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Synergistic Effect on Co-gasification of Pretreated Palm Kernel Shell and Mukah Balingian Coal

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Abstract. Co-gasification of pretreated palm kernel shell (PKS) and Mukah Balingian (MB) coal and gasification of individual feedstock were carried out in a fixed bed reactor system. The synergistic effect of pretreated feedstock in co-gasification was probed. The results showed that the co-gasification of pretreated biomass and coal samples had a synergistic effect at all blending ratios. The experimental value of co-gasification on 50 % biomass blending ratio generated the highest gas yield of 69.43 % and lowest tar yield of 10.11 %. This was supported with the different of experimental value and calculated mean value (Exp-Cal) that showed the highest synergistic effect on product yield using 50 % biomass blending ratio of the pretreated samples. Thus, the pretreated PKS and MB coal, by which their physical and chemical properties have been enhanced through pretreatment process are suitable to be used in co-gasification.

Keywords: Co-gasification; Palm Kernel; Mukah Balingan; Biomass

INTRODUCTION

In recent years, the increasing emission of CO_2, SO_x and NO_x has become a concern on the utilization of the world energy. In the midst of limited availability of fossil fuels and high level of air pollution, energy efficient technologies are gaining importance and gasification, being highly efficient technology, has received significant attention [1]. Currently, coal is the main feedstock in gasification and is expected to be applied as the energy resource for many decades ahead. However, this direction is difficult to achieve due to the increasing in energy demand that had caused the shortage supply and reducing of high rank coal [2]. Consequently, one of the approaches is to utilize the abundant low rank coal and biomass in gasification.

Co-gasification has been investigated by several researchers. Krerkkaiwan et al. [3] found the synergistic effect in terms of higher gas yield with lower tar and char yield at 50 % biomass blending ratio with coal. Howaniec and Smolinski [4] reported that the co-gasification increased the total gas yield and H_2 yield with comparison to individual gasification. Most of the blending in co-gasification utilized untreated biomass and coal. Dudynski et al. [5] reported that effective and stable gasification with lower tar production was obtained from torrefied biomass pellets in comparison to untreated biomass and suggested that the torrefied biomass are more appropriate to be applied for co-gasification. Therefore, the pretreated feedstock which had been improved in their physical and chemical properties enhance the gasification performance and H_2 production in syngas [6]. Consequently, the co-gasification of pretreated PKS and MB coal is absolutely novel in this area.

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The main purpose of this study was to investigate the synergistic effect between PKS and MB coal during co-gasification. The synergistic effect between untreated and pretreated feedstocks during co-gasification was highlighted and discussed in terms of conversion and product yields.

METHODS

Materials

PKS as biomass sample was obtained from United Oil Palm Mill Sdn. Bhd., Nibong Tebal, Penang, Malaysia. PKS sample was crushed and sieved through progressive finer screen to obtain particle sizes in the range of 200 to 400 µm. MB coal, which is classified as low rank sub-bituminous coal from Sarawak, Malaysia was used as the coal sample in this study. The untreated MB coal was pulverized and sieved through progressive finer screen to obtain particle sizes of less than 212 µm. The PKS and MB samples were dried in an oven overnight at 105 °C and finally stored in an air-tight container until the analyses were carried out. The pretreated PKS was produced from torrefaction of PKS at 270 °C for 1 h and the pretreated MB was produced from heating the MB coal at 250 °C for 1 h. The pretreated PKS and MB coal were prepared in a fixed bed reactor according to our previous work [7].

