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Fluidised Bed Gasification of Oil Palm Frond (OPF) and Napier Grass (NG): A Preliminary Study

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Energy poverty due to the lack of adequate access to modern energy services is a developmental challenge that still grips more than 180 thousand rural Malaysian households. Inadequate access to affordable energy presents a major obstacle to development in such communities, limiting educational and economic opportunities. Thus, sustainable power generation from in-situ biomass available via thermal conversion technology (gasification) is proposed in this study to overcome this issue. Two energy crops namely Oil Palm Frond (OPF) and Napier Grass (NG) have been characterized and tested in an electrical furnace bench-scale fluidised bed gasifier (54 mm diameter and 850 mm height) at gasifier bed temperature (800 °C) and equivalence ratio (ER) (0.20 - 0.4). Both OPF and NG were characterized as high volatiles (> 80 %), moderate calorific value (16 %) but low ash content (< 7 %). However, NG shows significant higher moisture content (30 %) as compared to OPF. These properties shows a great influence in their gasification performance where higher oil content (12 - 20 %) and lower syngas (< 5 %) were observed for NG as compared to OPF. Furthermore, it is evident from this research that ER showed a significance influence on enhancing hydrogen production. As a conclusion, these biomasses showed a potential candidate as gasification feedstock.

1. Introduction

Energy poverty due the lack of adequate access to modern energy services is a developmental challenge that still grips more than 180,000 rural Malaysian households (Department of Statistics, 2012). Access to grid electricity in these areas is mostly restricted by terrain and remoteness, since costs of providing such services in these areas are prohibitively expensive. Inadequate access to affordable energy presents a major obstacle to development in such communities, limiting educational and economic opportunities. Small scale biomass gasification can be the key in turning underutilised non-food biomass into clean and affordable energy, having several advantages over traditional sources of electricity(Choi et al., 2014). The two main processes for the conversion of biomass to energy are thermochemical and biochemical processes. The heat treatment is the dominant mechanism of conversion, while the latter uses a range of processes involving microorganisms and various chemicals to convert the biomass (Basu, 2010). Biomass gasification technology to produce hydrogen-rich fuel gas is highly interesting possibilities for biomass utilization as sustainable energy. Hydrogen production from biomass gasification has many advantages as secondary renewable energy source as it is has the potential to serve as renewable gaseous and liquid fuel for transportation vehicles. 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). Gasification is a thermochemical process that employs high temperature and partial oxidation to convert carbonaceous feedstock into a gaseous product, synthesis gas or “Syngas”, consisting primarily of hydrogen (H_2) and carbon monoxide (CO), with lesser amounts of carbon dioxide (CO_2), water (H_2O), methane (CH_4), higher hydrocarbons (CxHy) and nitrogen (N_2) (Laurence and Ashenafi, 2012). The main purpose of the

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production of the low or medium heating value syngas is to use it as fuel in an internal combustion engine for power production (Laurence and Ashenafi, 2012). Xiao et al. (2007) summarized that the process of biomass gasification occurs through the main three steps. At the first step in the initial pyrolysis step that it set in high bed temperature at the first part of reactor the major amount of gas is produced. Second step is tar-cracking step that favors high temperature reactions and more light hydrocarbons. Third step is char gasification step that was enhanced by the boudouard reaction. The gasification performance for optimized gas producer quality (yield, composition, 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 (Azlina et al., 2011).

