PAPER • **OPEN ACCESS**

Effect on Product Yield and Tar Composition through Co-Gasification of Pretreated Palm Kernel Shell and Mukah Balingian Coal

To cite this article: Razi Ahmad *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **864** 012210

IOP Conf. Series: Materials Science and Engineering **864** (2020) 012210 doi:10.1088/1757-899X/864/1/012210

Effect on Product Yield and Tar Composition through Co-Gasification of Pretreated Palm Kernel Shell and Mukah Balingian Coal

Razi Ahmad[1], Mohd Azlan Mohd Ishak[2,3], Nur Nasulhah Kasim[2] and Khudzir Ismail[2,3]

[1]School of Environmental Engineering, Universiti Malaysia Perlis, Malaysia.
[2]Faculty of Applied Sciences, Universiti Teknologi MARA, Campus Arau, Malaysia
[3]Coal and Biomass Energy Research Group, Universiti Teknologi MARA, Campus Shah Alam, Malaysia.

E-mail: razi@unimap.edu.my

Abstract. In this study, co-gasification of palm kernel shell (PKS) and Mukah Balingian (MB) coal was carried out in a fixed bed reactor. The effect of sample pretreatment of both samples were explored via co-gasification towards product yields and tar composition. Results indicated that, pretreated blending samples produced higher gas yield with lower tar and char yield than the untreated blending samples. This was due to low moisture and oxygenated components of the pretreated samples prior to co-gasification. The tar composition of the pretreated blending samples showed increasing in the aromatic and aliphatic alkane, whereas, noticeable decreasing of phenol and carbonyl. Thus, pretreated of PKS and MB coal have prominence influence on the distribution of product yields and tar composition through co-gasification.

1. Introduction

In recent years, 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]. Presently, coal is the leading feedstock in gasification and is projected to be applied as the energy resource for many decades onward. However, this direction difficult to succeed due to the increasing in energy demand that had caused the shortage supply of high rank coal [2]. Therefore, one of the approaches is to exploit the abundant low rank coal and biomass in gasification.

The usage of low rank coal in thermochemical conversion is cost-effective, due to its low pricing. However, low rank coal as a substitute to the high rank coal, has several restrictions such as low calorific value and high moisture and oxygen content [3]. These weaknesses can be reduced with using the pretreated low rank coal in gasification [4]. Similarly, the application of biomass which is an environmental friendly resource during gasification imposed several difficulties. Untreated biomass also has relatively low energy, high moisture and oxygenated compound, hygroscopic behavior and poor grindability [5,6]. Consequently, the pretreated biomass which has been upgraded in energy density, hydrophobicity and grindability overcome the disadvantages of untreated biomass, then driven to be applied in thermochemical conversion [7,8].

Biomass generally has a high content alkali and alkaline earth metals (AAEM) act as catalyst in gasification. Similarly, high silica (SiO_2) content in coal acts as an effective catalyst for tar cracking to lighter hydrocarbon in thermal conversion [9]. Biomass which has high oxygen and moisture content contributes to the weakness of low energy density than coal. Thus, co-gasification of biomass and coal can be an alternative to improve their weakness towards each other [10].

Co-gasification has been explored by several researchers. Krerkkaiwan et al., 2012 [11] found the synergistic effect in terms of higher gas yield, lower tar and char yield at 50 % biomass blending ratio with coal. Howaniec and Smolinski, 2013 [12] reported that the co-gasification increased total gas yield and H_2 yield compared to individual gasification. Yuan et al., 2012 [13] stated that there was synergistic effects in the decreasing of char yield and increase of gas yield in co-conversion of coal/biomass mixtures. Consequently, the synergistic between biomass and coal co-gasification increases the gas yield, gasification efficiency and reactivity of char whereas reduces the tar yield. Most of the blending in co-gasification utilized untreated biomass and coal.

Dudynski et al., 2015 [14] reported that effective gasification with low tar production was obtained from torrefied pellets in comparison to untreated biomass and recommended that pretreated biomass was more suitable to be applied for co-gasification. Kuo et al., 2014 [15] formed higher syngas yield using torrefied bamboo than raw bamboo in fixed bed reactor system. Definitely, pretreatment generates the gasification behaviour of biomass approach to that of coal which increasing gas yield and reducing tar yield. Therefore, the pretreated feedstock which had been improved in their properties enhance the gasification performance and product yield [16]. Thus, the co-gasification of pretreated PKS and pretreated MB coal is absolutely innovative in this area.

