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Air Gasification of Malaysia Agricultural Waste in a Fluidized Bed Gasifier: Hydrogen Production Performance

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1. Introduction

Recently, biomass gasification technology to produce hydrogen-rich fuel gas is highly interesting possibilities for biomass utilization as sustainable energy (McKendry, 2002). Hydrogen production from biomass gasification has many advantages as secondary renewable energy source as it is the universe's most abundant element, clean fuel has the potential to serve as renewable gaseous and liquid fuel for transportation vehicles. As a fuel, hydrogen is considered to be very clean as it releases no carbon or sulfur emissions upon combustion. The energy contained in hydrogen on a mass basis (120 MJ/kg) is much higher than coal (35 MJ/kg), gasoline (47 MJ/kg) and natural gas (49.9 MJ/kg). Additionally, the most important advantage for all the living beings is that when it is burned, hydrogen produces non toxic exhaust emissions. Clearly, the emissions from hydrogen combustion contain no carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (Veziroglu et al., 2005). Using biomass as an energy source can reduce the greenhouse gas emission that causes global warming which is a negative effect of using fossil fuels as an energy source.

In Malaysia, more than 2 million tonnes of agricultural wastes are produced annually and potentially an attractive feedstock for producing energy as the usage contributes little or no net carbon dioxide to the atmosphere. Major agricultural products are oil palms, sawlogs, paddy and tropical fruits. The palm oil sector is the biggest producer and hence the major contributor to the agricultural residues generation in Malaysia. The oil-palm solid wastes (including shell, fibre and Empty Fruit Bunch (EFB)) are abandoned materials produced during palm oil milling process. For every ton of oil-palm fruit bunch being fed to the palm-oil refining process, about 0.07 tons of palm shell, 0.146 tons of palm fiber and 0.2 tons of EFB are produced as the solid wastes. Bagasse which is the matted cellulose fibre residue from sugar cane that has been processed in a sugar mill were produced about 3×10^5T per year in 1999. Despite the decreasing acreage, coconut still plays an important role in the

socio-economic position of the Malaysian rural population that involves 80,000 households. About 63% of coconut production, coconut fronds and shells represent the largest amount as residues (about 8%) (Ninth Malaysia Plan 2006-2010). Table 1 summarize the estimations of the current and potential selected agicultural wastes (biomass) utilizations in annual energy productivity in Malaysia.

Thermo-chemical conversion processes, including gasification, pyrolysis and combustion have been proven the best available technology to convert these renewable materials into valuables fuel (hydrogen) and fine chemical feedstock. However gasification process offers technologically more attractive and useful options for medium and large scale applications due to presence of non–oxidation conditions and lower green house gases emission. Fluidized bed gasifier is proven to be a versatile technology capable of burning practically any wastes combination with low emissions. The significant advantages of fluidized bed gasifier over conventional gasifiers include their compact furnaces, simple designs, effective gasification of wide variety of fuels, relatively uniform temperatures and ability to reduce emissions of carbon dioxide, nitrogen oxides and sulfur dioxides.

Crops/ Activities	Energy productivity (boe/ha/year)	Current Annual Amount Used for Energy Purposes		Current Annual Energy Potential of Utilised Biomass (million boe)	
Oil Palms	88.7	Fruit shells Fruit fibres Effluents	23.609 13.630 0.022	Pruned fronds EFB Effluents Replanting wastes	77.665 11.444 2.928 12.94
Rubber trees	29.5	Wood	4.967	Wood Effluents	3.707 0.210
Paddy plants	11.54			Rice husks Rice straws	1.025 2.541
Coconut trees	28.21	Fronds Shells	1.578 0.785	Fronds	0.164
Cocoa trees	80.33	N.A.	N.A.	Pruning wastes Pod husks Replanting wastes	16.850 0.085 0.630
Sugarcane	54.9	Bagasse	0.421	Leaves and tops	0.298
Logging	-	-		Residues	19.060
Timber processing	-	Sawdust & waste	3.733	Tree bark and sawdust	1.0

Table 1. Estimates of the energy productivity and biomass production and utilization (Ninth Malaysia Plan 2006-2010)

1.1 Hydrogen fuel

Technology development for conversion of waste feedstock to hydrogen has an economical potential. Depletion of fossil fuel source such as oil, gas and coal is going to become the biggest problem in the near future. Therefore, hydrogen fuel from the biomass waste is the best supersede for fossil fuels. Hydrogen is not widely used today but it has a great potential as an energy carrier such as fuel cell that can be applied to power cars and factories and also for home usages in the future. In comparison with fossil fuels, 9.5 kg of hydrogen produce energy equivalent to that produced by 25 kg of gasoline (Mirza et al., 2009).
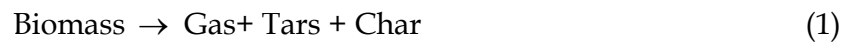
Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline). Hydrogen is an odorless, tasteless, colorless and non-poisonous gas. It is a renewable resource found in all growing things. Hydrogen is an important raw material for chemical, petroleum and agro-based industries. The demand for hydrogen in the hydrotreating and hydrocracking of crude petroleum is steadily increasing (Min et al., 2005). Hydrogen is catalytically combined with various intermediate processing streams and is used in conjunction with catalytic cracking operations to convert heavy and unsaturated compounds to lighter and more stable compounds. Large quantities of hydrogen were used to purify gases such as argon that contain trace amounts of oxygen. Furthermore, in the food and beverages industry, hydrogen was used for hydrogenation of unsaturated fatty acids in animal and vegetable oils, to produce solid fat and other food products. While in manufacturing of semi conducting layers in integrated circuits, hydrogen were used as a carrier gas. The pharmaceutical industries use hydrogen to make vitamins and other pharmaceutical products. Hydrogen is mixed with inert gases to obtain a reducing atmosphere that is required for many applications in the metallurgical industry such as heat treating steel and welding (Delgado et al., 1997 and Dupont et al., 2008).