The total land area in Malaysia amounts to 32.90 million hectares. According to Abdullah and Sulaiman (2013), the major agricultural crops grown in Malaysia are rubber (39.67 %), oil palm (34.56 %), rice (12.68 %), cocoa (6.75 %) and coconut (6.34 %) which indicated that major production of the agricultural sector. Although potentially all types of biomass can be converted into energy, this research will focus on two carefully selected crops as a feedstock namely Oil palm fronds (OPF) and Napier grass (NG). Oil-palm fronds have been successfully used as a substitute for tropical grasses by ruminant producers in Malaysia. Nowadays, the OPF is usually burnt in the palm oil processing plant as fuel and the excess is disposed of in the plantations. The OPF are burnt in a boiler with some palm shells to produce the power for running the mill (self-sufficient) (Abdullah and Sulaiman, 2013). Napier grass, on the other hand, is chosen due to its high dry matter yielding capability and other favourable characteristics such as fast growth, disease resistance, adaptability, minimal management and easy propagation (Okaraonye and Ikewuchi, 2009). Fluidised bed is chosen in this study as it is proven to be a versatile technology capable of burning practically any wastes combination with effective gasification of wide variety of fuels, relatively uniform temperatures and ability to reduce emissions of carbon dioxide, nitrogen oxides and sulfur dioxides. This paper covers the fluidised gasification of two feedstocks (OPF and NG) in a fluidised bed gasifier at different temperature (700 °C and 800°C) and equivalence ratio (ER) ranging 0.2 - 0.6.

2. Material and Methodology

2.1 Materials

Oil Palm Frond (OPF) and Napier Grass (NG) obtained from Crops for the Future Research Centre (CFFRC), Semenyih, Malaysia used as feedstock. The proximate and ultimate analysis of the sample is reported in Table 1.

Table 1: Feedstock characterization

	Oil palm frond (OPF)	Napier grass (NG)
Proximate analyses (wb wt%)		
Moisture	9.82	30.07
Ash content	4.84	6.31
Volatile matter	83.28	85.52
Fixed carbon	11.88	8.17
Ulitmate analyses (db wt%)		
Carbon	45.05	45.10
Hydrogen	5.86	5.94
Oxygen	48.82	48.52
Nitrogen	0.23	0.45
Sulphur	0.04	0.00
Calorific value, HHV(MJ/kg)	16.99	16.73
Organic analyses (db wt%)		
Hemicelluse	22.29	4.64
Cellulose	24.80	26.96
Lignin	28.05	38.93

Both OPF and NG were characterized as high volatiles (>80 %) but low ash content (< 7 %). However, NG shows significant higher moisture content (30 %) as compared to OPF. The ultimate analysis shows both samples have high carbon content which is main factor for carbon conversion. The HHV found for both Oil Palm Fronds and Napier Grass is in accordance to (Scala, 2014). Furthermore, based on organic analyses, NG was characterized by high lignin but low hemicelluloses content which resulted significant influence in their gasification performance.

2.2 Experimental set up and procedures

The gasification of the grinded Oil Palm Fronds / Napier grass was carried out in a bubbling fluidised bed gasifier. 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 54 mm, directly heated via electrical furnace equipped with Temperatures Indicator Controller (TIC) and thermocouples, feeder, condenser, gas cleaning, gas drying and sampling section. 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. During each experiment, the air stream and the biomass feedstock were introduced from bottom and top of the gasifier. The biomass sample was grinded down to a size of 2 - 5 mm and then batch fed into the preheated reactor (800 °C) filled with oven dried sand as a heating medium. The continuous air as gasification agent is supplied through the bottom part. 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 just leaving the cooler for off line gas analysis or was fed into the gas analyser (Testo 350). The fluids (oil) were captures and the formed ash was captured inside the reactor, and the weight difference is determined. The experiment was carried out at 3 different temperatures (700 °C and 800 °C) and three different flow rates air to biomass ratio(ER) (0.2, 0.4 and 0.6).

