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INTEGRATED GASIFICATION AND FUEL CELL FRAMEWORK: BIOMASS GASIFICATION CASE STUDY

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ABSTRACT

The increase prices of conventional energy sources particularly fossil fuels are usually based on the needs to match the energy demands which consequently accelerating the depletion of fossil fuels. Therefore, a renewable energy provides an attractive alternatives to replace the fossil fuels. One of the widely used renewable energy source is biomass waste such as wood sawdust due to its abundances and availabilities. This biomass waste can be used in gasification process in order to produce the hydrogen gas which is useful for energy production. Therefore, the objective of this paper is to develop a comprehensive integrated gasification and proton exchange membrane fuel cell (PEMFC) framework for a wide range of gasification process. The application of the integrated framework is highlighted through biomass gasification using fluidized bed by utilizing sawdust as biomass input. The biomass gasification model is developed in Aspen Plus and it is also considering the hydrodynamic and reaction rate kinetics simultaneously. The developed biomass gasification using pine sawdust is tested and the results obtained are in good agreement with literature data where the slight relative mean square erros of 0.018, 0.226, 0.726 and 0.317 for the H_2, CO_2, CH_4 and CO respectively are achieved indicating a reliable gasification model is obtained. Subsequently the wood sawdust is used as an input and the results show 23.47% hydrogen gas has been produced from wood sawdust which is relatively higher than 20.86% of hydrogen gas produced using pine sawdust. Finally it has been shown through sensitivity analysis the hydrogen gas can be produced up to 47.37% when the temperature is operated at 900 °C and up to 34.96% when equivalence ratio is at 0.205 indicating an improved better gasification performance.

Keywords: framework, gasification, PEMFC, biomass.

INTRODUCTION

The total energy demands from the entire global is increasing everyday meanwhile the level of non-renewable energy like fossil fuels is depleting in alarming rate (Jing, 2011). Although the fossil fuels are widely used in many application such as plastics, medicines, cosmetics, providing electricity and fueling transportation but it is also creates a greater concern with respect to environmental pollution. The combustion fossil fuels usually produce a significant amount of pollutants such as carbon dioxide (CO2) and this can lead towards a greenhouse effect and promotion of global warming. Hence, the reasonable, sustainable and environmentally friendly renewable energy sources to replace the fossil fuels become necessary. Moreover, the usable of renewable energy is basically for renewable technologies. In addition to renewable technologies, using energy more efficiently is also an important part of moving to a clean energy future (Miller, 2011). Besides, renewable energy is currently able to provide affordable electricity across the world, and this will stabilize energy prices in the future (UCS, 2009). The costs of renewable energy technologies now have declined steadily, and are projected to drop even more in the future. As a consequence, there has been a great interest in the research and development of alternative energy sources. This can be seen from the investment of huge sum of money by various governments around the world. For example, the Malaysia government, now recently finds a way forward in renewable energy development and utilization, which established more energy research centers and propose new pragmatic policy to facilitate more environmental-friendly energy development path (Islam *et al.* 2009). This growing concern for alternative energy can be attributed to the need to reduce the dependence on foreign sources of energy (Nwakaire *et al.* 2013). There are several renewable energy sources that act as alternative energy are in used today such as hydropower, geothermal and biomass (Shamsuddin, 2010). One of the renewable energy sources that have been widely used is biomass waste considering it is most abundances resources and its availabilities as a waste in Malaysia.

Generally, biomass is a term for all organic material that stems from plants (including algae, trees and crops). The biomass resource can be treated as organic matter, in which the energy of sunlight is stored in chemical bonds. When the bonds between adjacent carbon, hydrogen and oxygen molecules are broken by combustion, digestion, or decomposition, these substances release their stored chemical energy. Biomass has always been a major source of energy for mankind and is presently estimated to contribute of the order 10-14% of the world's energy supply (Gimelli *et al.* 2012). In other words, bioenergy is expected to become one of the major energy resources in the future because biomass is renewable and free from net CO2 emissions. It is also the only sustainable source of organic carbon. Using biomass as a fuel offers certain advantages, in terms of energy, environment, society and economy.

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Malaysia, which covered about 204560 km2 of forest area is one of the country with significant amount of biomass resources. The forestry and agriculture activity sectors in the country produce a large amount of residue from oil palm, wood (forest residue), rubber trees and rice that has no other commercial values than potential energy generations (Kammaruzzaman *et al.* 2000). For example, the forestry industry in Terengganu, Malaysia produced about 711,400 m3 of wood sawdust waste product per annum while it is estimated that in 1995 the timber industry in Malaysia generated roughly 0.226 million dry tones of sawdust. The existences of these wastes and residues have created some disposal problems to the country. The Department of Environment (DoE) Malaysia for example, has discouraged burning the materials due to the pollution and possible forest burning problems. The best solution to overcome this problem is to extract energy from these materials through certain process called gasification process.