In 2005, the overall U.S. hydrogen market is estimated at $798.1 million and it is expected to rise to $1,605.3 million for U.S. and $740 million for European in 2010 (Keizai, 2005). However, hydrogen production is not enough to uphold this value. The hydrogen technology had been intensively studied to find a variety of hydrogen source with different treatment processes because hydrogen has great potential as an environmentally clean energy fuel and as a way to reduce reliance on imported energy sources. In Asian region, the biomass from agriculture sector is the largest source of hydrogen production. Many experts predict that hydrogen will eventually power tomorrow's industries and thereby may replace coal, oil and natural gas. However, it will not happen until a strong framework of hydrogen production, storage, transport and delivery is developed.
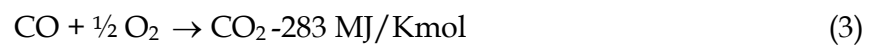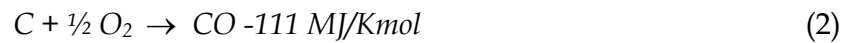
1.2 Biomass gasification

According to Xiao et al. (2007), it is generally reported by different authors that the process of biomass gasification occurs through main three steps. At the first step in the initial heating and pyrolysis, biomass is converted to gas, char and tar. Homogeneous gas-phase reaction resulted in higher production of gaseous. High bed temperature during this phase allowed further cracking of tar and char to gases. Second step is tar-cracking step that favours high temperature reactions and more light hydrocarbons gases such as Hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4). Third step is char gasification step that is enhanced by the boudouard reaction.

The gasification mechanism of biomass particles might be described by the following reactions:

$$Biomass \rightarrow Gas + Tars + Char \tag{1}$$

The Combustion reactions:

$$C + \tfrac{1}{2}\,O_2 \rightarrow CO \text{ -111 MJ/Kmol} \tag{2}$$

$$CO + \tfrac{1}{2}\,O_2 \rightarrow CO_2 \text{ -283 MJ/Kmol} \tag{3}$$

$$H_2 + \tfrac{1}{2}\,O_2 \rightarrow H_2O \text{ -242 MJ/Kmol} \tag{4}$$

The Boudouard reaction:

$$C + CO_2 \rightleftarrows 2CO \text{ +172 MJ/Kmol} \tag{5}$$

The Water gas reaction:

$$C + H_2O \rightleftarrows CO + H_2 \text{ +131 MJ/Kmol} \tag{6}$$

The Methanation reaction:

$$C + 2H_2 \rightleftarrows CH_4 \text{ -75 MJ/Kmol} \tag{7}$$

The Water gas shift (CO shift) reaction:

$$CO + H_2O \rightleftarrows CO_2 + H_2 \text{ -41 MJ/Kmol} \tag{8}$$
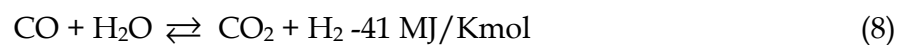
The gasification performance for optimized gas producer quality (yield, composition, production of CO, H_2, CO_2 and CH_4 and energy content) depends upon feedstock origin, gasifier design and operating parameters such as temperatures, static bed height, fluidizing velocity, equivalence ratio, oxidants, catalyst and others which are summarized in Table 2.

In summary, most of performed researches have explored the effect of different gasifying agent (air or steam) and applied different types of catalysts on gasification or pyrolysis process. Temperature and equivalence ratio of biomass with fuel (either air or steam) is the most significant parameter to contribute to the hydrogen production. However, less emphasis has been given to experimental investigation on the optimization of pyrolysis and gasification processes integration for the conversion of low value biomass into hydrogen and value-added products, which is the focus of this paper.

2. Materials and experimental

2.1 Raw materials

Three types of agricultural residues were investigated in this research namely palm kernel shell, coconut shell and bagasse as they are abundantly available in the agriculture sector in Malaysia. The samples were open air dried for 2 to 3 days to remove moisture and to ease crushing. Both of these samples were pulverized into powder and were sieved into specific particle size of (0.1-0.3 mm). Sieving was accomplished by shaking the ground biomass samples in a Endecotts Shaker Model (EFL2 MK3) for 30 minutes and dried in a vacuum oven at 80°C overnight and were kept in a tightly screw cap bottle. Table 3 summarized fuel properties investigated in this research.

