2D_{H_2}$		(13)

Where, X_e and X_p is the experimental data and the predicted value of product gas from the thermodynamic equilibrium model respectively and N is the number of data used. In the last step, the performance of the selected gasifier is analyzed or compared in terms of the effects of gasifier temperature and moisture content to the total gas component produced. Based on this performance, the important parameters for gasifier are identified and optimized in order to further improve the performance of the gasifier.

Application of Thermodynamic Equilibrium Model
The application of the thermodynamic equilibrium model is highlighted through 4 different biomasses using 2 gasifiers. The biomasses used are wood, rice husk, sawdust, empty fruit bunch. Meanwhile both gasifiers consist of downdraft and fluidized bed gasifiers are also used for performance comparison.

Problem Definition (Step 1)
In this work, 2 objectives are proposed, Firstly, the objective is to validate the thermodynamic equilibrium model where the comparison is implemented between the

gas composition produced using thermodynamic equilibrium model and the experimental result from the literature. The experimental data used in this validation stage are obtained based on gas composition from wood from Zainal *et al.* (2001) using downdraft gasifier and from Karmakar and Datta. (2011) for fluidized bed gasifier using rice husk. Therefore the similar assumptions and operating conditions are employed as in the literature for the validation purpose. The second objective is to analyse the performance of downdraft and fluidized bed gasifier using thermodynamic equilibrium model using wood, rice husk, empty fruit bunch and sawdust. The analysis also optimizing the important parameters in term of operating condition including gasifier temperature, moisture content and steam biomass ratio.

Process and Product Specifications (Step 2)
In the second step, the decision on the process and product specifications need to be specified. The summaries of process and product specifications for the validation process are shown in Table-3. In this work two gasifiers are used which is downdraft gasifier and fluidized bed gasifier.

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Table-3. Process and product specifications.

Process and product Specification	Chosen	Chosen
Type of Gasifier	Downdraft gasifier	Fluidized Bed gasifier
Biomass	Wood	Rice Husk
Biomass chemical formula	$CH_{1.44}O_{0.66}$	$CH_{1.777}O_{0.775}$
Temperature(°C)	800	690
Moisture Content (%)	20	20
Steam Biomass Ratio	-	1.32
Reactant	Air	Water
Product	Hydrogen gas	Hydrogen gas

Thermodynamic Equilibrium Model (Step 3) and Model Validation (Step 4)

Based on the specifications made in step 2, the gas composition is then calculated using thermodynamic equilibrium model steps in step 3. The gas produced for both cases are then compared with the experimental data (step 4) for model validation. Tables-4 and 5 show the model comparison for downdraft gasifier and fluidized bed gasifier.

Table-4. Model validation for downdraft gasifier.

Type of gasifier	Downdraft gasifier		
Components	Experimental Data	Model Data	RMSE
H_2	15.23	15.23	0.00
CO	23.04	27.71	0.04
CO_2	1.58	6.43	9.42
CH_4	16.42	0.32	0.96
O_2	1.42	0.00	1.00
N_2	42.31	50.32	0.04

Table-5. Model validation for fluidized bed gasifier.

Type of gasifier	Fluidized bed gasifier		
Components	Experimental Data	Model Data	RMSE
H_2	50.50	50.00	0.00009
CO	12.83	12.83	0.00000
CO_2	28.51	28.45	0.00004
CH_4	8.16	8.71	0.00456
O_2	0.00	0.00	0.00
N_2	0.00	0.00	0.00

Based on the calculated RMSE for both gasifiers, the predicted model data is quite compatible with the experimental data especially for the hydrogen gas production. The other types of gas have a slight different from experimental data except for CO2 (carbon dioxide) gas composition in downdraft gasifier as shown in Table-4 where the difference is a bit too high but it does not effect much since our main product is the hydrogen gas.

Meanwhile the gas composition obtained for fluidized bed gasifier is in good agreement with experimental data as summarized in Table-5. Generally, the validation shows that the model is applicable to be used to analyse the hydrogen gas produced in the downdraft and fludized bed gasifiers. Therefore it can be concluded that the thermodynamic model in used is valid and applicable for further studies.

