CHEMICAL ENGINEERING TRANSACTIONS

VOL. 56, 2017

A publication of
AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jiří Jaromír Klemeš, Peng Yen Liew, Wai Shin Ho, Jeng Shiun Lim

ISBN 978-88-95608-47-1; **ISSN** 2283-9216

DOI: 10.3303/CET1756279

Feasibility Study of Napier Grass and Oil Palm Frond Blend Pellets for Syngas Production

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To date, Malaysia is mainly relying on the fossil fuels for electricity generation and it is expected that the energy demand will increase continually and soon facing the shortage of fossil fuel. Biomass is identified as one of the key resources for electricity generation due to strategic location and climate condition of Malaysia. Napier grass (NG) should be considered as alternative fuel due to its desirable characteristics such as growth and carbon neutrality. Oil palm frond (OPF) is found that has contributed to major portion of other oil palm residues in Malaysia. Thus, this study is aimed to investigate the feasibility of NG-OPF blends with variety blending ratio (0, 0.25, 0.5, 0.75, 1) for syngas production in a fluidised bed reactor (54 mm in internal diameter and 370 mm in height) at temperature (850 °C) and equivalence ratio (ER) (0.2) via gasification process. As a result, single OPF feedstock has obtained higher quality syngas (H_2: 14.39 vol%, CO: 32.58 vol%) and higher heating value (5.49 MJ/Nm^3). However, NG:OPF (50 : 50) was found to obtained a higher H_2 composition (13.04 vol%) and higher HHV of gas product (3.42 MJ/kg) as compared to NG-OPF blends (0.25, 0.75). The optimum carbon conversion efficiency, CCE (86.08 %) was found in NG-OPF (25 : 75). NG is found feasible to blend with OPF.

1. Introduction

Since the industrialisation of Malaysia, energy demand has risen continuously and soon facing the shortage of fossil fuels which are important primary energy resource. Malaysia is considered as one of the largest electricity consumer among Association of Southeast Asian Nations number countries (Tang and Tan, 2013). In 2004 – 2030, it is forecasted that the GDP in Malaysia will increase to 4.6 % (Gan and Li, 2008) whereas, the energy demand can grow up to 216 TWh in 2030 (Ahmad and Tahar, 2014). It is inevitable that all parties such as government, academic society and communities have to explore new alternative fuel resource urgently to ensure the reliability and security of energy supply for future energy demand.

Due to strategic location and climate condition of Malaysia, plenty of the natural renewable resources (agricultural and tropical forest) are available all year around. Biomass has huge potential as a promising alternative renewable energy source for energy production via different type of conversion technologies (e.g., biological and thermo-chemical conversions). In Malaysia, oil palm plantation is occupied about 5 × 10^4 km^2 of Malaysian land which is equivalent to almost three-quarter of total agricultural land (Ng et al., 2012). According to Malaysian Palm oil Council (MPOC), Malaysia has become the second most productive palm oil producer in the world because of the high demand of vegetable oil. Malaysia produces around 42.3 % of worldwide palm oil and 48.3 % of global palm oil export (Hosseini and Wahid, 2013). The oil palm solid wastes (including palm kernel shell (PKS), empty fruit bunches (EFB), oil palm frond (OPF) are discharged from the mill and plantation. It is found that oil palm frond (OPF) (44.48 MT) contributed to major portion of other oil palm residues. OPFs are underutilised and usually just left rotten in the plantation.

The latest research, NG has been proved that can be capable intercropped with oil palm (Mohammed et al., 2015). NG is increasingly gaining interest as sustainable energy source in Malaysia. NG can grow rapidly and

Please cite this article as: Tan H.B., Ghani W.A.W.A.K., Hussian S.A., Ng D.K.S., 2017, Feasibility study of napier grass and oil palm frond blend pellets for syngas production, Chemical Engineering Transactions, 56, 1669-1674 DOI:10.3303/CET1756279

potentially offer 40 t/ha.y of dry biomass yield (Woodard and Prine, 1993). Low energy input is required for harvesting process and high energy output is provided from NG which is around 25 : 1 (Samson et al., 2005). NG has potential and could be blended with OPF due to its desirable characteristics. Utilisation of OPF and NG could bring a significant benefit in term of economic and environmental aspects into the oil palm industries.