	Raw materials	Gasifier design	Gasification performance	References
1	Wood sawdust	Integrated gasifier	Efficiencies: > 87.1% LHV: of 5000 kJ/Nm³.	Cao et al. (2006)
2	Pine wood block	down draft gasifier	Fuel gas yield: (0.82-0.94) Nm3/kg biomass, Hydrogen yield: (21.18- 35.39) g/kg biomass LHV : (4.76-5.44) MJ/Nm³	Pengmei et al (2007)
3	Hazelnut shell	applied air-blown gasification	Hydrogen yield: 24 g/kg hazelnut shells.	Midilli et al. (2001)
4	Biomass	two-step process	Hydrogen content : 60% Hydrogen yield : 65 g/kg biomass	Zhao et al. (2010)
5	Palm kernel	Fluidized bed gasifier	Hydrogen yield : 67 mol % LHV : 1.482 - 5578 MJ/Nm³	Wan Ab Karim Ghani et al.,(2009)
6	Biomass	downdraft gasifier	LHV: 9.55 MJ/Nm³ H2 yield : 52.19-63.31%	LV et al. (2007)
7	Woody biomass	Fixed bed	The product gas composition: a)cellulose : 35.5% mol CO, 27% mol CO_2 and 28.7% mol H_2. b) Xylan and lignin were approximately 25% mol CO, 36% mol CO_2 and 32% mol H_2.	Hanaoka et al. (2005)
8	Biomass	Fixed bed	H2 concentration: air- 59% mol steam – 87% (increasing trend from 600 to 1050K)	Florin and Harris (2007)
9	Biomass	updraft gasifier	H2 composition: 22.3 mol% (air) and 83% mol % (steam)	Lucas et al. (2004)
10	Biomass	catalytic fluidized bed	Hydrogen yield: 28.7% Conversion efficiencies79%.	Miccio et al. (2009)

Table 2. Selected review on biomass gasification performance for hydrogen production.

	Palm Kernel shell	Coconut shell	Bagasse
Proximate Analysis (wt% wet basis)			
Volatile matter	30.53	51.10	43
Fixed carbon	48.5	26.4	32.40
Ash	8.97	12.50	10.20
Moisture	12	10	14.40
Ultimate Analysis (wt% dry basis)			
Hydrogen	5.52	5.40	5.30
Carbon	51.63	50.20	43.80
Oxygen	40.91	43.40	47.10
Nitrogen	1.89	1.46	1.20
Sulfur	0.05	0.06	0.03
Cellulose	20.80	28.60	30
Hemicellulose	22.70	28.60	23
Lignin	50.70	24.40	22
Bulk Density (kg/m^3) HHV (MJ/kg)	733 24.97	661 21.50	111 16.70

Table 3. Proximate and Ultimate Analysis of Feedstock Sample

2.2 Experimental set up and procedures

The schematic diagram of the experimental facility used in this study is shown in Figure 1. The reactor was made of stainless steel pipe and the total high of reactor is 850 mm with an internal diameter of 50 mm, directly heated via electrical furnace equipped with Temperatures Indicator Controller (TIC) and thermocouples that those installed in two different zones of reactor, screw feeder, condenser, gas cleaning, gas drying and sampling section, gas chromatograph (GC).
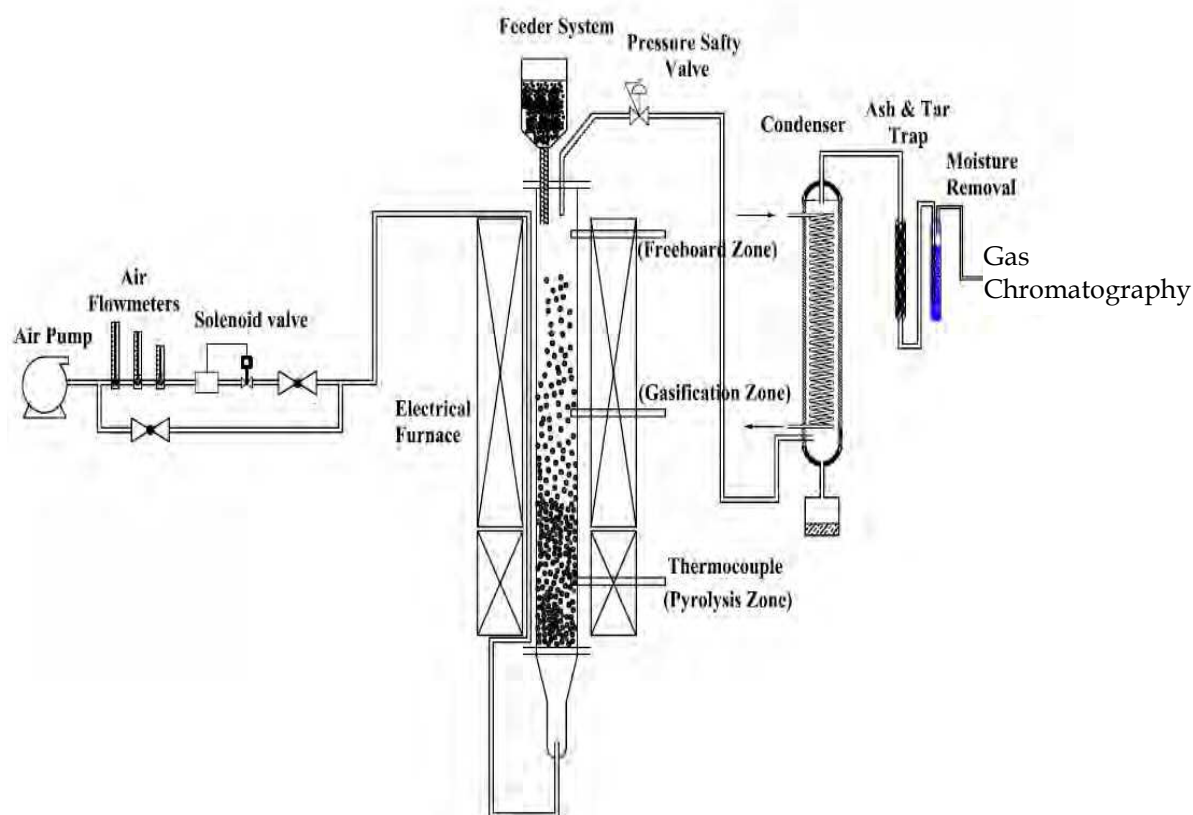
Fig. 1. Schematics diagram of biomass air gasification in fluidized bed reactor