The main purpose of this study was to investigate the influence of pretreated PKS and MB on co-gasification. The effect on products yield and tar composition were discovered through co-gasification in fixed bed reactor.

2. Experimental

2.1. Material

PKS as biomass sample was obtained from United Oil Palm Mill Sdn. Bhd., Nibong Tebal, Penang, Malaysia. PKS sample was crushed and sieved through finer screen to obtain particle sizes of 212 µm. MB coal, which is classified as Malaysian low rank sub-bituminous coal from Sarawak, Malaysia was used as coal sample in this study. Untreated MB coal was pulverized and sieved through finer screen to obtain particle sizes of 212 µm. 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.

Pretreated PKS and MB were produced through pretreatment using fixed bed reactor at temperature of 270 °C and 250 °C, respectively, with holding time of 1 hour. Pretreated PKS and MB were prepared and selected according to our previous work [17,18]. The samples blending used in this studies were; (i) untreated PKS and MB as 'PKS_{Un}/MB_{Un}' and (ii) pretreated PKS and MB as 'PKS_{To}/MB_{Pr}'.

2.2. Co-gasification Experiment

Co-gasification of PKS and MB coal blending was carried out using 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 use to heat the reactor. A schematic diagram of the experimental set-up is shown in figure 1.

Approximately 5 g of sample was weighed and placed inside the reactor. The reactor was flushed with nitrogen gas for 10 min before the experiment. Then, the sample was heated to the preferred gasification temperature with heating rate of 50 °C/min. A nitrogen flow rate of 500 mL/min was flowed continuously to create an inert atmosphere inside the reactor. After the reactor reached the chosen gasification temperature, the steam that was produced from steam generator was flowed into the reactor, and the nitrogen flow was stopped. The steam co-gasification of the blending sample was held for 60

IOP Conf. Series: Materials Science and Engineering **864** (2020) 012210 doi:10.1088/1757-899X/864/1/012210

min. The experiment was conducted under optimise condition at gasification temperature of 767 °C, biomass blending ratio of 52 % and steam flow rate of 55 mL/min based from our previous study [19].

The volatile product which left the reactor from the upper side was condensed in a tar trap. The gas was collected in a gas bag every 15 min from the starting of steam gasification. The remained char was weighted. The gas yield was calculated by difference based on the total mass balances considering the tar and char yield. The tar composition was analysed using gas chromatography-mass spectrometry (GC-MS) model Agilent 6890N.

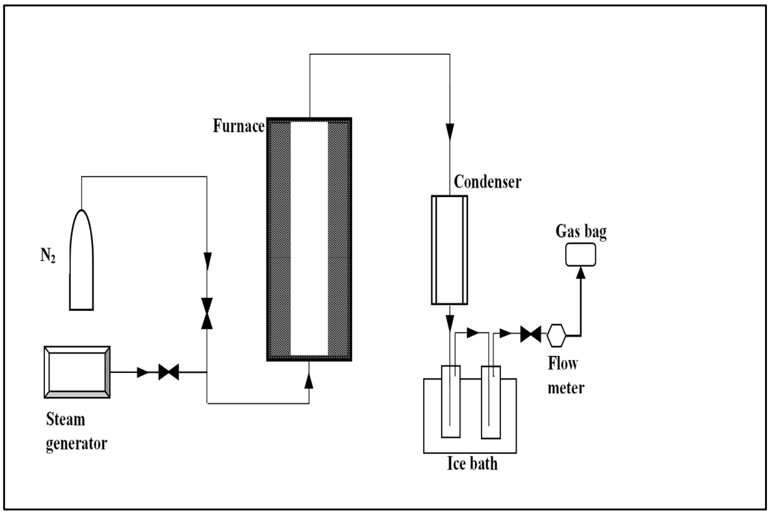

Figure 1. Schematic diagram of co-gasification reactor.