Gasification is one of the most important areas in the research, development and demonstration (RDandD) of the biomass-to-energy framework. Biomass gasification is a process of incomplete combustion of biomass resulting in production of combustible gases consisting of carbon monoxide (CO), hydrogen (H2) and traces of methane (CH4). There are several type of reactor that involved in the gasification process which are: 1) fixed beds (updraft, downdraft, crossdraft), 2) fluidized beds (bubbling, circulating, dual), and 3) entrained flow reactors (Siedlecki, 2011). In this work, fluidized bed reactor is chosen because it is easy to scale up, the ability to give near isothermal condition inside bed and its controllability feasibility of the process. Moreover, fluidized bed gasifier also share this fuel-flexibility feature of fluidized beds. Unlike fixed bed gasifiers, a fluidized bed gasifier is not restricted to one type or size of fuel (Basu, 2006).

In terms of the modelling, Aspen Plus process simulator is widely applied to represent the desired gasification process. For examples, in the early works of Schwint (1985) tested gasification process involving methanol and meanwhile Barker (1983) studied the gasification with indirect coal liquefaction processes in Aspen Plus. Another works implemented using this simulator involves the integrated coal gasification combined cycle (IGCC) power plants (Phillips, 1986), atmospheric fluidized bed combustor processes (Douglas, 1990), compartmented fluidized bed coal gasifiers (Yan, 2000), coal hydrogasification processes (Backham, 2003), and coal gasification simulation (Lee, 1992). However, the work carried out in the biomass gasification area is very limited. Mansaray *et al.* (2000) used Aspen Plus to simulate rice husk gasification based on material balance, energy balance, and chemical equilibrium relations (Mansaray *et al.* 2000). Due to the high amount of volatile material in biomass and the complexity of biomass reaction rate kinetics in fluidized beds, they ignored the char gasification and simulated the gasification process by assuming the biomass gasification follows the Gibbs

equilibrium. In a typical atmospheric fluidized bed gasifier, feed together with bed material are fluidized by the gasifying agents, such as air and/or steam, entering at the bottom of the bed. The product gas resulting from the gasification process is fed to a gas–solid separator (i.e., cyclone) to separate solid particles carried by exhaust gas. Therefore, the objective of this study is to develop an integrated gasification and proton exchange membrane fuel cell (PEMFC) framework. Through this framework, it is possible to generate a standalone models for gasification process and PEMFC as well as integrated gasification and PEMFC system. However, in this paper, the application of the integrated framework is highlighted through gasification process in fluidized bed to produce the amount of synthetic gas (syngas) particularly hydrogen gas by considering the hydrodynamic and reaction rate kinetics simultaneously. This paper also provides the syngas production comparison between total amount of syngas produced after different inputs such as pine sawdust and wood sawdust as biomass inputs. In addition the sensitivity analysis is also implemented to investigate the effects of operating parameters on the total syngas produced.

INTEGRATED GASIFICATION AND PEMFC SYSTEMATIC FRAMEWORK

Introduction to Integrated Gasification and PEMFC Framework

The systematic framework for integrated gasification and PEMFC has been developed as shown in Figure-1. Through this framework it is possible to study the gasification process and PEMFC system as a standalone models or integrated of gasification and PEMFC systems. This framework consists of 5 main steps and will be explained in more detail below.

Step-1 is the problem definition where the overall objective is defined. For example, design of biomass gasification process to produce the desired syngas.

Step-2 involves the process and product specifications. The process specification in this step covers the raw material selection and the reactor selection for gasification process. For raw material selection, specific biomass database has been developed in Excel software where it contains the biomass based on its type together with information relating ultimate and proximate analysis for each biomass available in the database. For example, the raw materials have been classified as coke (Sun *et al.* 2012), coal, methanol gasoline, ethanol, glycerol (Skoulou and Zabaniotou, 2013) and biomass. For coke, there are four constituent which are browncoal, lignite, sub-bitumious and antharacite. For biomass, there are seven fractions which are animal waste, forest residue (Figueroa *et al.* 2013), agriculture crop residue (Kumar *et al.* 2009), municipal waste, industrial waste, municipal solid waste and floating solid waste. The example of agriculture crop residue in this research are wood pellet, rice straw, wheat straw, palm waste, sugarcane, bio-nutshell, crop straw, tea waste, pulp and paper waste and olive husk. All of this

