Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 12 (24): 2555-2561, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.2555.2561

Syngas Production from Gasification of Oil Palm Fronds with an Updraft Gasifier

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Abstract: In present study, gasification of Oil Palm Fronds (OPF) is performed in a pilot-scale updraft gasifier. Gasification experiments were conducted at atmospheric pressure using air as oxidizing agent. The effects of equivalence ratio on temperature profile, gas composition and gas calorific value are studied. The equivalence ratios employed in this study are 0.18, 0.22, 0.29, 0.35 and 0.4. The results showed that the amount of combustible gases which are H_2, CO and CH_4 was found to be in the range of 16.79-33.9% of the total produced gases and the average composition of the syngas at an optimum equivalence ratio of 0.29 was found to be 20.10% CO, 10.41% CO_2, 1.20% CH_4 and 6.60% H_2 with an average calorific value of 4.42 and 4.62 MJ Nm^{-3} as Low Heating Value (LHV) and Higher Heating Value (HHV). While the maximum molar ratios of H_2/CO and CO/CO_2 was found to be 0.3 and 2.51, respectively.

Key words: Gasification, oil palm fronds, syngas, updraft gasifier

INTRODUCTION

The world's energy consumption, is still dependent on fossil fuels such as petroleum, coal and natural gas (Mohammed *et al*., 2005) which provide more than 80% of the total global energy demand and almost 100% of the energy needed for transportation sector (Chew and Bhatia, 2008). However, the excessive usage of fossil fuels leads to serious energy crisis and environmental problems such as fossil fuels depletion and pollutant emission. As most of the global economic and social activities depend on fossil fuels, the steep rise in energy demand will increase up the production of greenhouse emission and other toxic gases such as such as CO_2 and NO_x, causing global warming and acid rain (Mohammed *et al*., 2005). In order to imitate the above energy and environmental problems, it is highly important to develop clean, cheap and renewable energy source (Ni *et al*., 2006; Pratik and Babu, 2010). Among all the renewable energy sources, biomass is unique in that it effectively stores the solar energy inherently (Pratik and Babu, 2009). Moreover biomass has significant features such as renewable, cheap, available and lower emissions of CO_2 and greenhouse gases (Gao *et al*., 2008). As an agriculture country, Malaysia generates a tremendous amount of biomass waste each year (Atnaw *et al*., 2011). The main types of biomass generated in Malaysia are forest residues and oil palm wastes. However, Malaysia is still the leader in palm oil producing and exporting, it produces about 51% of the world's supply of palm oil and account about 62% of the world exports of palm oil (Mohammed *et al*., 2005). Malaysian palm oil industries and plantations generate a huge amount of oil palm wastes, including Empty Fruit Bunches (EFB), Oil Palm Fronds (OPF), Oil Palm Trunk (OPT), Palm Kernel Cake (PKC), Oil Palm Shell (OPSh), Palm Press Fiber (PPF), Palm Oil Mill Effluent (POME) and Oil Palm Stone (OPS) (Mohammed *et al*., 2005).

It is estimated that around 4.88 million hectares (67% of the total agricultural land) of land in Malaysia was used for oil palm plantation, producing a significant amount of OPF (Mazaheri *et al*., 2010). Generally, almost all pruned fronds are left rotting in the plantations mainly for nutrient recycling, soil conservation and erosion control. As the fronds require a long time to decompose and rot, causing mobilization problems within the plantations, a proper way for disposal needs to be developed and improved. Recently, OPF has started to be used as roughage source for animals (Kawamoto *et al*., 2001). Nevertheless, the current utilization of OPF doesn't consume the significant quantity of the fronds produced annually. Therefore, converting the surplus into useful energy via the present conversion technologies could be a good opportunity for the palm oil industry.