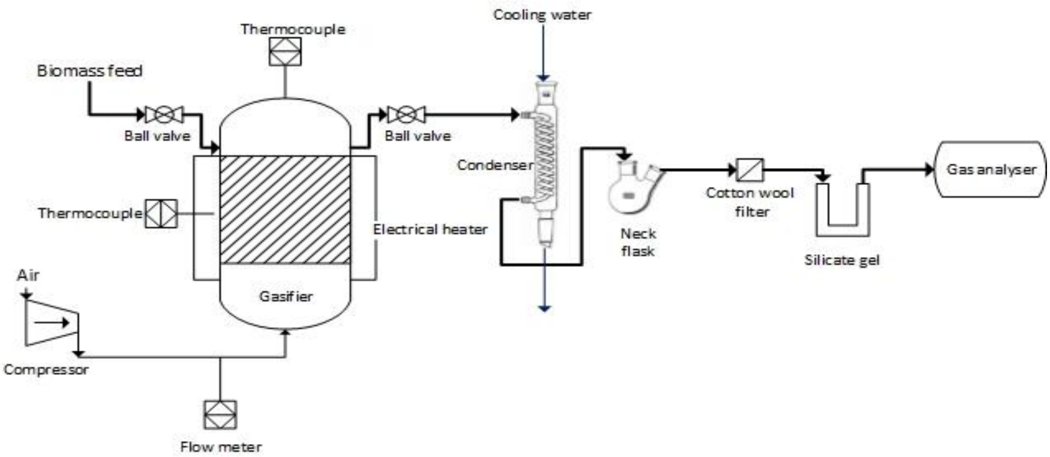

Figure 1: Schematic diagram of biomass air gasification in fluidised bed reactor

3. Results and discussion

3.1 Effect of gasification temperature

Table 2 shows the average gas composition, oil and ash yield using OPF and Napier Grass as feedstock. In general, higher temperature favoured production gas as compared to ash and oil. Hydrogen yield increased as the temperature increased from 700 to 800 °C with the value ranging from 0.95 to 2.81 wt%. However, these values much lowered compared to Palm kernel shell due to the highest lignin content in their structure (Worasuwannarak et. al., 2007). Ash and oil products yield ranging between 0 - 5 % and 6 – 27 %. As expected, the increase in temperature led to higher gas yields with a reduction in the amounts of ash and tar formed which could be due to further cracking of liquids and enhanced char reaction with the gasifying medium (air). This increase in gas yield with temperature, could be due to various reasons, such as; (i) higher production gases in the initial pyrolysis step, whose rate is faster at higher temperatures. (ii) the production gas through the endothermal char gasification reactions, which are favourable at elevated temperatures and, (iii) the increase of gas yield resulting from the stream reforming and cracking of heavier hydrocarbons and tars (Azlina et al, 2009).

Table 2: Average gas composition as % of the outlet gas of the gasifier using OPF as feedstock

	Oil palm frond (OPF)		Nappier grass (NG)		Palm kernel shell
	700 °C	800 °C	700 °C	800 °C	800 °C
Gas composition					
ER					
0.2					
CO %:	0.95	1.91	0.56	5.36	10.13
H2 %:	0.88	1.67	0.36	33.69	20
CO2 %:	2.30	2.60	2.28	12.53	5.30
Oil wt%	10.3	21.7	19.4	NA	0.13
Ash wt%	5	0	0	NA	0.16
0.4					
CO %:	2.67	3.44	2.23	2.84	NA
H2 %:	2.46	2.81	2.31	10.86	NA
CO2 %:	4.78	5.62	5.23	15.31	NA
Oil wt%	6.1	20.8	12.2	NA	NA
Ash wt%	5	5	4.3	NA	NA
0.6					
CO %:	1.14	1.48	1.22	2.15	NA
H2 %:	0.92	1.30	1.22	5.79	NA
CO2 %:	3.97	4.05	2.57	12.38	NA
Oil wt%	18.8	20.7	20.8	NA	NA
Ash wt%	0	0	4.3	NA	NA

Figure 2 illustrates that hydrogen mol fraction significantly increased with increasing temperature. while the content of other produced gas particularly methane (CH_4) showed an opposite trend 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 which occur and predominate between 500 – 600 °C (Ghani et al, 2011). 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. 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 Mohammed et al (2011) where they found that the pyrolysis temperature below 600°C should be favoured for overall hydrogen production.