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information is then collected and arranged in the biomass database. Therefore it allows the user to study the gasification process and analyze the syngas produced for a wide range of inputs. While in PEMFC, according to Beheshti *et al.* (2015) the component that is considered are oxygen, hydrogen and water. For the feed of PEMFC the hydrogen is fed non-stop to the anode while on the anode the oxygen is reduced.
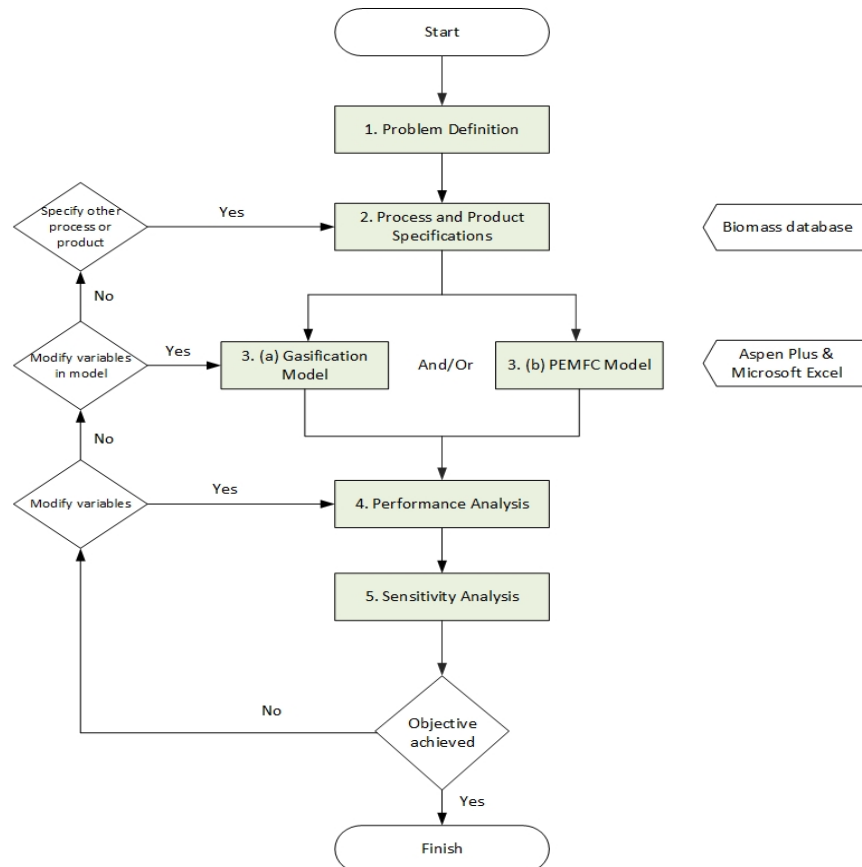
Figure-1. Integrated gasification and PEMFC systematic framework.

In the reactor selection, the assumptions must be made on the selected reactor. Typically, gasification process have three types of reactors that are usually being used which are fixed bed, fluidized bed and entrained flow. In PEMFC, two types can be considered either for high temperature or low temperature which is depending on the temperature selection.

In addition, the operating parameters need to be specified for process specification. In gasification, some of the main parameters are moisture content, temperature of the gasifier, operational pressure, equivalence ratio (air or oxygen gasification), steam to biomass gasification, gasification ratio, and residence time of the biomass into the gasifier, possible use of the catalyst and the related composition and size. The variables in PEMFC include the moisture contents, the ratio of carbon and oxygen and the number of fuel stack (Ersoz *et al.* 2006).

The last part for step 2 is the product specifications. Synthesis gas (syngas) are normally the common products that are measured in gasification

process. Syngas normally consists of hydrogen (H2), carbon monoxide (CO), carbon dioxide (CO2) and methane (CH4). Here the hydrogen gas production is the main focus in this work because it will be served as an input for fuel cell for power production. While in PEMFC the product normally the amount of energy generated from the fuel cell with the specific amount of feed.

Step 3 concerns with the modelling of gasification or the PEMFC process/system. This modelling parts basically is depending on the step 2 specification selection, For example, if the objective is to study the gasification process using fluidized bed then the gasification modelling will be proceed in the framework. If the objective is to analyze the performance of the PEMFC, then PEMFC modelling in the systematic framework is selected. For integrated gasification and PEMFC system, both of the models in the step 3 will be combined as one integrated system before proceeding to the subsequent step. In the step 3 of this framework, the gasification modelling has been developed in the Aspen

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Plus. Meanwhile the PEMFC modelling is still under development and will be subject of the future work.