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Amongst the biomass conversion technologist, biomass gasification is considered as the promising technology for converting solid biomass into a fuel gas (Miskam *et al.*, 2008) which consist of H_2, CO, CO_2, CH_4, char and tar. The resulting gas which is known as producer gas or synthetic gas is more versatile in its use than the original biomass (Iqbal *et al.*, 2010). The energy content of the gas produced through gasification process depends on number of factors, such as operation conditions, physical characteristics of biomass and gasifier design as well as the gasifying agent such as air, oxygen, steam (Lucas *et al.*, 2004). Hence, in the present study, gasification of OPF in an updraft gasifier with air as a gasifying agent was carried out to investigate the effect of equivalence ratio on temperature profile, synthetic composition and gas calorific value.

MATERIALS AND METHODS

The biomass material (OPF) used for these experiments were obtained from a plantation in the state of Perak, Malaysia. OPF (after removing leaves) were cut and dried into the required size and moisture content, respectively. The proximate and ultimate analyses of the feedstock are presented in Table 1.

The experimental apparatus setup that used for gasification of OPF is shown in Fig. 1. It consists of batch type gasifier, air blower, cyclone, cooling unit, oil path filter and gas analyzer. The gasifier unit used in this study was made from mild steel and cement with 25 mm thickness and volume of 0.16 m^3. The gasifier is square in cross section. The height from the top of the gasifier to the grate is 1.0 m. The internal length is 0.4 m the grate is in square shape with 0.3 m length. The ash container with square shape is fixed below the grate, has a height of 0.2 m and outside length of 0.45 m. The grate is directly supported to the combustion zone and must be capable of letting the ash fall through, without loss of fuel. The grate is used as an air distributor; however the holes are distributed across the whole section of the grate. The bottom zone under the grate is for collecting and then discharging the ash.

Five Type-K thermocouples are installed along the height of the gasifier in order to measure the temperature

Table 1: Ultimate and proximate analysis of biomass feedstock

Analysis	Value
Physical analysis	
Size (cm)	1.5×1×1
Bulk density (kg/m^3)	712.8
Higher heating value (MJ/m^3)	18.03
Proximate analysis (w/w % dry basis)	
Volatile matter	51.3
Fixed carbon	41
Moisture content	12
Ash	6.3
Ultimate analysis (w/w % dry basis)	
C	42.55
H	5.48
N	2.18
S	0.20
O (Difference)	43.38
Ash	6.31
Empirical formula	$CH_{1.55}O_{0.88}$

