Air co-gasification of palm kernel shell and polystyrene: Effect of different polystyrene content

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Abstract. Plastic waste management has been a problem as most of the plastics are not biodegradable. Although plastics are recyclable, only 21% of total plastic wastes are recycled. Using plastics as gasification feedstock/co-feedstock and converting it to usable energy is one of the solutions of removing plastics waste. Co-gasifying polystyrene (PS) with palm kernel shell (PKS) is promising as both of the feedstocks are abundant and have high energy content. However, the performance of air gasification of PKS and PS has not been studied previously. In this work, co-gasification of PKS and PS was carried out, focusing on the effect of PS content in the feedstock. The PS content was varied from 0 to 30 wt%. By increasing the PS content, the CH₄ volume percentage increases, while CO and H₂ volume percentage decreases. The high heating value of the producer gas increases with PS content, from 11.95 MJ/Nm³ at 10 wt% PS, to 12.36 MJ/Nm³ at 30 wt% PS. Higher PS content also increases the gas yield percentage.

1. Introduction

As the world’s inhabitant increase, the use of plastic, a non-biodegradable material increases, causing a problem of plastic waste. In Malaysia, about a quarter of all solid waste consist of plastic waste [1]. The management of these plastic wastes remains a highly debated issue. Recycling is seen as a viable way to manage these wastes, but not with its challenges [2]. Polypropylene (PP), polyethylene terephthalate (PET) and polyethylene (PE) recycling used a widely common process. However, it cannot be said to same to polystyrene. The recycling of expanded polystyrene requires an additional process that are costly [3]. Thermochemical process is seen as a way to dispose of plastics. Gasification technology is one of them. Gasification uses heat to convert carbon materials to gas. The gas can be used directly as fuel, or as chemical feedstock for subsequent chemical process. Numerous gasification of plastics waste research has been done [4–8]. However, in an operation point of view, the gasification of plastics only can cause clogging problems when the plastic is melted and stick to the tubes. This problem can be solved by mixing plastics with biomass. Palm kernel shell (PKS) has a potential to be a co-feedstock as it has a high energy density.

In this work, co-gasification was performed using a batch type, externally heated gasifier with mixed blends of polystyrene (PS) and PKS as feedstocks, focusing on the effect of different polystyrene content of the blends. This study will analyze the gas composition and the heating value of the producer gas. The amount of tar produced from the gasification process will also be measured and
analyzed. Information on the characteristics of the co-gasification reaction is essential before any real world use is considered.

2. Experimental

2.1. Feedstock and characterization
PKS is collected from FELCRA oil palm mill in Bota, Perak, Malaysia. The PKS was processed using a grinder, and sieved to obtain particle size of 2-4 mm. Prior to the experiment, the PKS was dried inside an oven at 105 °C for 24 hours. The polystyrene (PS) granule was supplied by Dow Plastics.

For mixed blends preparation, PKS and PS were weighted respectively according the desired percentages. The feedstock were mixed and stirred until it is uniformed. Table 1 shows the ultimate and proximate analysis of the feedstocks.

| Table 1. Proximate analysis, ultimate analysis and calorific value of the feedstocks. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  |                 |                 |                 |                 |                 |
| Elemental analysis (wt%) | Proximate analysis (wt%) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| C       | H       | N       | O        | Ash   | Volatile Matter | Fixed Carbon | Calorific value (MJ/kg) |
| PKS     | 41.95   | 5.49   | 1.43    | 50.97 | 8.27           | 60.78        | 30.94           | 22.59           |
| PS      | 91.33   | 8.67   | -       | -     | -              | 99.6         | 0.04            | 40.9            |