To date, most of the solid oil palm biomass has been treated by traditional and inefficient approach which is direct burning or incineration in mill and plantation site for waste reduction in Malaysia. This approach is not environmental friendly because of pollutants and dust emission into air due to incomplete combustion. Recently, other than direct combustion, gasification technology has gaining interest and recognised as promising route to transform biomass to energy due to its simplicity, flexible efficient and less pollutants emission (Howaniec and Smolinski, 2014). In recent studies, co-gasification has been extensively carried out to investigate the synergistic effects of biomass and coal blends (Lapuerta et al., 2008). However, it is noted that no research has been published that investigated the gasification of biomass-biomass blends. In this study, the effect of blending weight ratio of NG-OPF blend pellets on syngas quality and performance were carried out via gasification process.

2. Material and Methodology

2.1 Feedstock preparation

The gasification experimental study has been carried out using fuel blends (NG-OPF), pure NG and pure OPF. NG and OPF biomass obtained and provided by Crops for the Future Research Centre (CFFRC). The NG (diameter 0.6 cm, length 1.8 - 4.3 cm), OPF and NG-OPF blend pellets (diameter 1.2 cm, 1 - 2 cm length) were in cylindrical shape. NG and OPF were blended a different proportion (25 : 75, 50 : 50, 75 : 25) prior to experimental tests.

The proximate and ultimate analysis of the sample is presented in Table 1. Both of NG and OPF were analysed by using thermo-gravimetric analyser (model Mettler Toledo, TGA851/UT5, USA) and CHNS/O analyser (model LECO CHN628S, USA) following the ASTM D-5291 method. The calorific value of the samples was evaluated by using bomb calorimeter (Parr 6100 model) following BS EN 14918.

Table 1: The proximate and ultimate analysis of feedstocks

	NG	OPF
Proximate analysis (w.b. wt%)		
Moisture	30.07	9.82
Volatile matter	85.52	83.28
Fixed carbon	8.17	11.88
Ash content	6.31	4.84
Ultimate analysis (d.b. wt%)		
Carbon, C	45.10	45.05
Hydrogen, H	5.94	5.86
Nitrogen, N,	0.45	0.23
Sulphur, S	0.00	0.04
Oxygen, O	48.52	48.82
Calorific value, HHV (MJ/kg)	16.73	17.00

Both NG and OPF contain a large amount of volatile matter (> 80 %) and low ash content (< 7 %). Biomass with high volatile matter content exhibits high reactivity which can enhance the gasification resulting in efficient conversion and low char production (Basu, 2006). NG shows significant higher moisture content (30.07 %) as compared to OPF (9.82 %). The ultimate analysis shows both samples have high carbon content (> 45 %) which is main factor for carbon conversion. Both NG and OPF contain larger fraction of oxygen (> 48 %). The calorific value of biomass is greatly affected by higher fraction of oxygen due to the strong carbon-oxygen bond (McKendry, 2002). The higher heating value (HHV) is found to be comparable between both NG and OPF.

2.2 Experimental set up

The experimental tests have been carried out in a gasification system presented in Figure 1. The entire gasification system consists of a heat resistant stainless steel fluidised bed reactor, condenser unit, gas clean-up unit and gas sampling unit. The reactor 370 mm height and 54 mm internal diameter equipped with two individually controlled electric furnaces were used to heat up purpose and a thick layer of glass wool was put and cover on the top of reactor to prevent heat loss to atmosphere during the test. Two K-type thermocouples were installed on the middle of reactor and the top of reactor to control the temperature, which used to measure and control the temperature of the zones of the reactor. Prior to the experiment, the air valve connected to external compressor was open and the air was introduced from the bottom of bed to the reactor. The produced gas generated from feedstock combustion entered into gas condenser unit and then flowed into gas clean-up section for dust particle filtration during the experiment. The clean dry gas was collected by gas bag and sent for offline Gas chromatography (GC) analysis.