Gasification Experiment

The gasification and co-gasification of PKS and MB were carried out using a vertical fixed bed reactor with an internal diameter of 60 mm and 300 mm in height at an ambient pressure. An electric furnace surrounding the reactor was used to heat the reactor. Approximately 5 g of sample was weighed and positioned inside the reactor. The reactor was flushed with nitrogen gas for 10 min before the experiment. Then, the samples were heated to the desired gasification temperature with heating rate of 50 °C/min. 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 preferred gasification temperature, the steam was introduced into the reactor, while the nitrogen flow was stopped. The steam gasification of the sample was held for 45 min. The volatile product and steam which left the reactor from the upper side were condensed in a tar trap. The dry gas was collected in a gas bag each 15 min from the beginning of steam gasification. When the process ended, the furnace was turned off and the reactor was left to cool to the ambient temperature. The final weight of the remained solid, which is defined as char, was measured once it reached the room temperature. The condensable products which consist of tar and water fraction was separated and measured. The gas yield was calculated by difference based on the total mass balances considering the tar and char yield. The experiment under all of the studied conditions was replicated to ensure the measurement value and repeatability of the achieved results.

RESULTS AND DISCUSSION

Individual Gasification

Figure 1 shows the gasification properties of untreated and pretreated samples at gasification temperature of 800°C. The pretreated PKS and MB coal showed increasing conversion of 11.6 % and 8.3 %, respectively higher than untreated sample. This phenomenon was due to the low moisture and oxygenated compound of pretreated feedstock which made it easier to gasify. Chen et al. [8] demonstrated a comparable result as the gasification performance was enhanced significantly using pretreated bamboo with increasing syngas yield. As presented in Fig. 1, the tar production from torrefied PKS and preheated MB is lower than the untreated samples. This observation can be explained by the fact that both pretreatments i.e. torrefaction of biomass and preheating of coal are essentially mild pyrolysis processes, which cause initial devolatilisation and consequently leads to a lower production of tar and light molecular mass volatiles in the gasification process. The tar yield was noticeably different for the two types of pretreated samples where 24.1 % for the pretreated PKS and 8.9 % for the pretreated MB coal. This observation may be due to the differences of material and the volatile content of these feedstocks.

