HIGH QUALITY SOLID FUEL PRODUCTION FROM OIL PALM BIOMASS USING COMBINATION OF TORREFACTION AND LEACHING TREATMENTS

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INTRODUCTION

Biomass pretreatment has been recognized as a potential key player in both logistic and handling on. Pretreatment of biomass using torrefaction improves the heating value and it is a promising method to convert low quality biomass into high energy density solid biofuel with consistent and uniform physical and chemical characteristics. Although torrefaction has been shown to improve the biomass fuel properties in terms of energy density, a challenge remains because a large amount of alkali metals, is retained in the char and therefore mitigate their adverse impact on the heat transfer and corrosion rates in the boiler (Chin *et al.* 2013, Saddawi *et al.* 2012). On the other hand, leaching method has been proven to significantly reduce the ash content and increase the ash melting temperature of biomass. Only a slight increment in heating value was observed due to total ash reduction. Thus, leaching does not essentially increase the heating value as in using torrefaction method. In general, both torrefaction and leaching benefit only in one respective factor, i.e. heating value and ash sintering characteristic, respectively, but neglected the other factor.

Nature provides diversity of biomass with different characteristics. To achieve a highly efficient biomass-to-energy chain, a method to overcome logistic economics in large-scale sustainable energy solutions, better energy density and combustion efficiency has to be established. A combination of leaching and torrefaction may be an ideal pretreatment method for both biofuels and biopower. The following work explores the possibility of combining leaching and torrefaction treatment to create an improved fuel from oil palm biomass to achieve high energy density and low ash percentage. Laboratory studies were conducted to evaluate the process sequence of both methods: a torrefaction followed by leaching or leaching followed by torrefaction. The purpose of the work is to determine the effects of the combination treatments on ash removal efficiency, as well as ash melting characteristic of the treated oil palm lignocellulosic biomass.

COMBINED TREATMENT PROCESS

For the AB combination treatment, the oil palm biomass; empty fruit bunch (EFB) and oil palm trunk (OPT) were torrefied before undergo leaching treatment. The lignocellulosic biomass was dried at 105 ºC for 24 h before torrefaction in order to remove the residual water remaining in the biomass. The dried lignocellulosic biomass fines (10 g) was placed in a furnace and torrefied under the optimized torrefaction conditions obtained by Chin *et al.* 2013. After torrefaction, the oil palm biomass fines were left to cool in desiccators. After cooling process, 10 gram samples were soaked and submerged in 100 ml of 1% acetic acid under the optimized leaching conditions obtained by Chin *et al.* 2015. After acetic acid leaching, the solutions were filtered and washed with 100 ml distilled water and the leached samples were oven dried at 105 ºC over 24 h.

For the BA combination treatment, the dried samples were leached followed by torrefaction treatment. Ten gram samples were soaked and submerged in 100 ml of 1% acetic acid under selected leaching conditions obtained by Chin et al. 2015. After acetic acid leaching, the solutions were filtered and washed with 100 ml distilled water. The leached samples were oven dried at 105 ºC over 24 h before torrefaction in order to remove the residual water remaining in the biomass. The dried wood fine (10 g) was placed in a furnace and torrefied under the optimized torrefaction conditions obtained by Chin et al. 2013. After torrefaction, the lignocellulosic biomass fines were left to cool in desiccators.

ASH REMOVAL

From Table 1, it can be clearly seen that leaching followed by torrefaction (BA combination) generated the acceptably low ash content. These values however are still higher when compared with those recorded for when using leaching alone, 0.21 – 0.82%. Carrier et al. (2011) conducted an experiment by combining leaching and pyrolysis treatment. From the study Carrier et al. (2011) found that the total ash reductions are contributed partially by the leaching pretreatments and further reduce through devolatilization (vaporized inorganic elements such as potassium, chlorine, phosphorus n sulphur) during the pyrolysis process.

The extent of leaching diminishes as the biomass undergone thermal treatment prior to leaching in the AB combination treatment (torrefaction followed by leaching). Comparing the ash yield of raw and torrefied (AB treatment) oil palm biomass revealed higher removal efficiencies were observed for raw lignocellulosic biomass using acetic acid leaching treatment. The ash yield reduction from raw biomass ranged 60 – 86%, whereas the ash yield reduction from torrefied biomass ranged 47 – 68%. The reduction of ash removal efficiency from torrefied biomass can be due to the physicochemical changes which affects the char matrix and to a different mode of occurrence of ash forming elements as soon as the thermal degradation occurred. Following torrefaction treatment, the originally leachable ash is most probably transformed into increasingly stable forms such as carbonates and/or oxides which reduce the solubility in mild acid (Li et al. 2004). From the observations by Raveendran and Ganesh (1998), lignin and hemicelluloses undergo a phase change during the thermal degradation process, forming a molten-phrase intermediate which traps the ash components thus making ash removal more difficult as char is formed. Microscopic analysis by Jensen et al. (1999) also proved that ash forming elements such as potassium is bound to the organic matrix after thermal treatment.

