Assessment of Palm Oil Mill Effluent (POME) Gasification in Supercritical Water for Hydrogen Production

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Abstract: Nowadays, the expanding of oil palm Industry has given both significant benefit and drawbacks. Besides as a source of national income, production of palm oil obtain a substantial amount of wastes byproducts. One of the most challenging problem is Palm Oil Mill Effluent (POME). In this work, characteristics of supercritical water gasification of POME were investigated in a continuous reactor at constant pressure of 25 MPa. The effect of temperature (500–600 °C) and residence time (1–50 s) on gas yield, composition, and carbon gasification efficiency (CGE) were studied. The results showed that a higher reaction temperature and a longer residence time could enhance the carbon gasification efficiency of POME.

1. Introduction

In past few years, Indonesia become the largest palm oil producing country in the world. In 2017, total production of crude palm oil reached 35.35 million ton. The total palm oil plantation in Indonesia has grown rapidly from 10.40 to 12.30 million hectares in five years until 2017 [1]. Consequently, palm oil provides a vital part of Indonesian national revenue. Development of rural munities is also.

However, this rapid growth leaves severe drawbacks to the environment. In the wet process of crude palm oil production, an enormous quantity of palm oil mill effluent (POME) will be produced. POME (made up of about 95–96 % water, 0.6–0.7 % oil, and 4–5 % total solid, and 2–4 % suspended solid) is the most problematic waste from the palm oil industry which is produced from sterilization process of fresh fruit bunch, clarification of palm oil, and effluent from hydrocyclone operations[2–4]. One ton of crude palm oil production will generate 3 ton of POME. Hence, an effective technology is important to handling this huge amount of POME.

Various technique for converting POME into usable energy via anaerobic digestion, open digesting tank, has been attempted [4, 5]. However, a very large treatment area and long reaction time are required to apply these method. Supercritical Water Gasification (SCWG) is a technology employing small-compact reactor and only requires short time to treat organic matters. Because water is required as reaction field, no drying is required in this method to process high moisture content biomass such as POME. Therefore, SCWG has high potential to convert POME to valuable gas.

This far only Sivasangar et al. gasified POME under supercritical water using batch reactor [6]. Result shows a slightly increasing of gas yield when POME was employed to substitute deionize. However, detail study of product yields of POME in the form of gas, liquid, and solid has not been carried out yet. Therefore, the purpose of this study was to conduct a comprehensive study to assess the potential of POME as a source of gas products, and behavior of POME gasification under hydrothermal conditions.

2. Material and methods

POME was acquired from PKS PTPN V Kebun Terantam, Desa Kasikan Kecamatan Tapung Hulu, Kab. Kampar, Riau, Indonesia. Feedstock was collected as slurry with water content 95 %. Then after POME was received, it was draught in the oven at setting temperature of 100 °C for 48 hours to remove all water contain in wet slurry. This treatment was carried out to maintain exact concentration at 0.1 wt % when POME mixed with deionized water to make a feedstock solution.

2.1. Experimental

Experiment was started by sending deionized water into the reactor systems. Subsequently, pressure was set at 25 MPa using a back pressure regulator. After pressure stabled, temperature was set to the desired
temperature at 500-600 °C. Then, system was waited until all reactor reach a stable experimental conditions. When condition stabled, the feedstock was fed to the reactor with a feeding system. This feeding system was stirred continuously with a constant agitation speed 400 rpm to maintain homogenous of the solution. The range of flowrates 4-23 ml/min was set at high pressure pump to achieve reaction time 10-50 s. All reaction products were cold at heat exchanger to be then collected in sampling port. The apparatus and detail experimental procedures were presented elsewhere [7].

2.2. Analytical method

Reaction products from experiments were liquid, gas, and solid phase. Each products was quantify at particular purposes. The products yield were calculated based on following equation:

\[
\text{(Carbon yield [-])} = \frac{\text{Carbon in product [mg-C/min]}}{\text{Carbon in feedstock [mg-C/min]}}
\]  

(1)

2.2.1. Liquid

Amount of carbon in liquid products were analyzed by using total organic carbon (TOC) analyzer. This analyzer quantifies the amount of carbon present in the liquid phase (non-purge able organic carbon) and the dissolved carbon dioxide (inorganic carbon).