The simulation of the standalone model for example gasification model will be performed in step 4 (performance analysis). Using the operating parameters specified in step 2, the model will be simulated and the performance will be further analyzed based on the information set in the product specification step (i.e. total amount of syngas produced). In addition, the model validation is also included in this step where the results obtained from simulated model will be compared with literature/experimental data if available to validate and check the reliability of the model.

In order to investigate the effects of operating parameter on the output prediction, the sensitivity analysis can be carried out in step 5. Here the selected parameters such as gasifier temperature will be varied in the given ranges and its effect on the output prediction will be analyzed. Through this analysis, it is possible to obtain the improved performance in achieving the gas produced based on the optimum operating condition.

Finally, if the objective specified in step 1 is achieved then the final model for desired process is obtained. In the case of the objective is not achieved, then it is possible to repeat the steps again by modifying the variables or changing the specifications until the objective is achieved.

Application of the systematic Framework: Biomass Gasification Using Fluidized Bed Case Study

Application of the systematic framework is demonstrated for biomass gasification using fluidized bed case study (adopted from Nikoo and Mahinpey (2008)) where the model will be validated using pine sawdust as the chosen biomass. For this purpose the same operating conditions and assumptions are used as provided in the literature.

Problem Definition (Step 1)

In this part, the objective is to develop a biomass gasification model using fluidized bed gasifier in Aspen Plus software.

Process and Product Specifications (Step 2)

Firstly for the process specification, the selected reactor is fluidized bed gasifier. For the raw material selection, two biomasses are considered which is pine sawdust and wood sawdust. The pine sawdust is tested first for model validation. Once the model is validated then wood sawdust is employed as biomass gasification input and the performance of these two biomasses is compared in terms of syngas produced.. To simulate the gasification process the charictieristic of pine sawdust must be known. Table-1 shows the characteristic of pine sawdust in terms of proximate and ultimate analysis.

**Table-1.** Characteristic of pine sawdust (Nikoo and Mahinpey, 2008).

Moisture content (wt%)	8
Proximate analysis (wt% dry basis)	
Volatile Matter	82.29
Fixed Carbon	17.16
Ash	0.55
Ultimate analysis (wt% dry basis)	
C	50.54
H	7.08
O	41.11
N	0.15
S	0.57
Average particle size (mm)	0.25-0.75
Char density (kg/m³)	1300
Flow rate (kg/h)	0.445-0.512

The assumptions used for the gasification model is shown below:

- The process is isothermal and steady state.
- During emulsion phase, all the gases are distributed evenly.
- Based on the shrinking core model, the particles are in uniform size, spherical and the average diameter remains constant.
- Volatile products consist of H_2, CO, CO_2, CH_4 and water (H_2O) and the devotalization instantaneously takes place (Sadakaa *et al.* 2002).
- Char only compose of carbon and ash.
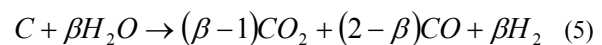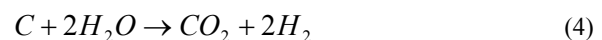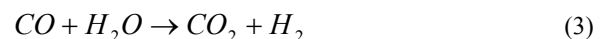- Gasification of char started in the bed and finishes in the freeboard.

The gasification process start from pyrolysis, followed by combustions and steam gasifications. The following reactions occur for each of combustion and steam gasification:

- Combustions reaction (Lee *et al.* 1998):

$$C + \alpha O_2 \rightarrow 2(1-\alpha)CO + (2\alpha-1)CO_2 \qquad (1)$$
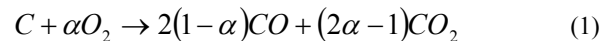
a = Mechanism factor

- Steam gasification reaction (Matsui *et al.* 1985):

$$C + H_2O \rightarrow CO + H_2 \qquad (2)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad (3)$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2 \qquad (4)$$

$$C + \beta H_2O \rightarrow (\beta-1)CO_2 + (2-\beta)CO + \beta H_2 \qquad (5)$$

β = Fraction of steam consume by reaction

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The α here changes during the combustion of char when CO or CO_2 is taken away from char particles. The range of α is between 0.5 to 1.0. It also acts as average diameter of char particles and a function of temperature. Meanwhile, the range of β is set between 1.1 to 1.5 at 700 °C to 900 °C and it is usually determined by experiment (Matsui *et al.* 1985). For this work, the value for α and β are 0.9 and 1.4 respectively.