Prior each experiment, the reactor was charged with 20 g of silica beads as the bed material to obtain a better temperature distribution, to stabilize the fluidization and to prevention coking inside the reactor. The solenoid valve (S.V) was turned on and a pre-heated air flow passed through the bed and the reactor when the temperatures in the bed (pyrolysis zone) and in the gasification zone reached the desired temperature. The feeder was turned on once the temperatures of these two parts stabilized. Typically, each test took about 20 to 25 minutes to stabilize and measurements were taken at intervals of 2 minutes. During each experiment, the air stream and the biomass feedstock were introduced from bottom and top of the gasifier, respectively. The clean gas was then sent to a water cooler to separate the condensed and un-condensed tars and steam. Sampling gas bags were employed to collect the product gas leaving the cooler for off line gas analysis.

3. Results and discussion

The gasification performance mainly will be evaluated based on the gas production quality (hydrogen yield and carbon conversion efficiency) and quantity (gas composition). Furthermore, the ash and oil yield will also be determined and quantified.

3.1 Effect of gasification temperature

The product yields (hydrogen, ash and oil) and detail gas composition of studied biomass at different gasification temperature are summarized in Table 4 and Figure 2, respectively. In this study, reactor temperature is increase from 700 to 1100 °C in 50°C and at constant feeding rate (0.78 kg/h) and equivalence ratio(ER)(0.26).

Reactor Temperature (°C)	750	800	850	900	950	1000	1100
a) Palm kernel shell							
Hydrogen yield	14.08	16.8	22.88	23.44	26.7	28.56	31.04
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	25.776	29.964	25.451	24.954	24.439	21.3	18.3
Ash (w/w)	0.174	0.158	0.142	0.136	0.12	0.114	0.1
Oil (w/w)	0.1	0.13	0.164	0.144	0.29	0.16	0.1
b) Coconut shell							
Hydrogen yield	18.93	19.8	20.64	22.37	23.7	25	25.44
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	24.68	26.328	25.872	25.489	23.274	20.936	20.247
Ash (w/w)	0.183	0.167	0.156	0.132	0.128	0.122	0.114
Oil (w/w)	0.06	0.078	0.11	0.11	0.12	0.07	0.05
c) Bagasse							
Hydrogen yield	11.6	13.1	13.47	17.44	19	21.4	23
(g H_2/kg biomass, wet basis)							
LHV (MJ/kgNm³)	23.245	26.74	26.224	25.674	25.152	24.53	21.653
Ash (w/w)	0.178	0.143	0.122	0.1	0.092	0.088	0.083
Oil (w/w)	0.052	0.052	0.064	0.084	0.072	0.052	0.03

Table 4. Summary of results for effect of gasification temperature on hydrogen production