Table 1. Ash content of oil palm biomass after pretreatment

Lignocellulosic biomass	Ash Content (%)				
	Untreated	Torrefaction[1] (A)	Leaching[2] (B)	Torrefaction-Leaching (AB)	Leaching-Torrefaction (BA)
EFB	5.96	6.36	0.82	2.04[b]	0.96[a]
OPT	1.33	2.05	0.53	1.08[b]	0.63[a]

[1] Values are taken from optimum pretreatment condition by Chin *et al.* 2013

[2] Values are taken from optimum pretreatment condition by Chin *et al.* 2013.

Note: *Means followed by the different letter in the same row of a species are significantly

HIGHER HEATING VALUE (HHV)

Slightly lower heating value was observed for samples treated with combined treatment process compared to samples that solely undergone torrefaction as shown in Table 2. Significantly higher HHV was obtained using BA combination treatment for all types of lignocellulosic biomass used in this study. Thermal pretreatment split and decompose a significant part of the lignocellulosic biomass fraction into soluble and less complex molecules (Haug et al. 1983). In AB combination treatment process, torrefaction was positioned before the leaching treatment with most of the ash forming elements (inorganic materials) were strongly locked in the biomass due to the physicochemical changes of the organic and inorganic materials during thermal treatment (Li et al. 2004; Jensen et al. 1999 and Raveendran Ganesh, 1998). This results a higher concentration of inorganic materials which have no contribution to the HHV and this directly reduced the HHV of the lignocellulosic biomass from AB combination treatment.

Table 2. Higher heating value of oil palm biomass after pretreatment

Lignocellulosic biomass	Higher Heating Value (Mj/kg)				
	Untreated	Torrefaction[1] (A)	Leaching[2] (B)	Torrefaction-Leaching (AB)	Leaching-Torrefaction (BA)
EFB	18.06	23.08	18.47	22.55[b]	22.82[a]
OPT	17.18	22.22	16.53	22.13[a]	22.50[b]

[1] Values are taken from optimum pretreatment condition by Chin *et al.* 2013

[2] Values are taken from optimum pretreatment condition by Chin *et al.* 2015.

Note: *Means followed by the different letter in the same row of a species are significantly different at $P \leq 0.05$.

ASH MELTING CHARACTERISTIC

Comparison of the ash melting characteristic of the combination treatments to the torrefied biomass demonstrates the benefits of incorporating the leaching treatment with the torrefaction process. As shown in Table 3, oil palm biomass treated with both combination treatments display a substantial improvement in ash melting characteristic compared to oil palm biomass that solely undergone torrefaction.

Table 3. Ash sintering characteristics for pretreated oil palm biomass under high heating temperature[1]

Ash Heating Temperature	Torrefaction[2] (A)	Leaching[3] (B)	Torrefaction-Leaching (AB combination)	Leaching-Torrefaction (BA combination)
		EFB		
700	molten	loose	loose	loose
800	molten	loose	loose	loose
900	molten	loose	Slightly sintered	loose
1000	molten	Slightly sintered	Strongly sintered	Slightly sintered
		OPT		
700	Strongly sintered	loose	loose	loose
800	molten	loose	loose	loose
900	molten	loose	Slightly sintered	loose
1000	molten	loose	Slightly sintered	loose

[1]Note: Refer to Chin et al, 2018 for the ash classification
[2]Values are taken from optimum pretreatment condition in Chapter 4
[3]Values are taken from optimum pretreatment condition in Chapter 5

Torrefied EFB and OPT will cause severe problems during combustion. However, combining the leaching and torrefaction treatment had reduced the risk of ash sintering. It is anticipated that oil palm biomass will require pretreatment, and that a combined leaching and torrefaction are now predicted not to be problematic in terms of fouling when combusted at temperature below than 1000 °C, except for EFB. EFB treated with torrefaction followed by leaching treatment (AB combination treatment) vastly improved the ash sintering but still potentially problematic if combusted above 900 °C. OPT ash were in a loose form even after heated at temperature 1000°C. By applying the BA combination treatment, EFB resulted in a better ash melting characteristic. At 1000°C, ash from EFB treated with AB combination treatment was strongly sintered but upon way BA combination treatment, a slightly sintered ash was generated. This can be attributed partly to the trapping of ash components inside the char matrix in AB combination treatment, following the formation of a molten phase of EFB during combustion due to the changes undergone by the alkali metals under high temperature.

CONCLUSION

The study shows that by applying leaching procedure followed by torrefaction treatment generated an improved quality of biomass solid biofuel particularly in HHV, ash content and ash melting temperature compared to the fuel treated with singular treatment; torrefaction or leaching alone. Leaching gives rise to a remarkable increment in the ash melting temperature of torrefied oil palm biomass. This suggests that acetic acid leaching is an important treatment for the preparation of torrefied fuels. Acetic acid leaching on torrefied oil palm biomass was less effective than on raw lignocellulosic biomass. Most ash forming elements in the torrefied samples may had transformed into increasingly stable forms that are difficult to be leached. Thus, lower ash content was observed on samples undergone leaching followed by torrefaction (BA combination treatment). Leaching prior to torrefaction proved to be a better combination; significantly increased the HHV of the lignocellulosic biomass and improved the ash melting characteristic.

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