Devolatilization studies of oil palm biomass for torrefaction process optimization

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Abstract. Torrefaction of palm biomass, namely Empty Fruit Bunch (EFB) and Palm Kernel Shell (PKS), was conducted using thermogravimetric analyser (TGA). The experiment was conducted in variation of temperatures of 200 °C, 260 °C and 300 °C at a constant residence time of 30 minutes. During the torrefaction process, the sample went through identifiable drying and devolatilization stages from the TGA mass loss. The percentage of volatile gases released was then derived for each condition referring to proximate analysis results for both biomass. It was observed an average of 96.64% and 87.53 % of the total moisture is released for EFB and PKS respectively. In all cases the volatiles released was observed to increase as the torrefaction temperature was increased with significant variation between EFB and PKS. At 300°C EFB lost almost half of its volatiles matter while PKS lost slightly over one third. Results obtained can be used to optimise condition of torrefaction according to different types of oil palm biomass.

1. Introduction
Utilization of biomass nowadays is considered as a near term energy solution in reducing dependence on fossil fuel. Biomass is a source of renewable energy and can be considered as a part of the natural carbon cycle as carbon dioxide (CO₂) released from biomass combustion has been absorbed from the atmosphere during its lifetime. Globally, biomass energy such as agricultural waste and crop residue has been replacing fossil fuel and increasingly becoming their prime energy source [1].

In 2010, 93.7% of Malaysia’s electricity generation of 125,045 GWh was sourced from fossil fuel, mainly natural gas and coal, while biomass stood at only 1.01% [2]. This fact does not reflect the nation’s abundance of biomass that can be sourced from its forestry and agricultural sector. According to the National Biomass Strategy, the palm oil industry alone produced almost 80 million dry tonnes of solid biomass in 2010 and this is predicted to grow to 85 – 110 million dry tonnes by 2020 [3]. Increasing biomass utilization in Malaysia’s energy mix will directly reduce its overly dependence on fossil fuel and hence reduce its greenhouse gas (GHG) emission intensity.

Oil palm biomass is a difficult fuel to use mainly due to its low bulk density and high moisture content resulting in low calorific value, and heterogeneous nature and uneven composition [4]. The structure of the Malaysian oil palm biomass is mainly tough and fibrous in nature making it difficult to grind for further utilization. Hence, it is essential that oil palm biomass undergoes pretreatment in order to utilize it. A few techniques for upgrading biomass as a better solid bio-fuel have been introduced and one of the techniques is the torrefaction process.

Torrefaction is one form of thermal treatment and can be regarded as a process before gasification and combustion stages [5]. In this process, biomass is heated in an inert atmosphere within the temperature range of 200 °C and 300 °C [6]. The advantages of torrefaction process is that it removes moisture content, decrease light organic volatile component and increase energy density in mass basis.
as well as increasing the grindability of biomass through degradation of hemicellulose [7]. Torrefaction of biomass also homogenizes its physical nature which is a desirable characteristic in a fuel for power generation. Biomass upgrading via torrefaction would be able to enhance the structure of solid biomass fuel and at the same time minimizes the drawbacks of biomass utilization.

Different biomass will react differently during torrefaction due to the varying compositional moisture content and volatile matter [8]. The presented work studies the effect during devolatilization of two different oil palm biomass at varying degrees of torrefaction conditions.

2. Methodology
Two types of oil palm biomass, namely empty fruit bunch (EFB) and palm kernel shell (PKS), were selected as a raw material for this experiment. The samples were sourced from an oil palm mill in Bidor, Perak, Malaysia. Each biomass sample underwent the fuel preparation steps of weighing, drying, shredding, blending and sieving before it is analyzed. Initially, proximate analysis was carried out according to ASTM D5142-04 to establish the baseline moisture content and volatile matter for both types of biomass. The proximate analysis results are as shown in Table 1.