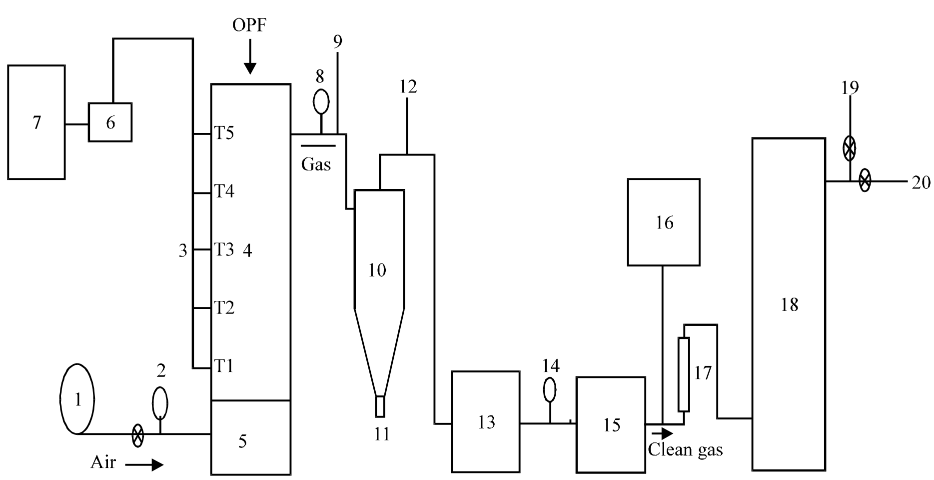

Fig. 1: Schematic diagram of an updraft experiment set-up (1) Air blower (2) Air flow meter (3) Thermocouples (4) Updraft gasifier (5) Ash container (6) Data logger (7) Computer (8) Temperature probe (9) Flare point No. 1 (10) Cyclone (11) Condensate and particulate collector (12) Flare point No. 2 (13) Cooling system (14) Temperature probe (15) Oil path filter (16) X-STREAM Gas analyzer (17) Gas flowmeter (18) Accumulation tank (19) Flare point No. 3 (20) Gas to burner

inside the gasifier and classify the gasification reactions zones. These thermocouples are placed at 10, 30, 50, 70 and 90 cm above the grate. Two more thermocouples mounted at outlet pipe and after the gas conditioning system (cooling and cleaning units) are used to measure the temperature of the outlet gas and the temperature of the gas leaving the conditioning unit, respectively. All thermocouples are connected to data logger (USB TC-08) and the readings of the temperature are stored in the computer.

RESULTS AND DISCUSSION

Temperature profile: The temperatures profile inside the gasifier was measured every 30 sec by a set of thermocouples located at different heights in the gasifier as shown in Fig. 1. As discussed in our previous study (Elneel *et al*., 2011), the position of these thermocouples represent the dynamic temperature profile for gasification of OPF in an updraft gasifier, however T1, T2, T3 and T4 represents the oxidation, reduction, pyrolysis and drying zone, respectively. The temperature profile along the gasifier axis for different equivalence ratios during the operation time is presented in Fig. 2a-e. From the same figures, it is observed that, the top part of the gasifier (at 70 cm above the grate) showed a temperature lower than 200°C, this indicate that the feedstock is undergoing drying. While the temperature profiles near the grate (10 cm above the grate) showed a temperature between 700-1000°C, indicating that the fuel in this region is undergoing oxidation process. The regions between those zones showed decomposition and reduction processes.

It is also observed that the temperature profiles of the oxidation zone for all the runs (except at equivalence ratio of 0.4) are relatively stable at temperature above 700°C. This is due to the fact that, higher increase in equivalence ratio may provide more nitrogen which acts as a heat carrier, however lower oxidation zone temperature and higher temperature for the others zones compare to other equivalence ratios could be observed as shown in Fig. 2e.

Syngas composition: The composition of the producer gas was analyzed online at a five-minute interval during the experiment runs and the gas analyzed by using X-STREAM gas analyzer, the gas analyzer was used to analyze four gases of the producer gas; these gases are