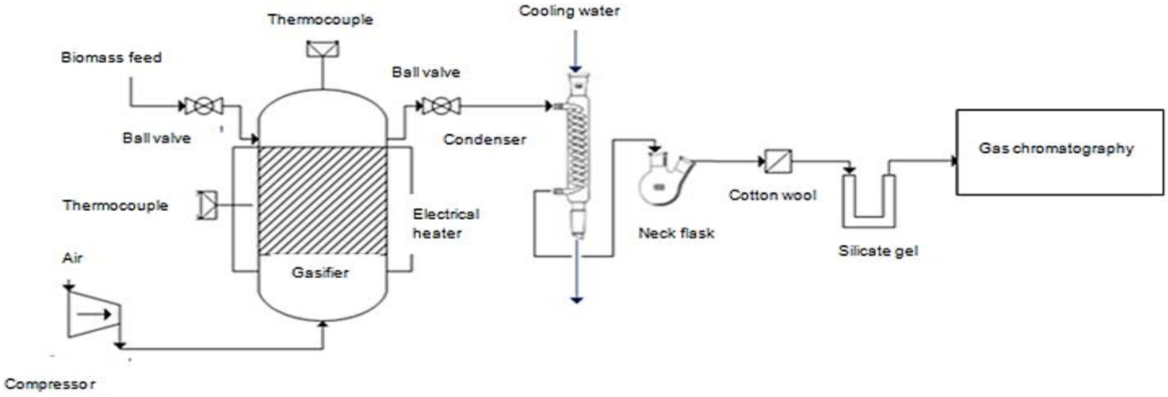

Figure 1: Schematic diagram of lab scale gasifier system

2.3 Experimental procedures

The operating conditions of the experimental test are presented in Table 2. At the beginning of experiment, the minimum fluidisation velocity was determined by using Eq(1) (Wen and Yu, 1966) based on the sand property as shown in Table 3. The sand is a good material as it is an inert particle and has higher heat retention capacity. It also can offer uniform fluidisation and maintain the temperature in the gasification zone during the test. The air velocity for the experiment was 0.017 m^3/s. Before each run, about 102 g of bed material sand is used and added into reactor.

Table 2: The operating conditions for gasification tests

Pressure, P (kPa)	101.325
Bed temperature, T (°C)	850
Biomass flow rate (kg/h)	0.167
Superficial gas velocity, U (Nm/s)	0.017
Equivalence ratio, ER	0.20

$$U_{mf} = \left(\frac{\mu}{D_p \rho_{air}} \left[33.7^2 + 0.0408 \frac{D_p^3 \rho_{air} (\rho_p - \rho_{air}) g}{\mu^2} \right]^{\frac{1}{2}} - 33.7 \right) \quad (1)$$

where U_{mf}, μ, D_p, ρ_{air}, and g represent the minimum fluidisation velocity, viscosity of fluid media, diameter of sand particle (bed material), density of fluid media (air) and acceleration due to gravity.

Table 3: Bed material properties

Bed material	Geldart group	Particle density, ρ_p (kg/m^3)	Particle size, d_p (μm)
Sand	Group B (sand like) (Geldart, 1973)	2,650 (Fotovat et al., 2015)	90 - 125

The electric heater was switched on and set on selected gasification temperature (850 °C). The heating process usually took around 2 h. The ambient air is started introduced into reactor once the desirable temperature is achieved. The NG-OPF blend pellets are fed into reactor. In that moment, the gasification run started. The produced bio-liquid was captured by neck flask and the non-condensable gas was collected (every 3 min) by the sampling bag. Both samples were analysed using GC and GC-MS. At the end of each test, the produced by-product char contained in the bottom of reactor was discharged out and weighed when the temperature was same as ambient temperature.