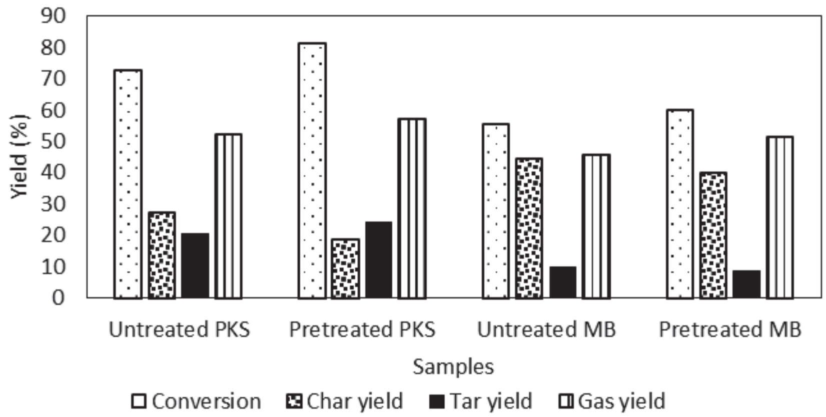


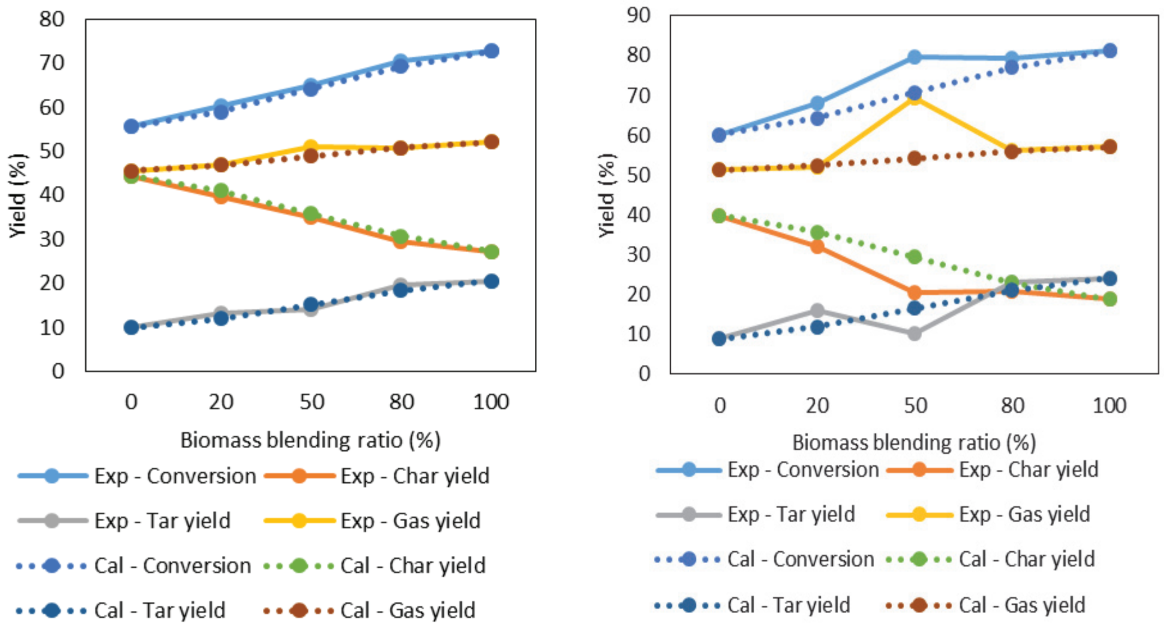
FIGURE 1. Conversion and product yield on individual gasification of untreated and pretreated samples at 800 °C

Co-gasification and Synergistic Effect

In order to observe the synergistic effect of co-gasification of untreated and pretreated sample, the mixture of PKS and MB coal at various blending ratios underwent a co-gasification at 800 °C for 45 min reaction time. The comparison of the experimental (Exp) product distribution at the same co-gasification conditions among different blending ratios during co-gasification are shown in Figure 2 (a) and (b). Assuming that there is no interaction between biomass and coal during co-gasification, the co-gasification product yield should be equal to the weighted mean value of the individual gasification of PKS and MB coal. In order to investigate the synergistic effects during the co-gasification of PKS and MB coal, the weighted mean values of the co-gasification conversion and product yield were calculated based on the individual gasification of PKS and MB coal for untreated sample and pretreated sample. These weighted mean values were defined as calculated value (Cal). Obviously, from Fig. 2 (a) and (b), the Exp values of conversion are higher than Cal values at all blending ratios. These results suggest the occurrence of synergy between untreated and pretreated feedstock during co-gasification. As shown in Fig. 2 (a), through blending of untreated sample, the conversion, tar and gas yield were increased, while the char yield decreased with the increased of biomass ratio. The untreated biomass blending ratio of 80 % showed the highest conversion and tar yield. This is probably due to the production of excess volatiles at high biomass blending in the co-gasification [9]. Also, the observed synergy during the co-gasification of biomass-coal could be attributed to the roles of alkali and alkaline earth metallic species (AAEM) present in the coal and biomass feedstock. Potassium in AAEM has been reported to act as a catalyst for the decomposition of secondary char and char gasification [10].

Furthermore, it was observed that the Exp value of product yields obtained from the co-gasification of the torrefied PKS and preheated MB coal were somewhat different from Cal values, deviating the most at biomass blending ratio of 50 % with higher gas yield while lower char and tar yield than the Cal yields, especially in gas production level. The observed synergy and high gas yield could be attributed to the OH and H radicals formed from the biomass pyrolysis transferring to the coal structure resulting in improving the decomposition of coal. In addition, the potential catalytic effect of AAEM species in biomass, especially potassium (K), appeared to be a potentially significant parameter affecting the observed synergy during co-gasification [3]. So, the co-gasification of the pretreated PKS and MB exhibited a higher reactivity than co-gasification of untreated PKS and MB.