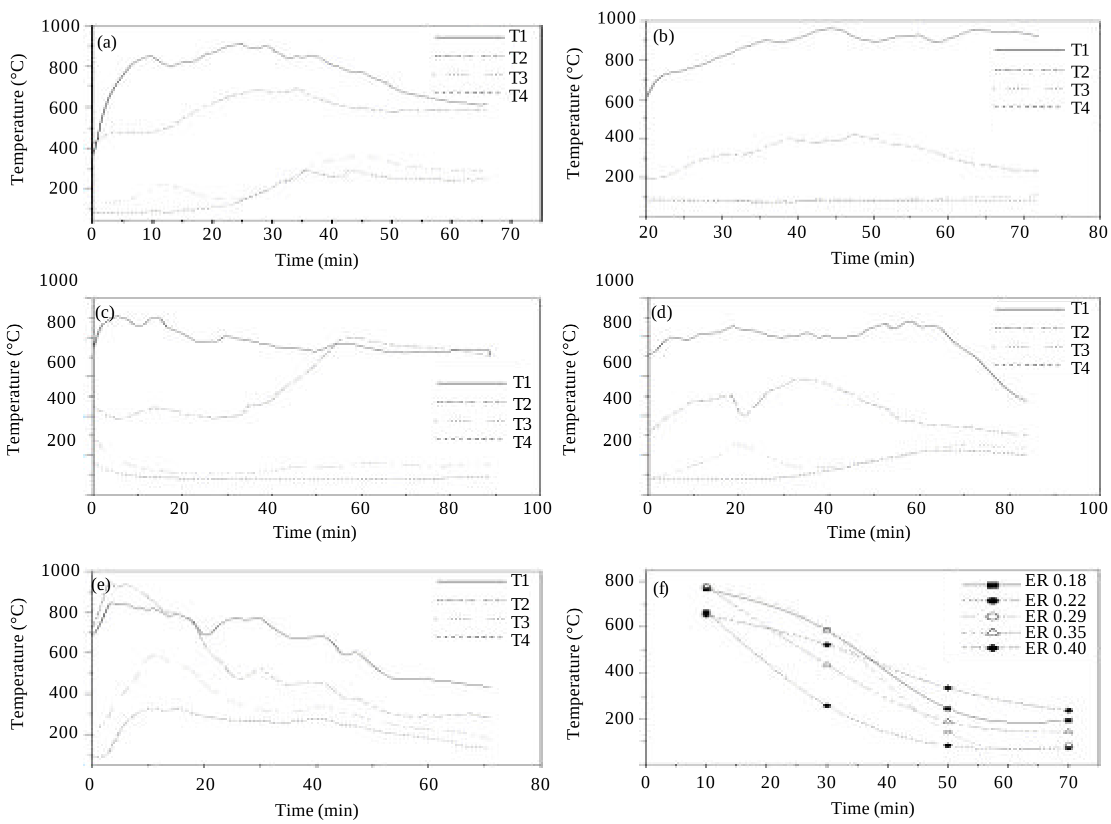

Fig. 2(a-e): Temperature profile during operation time for several ERs (f) Average temperature profile along the gasifier axis for several ERs, (a) ER 0.18, (b) ER 0.22, (c) ER 0.29, (d) ER 0.35 and (e, f) ER 0.40