3. Results and discussion

3.1 Effect of blending ratio of NG and OPF on the syngas quality

In this study, the effect of blending ratio of NG-OPF (25 : 75; 50 : 50; 75 : 25); and pure NG and OPF on the quality of synthesis gas was investigated under the temperature of 850 °C and ER 0.2 is shown in Table 4. Biomass composition strongly affects the characteristics of the product gas during the gasification test. It can be seen that pure OPF shows larger fraction of combustible gases (H_2, CO, CH_4) than pure NG. By referring to Table 1, both NG and OPF are found to be comparable in term of composition but the moisture content of NG (> 30 %) is higher than OPF (> 9 %). Moisture content is a key factor which strongly affects the gasification efficiency and the quality of producer gases (Sheth and Babu, 2009). This may be the reason caused significant amount of gas composition between NG and OPF. The concentration of (H_2, CO, CO_2, CH_4) of blended fuel (NG-OPF 25 : 75; 50 : 50; 75 : 25) were in the range of 8.09 – 13.04 vol%, 27.04 – 30.83 vol%, 46.20 – 55.45 vol% and 9.43 – 11.94 vol%. It can be realised that, there are no any sign of synergistic effect between NG and OPF except of the NG-OPF with 50 : 50 blending ratio. It is expected that combustible gases (H_2, CO, CH_4) to increase with increasing blending ratio proportionally. It is difficult to understand the behavior of the product gas by blending effect. This may be attributed to the inorganic content of NG and OPF. Both NG and OPF have different ash properties and particular ash composition which has negative impact on the gas performance under high temperature of combustion (Quaak et al., 1999). The synergistic effect between NG and OPF might be influenced by the metal oxides existed in biomass char as they might act as catalyst to promote the water gas shift reaction ($CO + H_2O \leftrightarrow CO_2 + H_2$) during gasification process (Franco et al., 2003).

Table 4: The effect of blending ratio on the producer gas

Blending ratio	NG 100	NG:OPF 25 : 75	NG:OPF 50 : 50	NG:OPF 75 : 25	OPF 100
Gas composition (vol%)					
H_2	11.55	8.09	13.04	8.65	14.39
CO	26.35	27.04	28.81	30.83	32.58
CO_2	52.27	55.45	46.20	48.61	35.15
CH_4	9.84	9.43	11.95	11.94	13.62

3.2 Effect of blending ratio of NG and OPF on the gasification performances

The effect of blending ratio of NG and OPF on the high heating value of producer gas is shown in Figure 2. Composition of the producer gas (H_2, CO, CO_2, CH_4) is the main role and used to determine the higher heating value of producer gases by Eq(2) (Xiao et al., 2006). The higher heating value of pure OPF and pure NG are 5.49 MJ/Nm^3 and 3.37 MJ/Nm^3. The ash content of biomass has positive effect on the calorific value of dry product gas because ash is a material that does not generate any energy (El Bassam and Maegaard, 2004). By referring to Table 1, OPF is amounted 4.84 % of ash content while NG is amounted 6.31 % of ash content. It revealed that the higher heating value of OPF is higher than NG. The higher heating value of NG-OPF blends is found to be from 2.57 – 3.42 MJ/kg. The maximum of higher heating value of NG-OPF blends (3.42 MJ/kg) was determined in ratio of 50 : 50.

$$\mathrm{HHV} = (\mathrm{CO}\,\% \times 3018 + \mathrm{H_2}\,\% \times 3052 + \mathrm{CH_4}\,\% \times 9500)(0.01 \times 4.1868)(\frac{\mathrm{kJ}}{\mathrm{Nm^3}}) \qquad (2)$$

where, CO %, H_2 % and CH_4 % are the volumetric composition of the syngas produced.

The carbon conversion efficiency, CCE of blended biomass samples, pure NG and OPF is shown in Figure 3.The carbon conversion is defined by the carbon content in the product gas divided by the carbon content in the feed biomass. The calculation of CCE can be performed by employing the Eq(3) as shown in below (Hernandex et al., 2010).The CCE of pure NG, OPF and NG-OPF blends are found in the range of 77.04 – 86.20 %. This result is in good agreement with previous literatures on a single biomass feedstock (Cao et al., 2006). The CCE of NG-OPF blends were showed higher value than those obtained by previous researches on coal-biomass blends (Fermoso et al., 2010). This can be explained that biomass has high reactivity than coal due to the relatively weak ether bond which linked together with cellulose, hemicelluloses and lignin (Krerkkaiwan et al., 2013).The CCE of NG-OPF blends, pure NG and OPF were found to be comparable with each other. A possible explanation is that both NG and OPF contain almost same amount of volatile matter content which is 85.52 % and 83.28 %.

$$\mathrm{CCE} = 1 - \frac{\mathrm{M_a}}{\mathrm{M_b}} \times 100\ \% \qquad (3)$$

where M_a is the total mass of biomass after experiment and M_b is total mass of biomass before experiment.