Performance Evaluation (Step 5)

In this step, the performance evaluation is performed on wood, rice husk, sawdust and empty fruit bunch by varying the gasifier temperature and moisture content for both gasifiers. Tables-6 and 7 show the specification for the comparison of downdraft and fluidized bed gasifier at different temperature. After the specification is made, the thermodynamic model is used to predict the amount of hydrogen gas produced by both type of gasifiers.

Table-6. The specification for the comparison of downdraft and fluidized bed gasifiers at different temperature.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (°C)	650, 690, 730, 770
Moisture content	0.2
Steam Biomass Ratio	1.32
Product	Hydrogen gas

Table-7. The specification for the comparison of downdraft and fluidize bed gasifier at different moisture content.

Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (°C)	700
Moisture content	0, 0.1, 0.2, 0.3, 0.4
Steam Biomass Ratio	1.32
Product	Hydrogen gas

The hydrogen gas produced at different temperature is shown in Figures-3 and 4 for downdraft and fluidized bed gasifiers. Figure-3 shows that as the temperature increase as high as 770 °C with moisture content of 0.2 and steam biomass ratio 1.32, the hydrogen gas composition produced will be increased. The empty fruit bunch is the biomass producing the highest amount of hydrogen gas (50.12%) in downdraft gasifier compared to the wood (16.38%), rice husk (17.02%), sawdust (15.11%) since empty fruit bunch undergo partial combustion process faster due to high heating value (HHV) which tend to react with air in more efficient way. However, in the fluidized bed gasifier, when the temperature is increased around 770 °C, the hydrogen gases produced by sawdust approximately 73.24% is the highest hydrogen production

compared to the wood (38.75%), rice husk (50.00%) and empty fruit bunch (71.77%). Therefore for fluidized bed gasifier, the sawdust is the biomass that produce the highest amount of hydrogen gas at high temperature. This mainly due to the fact that when temperature increase, the steam contain hydrogen gas compound will tend to react and activate the hydrogen component in sawdust which have highest hydrogen component compare to other type of biomass. It is also shown that the wood and rice husk produced only a small amount of hydrogen gas compared to empty fruit bunch and sawdust for both cases. Figure-4 shows that as the moisture content of biomass increase, the hydrogen gas composition produced will slight increase except for the wood and empty fruit bunch in fluidized bed gasifier where here when the moisture content increase the hydrogen gas produced is also decreased. In the end at mosture content of 0.4, the hydrogen gas produced is 18.79% (wood), 21.31% (rice husk), 21.69% (sawdust) and 44.48% (empty fruit bunch) respectively using downdraft gasifier. Meanwhile the gas compositions approximately 33.36% (wood), 66.07% (rice husk), 83.57% (sawdust) and 69.32% (empty fruit bunch) are

achieved using fluidized bed gasifier at moisture content of 0.4. In the end, the fluidized bed gasifier is more efficient than downdraft gasifier in hydrogen gas production for all types of biomass tested. The empty fruit bunch is the types of biomass which produce the highest amount of hydrogen gas in downdraft gasifier, meanwhile sawdust is the biomass producing the highest amount of hydrogen in fluidized bed gasifier. Meanwhile, rice husk and wood is not recommend for hydrogen production.

Another important parameter which affects the performance of fluidized bed gasifier is steam biomass ratio. Note that the steam biomass ratio is not applicable to the downdraft gasifier due to the fact that the air is used as reactant and thus it is not influenced by the use of steam. The performance analysis of fluidized bed gasifier at different steam biomass ratio range 0.60-1.70 is perform using wood, rice husk, sawdust and empty fruit bunch. The summaries of process and product specifications for steam biomass ratio used in the fluidized bed gasifier are shown in Table-8.
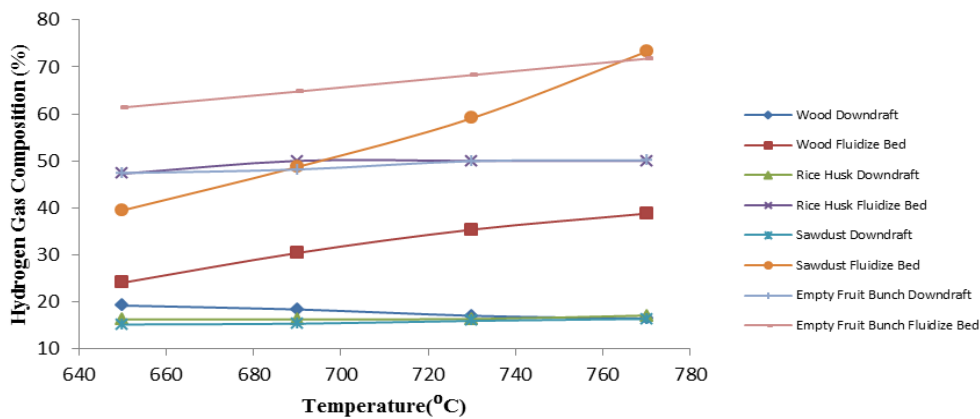