3. Results and Discussion

3.1. Effect of product yield

Figure 2 presents the results obtained in term of product yield (char, tar and gas) during the co-gasification. The pretreated sample produced higher gas yield than untreated sample. The gas yield increased about 32.2 % using pretreated sample, than untreated sample. The pretreated sample exhibited notable impact on gas production to produce high gas yield compared to untreated sample. The gas production using pretreated sample was higher than Berrueco, 2014 [20] which increase only 7 % than untreated sample on gasification of pretreated Norwegian forest residue.

The tar yield decreased almost 19.3 % using pretreated sample than untreated sample. Reduction and low tar yield is essential during co-gasification. Therefore, the pretreated of both sample (PKS and MB) was markedly reduced the tar yield in co-gasification as an implication of the removal of oxygenated compounds in biomass and low rank coal and volatiles through the pretreatment process.

The char yield decreased nearby 40.3 % for pretreated sample than untreated sample. Low char yield for pretreated sample was associated with the increased of conversion to gas product using pretreated feedstock. Moreover, this result was affected since the low moisture and oxygenated compound of pretreated feedstock made it compliant to be converted in co-gasification.

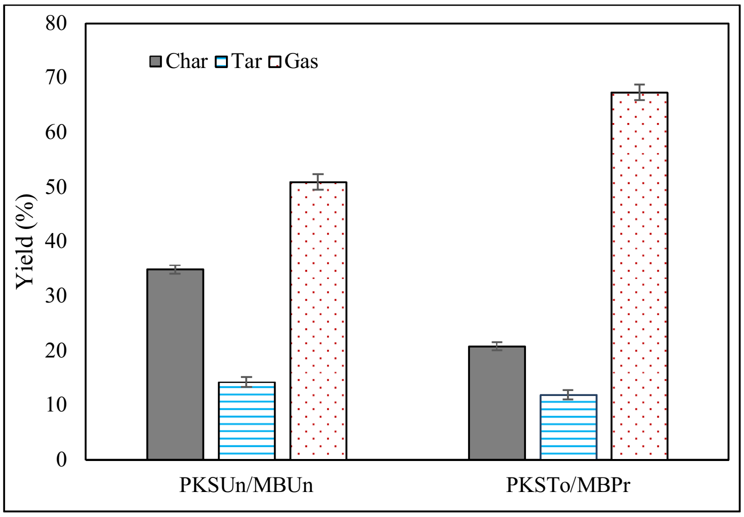

Figure 2. Effect on product yield of co-gasification of PKS_{Un}/MB_{Un}, and PKS_{To}/MB_{Pr}.

3.2. Effect on tar composition

Figure 3 displays the tar composition on co-gasification of PKS_{Un}/MB_{Un}, and PKS_{To}/MB_{Pr}. It can be realized that, during co-gasification, the richest compounds are phenol, aliphatic alkane, cycloalkane, aromatic and carbonyl. These results are consistent with those found by previous researchers. The tar obtained from the co-gasification of PKS_{Un}/MB_{Un} was largely composed of phenol with 63.5 %. The carbonyl, aromatic and aliphatic alkane were also composed, but in smaller quantity of 23.4, 4.8 and 8.2 %, respectively. However, the co-gasification of PKS_{To}/MB_{Pr} showed a noticeable reduction of phenol and carbonyl, while, promoted the aromatic and aliphatic alkane and cycloalkane composition. The reduction of phenol in PKS_{To}/MB_{Pr} co-gasification designates that the influence of pretreatment had partially decomposed the lignin which caused the phenol compound to be produced earlier during the pretreatment [21]. Therefore, the phenol contents was reduced in co-gasification of PKS_{To}/MB_{Pr}.