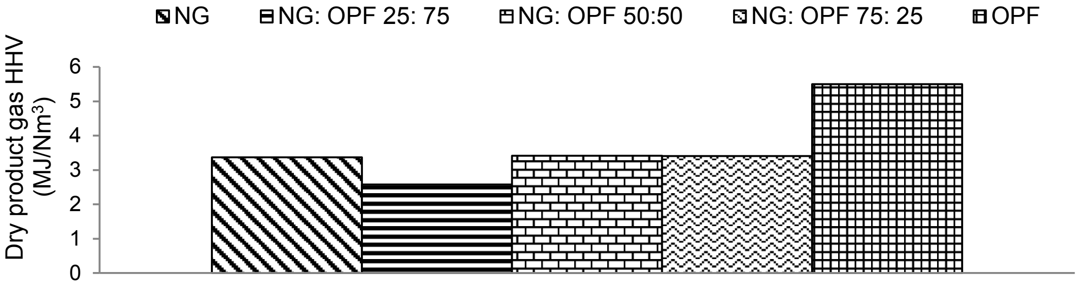

Figure 2: The effect of blending ratio on dry product gas HHV

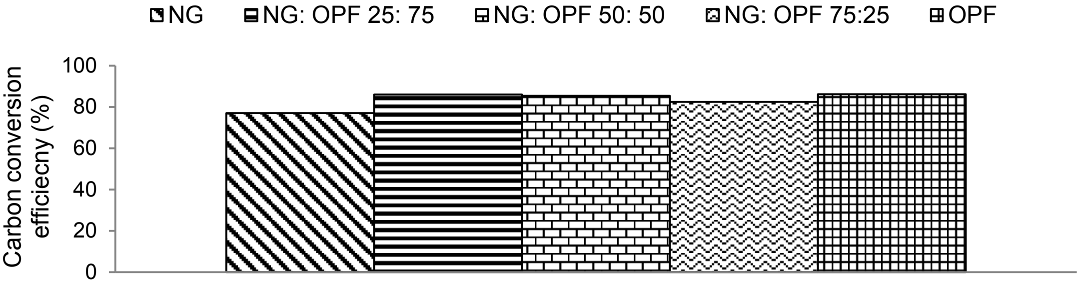

Figure 3: The effect of blending ratio on CCE

4. Conclusion

The effect of blending ratio of NG-OPF (0, 0.25, 0.5, 0.75, 1) under gasifying temperature (850 °C) and equivalence ratio (ER) (0.2) on gasification technology have been investigated in a fluidised bed reactor. This study shows that single OPF feedstock has obtained higher quality syngas (H_2: 14.39 vol%, CO: 32.58 vol%) and higher heating value (5.49 MJ/Nm^3). There are no sign of synergistic effect between NG and OPF (25 : 75, 75 : 25). NG:OPF (50 : 50) was found to obtained a higher H_2 composition (13.04 vol%) and higher HHV of gas product (3.42 MJ/kg) as compared to NG-OPF blends (25 : 75, 75 : 25). This phenomenon may be caused by metal oxide existed in biomass char and poor mixing between NG and OPF. The CCE of NG-OPF blends, pure NG and OPF were found to be comparable because both NG and OPF contain almost same amount of volatile matter content which is 85.52 % and 83.28 %. The maximum CCE is 86.20 % with the biomass ratio of 0.25. To understand clearly about the behavior of the syngas quality by different blending ratio, further analysis on the ash composition of fuels and uniform distribution between NG and OPF should be done.

Acknowledgments

Authors would like to acknowledge the financial support from Ministry of Education (MOE), Malaysia via LRGS grant (LRGS/2013/UKM/PT) and express gratitude you to CFF (Crop for Future) provides feedstock for this work.

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