2.2.2. Gas

A gas chromatography equipped with flame ionization (FID) detector and thermal conductivity detector (TCD) were used to quantify carbon existed in gas samples which are CH\(_4\), C\(_2\)H\(_2\), C\(_2\)H\(_6\), CO\(_2\) and CO. He was used as carrier gas. TCD was also use to detect H\(_2\) gas with N\(_2\) as the carrier gas.

2.2.3. Solid

Solid samples were quantified by an analytical balance measurement.

3. Results and Discussion

3.1. Product yields

Effect of reaction time on carbon yields of POME in SCW was investigated by employing five different reaction times 10-50 s. At temperature of 500 °C, liquid carbon yields are increase from 0.5 at residence time 10 s to 0.7 at 50 s. This is because some part of POME was not reacted due to high flowrates employed at short residence time. Therefore some amount of POME remained in solid phase at the end of reaction. This condition was confirmed by high amount of solid found at short residence times. On the other hand, at temperature of 600 °C liquid products tend to decrease at longer reaction times. This is indicated reaction has been completed occurred at short residence time. Moreover, decomposition POME to gas increase at longer residence times. Products yields was shown in Table 1.

Table 1. Product yields of POME treated in SCW.

<table>
<thead>
<tr>
<th>Carbon yield [-] at 500 °C</th>
<th>Carbon yield [-] at 600 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>carbon balance</td>
</tr>
<tr>
<td>liquid</td>
<td>gas</td>
</tr>
<tr>
<td>0.51</td>
<td>0.22</td>
</tr>
<tr>
<td>0.53</td>
<td>0.22</td>
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<tr>
<td>0.53</td>
<td>0.28</td>
</tr>
<tr>
<td>0.67</td>
<td>0.32</td>
</tr>
<tr>
<td>0.73</td>
<td>0.32</td>
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</tbody>
</table>

3.2. Carbon gasification efficiency

One parameter that can be used to assess feasibility of biomass gasification is carbon gasification efficiency. This parameter is describe in equation 2.

\[
(CGE [-]) = \frac{\text{mass of gaseous product [mg-C/min]}}{\text{mass of feedstock [mg-C/min]}}
\]  

(2)
Results shows that CGE increase at longer residence time exponentially as can be seen in Table 2. An increasing of temperature enhanced formation of gaseous products. This is in a good agreement with previous study. [8–10]

Table 2. Carbon gasification efficiency.

<table>
<thead>
<tr>
<th>Residence time [s]</th>
<th>Temperature 500 °C</th>
<th>Yields [-]</th>
<th>Residence time [s]</th>
<th>Temperature 600 °C</th>
<th>Yields [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td></td>
<td>0.22</td>
<td>10</td>
<td></td>
<td>0.31</td>
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<tr>
<td>20</td>
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<td>30</td>
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<td>0.28</td>
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<td>0.63</td>
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<tr>
<td>40</td>
<td></td>
<td>0.32</td>
<td>40</td>
<td></td>
<td>0.65</td>
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<tr>
<td>50</td>
<td></td>
<td>0.32</td>
<td>50</td>
<td></td>
<td>0.66</td>
</tr>
</tbody>
</table>

3.3. Gas composition

Temperature has significant impact to formation of gas products in SCW. Mainly, gas compound found in this study are CO₂, CO, H₂, CH₄ and small proportion of C₂H₄ and C₂H₆.

4. Conclusions

Assessment of continuous gasification of palm oil mill effluent (POME) had been carried out in supercritical water (SCW). POME was mainly converted to gaseous products CO₂, CO, H₂, and CH₄. CGE of nearly 0.7 was achieved at temperature of 600 °C at residence time 50 s. Effect of temperature and residence time has significant effect to enhance gasification of raw POME and composition of gas obtained in SCWG. POME are recommended feedstock to be gasified in SCW because it can produce high amount of hydrogen.

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References