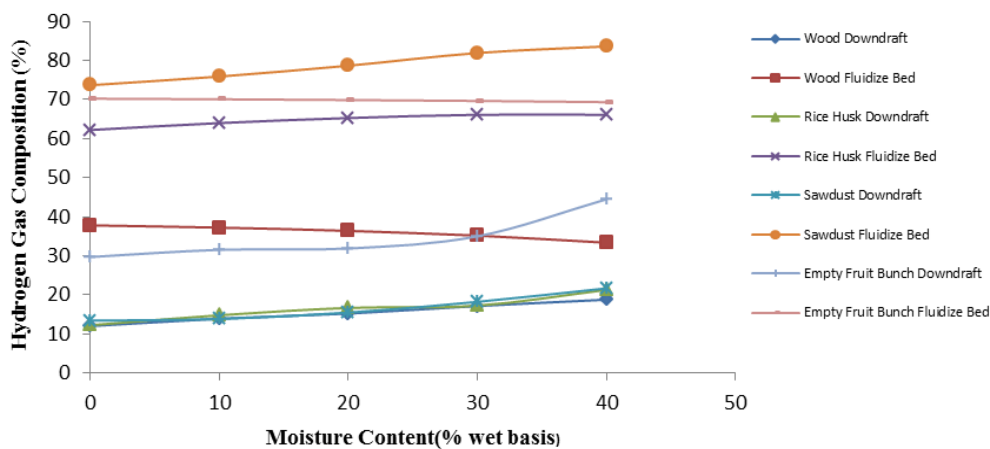**Figure-3.** The comparison of downdraft and fluidize bed gasifier at different temperature.

Figure-4. Downdraft and fluidized bed gasifiers comparison at different moisture content.

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Table-8. Process and Product Specifications for Steam Biomass Ratio Different in Fluidized Bed Gasifier.

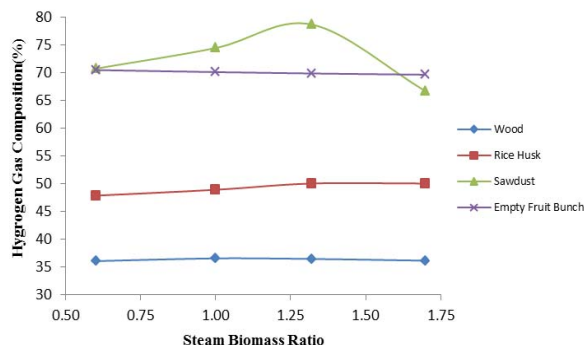| Material	Wood, Rice Husk, Sawdust, Empty Fruit Bunch
Gasification temperature (^{0}C)	770
Moisture content	0.2
Steam Biomass Ratio	0.60, 1.00, 1.32, 1.70
Product	Hydrogen gas

Figure-5. Hydrogen gas composition produced by each types of biomass at different steam biomass ratio.

The simulated results for this case is shown in Figure-5. The optimum steam biomass ratio is 1.32 where it produces the highest hydrogen gas for all biomasses. Based on Figure-5, sawdust is the biomass producing the highest amount of hydrogen at 78.68% followed by empty fruit bunch (69.86%), rice husk (50%) and wood (36.38%).

