Production of Syngas Through Co-gasification of Torrefied Palm Kernel Shell and Low-Density Polyethylene

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ABSTRACT

In this paper, the investigation of palm kernel shell (PKS) waste and Low-Density Polyethylene (LDPE) plastic waste led to the major environmental problem. Then, to overcome this problem, syngas production from these waste needs to be achieved. To achieve this, co-gasification process needs to be applied. From these results, it can be conclude that co-gasification of TPKS:LDPE (85:15 wt/wt) is the best to produce syngas where it content the highest H_2 *production and lowest* CO_2 *production compared than individual gasification.*

Keywords: Palm kernel shell (PKS), low-density polyethylene (LDPE), syngas, co-gasification.

1. INTRODUCTION

One of the leftovers of palm oil production which is palm kernel shell (PKS) is being used for energy generation, biofuels production processes (Hussain *et al.*, 2019). Palm kernel shells (PKS) waste that was generated will require utilization for diverse applications especially due to their perceived low carbon (Uchegbulam *et al.*, 2022). PKS has higher calorific value, lower sulphur content and can be found easily. Therefore, to reduce the instant fossil fuel greenhouse gases, the conventional fuel needs to be replaced with organic crude fuels (unconventional fuels) (Qarizada *et al.*, 2018).

The continuous demand of plastics causes the plastic wastes accumulation in the landfill, which consumes a lot of space which contributes to the environmental problems. Therefore, the processes for converting waste plastics into fuels and value-added chemicals through extensive research and technology development have attracted much interest. Among the plastics, LDPE is suitable for producing fuel-ranged hydrocarbons because it has a high effective H/C ratio and molecular chain structure. The recovery of plastic to biofuel through thermal process had a great potential since petroleum was the main source of plastic manufacturing.

Gasification is a clean and effective thermochemical conversion process that may be used to use bioresources with lower energy density, greater volatile content, and higher tar yield. A potential method is thermochemical gasification, which can extract the energy contained in different kinds of biomass and plastics and transform them into useful products appropriate for diverse industrial uses. As a result, the gasification process was chosen as the best method for producing hydrogen in this study.

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2. EXPERIMENTAL PROCEDURE

2.1 Pretreatment of PKS

Prior co-gasification, PKS was undergo torrefaction as pre-treatment process at 250 °C and 40 min reaction time in fixed bed reactor. After the torrefaction process completed, the heater was turned off and the reactor was left to cool to the ambient temperature. Then, the solid product was weighed to measure the yield of torrefied PKS (TPKS).

2.2 Co-gasification of TPKS and LDPE

Approximately 5 g of sample at 85:15 wt/wt (TPKS:LDPE) was weighed and positioned inside the reactor for temperature of 850 °C and 60 min reaction time. A nitrogen flow rate of 0.5 L/min was remained constant to create an inert atmosphere inside the reactor. After the reactor reached the gasification temperature, the steam that was produced from the steam generator was introduced into the reactor, and the nitrogen flow was stopped. Then, the dry gas was collected in a gas bag every 20 min from the beginning of steam gasification.

2.3 Gas Analysis

The gas composition was analysed using gas chromatography with thermal conductivity detector (GC-TCD). The produced gases of H_2, CO, CO_2 and CH_4 was quantitatively analysed by GC-TCD using purified argon as carrier gas. The CO, H_2 and CH_4 was analysed by a molecular sieve column. The sample injection volume is 10 µl and were splitted at 21.2:1. The detector temperature was set at 250 °C. The oven programming was set at 60 °C and held for 15 min.