The product specification for this gasification is the amount of syngas produced particularly hydrogen gas.

Gasification Modelling (Step 3)

Generally, the gasification process is classified into 4 stages which consists of decomposition of feed, volatile reactions, char gasification and the separation of gas and solid. All of these stages are developed in Aspen Plus software. Figure-2 shows the Aspen Plus flowsheet to represent the gasification process using fluidized bed.
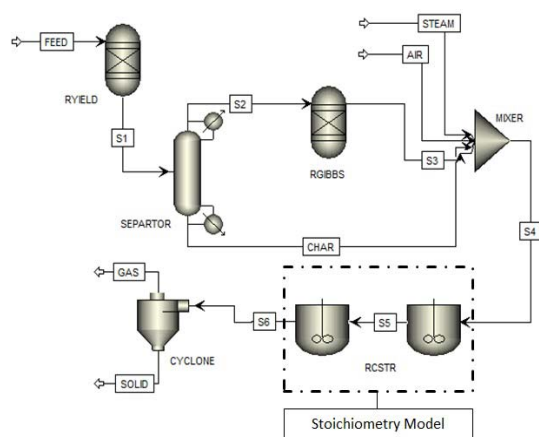
Figure-2. Fluidized bed gasification process flowsheet.

Based on Figure-2, the first stage of the gasification process is represented by RYIELD which is the yield reactor. In this stage the feed which is the biomass are decomposed and converted into its components. For example, in the case of pine sawdust, the atoms of carbon (C), hydrogen, oxygen, sulfur (S), nitrogen (N) and ash is converted by specifying the yield distribution based on the ultimate analysis in Table-1.

For volatile reactions, it involves two units which are the SEPARATOR and RGIBBS. In the SEPARATOR, the products from the yield reactor are separated into volatile matter and solids. Here the amount of volatile matter is specified in Aspen Plus based on the information from approximate analysis in Table-1. After the volatile material are separated, it is then fed to the Gibbs reactor (RGIBBS). In the Gibss reactor, the volatile combustion will takes place by assuming the reaction occurs according to the Gibbs equilibrium.

The next stage in the gasification process is the char gasification process where it is represented by using

two units of CSTR reactor (RCSTR). The first CSTR reactor is used for combustion reaction as shown in Equation (1) and the steam gasification reaction (Equations (2)-(5)) is assumed to take place in the second CSTR reactor. Lastly, the syngas produced from these CSTR reactors are then separated in the CYCLONE into gas and solid products. The operating conditions used for this gasification process is shown in Table-2.

Table-2. Operating conditions for gasification process.

Fluidized bed reactor	
Temperature (°C)	700-900
Pressure (bar)	1.05
Bed diameter (mm)	40
Freeboard diameter (mm)	60
Height (mm)	1400
Air	
Temperature (°C)	65
Flow rate (N m³/h)	0.5-0.7
Steam	
Temperature (°C)	145
Flow rate (kg/h)	0-1.8

Performance Analysis (Step 4)

The fluidized bed gasification process using pine sawdust is simulated in the step 4 (performance analysis). In this work, the predicted gas components are compared with the literature data (Nikoo and Mahinpey, 2008) on two different conditions. The root mean square errors are also calculated for both conditions. Tables-3 and 4 show the performance comparison between predicted syngas and literature datas for temperature and equivalence ratio.

Table-3. Performance comparison based on temperature at 900 °C.

Components (%)	This Work	Nikoo and Mahinpey (2008)	Root Mean Square Error
H_2	45.81	44.00	0.01767
CO_2	32.40	16.00	0.22646
CO	18.73	32.00	0.31684
CH_4	3.05	8.00	0.72581

Table-4. Performance comparison based on equivalence ratio of 0.2871.

Components (%)	This Work	Nikoo and Mahinpey (2008)	Root Mean Square Error
H_2	29.80	39.00	0.13807
CO_2	28.80	16.00	0.19876
CO	27.85	35.00	0.11494
CH_4	13.55	10.00	0.11716

Based on Tables-3 and 4, the root mean square errors obtained are relatively low and generally in good

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agreement with the literature data indicating the developed model in this work is validated and indeed reliable. The validated model is then further tested using different biomass. Here the wood sawdust is selected as an input for the gasification process and the characteristic of wood sawdust is shown in Table-5.

Table-5. Characteristic of wood sawdust (Miskam *et al.* 2009).