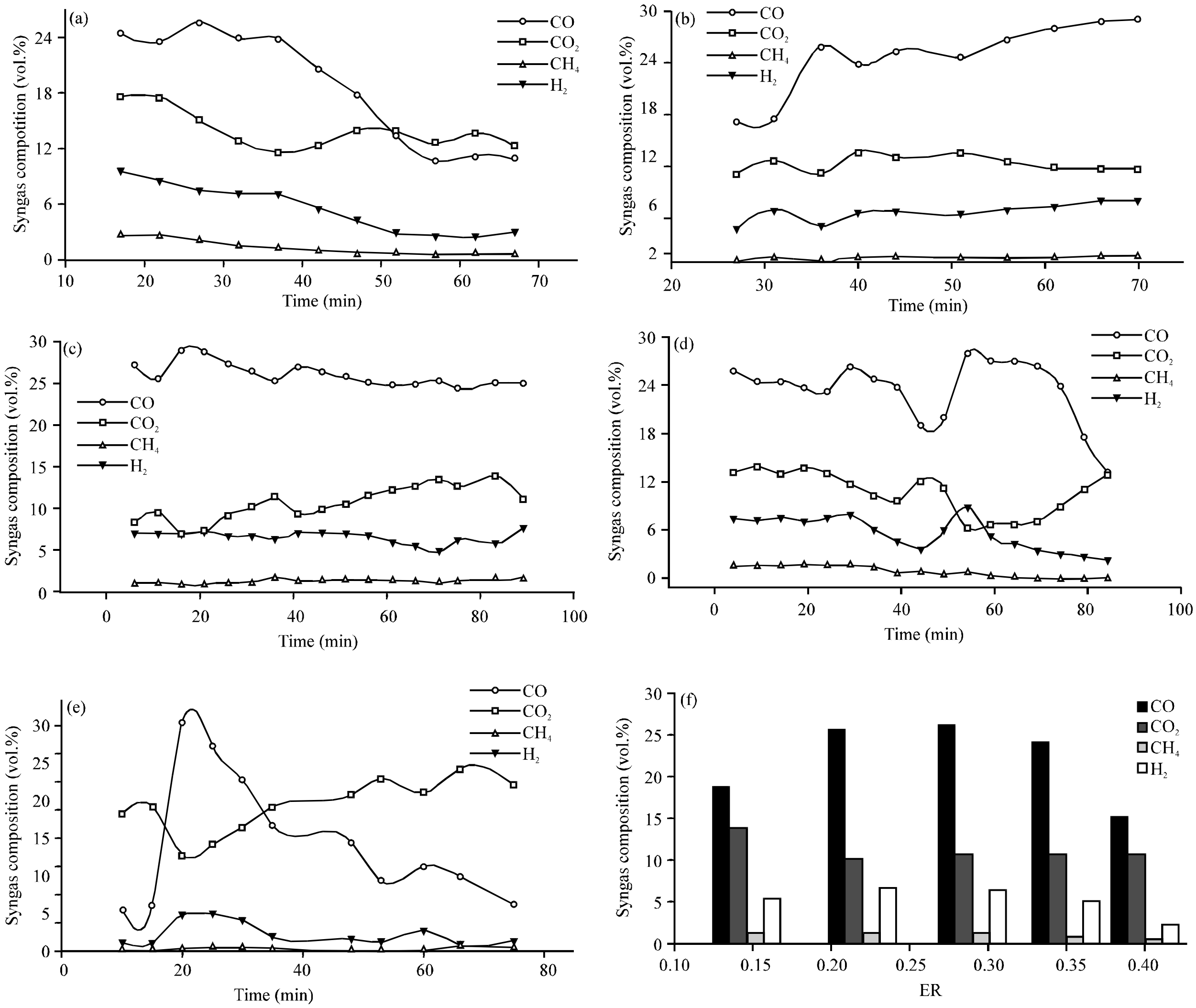

Fig. 3(a-e): Syngas composition profiles with the elapsed time, (a) ER 0.18, (b) ER 0.22, (c) ER 0.29, (e) ER 0.35, (f) ER 0.40 and (g) Average value of syngas composition with different ER

CO, CO_2, CH_4 and H_2 while N_2 could be calculated by the difference. Figure 3a-e shows the profile of syngas composition during the gasification operation time for a gasification equivalence ratio of 0.18-0.40 while Fig. 3f presents the average concentration of generated syngas.

The average composition of the syngas at optimum equivalence ratio (0.29) was found to be 20.10% CO, 10.41% CO_2, 1.20% CH_4 and 6.60% H_2. The remaining gases are mostly nitrogen originated from air. It can be seen from the same figure that for equivalence ratio of 0.22 and 0.29, the syngas composition is quite stable during the gasification operation time while it is unstable for the rest employed equivalence ratios.

Figure 4 shows that the total amount of combustible gases (H_2, CO, CH_4) increase from 25.64-33.5% with an increase in equivalence ratio up to 0.29 then decrease to 16.79% with further increase in equivalence ratio up to 0.4, this could be to the fact that at low equivalence ratio the process seems like pyrolysis and produce high amount of char and tar beside the gas while at higher equivalence ratio more oxygen is supplied into the gasifier and hence enhance the degree of combustion reactions that lead to improve char burning to produce CO_2 at the expense of combustible gases such as CO, H_2 and CH_4. Figure 5 shows the change of H_2/CO, CO/CO_2 and CH_4/H_2 molar ratio in the product gas with the employed equivalence ratio. It is observed that the molar ratio of H_2/CO and CH_4/H_2 decrease from 0.3-0.16 and from 0.25-0.12, respectively with an increase of equivalence ratio while the molar ratio of CO/CO_2 increase from 1.34-2.51 as the equivalence ratio increase up to 0.35 then decrease sharply to 0.75 with equivalence ratio of 0.4, this could be