Figure 3 shows the effect of biomass blending ratio on the Exp-Cal different conversion and product yield in the co-gasification of untreated and pretreated sample. It can be observed from Fig. 3 that the synergistic effect of the co-gasification of PKS and MB coal is mainly reflected using blending of pretreated sample. With the increase of pretreated PKS in blending ratio, the difference in Exp-Cal value is larger than untreated sample in blending ratio. The Exp-Cal gave maximum values for conversion and gas yield and the minimum values for char and tar yields, suggesting that the promising synergistic effect has occurred at 50 % biomass blending ratio using preteated PKS and MB coal. Further, the largest enhancement in Exp-Cal value of gas yield of 28.2 % was obtained at 50 % biomass blending ratio using pretreated feedstock. By increasing biomass ratio in pretreated blending to 80 %, the difference in Exp-Cal of conversion and product yields obviously decreased, and the synergistic effects became weak. This is because the gasification activity decreased at higher than 50 % biomass blending ratio, therefore weakening the synergistic effects due to the addition of excess biomass. However, this situation is not applicable to untreated blending sample. Thus, the interactions between pretreated biomass and coal during co-gasification are expected to be enhanced with the raised fuel quality of biomass and coal.



(a) (b)

FIGURE 2. (a) Co-gasification properties of untreated PKS and MB coal at gasification temperature of 800 °C, (b) Co-gasification properties of pretreated PKS and pretreated MB coal at gasification temperature of 800 °C.

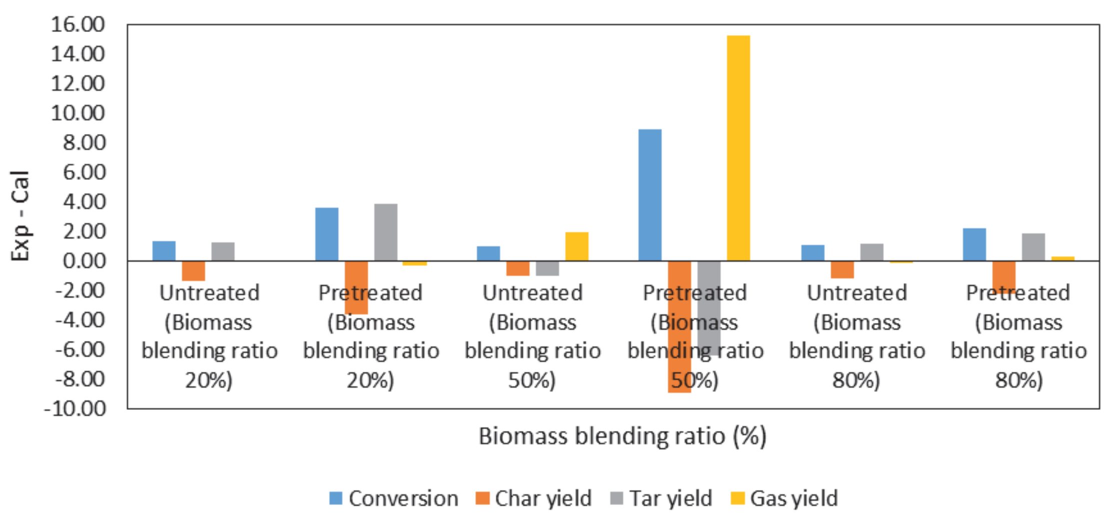


FIGURE 3. Exp-Cal of conversion and product yields from co-gasification of untreated and pretreated samples using different biomass blending ratio

CONCLUSIONS

This present study demonstrated that the co-gasification of pretreated PKS and MB coal was more suitable than of untreated PKS and MB coal using fixed bed reactor system. The synergistic interactions between feedstocks were more pronounced at biomass blending ratio of 50 % using pretreated PKS and MB coal. The observed synergy between untreated PKS and MB coal blends was limited. Thus, the thermal pretreatment method which involved torrefaction and preheated for PKS and MB coal, respectively, enhanced the co-gasification performance by producing high gas yield with low tar and char yield.

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