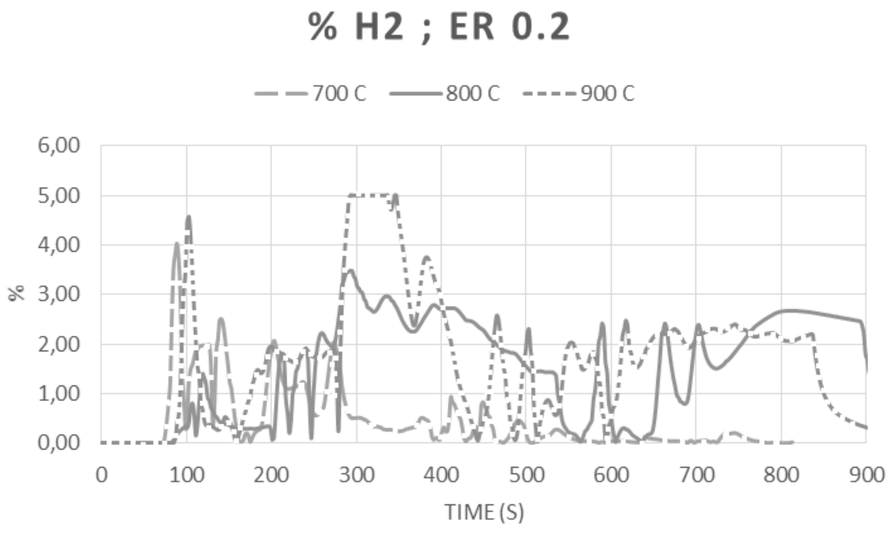

Figure 2: Real time H2 composition of Oil palm Frond (OPF) at different temperatures

3.2 Effect of equivalence ratio (ER)

ER is defined as the ratio of the amount of oxygen (air) supplied and the amount of oxygen (air) needed for stoichiometric combustion of the fuel. Table 2 shows that H_2 yield increased first and decreased as ER increased for both samples. The optimum value of ER was found 0.4 for both samples and operating temperatures. As stated by Lv et al (2007), ER not only represents the oxygen quantity introduced to the reactor but also affects the gasification temperature under the condition of auto thermal operation. On one side, higher ER will cause higher gasification temperature can accelerate the oxidation reaction and hence improve the product quality to a certain limit. On other side, small ER will cause of lower oxygen be available for complete the gasification reactions which is not favourable for process. Furthermore, Xiao et al (2007) suggested that this increase in CO and H_2 content can be explained as due to thermal cracking of hydrocarbons and tars at a higher temperature. While the decrease in CO and H_2 content with further increase ER due to partial combustion of different gaseous components which resulted a large increase in CO_2 concentration.

Figure 3 show that hydrogen fraction is optimized at ER 0.4. This can be explained by the fact that at low ER the combustion reaction was dominated by CO production because of lack of oxygen. This is further verified by Wan Ab karim Ghani et. al. (2011) 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. By study and the analysis on the experimental data of varying ER, it can be understood applying too small and too large of ER for gasification process is not suitable. Hence, 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 (Muhamed et al, 2011). 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.