* by difference

2.2. Experimental set-up
In this work, the effect of different PS content was investigated. The electric heated batch downdraft gasifier used for the experiments is shown in figure 1. The diameter and vertical length of the cylinder reactor is 8 cm and 50 cm, respectively. Before the feedstock was fed, the reactor was heated to the desired temperature. The reaction temperature was set to 900 °C for all runs. Air was supplied by the air compressor, with the flow meter regulating the amount of air that was fed to the reactor. The air flow rate was set to 2.5 L/min. The reaction starts directly after the feedstocks were fed to the reactor. Condenser bottles condensed the liquid, and impinger bottles filled with solvents captures tars inside the producer gas. The gas product is directly analysed by the Emerson-Rosemount Analytical X-Stream X2GP online gas analyser, where the volume percentages of CO, CO₂, CH₄ and H₂ gas were measured. The experiment lasts about 10 minutes. The solid residue of the reaction was measured after the experiment ended. The polystyrene content that was tested are 0 wt% up to 30 wt%. Total mass of the feedstock was 100 grams.

2.3. Data analysis
The high heating value (HHV) of the producer gas was calculated using equation (1):

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HHV_{gas} = HHV_{CO} \times CO\% + HHV_{H_2} \times H_2\% + HHV_{CH_4} \times CH_4\%
\]  

(1)

where HHV of CO, H₂ and CH₄ are 12.63 MJ/Nm³, 12.74 MJ/Nm³ and 39.82 MJ/Nm³ respectively [9]. CO%, H₂%, and CH₄% are the average volumetric percentage of the respective gases. To calculate the mass gas yield of the produced gas, the solid, liquid and tar product of the reaction was measured respectively, and the mass gas yield was then calculated using the mass balance equations.
3. Results and discussion

3.1. Producer gas composition

Figure 2 shows the relationship of the gas composition and the plastics percentage of the feedstock blend. With increasing PS content, CO and H$_2$ percentage decreases. The CO$_2$ percentage does not seem to affect much with increasing PS content. On the contrary, by adding PS as low as 10% to the feedstock the CH$_4$ percentage increases significantly from 15.6% to 19%. CH$_4$ shows an increasing trend with the increase of PS. This can be attributed to the degradation mechanism of PS which is a polymer. The polymeric hydrocarbon chain is cut into smaller piece of molecules, and ended up as the most simple form of hydrocarbon, which is methane [10].

![Figure 2](image2.png)

**Figure 2.** Effect of different polystyrene content on the gas composition of the producer gas of the co-gasification of PKS and PS at 900 °C.

3.2. High heating value (HHV) of producer gas and product distribution

Figure 3 shows the effect of PS content on the HHV of the producer gas. Feedstocks blend with PS yields producer gas with higher HHV, compared to the gas produced by the gasification of PKS only. Adding 10 wt% of PS to the feedstock blend yielded gas with HHV value of 11.95 MJ/Nm$^3$, an
increase compared to the HHV value of gasification of PKS only, in which the HHV value of the producer gas is 10.72 MJ/Nm³. This can be explained by observing the gas composition of the producer gas, in which adding plastic will increase the CH₄ content. CH₄ has high HHV, so the increase of CH₄ certainly affects the HHV value of the producer gas. Further increasing the PS content will show an increasing trend of HHV.

The product yield percentage is shown in also shown in figure 3. Increasing the PS content will increase the gas yield, while decreasing the solid yield and liquid yield. This can be attributed to the high volatile matter of PS. With increasing PS content in the feedstock, higher volatile content of the feedstock mixture will yield more gas, as more solids are converted to gas. The tar yield percentage shows a slight increment, with the increase of PS content.

![Figure 3. Effect of different polystyrene content on the product distribution and HHV of the producer gas of the co-gasification of PKS and PS at 900 °C.](image)

4. Conclusion
In this work, the effect of PS content on the co-gasification of PKS and PS has been investigated. Increasing the PS content will increase the CH₄ percentage of the producer gas, while decreasing the CO and H₂ volume percentage. The HHV of the producer gas increased with PS content. With increasing PS content, the gas yield increases, while the solid and liquid yield decreases. Tar yield shows a slight increase with PS content. Co-gasification of PKS and PS is feasible for power generation as the produced gas has HHV in the range of 11.95 MJ/Nm³ to 12.36 MJ/Nm³, which is high enough for power generation. However, further study need to be done in order to investigate other parameters such as the reaction temperature and the equivalent ratio on the reaction.

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