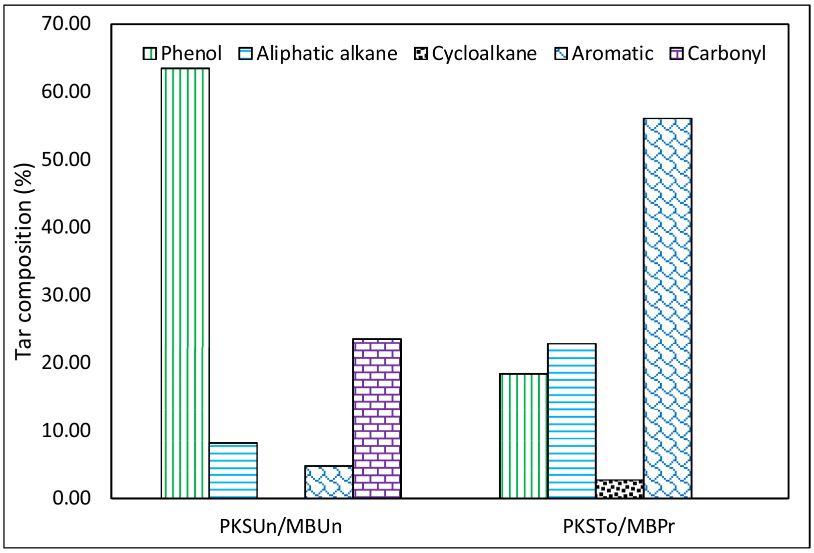

Figure 3. Effect of Tar Composition on Co-gasification of PKS_{Un}/MB_{Un}, and PKS_{To}/MB_{Pr}.

4. Conclusion

Co-gasification of PKS and MB coal was studied in a fixed bed reactor. The outcomes of the pretreated sample blending were studied on product yield and tar composition. Pretreated blending sample produced higher gas yield with lower tar and char yield than the untreated blending sample. The tar composition of the pretreated blending samples showed clear decreasing of phenol and carbonyl; but, promoted the composition of aromatic and aliphatic alkane. These offers great view towards application of pretreated biomass and low rank coal through co-gasification on synthesis of value-added chemical from tar product.

References

[1] Heidenreich S. and Foscolo P U 2015 *Prog. Energy Combust. Sci.* **46** 72
[2] Mohr S H, Wang J, Ellem G, Ward J and Giurco D 2015 *Fuel* **141** 120
[3] Rao Z, Zhao Y, Huang C, Duan C and He J 2015 *Prog. Energy Combust. Sci.* **46** 1
[4] Xia W, Xie G and Peng Y 2015 *Powder Technology* **277** 206
[5] Chen W H, Peng J and Bi X T 2015 *Renew. Sustain. Energy Rev.*, **44** 847
[6] Ahmad R, Ishak M A M, Ismail K, and Kasim N N 2019 *J. Mech. Eng. Sci.* **13** 5791
[7] Nhuchhen D, Basu P and Acharya B 2014 *Int. J. Renew. Energy Biofuels* **2014** 1
[8] Kasim N N, Ishak M A M, Ismail K and Ahmad R 2019 *J. Therm. Anal. Calorim.* **8**
[9] Mallick D, Mahanta P and Moholkar V S 2017 *Fuel* **204** 106
[10] Brar J S, Singh K, Wang J and Kumar S 2012 *Int. J. For. Res.* **2012** 1
[11] Krerkkaiwan S, Fushimi C, Tsutsumi A and Kuchonthara P 2013 *Fuel Process. Technol.* **115** 11.
[12] Howaniec N and Smoliński A 2013 *Int. J. Hydrogen Energy* **38** 16152
[13] Yuan S, Dai Z, Zhou Z, Chen X, Yu G, and Wang F 2012 *Bioresour. Technol.* **109** 188
[14] Dudyński M, van Dyk J C, Kwiatkowski K and Sosnowska M 2015 *Fuel Process. Technol.* **131** 203
[15] Kuo P C, Wu W and Chen W H 2014 *Fuel* PARTB **117** 1231
[16] Chen W H, Chen C J, Hung C I, Shen C H and Hsu H W 2013 *Appl. Energy* **112** 421
[17] Ahmad R, Ishak M A M, Ismail K, Kasim N N and Abidin C Z A 2016 *Proc. 4th IET Clean Energy and Technology Conf.* (Malaysia: Kuala Lumpur) p 1
[18] Ahmad R, Ishak M A M, Kasim N N and Ismail K 2019 *Energy* **167** 538

IOP Conf. Series: Materials Science and Engineering **864** (2020) 012210 doi:10.1088/1757-899X/864/1/012210

[19] Ahmad R, Ishak M A M, Kasim N N and Ismail K 2018 *AIP Conference Proc.* **105** 020019
[20] Berrueco C, Recari J, Güell B M and Alamo G del 2014 *Energy* **70** 68
[21] Ren S, Lei H, Wang L, Yadavalli G, Liu Y and Julson J 2014 *J. Anal. Appl. Pyrolysis* **108** 248