In general, higher temperature favoured production gas as compared to ash and oil. Hydrogen yield increased as the temperature increased from 750 to 1000°C with the value of 14 to 31 mol%, 18 to 25.44 mol% and 11 to 23 mol% for palm kernel shell, coconut shell and bagasse, respectively. Palm kernel shell gave the highest H_2 compared to other samples due to the highest lignin content in their structure (Worasuwanarak et. al., 2007 and Dawson and Boopathy, 2008). Meanwhile, the product gas low heating value (LHV) showed a maximum value, 30, 23, 23 and 27 MJ/KgNm³ for palm kernel, coconut shell and bagasse, respectively. Ash and oil products yield ranging 0.10-0.29 % and 0.02-0.29%, respectively. These phenomena would be due to various reasons namely (i) higher production of gases in initial pyrolysis step whose rate is faster at higher temperature (Franco et al., 2003); (ii) higher gas production caused by endothermic char gasification reactions, which are favored at high temperature in pyrolysis zone, (iii) elevated temperature in gasification zone is favourable for tar and heavy hydrocarbons cracking that result to higher gas production (Tavasoli et al., 2009).
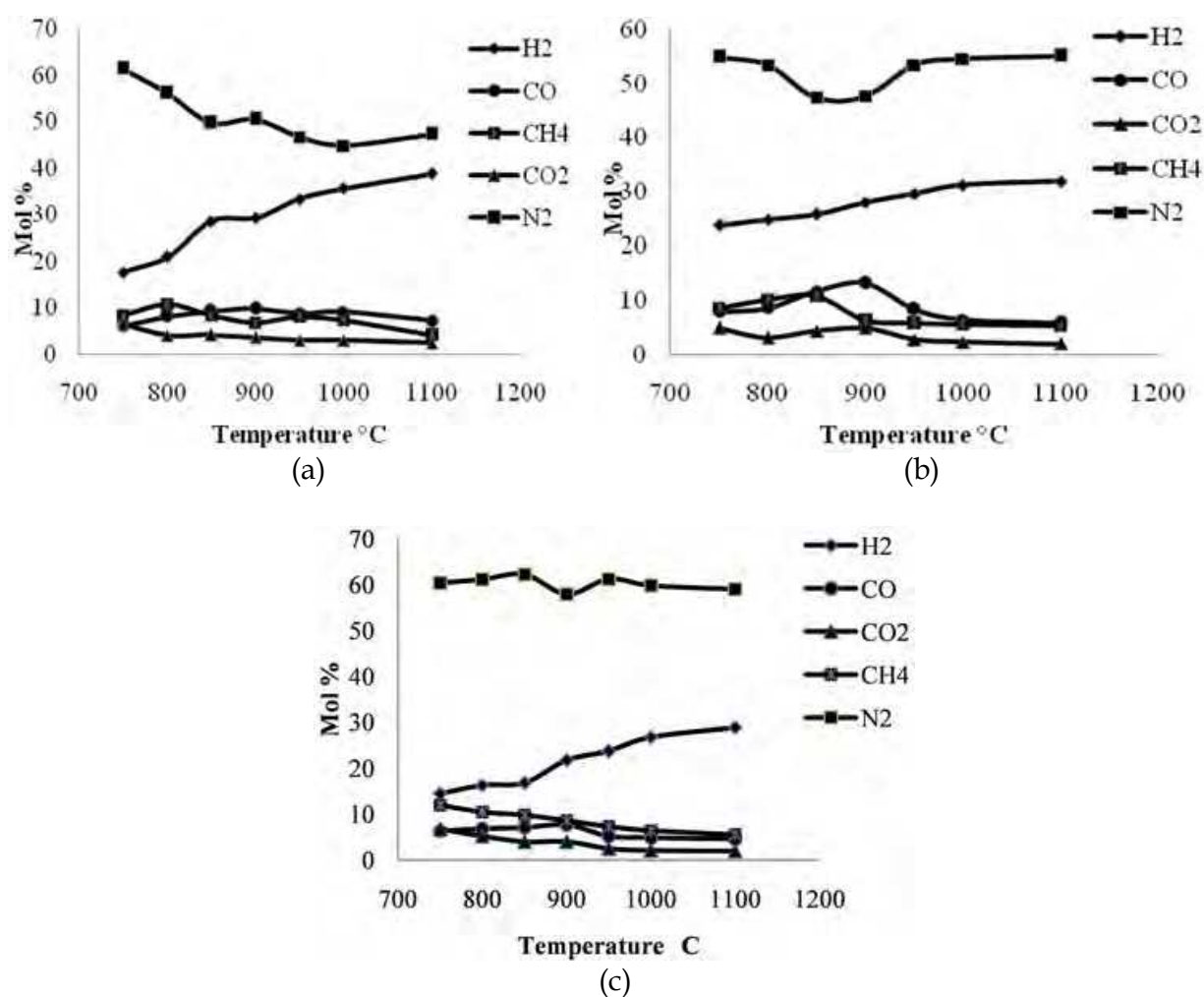
Fig. 2. Comparison gas composition for (a) palm kernel shell, (b) coconut shell and (c)
bagasse at different temperature

Figure 2 illustrates that hydrogen mol fraction significantly increased while the content of
other produced gas particularly methane (CH_4) showed an opposite trend for all studied
samples. This is in accordance with Le Chatelier's principle; higher temperatures favour the
reactants in exothermic reactions and favour the products in endothermic reactions. The H_2
formation is favoured by increasing of the gasification temperature, which could be due to
the combination effect of exothermal character of water-gas shift reaction (Eqn. 8) which
occur and predominate between 500-600°C and the water-gas reaction (Eqn. 6) which
becomes significant at the temperature from 1000 to 1100°C and upward (Midilli et. al.,
2001). The water shift reaction occurred in any gasification process due to the presence of
water inside of fuel and water vapour in side of air. Water vapour and carbon dioxide
promote hydrogen production in biomass gasification process (Cao et. al, 2006).
Furthermore, increasing of gasification temperature also increases thermal cracking of tar
and heavy hydrocarbons into gaseous components (Babu, 1995). At the same time, the gas
production also increased due to cracking of liquid fraction developed in this range of
temperature (300-500°C). These observations are in accordance with Encinar et al. (1996),
Fagbemi et al. (2001), Zanzi et al. (2002) and Chen et al. (2003) where they found that the
pyrolysis temperature below 600°C should be favoured for overall hydrogen production.

On the contrary, different trend were observed for other produced gaseous. Methane (CH_4) increased to 0.7%, 10.8% and 9.83% for palm kernel shell, coconut shell and bagasse, respectively when temperature rises from 750°C to 850°C but decreased gradually with temperature decreases. This can be explained as contribution of methanation reaction (Eqn. 7) during the gasification process. This was an expected result because as explained above most H_2 production reactions are endothermic and content of CH_4 decreases because temperature strengthens steam methane reforming reaction (McKendry, 2002, Lucas et al., 2004) and Pengmei et al., 2007). Furthermore, increasing of temperature contributes to decreases in CO_2 but increased CO. The content of CO was mainly determined by Bourdouard reaction (Eqn. 5) where the boudouard reaction only produces CO at high temperature around 800-900°C (Encinar et al., 2001 and Mathieu and Dubuisson, 2002). Moreover, Tavasoli at el. (2009) reported that decreasing the concentration of CH_4 and heavy hydrocarbons with increasing of the rise in temperature in gasification process results in higher conversion of biomass and exhausting of major energy that is the reason for decline in value of LHV, because produced gases contain less quantities of CH_4 due to contribution in stem reforming reaction.