3. RESULTS AND DISCUSSION

3.1 Gases Composition

From Figure 1 (a), the H_2 composition of LDPE was highest at 20 minutes compared than all sample. Compared to biomass sample, higher carbon and hydrogen contain in plastics resulted in higher amount of H_2. The H_2 composition of co-gasification were higher than individual gasification for each reaction time due to the present of LDPE. When LDPE present in the biomass, high hydrogen concentration was obtained due to the PE cracking and reforming reaction occurred. LDPE acted as a hydrogen donor in co-gasification to provide free radicals conductive to hydrogen and hydrocarbon generation. As a result, the individual gasification of LDPE and co-gasification produced more hydrogen and hydrocarbons but less CO than the gasification of biomass. This result is consistent with the previous studies which showed that higher amount of plastic in a blended mixture can yield more H_2 [1,2,3]. The occurance of this reaction would also explain the relatively low methane concentrations obtained. By comparing co-gasification between UnPKS:LDPE and TPKS:LDPE, TPKS:LDPE contains higher H_2 composition for each reaction time. The H_2 composition of TPKS: LDPE was increase continously from 48.86 % of 20 min to 51.74% of 40 min and 55.13% of 60 min. The high production of H_2 is in accordance with the high quantity of carbon content in treated sample (TPKS) compared to untreated sample (UnPKS). The H_2 production is mostly generated from the reaction of carbon with steam in co-gasification reactor. As a result, the pretreatment of biomass increased both its carbon content and its ability to produce H_2 gas. This offers a great opportunity to apply pretreated biomass for the production of hydrogen. Based on reaction time, the amount of H_2 production at 60 min were highest than 20 and 40 min for all sample. For higher production of H_2 at this reaction time could be consumed by the steam reforming reaction, water gas reaction and water gas shift reaction as Equation 1,2 and 3 respectively [4]. This effect has also been studied by other authors, who have reported that the co-gasification of plastics and biomass has a significant effect on H_2 composition [5]–[7].

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (1)$$

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

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

From Figure 1(b), the composition of CO for LDPE was the lowest than other sample due to the lowest oxygen content in plastics compared than biomass. By comparing individual gasification between TPKS and UnPKS, TPKS have lower CO composition than UnPKS. During the gasification process, TPKS led to decreased the CO composition. These results demonstrated that AAEM catalyst in TPKS inhibit decomposition process, while enhanced boundard reaction. Meanwhile, individual gasification of TPKS and UnPKS were found higher CO composition compared than co-gasification for each reaction time. This is because biomass as an oxygenated compound contributed to CO production. The individual gasification of LDPE and the co-gasification of the both samples produced more hydrogen and hydrocarbons but less CO compared than individual gasification of biomass. The composition of CO for UnPKS:LDPE increase from 26.85% of 20 min to 31.46% of 40 min but slightly decrease to 30.54% at 60 min. Meanwhile, the composition of CO for TPKS:LDPE continuously increase from 24.85% of 20 min to 25.41% of 40 min and 26.62% of 60 min. It was reported that the CO gas composition would be dominated by boundard reaction and water-gas reaction at higher temperature in co-gasification process as Equation 4 and 5 respectively.

$$C + CO_2 \rightarrow 2CO \quad (4)$$

$$C + H_2O \rightarrow CO + H_2 \quad (5)$$

On the other hand, based on Figure 1©, the CO_2 composition of LDPE was record as the lowest composition due to the lowest oxygen content in LDPE is 4.35 wt.% which agrees with the comparison results in Table 4.1. When reaction time increase, the composition of CO_2 also increases for individual biomass gasification from 7.18% of 20 min to 9.26% of 40 min and 10.71% of 60 min and from 8.01% of 20 min, to 8.56% of 40 min and 9.46% of 60 min for UnPKS and TPKS respectively. This can be explained by the water gas shift reactions as the following Equation 6 [8]:

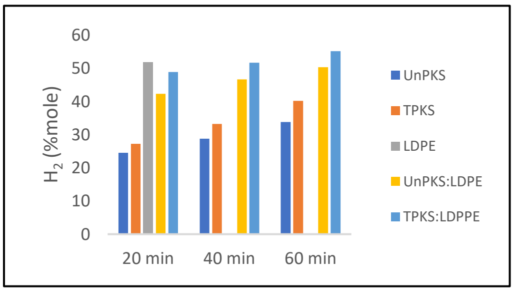
$$CO + H_2O \rightarrow CO_2 + H_2 \quad (6)$$

However, CO_2 composition was found to be negatively influence when LDPE was blend with biomass, for co gasification of UnPKS:LDPE and TPKS:LDPE. When reaction time increase, the amount of CO was decrease continuously from 7.86 % of 20 min to 7.52 % of 40 min and 6.21% of 60 min and from 7.23% of 20 min to 6.45% of 40 min and 4.98% of 60 min for UnPKS:LDPE and TPKS:LDPE respectively. The formation of CO_2 by this latter reaction could be consumed by the Boundard reaction, which would explain the decrease of CO_2 observed, mainly when PE was used [9]. By comparing UnPKS:LDPE and TPKS:LDPE, the amount of CO_2 for TPKS:LDPE was lower than UnPKS:LDPE for all reaction time due to the higher carbon content in TPKS than UnPKS.