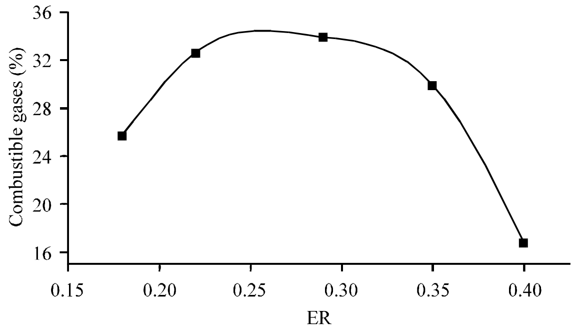

Fig. 4: Effect of ER on amount of combustible gases (H_2, CO, CH_4)

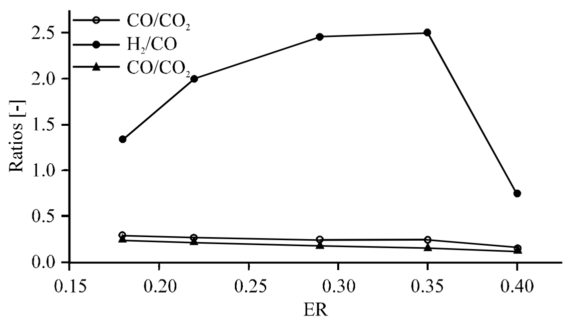

Fig. 5: Effect of ER on molar ratios of CO/CO_2, H2/CO, CH_4/H_2

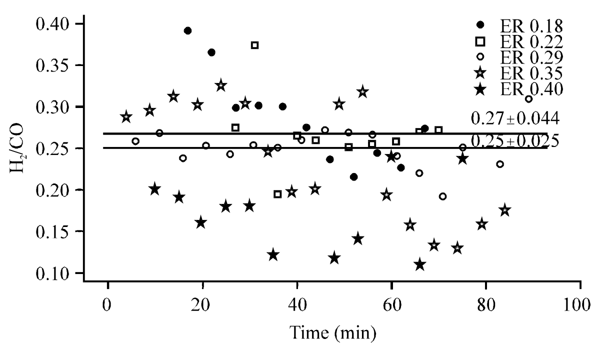

Fig. 6: Profile of molar ratio of H_2/CO with time at different ER

attributed to the fact that less equivalence ratio favors incomplete oxidation reaction ($C+0.5O_2 = CO$) and Boudouard reaction ($C+CO_2 = 2CO$) while at higher equivalence ratio (more oxygen is available) oxidation reaction ($C+O_2 = CO_2$) takes place and become stronger due to the higher quantity of oxygen. The trend of the H_2/CO of the syngas during the gasification operation time with equivalence ratio is illustrated in Fig. 6. It can be seen that the average value of H_2/CO varied from 0.3-0.16 which is reasonable for air gasification. The figure shows

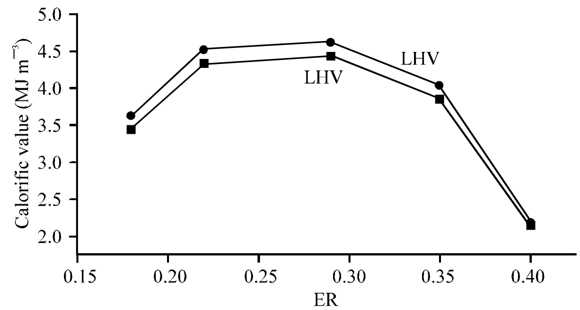

Fig. 7: Effect of ER on syngas calorific value

that it is preferable to run the gasifier at equivalence ratio in the range of 0.22-0.29 in order to obtain smooth operation for the equipment that use of the produced synthesis gas.