Torrefaction experiments were carried out using a Perkin Elmer Pyris 1 thermogravimetric analyzer (TGA) as shown in Figure 1. The inert condition is provided by purging a 20mL/min flow of Nitrogen gas throughout the experiment. For each experiment, a sample of approximately 10 mg of biomass is placed in a ceramic crucible in a hanging position at the centre of the furnace as shown in Figure 2. The sample is heated from ambient temperature at rate of 10 °C/min to 100 °C where it was held isothermally for 30 minutes to drive off moisture. The sample was then heated again at rate of 5 °C/min until the desired torrefaction temperature is reached and held isothermally for a further 30 minutes. Three different torrefaction temperatures were used; 200 °C, 260 °C, and 300 °C. The TGA recorded the sample mass throughout the experiment and graphs of temperature and percentage mass loss against time were generated using its Pyris software. Mass loss due to drying and devolatilization was then derived using the TGA plots compared to the proximate analysis results as the baseline.

3. Results and Discussion
It was observed that TGA analyses for all samples shown two significant regions of mass loss which corresponded to moisture loss during the first holding temperature of 100 °C and followed by subsequent volatile release during the second holding temperatures for torrefaction.
During the first stage, in the EFB samples, all three cases shown an average of 96.64% of all moisture was lost when compared to the initial moisture from the proximate analysis results. It can be assumed that the samples were fully dried during this stage as mass loss stop occurring within the 30 minutes holding period. The very small difference observed could be due to the samples had actually dried very slightly while in storage. The PKS samples showed a lower percentage of moisture loss at an average of 87.53%. It was determined that mass loss was still occurring very slightly at the end of the 30 minutes holding time. Therefor the results showed that not all moisture was released during this first stage. Thus a higher holding time for drying is recommended for PKS and is planned for the next phase of this study.

Varying degrees of devolatization was observed during the torrefaction stage where in general, more volatiles was released during the 30 minutes holding time at the higher temperatures. Percentage volatile yield when compared to initial proximate analysis results is shown in Figure 3. Both sample loses only 1.86 % and 1.66 % for EFB and PKS of its volatile matter at a torrefaction temperature of 200 °C. The result confirmed that this is the lower limit of torrefaction for oil palm biomass where little or no devolatilization would occur below this temperature.

Torrefying at of 260 °C for 30 minutes resulted in the amount of volatile matter being released at 16.70 % and 14.67% for EFB and PKS respectively. This small difference could have been due to the release of similar light volatile components shared by both type of biomass. At a torrefaction temperature of 300 °C PKS loses 36.23% of its volatile matter while EFB was significantly higher at 49.66%. The significant difference showed that EFB releases volatile matter easier compared to PKS and can be attributed to the difference in physical nature of the biomass. PKS fibres are more densely packed compared to EFB making it has less surface area exposed to heat for devolatilization to occur. Torrefying EFB at or close to this upper temperature limit would result in a low energy yield as too much energy containing volatile matter would be lost. Even if the resultant torrefied biomass have a high calorific value, this is undesirable for torrefaction as the total energy available of a particular biomass is lost with the released volatile matter. Further study on the effect on resultant calorific value is proposed for the next phase of this study. This results also confirmed the easiness of volatile matter release in EFB compared to other types of biomass found in the author's previous research [8].

Table 1. Proximate analysis of oil palm biomass

|                | EFB  | PKS  |
|----------------|------|------|
| Inherent Moisture | 8.70 % | 5.61 % |
| Volatile Matter  | 74.30 % | 68.35 % |
| Fixed Carbon     | 15.37 % | 18.79 % |
| Ash Content      | 1.57 %  | 7.22 %  |

Figure 3. Volatile yield of oil palm biomass torrefied at various temperatures

4. Conclusion
Torrefaction of EFB and PKS has been successfully conducted using a TGA at various torrefaction temperatures in order to identify the mass loss and the volatile yield. An average of 96.64% and 87.53% of the total moisture is released for EFB and PKS respectively. Volatile yield increased as the torrefaction temperature is increased with significant differences of volatile matter released between the two types of biomass. The study showed that EFB releases volatile matter easier, thus dictates a
lower torrefaction temperature compared to PKS to produce quality biofuel. It was also confirmed that little torrefaction occurred at 200 °C. Further study on the effect on calorific value would further optimize torrefaction process condition for both types of biomass.

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