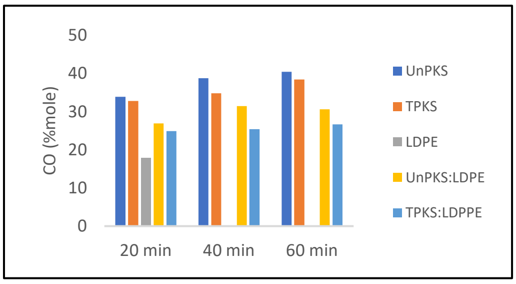
As shown in Figure 1(d), the composition of CH_4 increase when reaction time increase for all sample. At 20 min reaction time, the highest amount of CH_4 was recorded for LDPE compared than others. The increase of CH4 in LDPE content can be explained by the nature of polymers. Higher methane content is attributed to the degradation mechanism of LDPE which is hydrocarbon polymer. The polymetric chain was cut, producing smaller molecules, eventually forming light hydrocarbon such as methane. Several papers reported that high methane content in polymers such as plastics were gasified. However, there are also works that used plastics as feedstock reported otherwise in which the concentration of methane and other hyrdrocarbon gas was significantly lower than 5% of the total volume percentage [7,10]. Meanwhile, co-gasification of UnPKS:LDPE and TPKS:LDPE were found to be higher CH_4 composition than individual gasification of TPKS and UnPKS for each reaction time. This is because when LDPE was used and due to the cracking of its polymeric structure, carbon and hydrogen concentration might have been higher, ©h might have favoured methanation reaction as shown in Equation 7.

$$C + 2H_2 \rightarrow CH_4 \qquad (7)$$

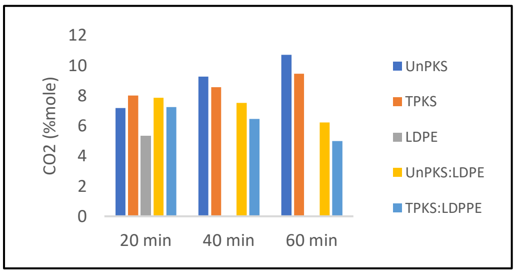
By comparing UnPKS:LDPE and TPKS:LDPE, the amount of CH_4 for TPKS:LDPE was higher than UnPKS:LDPE for all reaction time. When reaction time increase, the amount of CO was increase continuously from 10.98 % of 20 min to 11.621 % of 40 min and 13.48% of 60 min and from 11.76% of 20 min to 13.23% of 40 min and 14.91% of 60 min for UnPKS:LDPE and TPKS:LDPE respectively.



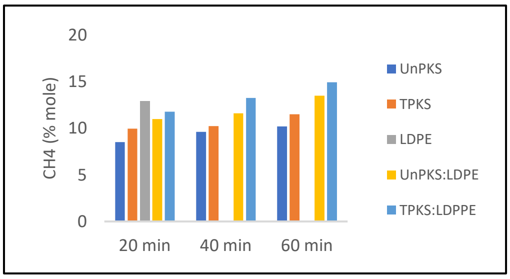
(a) H_2



(b) CO



© CO_2



(d) CH_4

Figure 1. Gas composition of co-gasification and individual gasification.

4. CONCLUSION

To conclude, the presence of LDPE clearly favoured the release of hydrogen and the decrease in CO content. The 15wt.% LDPE in TPKS led to a hydrogen richer gas of 55.13 %. Therefore, co-gasification of TPKS:LDPE is the best to produce syngas where it content the highest H_2 production and lowest CO_2 production compared than others.

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