3.2 Effect of equivalence ratio (ER)

The Equivalence Ratio (ER) varied from 0.23 to 0.27 through changing airflow rate at three constant temperatures (900°C, 950°C and 1000°C) at constant feeding rate (0.78 kg/hr) to find the optimum condition for hydrogen production. Table 5 summarize the obtained results and shows that the maximum molar fraction of hydrogen at 1000°C reached to (44.6% at ER: 0.23), (36.65% at ER: 0.23) and (36.38% at ER: 0.22) for palm kernel shell, coconut shell and bagasse, respectively.

Equivalence Ratio (ER)	0.23	0.24	0.25	0.26	0.27
a) palm kernel shell					
i) 900°C	20.48	22	26	23.44	20
ii) 950°C	25.28	30.2	27.44	26.7	21.6
iii) 1000°C	35.68	32.24	30.1	28.6	24.65
b) coconut shell					
i) 900°C	23.5	25.4	24.9	22.37	19.4
ii) 950°C	27.8	26.6	25.4	23.7	20.6
iii) 1000°C	29.32	28.9	26.8	25	21.05
c) Bagasse					
i) 900°C	22	23	24.52	22.26	19.86
ii) 950°C	21.9	28.1	26.8	23.72	21
iii) 1000°C	23.7	29.1	27.74	25.22	23.1

Table 5. Summary of results for effect of equivalence ratio on hydrogen yield (gH2/kg biomass

Figure 3 shows the gas composition for palm kernel shell gasification (selected sample for optimization study) at different temperature. Hydrogen yield were observed to increase first and decreased as ER increased. The obtained results are in accordance with other researchers where they found that increasing temperature in air gasification contributed to increasing of the hydrogen release (Midilli et al., 2001; Gonzalez et al., 2008; Lucas et al., 2004). In addition, they observed that increasing of the flow rate of air will decrease hydrocarbon contents due to partial combustion which subsequently contributed to decrease in tar and gaseous hydrocarbons. However, high flow rate of air will decrease the lower heating value (LHV) of the gasification gas (Pinto et al., 2003 and Lv et al., 2004). This phenomenon can be discussed by the following explanations.

(a)

(b)

(c)
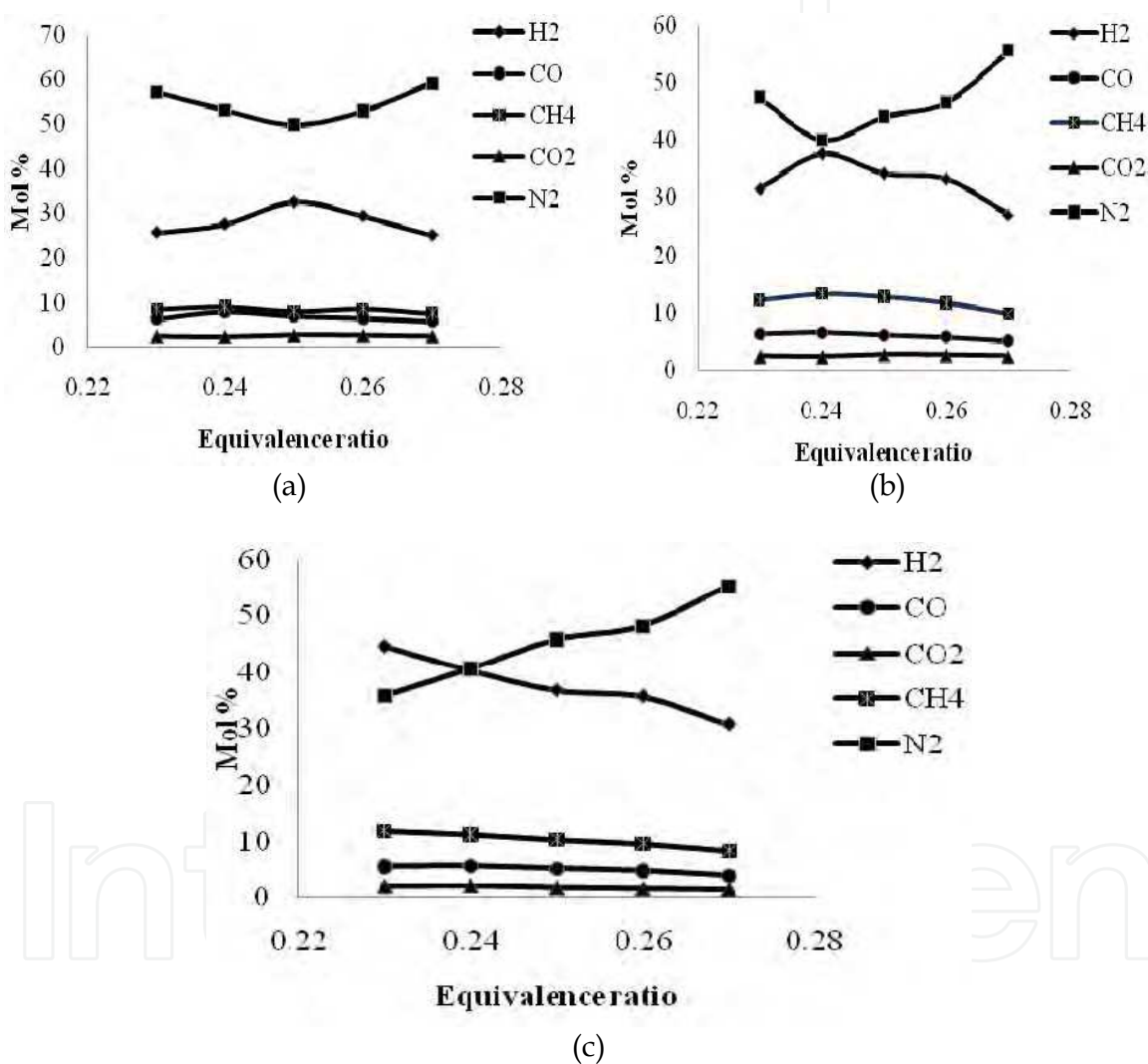
Fig. 3. Comparison gas composition at temperature (a) 900°C (b) 950°C and (c) 1000°C in different ER at optimized condition of palm kernel shell gasification