CONCLUSIONS

The thermodynamic equilibrium model-based framework has been developed to analyse the performance of downdraft and fluidized bed gasifier. The validity of the thermodynamic equilibrium model for downdraft and fluidized bed gasifiers has been performed through the biomass gasification using wood and rice husk respectively. The predicted gas compositions obtained for both biomasses are in good agreement with literature data thus confirming the valid model is achieved. Based on the performance analysis, fluidized bed gasifier is more efficient compare to downdraft gasifier since at temperature 770°C with moisture content of 0.2 and steam biomass ratio 1.32, the hydrogen gas produced from wood, rice husk, sawdust and empty fruit bunch in downdraft gasifier is 16.38%, 17.02%, 15.11% and 50.12 % respectively, while in the fluidized bed gasifier is 38.75%, 50.00%, 73.24% and 71.77% respectively. In addition it has been concluded that hydrogen gas production in most of the biomass are increased when the moisture content is increased except wood and empty fruit bunch in fluidized bed gasifier where the value is decreasing. The biomass

that produce the highest amount of hydrogen in downdraft gasifier is empty fruit bunch, while in the fluidized bed gasifier, empty fruit bunch is the highest hydrogen gas production at low temperature but as the temperature increase the sawdust become the biomass that produce the higher amount of hydrogen. As a conclusion, the proposed model is applicable for modelling of gasification process and can be used for preanalysis in determining the hydrogen gas production for any new biomass without the need to perform the full scale experiment.

REFERENCES

[1] Altafini, C.R, Wander P.R and Barreto R.M. (2003). Prediction of working parameters of a wood waste gasifier through an equilibrium model. Energy Conversion and Management, 44, pp.2763-2777.

[2] Bi, X.T. and Liu, X. (2010). High density and high solids flux CFB risers for steam gasification of solids fuels. Fuel Process Technology, 91, pp.915–920.

[3] Chen, W.H., Chen, J.C., Tsai, C.D. and Jiang, T.L. (2007). Transient gasification and syngas formation for coal particles in a fixed-bed reactor. International Journal of Energy Research, 31, pp. 895–911.

[4] Chowdhury, R., Bhattacharya, P. and Chakravarty, M. (1994). Modeling and simulation of a downdraft rice husk gasifier. International Journal of Energy Research, 18, pp. 581–594.

[5] Galindo, A.L., Electo, S.L., Rubenildo, V.A., Sandra, Y.G., Rene, L.J. and Vladimir, M.C. (2014). Biomass gasification in a downdraft gasifier with a two-stage air supply: Effect of operating conditions on gas quality. Biomass and Bioenergy, 61(6), pp. 345-456.

[6] Gao, N. and Li, A. (2008). Modeling and simulation of combined paralysis and reduction zone for a downdraft biomass gasifier energy. Energy Conversion and Technology, 49, pp. 3483-3490.

[7] Garcia, C.C., Tzimas, E. and Peteves, S.D. (2009). Technologies for coal based hydrogen and electricity co-production power plants with CO_2 capture. JRC Scientific and Technical, 54, pp. 268-339.

[8] Karmakar, M.K. and Datta, A.B. (2011). Generation of hydrogen rich gas through fluidized bed gasification of biomass. Bioresource Technology, 102, pp. 1907-1913.

[9] Miskam, A., Zainal, Z.A. and Yusof, I.M. (2009). Characterization of sawdust residues for cyclone gasifier. Energy Conversion and Management, 12, pp. 2294-2300.

www.arpnjournals.com

[10] Robert, H.P. and Don, W.G. (1984). Perry's chemical engineers' handbook. Sixth edition. New York: McGraw Hill.

[11] Salleh, M.A., Kisiki, N.H., Yusuf, H. M. And Ghani, W. A.W.A..K. (2009). Gasification of bio char from empty fruit bunch in a fluidized bed reactor, Open Access Energies MDPI, 3, pp. 1344-1352.

[12] Zainal, Z.A., Ali, R., Lean, C.H. and Seetharamu, K.N. (2001). Prediction of a downdraft gasifier using equilibrium modeling for different biomass materials. Energy Conversion and Management, 42, pp. 1499–1515.