Moisture content (wt%)	8.25
Proximate analysis (wt% dry basis)	
Volatile Matter	76.23
Fixed Carbon	14.01
Ash	1.49
Ultimate analysis (wt% dry basis)	
C	42.38
H	5.27
O	42.41
N	0.14
S	0.00
Average particle size (mm)	0.25-1.00
Char density (kg/m³)	1300
Flow rate (kg/h)	0.445-0.512

The gasification model is then simulated by using the same conditions (temperature at 700 °C, feed rate at 0.445 kg/h, air at 0.5 N m3/h and steam flowrate at 1.2 kg/h) as in the pine sawdust case and the results obtained is shown in Table-6.

Table-6. Syngas composition produced using pine sawdust and wood sawdust.

Components (%)	Pine Sawdust	Wood Sawdust
H_2	20.86	23.47
CO	61.74	58.14
CO_2	7.91	7.72
CH_4	9.48	10.67

Based on Table-6, the percentage of H_2 gas (23.47%) and CH_4 gas (10.67%) for wood sawdust is higher compared to the H_2 gas (20.86 %) and CH_4 gas (9.48%) for pine sawdust respectively. However, the amount of CO of 61.74% and CO_2 of 7.91% is obtained for pine sawdust compared to only 58.14% of CO and 7.72% of CO_2 using wood sawdust. Usually, biomass with higher volatile matter tends to gasify easily. It has a high tendency to yield CO and the yield of H_2 will be decreased at the same time (Basu, 2006). In this case, volatile matter for pine sawdust and wood sawdust is around 82.29 and 76.23 respectively which contributing to the more CO is being produced in the pine sawdust compared to wood sawdust. However, in this work, the main target syngas component is hydrogen gas which will be used in the further application. Therefore, the use of wood sawdust actually is capable to produce more hydrogen compared to pine sawdust.

Sensitivity Analysis (Step 5)

Usually, the gasifier temperature and equivalence ratio (ER) have a dominant effect on the syngas production in the gasification process. Therefore the effects of gasifier temperature and ER on the syngas production is studied and thus performed using sensitivity analysis in step 5. For the gasifier temperature, the sensitivity analysis is conducted based on different temperature ranging between 700 °C to 900 °C. The other operation conditions are applied as follows: biomass feed rate of 0.445 kg/h; air at 0.5 Nm³/h and steam rate of 1.2 kg/h. The outcome of the obtained result is shown in Figure-3.
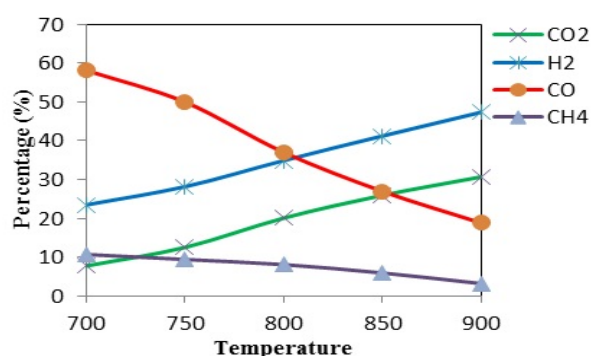

Figure-3. Effect of temperature on syngas production using wood sawdust as biomass.

The hydrogen gas and carbon dioxide gas are increased when the temperature is increased as shown in Figure-3. However, the carbon monoxide gas and methane gas show an opposite trend when the temperature is increased. According to Le Châtelier's principle, it states if a dynamic equilibrium is disturbed by changing the conditions, the position of equilibrium shifts to counteract the change to re-establish an equilibrium. The increasing of the temperature in the system will disturb the chemical reaction that in equilibrium state. The equilibrium chemical reaction will experiences a sudden change as the temperature increase, cause the equilibrium shifts in the opposite direction to offset the change (Petrucci *et al.* 1993). Therefore, the equilibrium shifts of the chemical reaction when the temperature is increased will cause the increasing of H_2 concentration and a decrease of CH_4 concentration. This result also supported by Turn et al. (1998), which state that the higher temperature contribute more favourable conditions for thermal cracking and steam reforming. More carbon and steam will be converted to CO and H_2 which increase the steam decomposition with temperature. The decomposition of methane also will cause the increasing amount of CO_2 by endothermic reaction ($CH_4 + 2H_2O = CO_2 + 4H_2 -165$ kJ) The content of CO was determined by exothermic reaction ($2C + O_2 = 2CO +246$ kJ). The increasing or higher temperature was not favorable for CO production, so the content of CO decreased with temperature.