At highest temperature 1000°C, low ER was suitable with compare to 900°C and 850°C. At low ER the combustion reactions in Eqn. 2 was dominated when compared to the combustion reaction in Eqn. 3 because of lack of oxygen. This is further verified by Wan Ab karim Ghani et. al. (2009) and Pengmei et. al. (2004) that explained that ER not only represents the oxygen quantity introduced to the reactor but also affects the gasification

temperature under the condition of auto thermal operation. Higher equivalence ratio caused gas quality to degrade because of more oxidization reaction. In addition, the usage of air as oxidants contributed to higher ER which introduced large percentage of nitrogen into the system and diluted the combustible constituents in fuel gas (Pengmei et. al., 2007). On other hand, small ER will cause of lower oxygen be available for complete the gasification reactions which is not favourable for process. Therefore the gas composition is affected by the two contradictory factors of ER.

3.3 Effect of feeding rate

Various feeding rate ranging from 0.20 to 1.21 kg/hr were tested for palm kernel shell to determine the time required for complete reactions of gasification of biomass and suitable feeding rate of reactor by considering of value of reactor and minimum fluidization velocity of biomass particles. Figure 4 shows that with increasing of the feeding rate, the hydrogen yield increased and reached to the maximum value of 29.1%. It was found that higher feeding rates did not have great influence neither on net gas production nor on the hydrogen yield. This is explained by the fact that the higher feeding rate attributed to less residence time per volume air which will caused less oxygen be in contact with the biomass particles (W.A.W.A.K. Ghani et. al., 2009). Thus, decreasing of temperature at pyrolysis and consequently gasification process will be occurred and hence the biomass samples will remain raw or partially gasified.
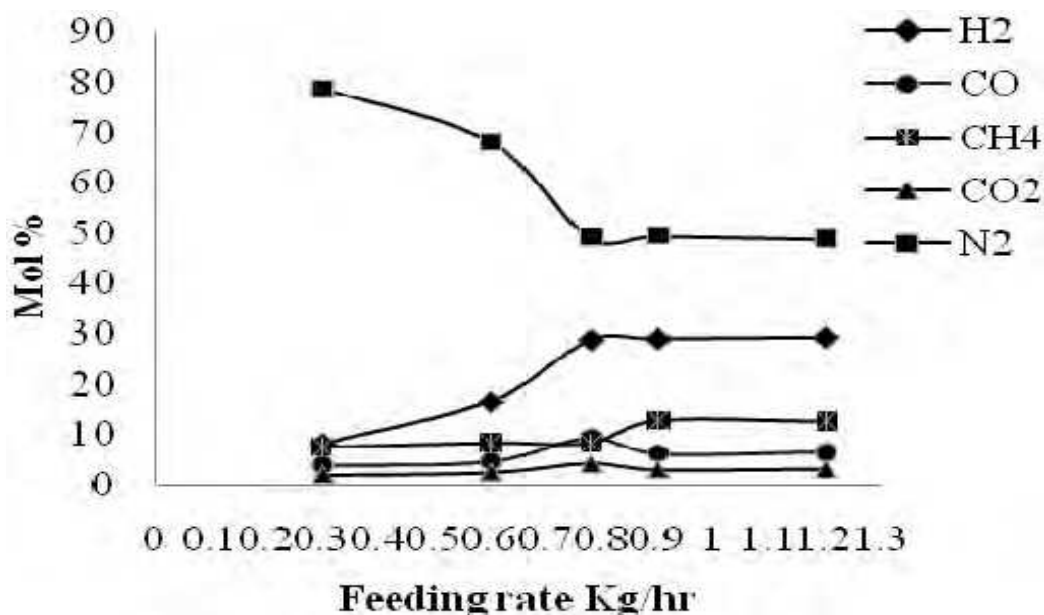

Fig. 4. Effect of feeding rate on gas composition at optimized condition of palm kernel shell gasification

3.4 Effect of biomass particle size

Figure 5 illustrates the hydrogen production performance for palm kernel shell at difference particle size (0.1, 2 and 5 mm). It was observed that with decreasing the particles size, the produced hydrogen and hydrogen yield decreased with the maximum value of 22.2% which belong to the smallest particle size. Lv et al. (2004) reported that pyrolysis process of small particles mainly controlled by reaction kinetics. Thus, as the size of biomass particles