Calorific value: The heating value of the synthesis gas was evaluated in terms of higher heating value, HHV and lower heating value, LHV, at standard temperature and pressure and can be determined by considering the volumetric percentage of the gas constitutes (CO, H_2 and CH_4), as shown below:

$$HHV = (H_2\%\times30.52+CO\%\times30.18+CH4\%\times95)\times4.2$$
$$HHV = (H_2\%\times25.7+CO\% \times30+CH4\%\times85.5)\times4.2$$

Figure 7 illustrates the effect of equivalence ratio on the LHV and HHV of the syngas produced from the gasification of OPF. Both LHV and HHV increase with equivalence ratio up to a peak value of 0.29. This is due to the increase of CO and H_2 and then starts to decrease and the decrease is due to consume of CO and H_2. The highest calorific value of the syngas was obtained at equivalence ratio of 0.29 with an average value of 4.42 and 4.62 MJ Nm^{-3} for LHV and HHV, respectively which corresponds to the highest percentage of combustible gases especially CO and H_2.

Mass balance: An overall efficiency of the gasification system was obtained through mass balance which could be performed for the input and output streams of the gasification process as shown in the equations below. The input stream (M_i) consisted of biomass fuel and air while the output stream (M_o) consisted of dry syngas, tar, char and ash. The total mass balance was found to be in the range of 74.8-94.8% as shown in Fig. 8. The mass balance does not reach 100% due to neglect of water component and experimental losses:

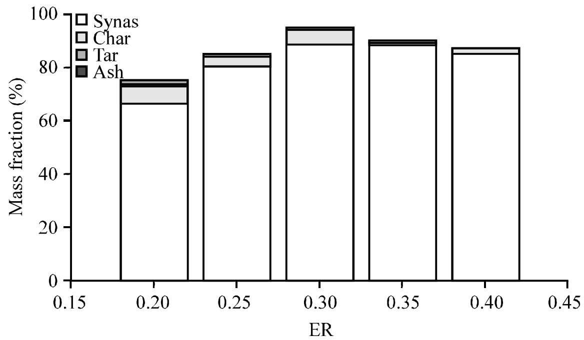

Fig. 8: Product distribution of OPF

$$\Sigma m_i = \Sigma M_o$$
$$\Sigma M_i = M_{fuel}+M_{air}$$
$$\Sigma M_o = M_{gas}+M_{tar}+M_{char}+M_{ash}$$

Bridging phenomenon: Bridging which considered as one of the gasification operational problem was occurred during the experiment runs. Once the bridging happen, the fuels stop to flow down towards the gasifier bed and some of the gas generated at the gasifier bed combusted at the gap occurred between fuels. This may lead to increase the temperature of the reduction zone above the oxidation zone as shown in Fig. 2c and e. Moreover, bridging may cause a reduction in CO and H_2 and increasing in CO_2 of the synthetic gas due to combustion of some of the gas generated as shown in Fig. 3c for the period of bridging. Bridging could be avoided by shaking the gasifier in order to allow the fuels to fall downwards the gasifier bed.

CONCLUSION

Production of combustible gas from oil palm from was experimentally investigated in a pilot-scale updraft gasifier. It was found that OPF can successfully converted into combustible gases and the combustible gases was found to be in the range of 16.79-33.9% of the total produced gases with an equivalence ratio between 0.18 and 0.4. Moreover, 0.29 was observed to be an optimum equivalence ratio, in which the average composition of the syngas was found to be 20.10% CO, 10.41% CO_2, 1.20% CH_4 and 6.60% H_2 with an average calorific value of 4.42 and 4.62 MJ Nm^{-3} as LHV and HHV. However, OPF can be assumed as one of the feedstock to produce synthetic gas. In the further, more experimental study is required to investigate the effect of other operation conditions such as moisture content and particle size.

ACKNOWLEDGMENT

The authors would like to acknowledge the Universiti Teknologi PETRONAS for providing the financial support and research facilities for this work.

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