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In Equivalence Ratio (ER), the range is varied from 0.21 to 0.29 by changing the air flow rate while the other parameters are kept constant as follows: biomass feed rate of 0.512 kg/h; temperature at 800 °C and steam rate at 0.8 kg/h.. The results obtained is shown in Figure-4.
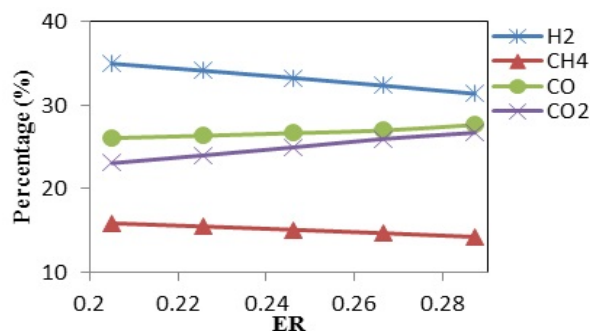
Figure-4. Effect of ER on syngas production using wood sawdust as biomass.

By increasing the air flow rate, the amount of gasification products can be increased to a certain degree. On the condition of autothermal, ER affects the gasification process temperature (Lv *et al.* 2004). At higher temperature the oxidization reaction is likely to occur more and this leads to higher composition of CO_2 (Sharma, 2008). Based on Lim and Alimuddin (2008), the CO increase when ER also increases. Some of the CO_2 is converted into CO, thus making the composition of CO increases (Sheth and Babu, 2010). While for hydrogen gas composition, it decreases with ER because its being consumed in oxidization reaction (Lv *et al.* 2004).

For wood sawdust, the optimum temperature is 900°C for producing the highest H2 (47.37%). Meanwhile, the lowest ER approximately around 0.205 should be employed to produce the highest amount of hydrogen gas (34.96%).

CONCLUSIONS

The systematic framework for integrated gasification process and PEMFC system is successfully developed and it covers a wide range of gasification process. The application of this systematic framework is illustrated using fluidized bed biomass gasification where pine sawdust is used as a biomass. The results obtained are in good agreement with literature data. Subsequently the gasification model is tested and simulated using different biomas which is wood sawdust. The results show the hydrogen gas produced by wood sawdust is higher compared to pine sawdust. This indicates that the wood sawdust have the capability to produce hydrogen gas at higher rate. Therefore sensitivity analysis is carried out to determine the effects of gasifier temperature and ER on the syngas production. Finally based on the sensitivity analysis it shows that the temperature of 900 °C and ER of 0.205 should be used as operating conditions to produce more hydrogen gas.

So far the gasification modelling part has been implemented in this systematic framework. In order to cover a wide range of gasification process, more case study should be considered and tested in this framework where it should emphasizes on the hydrogen production aspects. The hydrogen produced from gasification process will be served as an input for the PEMFC to produce the desired power production. Therefore, the future work will be focused on the PEMFC modelling in terms of the optimum operating conditions and its efficiency. Last but not least, both standalone models for gasification and PEMFC will be connected as an integrated system. Therefore it should be an interesting features for this systematic framework to show how the power can be produced consistently by employing the biomass waste.

REFERENCES

[1] Backham, L., Croiset, E., and Douglas, P. (2004). Simulation of a coal hydrogasification process with integrated CO2 capture. University of Waterloo.

[2] Baker, R. E., Begovich, J. M., Clinton, J. H., and Johnson, P. J. (1983). ASPEN modeling of the tri-state indirect liquefaction process. USA: OakRidge.

[3] Basu, P. (2006). Combustion and gasification in fluidized Bed. Taylor and Francis.

[4] Beheshti, S., Ghassemi, H., and Shahsavan-Markadeh, R. (2015). An advanced biomass gasification-proton exchange membrane fuel cell system for power generation. Journal of Cleaner Production, pp.1-6.

[5] Douglas, P., and Young, B. (1990). Modelling and simulation of an AFBC steam heating plan using ASPEN. Fuel, pp.145–154.

[6] Ersoz, A., Ozdogan, S., Caglayan, E. and Olgun, H. (2006). Simulation of biomass and/or coal gasification systems integrated with fuel cells. The American Society of Mechanical Engineers, pp.422-427.

[7] Figueroa, J. E., Ardila, Y. C., Lunelli, B. H., Filho, R. M., and Maciel, M. R. (2013). Evaluation of pyrolysis and steam gasification processes of sugarcane bagasse in a fixed bed reactor. AIDIC Conference Series, pp. 171-180.

[8] Gimelli, A., A., Luongo, A., and Amoresano, A. (2012). Experimental data and thermodynamic analysis of biomass steam power plant with two different configurations plant. International Review of Mechanical Engineering, pp.1109-1116.