increase, the production gas resultant inside the particles is more difficult to diffuse out and process is mainly controlled by gas diffusion. On other hand, larger particles are not only difficult to be entrained by fluidizing gas, but also produce fewer smaller particles after gasification reaction. This results in a reduction in fine particle entrainment, and hence decreases the amount of volatile matter and unburned char (Leung et al., 2003).
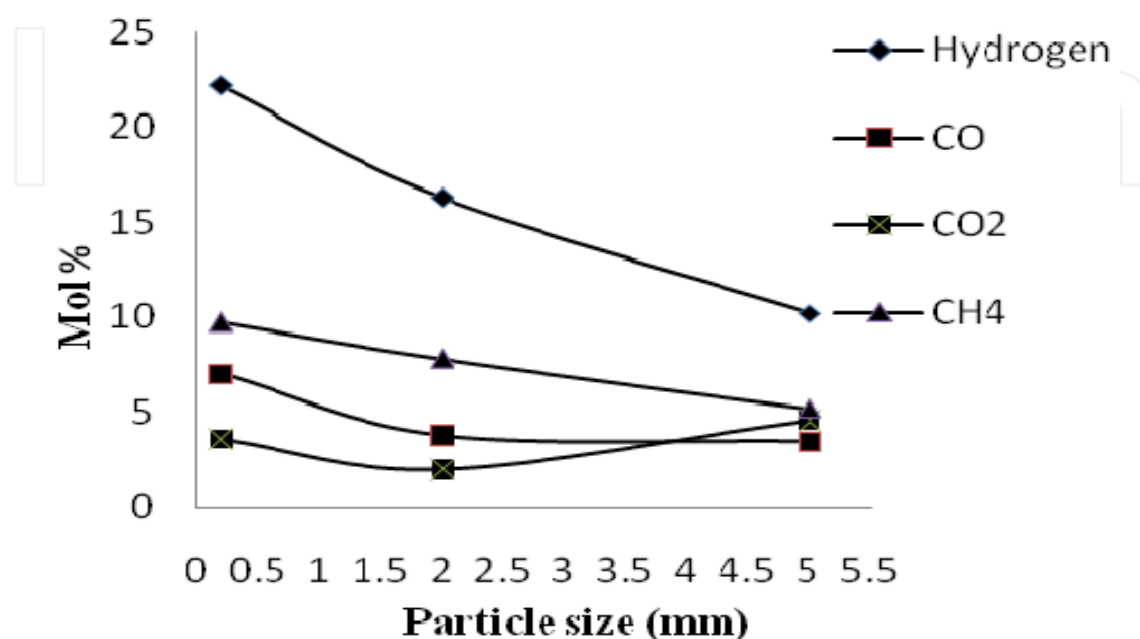

Fig. 5. Effect of particle size on gas composition at optimized condition of palm kernel shell gasification

3.5 Carbon conversion efficiency

The carbon conversion efficiency in this study were calculated based on the below equation (Eqn. 9).

$$\text{Carbon conversion efficiency} = (a/b) \times 100 \% \qquad (9)$$

Where:
    a = Total reacted carbon in the system (kg)
    b = Total carbon fed to the system (kg).

In this study, the maximum carbon conversion efficiency reached up to (89%), (88.6%) and (94.5%) for palm kernel shell, coconut shell and bagasse, respectively at 1100°C under the air/biomass ratio (1.12 Nm³/Kg). These variations were observed as resulted from the biomass properties (see Table 2). As expected bagasse with the lowest carbon content and lowest density should be burned completely under given fluidizing velocity. As for other samples, the unburned carbon out of the gasifier might attributed by the sort residence time of biomass particles to further react either with O_2 and CO_2 and H_2O at the same fluidizing conditions. This phenomenon is explained by Cao et al. (2006) that the carbon conversion also has relation with air/biomass ratio where they founded the maximum carbon conversion occurs at air/biomass ratio about 2.5 Nm³/kg. They reported that carbon conversion increased rapidly with increasing of the air/biomass ratio and decreased gradually with further air/biomass ratio increased. This is due to the fact that higher gas

velocity had contributed to longer residence time for carbon to complete the reaction with O_2 or with CO, CO_2 and H_2O and consequently decreasing in the carbon conversion efficiency.

4. Conclusion

Air gasification of agricultural wastes was successfully performed in a lab scale fluidized bed gasifier, producing producer gas mainly hydrogen which could replaced fossil fuel in the near future. Among the gasification parameters tested, the gasification temperature and equivalence ratio appeared to have the most pronounced effect on the hydrogen performance. Hydrogen production is favoured by an increasing temperature and hydrogen yield is enhanced as the water gas shift reaction goes to the completion with reducing of CO and CO2 in the product gas. The influence of equivalence ratio on the performance of a gasifier could be regarded as the effect of reactor temperature as the reactor was found to be ER dependent. As a higher equivalence (ER) had complex effects on tests results and there existed an optimal value for this factor, which was different according to different operating parameters. The feeding rate and biomass particle size would only show minor effect during the gasification process. In view of laboratory scale, the optimum conditions for hydrogen production in air gasification for studied biomass feedstock can be summarised as the following; a) temperature of gasification zone (950-1000°C); b) Equivalence ratio 0.23 and c) feeding rate at 0.70 kg/hr and d) Particle size (1-3 mm). The obtained results deduced to the conclusion that agricultural wastes are potential candidate for hydrogen production as an alternative renewable energy source and partially reduced the landfill problems of agricultural residues.

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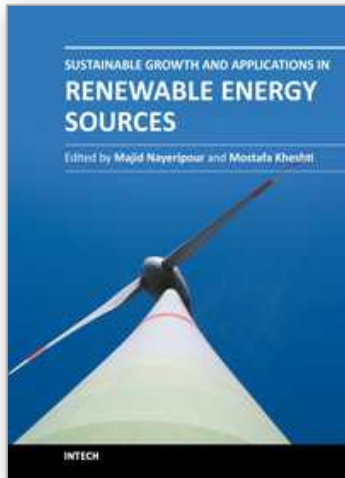
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