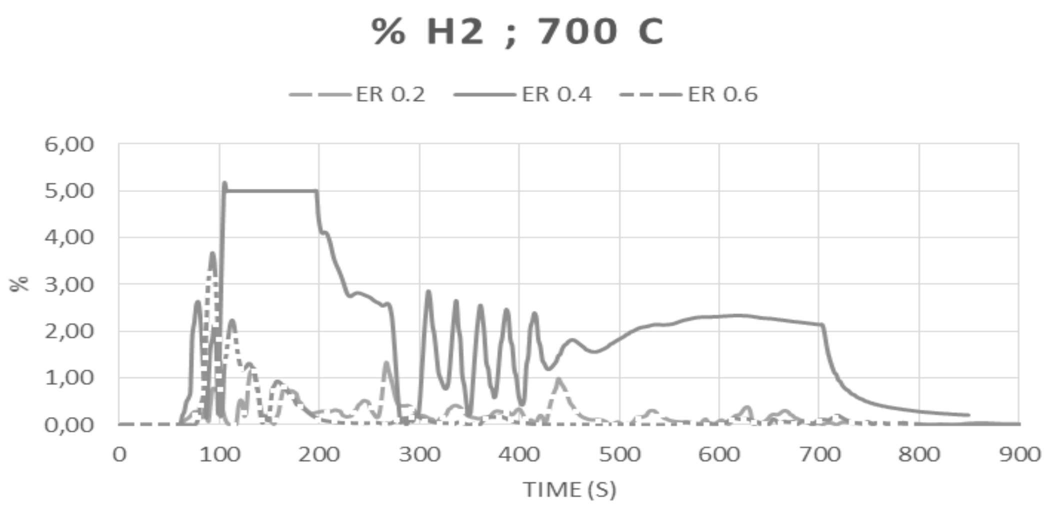

Figure 3: Real time H_2 composition of Oil palm Frond (OPF) at different temperatures

4. Conclusion

Air gasification of agricultural wastes was successfully performed in a lab scale fluidised bed gasifier, producing producer gas with low oil content. Among the gasification parameters tested, the equivalence ratio appeared to have the most pronounced effect on the reactor temperature and the gas composition particularly hydrogen. This paper shows an increasing yield in syngas with increasing temperature (optimum 800 °C). An ER of 0.4 is best performing for both feedstock. The overall bio-oil obtained from gasification had stability in percentage and component in all temperatures applied. The obtained results deduced to the conclusion that agricultural wastes are potential candidate for hydrogen production as an alternative renewable energy source.

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References

Abdullah N., Sulaiman F., 2013, The Oil Palm Wastes in Malaysia, "Biomass Now - Sustainable Growth and Use", Eds. Miodrag Darko Matovic, Intech, Croatia

Azlina W.A.K.G.W., Moghadam R.A., Salleh M.A.M., Alias A.B., 2011, Air Gasification of agricultural waste in a fluidized bed gasifier, World Review of Science, Technology and Sustainable Development, 8(2), 100-113.

Babu S.P., 1995, Thermal gasification of biomass technology developments, Biomas and Bioenergy, 9(15), 271-285.

Basu P., 2010, Biomass Gasification and Pyrolysis, Practical Design and Theory, Academic Press, USA

Cao Y., Wang Y., Riley J.T., Pan W.P., 2006, A novel biomass air gasification process for producing tar-free higher heating value fuel gas, Fuel Processing Technology, 87, 343-353.

Choi J.H., Woo H.C., Suh D.J., 2014, Pyrolysis of Seaweeds for Bio-oil and Bio-char Production, Chemical Engineering Transactions, 37, 121-126.

Department of Statistics, 2012, Basic Amenities Malaysia - Household Income Survey of 2012, Department of Statistics Malaysia, Kuala Lumpur, Malaysia.

Karim Ghani W.A; Moghadam R., Salleh M., Alias A., 2009, Air Gasification of agricultural waste in a fluidized bed gasifier, Energies, 2(2), 258-268.

Laurence L., Ashenafi D., 2012, Syngas Treatment Unit for Small Scale Gasification, Journal of Applied Fluid Mechanics, 5(1), 95-103.

Lee S., Shah Y., 2013, Biofuels and Bioenergy Processes and Technologies, CRC Press, Boca Raton, USA.

Lv P., Yuan Z., Ma L., 2007. Hydrogen-rich gas production from biomass air and oxygen/steam gasification in a downdraft gasifier, Renewable Energy, 32, 2173-2185.

Okaraonye C., Ikewuchi J., 2009, Nutritional and Antinutritional Components of Pennisetum purpureum (Shumach), Pakistan Journal of Nutrition, 12 (11), 957-959.

Scala F., 2014, Fluidized bed gasification of lignite char with CO_2 and H_2O: A kinetic study, Proceedings of the Combustion Institute, 35(3), 2839-2846.

Worasuwannarak N., Sonobe T., Tanthapanichakoon W., 2007, Pyrolysis behaviors of rice straw, rice husk, and corncob by TG-MS technique, Journal of Analytical and Applied Pyrolysis, 78(2). 265-271

Xiao R., Jin B., Zhou H., Zhong Z., Zhang M., 2007, Air gasification of polypropylene plastic waste in fluidized bed gasifier, Energy Conversion Management, 48(3), 778-786.