[9] Islam, M., Saidur, R., Rahim, N., and Solangi, K. (2009). Renewable energy research in Malaysia. Engineering e-Transaction, pp.69-72.

[10] Jing, L. (2011). Fossil fuels: The depletion of our world's dependency. Journal of Youths in Science.

[11] Kammaruzzaman, S., Mohd Yusof, O., and Baharuddin, Y. (2000). Renewable energy resources and applications in Malaysia. Pusat Tenaga Malaysia.

[12] Kumar, A., Noureddini, H., Demirel, Y., Jones, D. D., and Hanna, M. A. (2009). Simulation of corn stover and distillers grains gasification with aspen. Society of Agricultural and Biological Engineers.

[13] Lee, H., Chung, K., Kim, C., Han, S., and Kim, H. (1992). Coal gasification simulation using ASPEN PLUS. pp. 447–474.

[14] Lee, J. M., Kim, Y. J., Lee, W. J., and Kim, S. D. (1998). Coal gasification kinetics derived from pyrolysis in a fluidized bed reactor. Energy, pp.475-488.

[15] Lim, M. T., and Alimuddin, Z. (2008). Bubbling fluidized bed biomass gasification—Performance, process findings and energy analysis. Renewable Energy, pp.2339-2343.

[16] Lv, P., Xiong, Z., Wu, C., Chen, Y., and Zhu, J. (2004). An experimental study on biomass air–steam gasification in a fluidized bed. Bioresource Technology, pp.95-101.

[17] Matsui, I., Kunii, D., and Furusawa, T. (1985). Study of fluidized bed steam gasification of char by thermogravimetrically obtained kinetics. Journal of Chemical Engineering of Japan, pp.105-113.

[18] Miller, T. (2011). Dream of a nation: Inspiring ideas for a better america. SEE Innovation.

[19] Miskam, A., Zainal, Z. A., and Yusof, I. (2009). Characterization of sawdust residues for cyclone gasifier. Journal of Applied Sciences, pp.2294-2300.

[20] Nikoo, M. B., and Mahinpey, N. (2008). Simulation of biomass gasification in fluidized bed reactor using ASPEN PLUS. Biomass and Bioenergy, pp.1245-1254.

[21] Nwakaire, J., Ezeoha, S., and Ugwuishiwu, B. O. (2013). Production of cellulosic ethanol from wood sawdust. Commission Internationale du Génie Rural Journal, pp.136-140.

[22] Petrucci, R., Harwood, W., Herring, F., and Madura, J. (1993). General Chemistry. 9th ed. New Jersey: Pearson.

[23] Phillips, J., Erbes, M., and Eustis, R. (1986). Study of the off design performance of integrated coal gasification. In: Combined cycle power plants, computer aided engineering of energy systems. The American Society Of Mechanical Engineers.

[24] Sadakaa, S. S., Ghaly, A., and Sabbah, M. (2002). Two phase biomass air-steam gasification model for fluidized bed reactors: Part I—model development. Biomass and Bioenergy, pp.439-462.

[25] Schwint, K. (1985). Great plains ASPEN model development, methanol synthesis flowsheet. Scientific Design Company, INC.

[26] Shamsuddin, A. (2010). Status of renewable energy application in the Malaysian energy. Journal of Energy and Power Engineering, pp.24-30.

[27] Sharma, A. K. (2008). Equilibrium modeling of global reduction reactions for a downdraft (biomass) gasifier. Energy Conversion and Management, pp.832-842.

[28] Sheth, P. N., and Babu, B. (2010). Production of hydrogen energy through biomass (waste wood) gasification. International journal of hydrogen energy, pp.10803-10810.

[29] Skoulou, V. K. and Zabaniotou, A. A. (2013). Co-gasification of crude glycerol with lignocellulosic biomass for enhanced syngas production. Journal of Analytical and Applied Pyrolysis, pp.110-116.

[30] Sun, L.-y., Liu, Y.D., Zhai, C., and Zhou, H. (2012). Process simulation of an integrated coke dry quenching combined gasification. Petroleum and Coal, pp.34-41.

[31] Turn, S., Kinoshita, C., Zhang, Z., Ishimura, D., and Zhou, J. (1998). An experimental investigation of hydrogen production from biomass gasification. Hydrogen Energy, pp.641–648.

[32] UCS. (2009). Clean Power, Green Jobs. Union of Concerned Scientist.

[33] Yan, H. and Rudolph, V. (2000). Modeling a compartmented fluidized bed coal gasifier process using ASPEN PLUS. Chemical Engineering Communication, pp.1–38.