Development of a bench scale biomass torrefier

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Abstract. Cofiring biomass with coal has become very popular with power utilities to reduce fossil fuel carbon dioxide (CO₂) emission. It is relatively easy to implement on most common pulverised coal plants. However, raw biomass is difficult to utilise and requires upgrading to a higher quality fuel to substitute coal. Upgrading by torrefaction can improve the properties of biomass close to low rank coals suitable for cofiring. In this study, a bench scale torrefier was developed to produce torrefied biomass samples for further studies of its properties and combustion behaviour. The torrefier was developed from a domestic 1600W electric oven. Biomass pellets was then torrefied at 250 °C for 1 hour using this torrefier. Proximate analysis and gross calorific value (GCV) of the torrefied biomass were carried out. The results showed that GCV of the torrefied biomass had increased when compared to raw. The moisture content and volatile matter had decreased, and ash content and fixed carbon had increased as expected.

1. Introduction
Malaysia’s primary energy supply has been steadily growing at an average of 2.6 % from 2006 to 2010 [1]. Furthermore, a significance increase of over twice as much is seen in the use of coal and coke as the source of primary energy from 7,299 ktoe in 2006 to 14,777 ktoe in 2010. This dependence on coal and coke had resulted in a significant increase in carbon dioxide (CO₂) emission from 23.028 million tonnes in 2006 to 39.781 million tonnes in 2010 [2]. Cofiring biomass with coal is a relatively easy, safe, more economical and more efficient utilization of biomass as well as to reduce the amount of fossil fuel CO₂ emission [3, 4]. Combustion of biomass considered as zero net CO₂ emitted because the amount of CO₂ released during combustion equals with the amount of CO₂ the biomass absorbed during its growth [5].

Malaysia is abundance in biomass especially from the oil palm industry that can be used for cofiring at its coal power plants [6]. However, raw biomass is a difficult fuel to utilize mainly due to its heterogeneous nature and uneven composition, quality decay by biodegradation, lower calorific value, high ash content and the thermal instability resulted from high oxygen/carbon (O/C) ratio when compared to coal [7]. Torrefaction is a biomass pre-treatment that could be used to minimize these drawbacks and in the process upgrades the biomass to a higher quality fuel close to low rank coals making it suitable for cofiring. Coal power plant operators can utilize torrefied biomass as a direct thermal substitution, with only minor modification to its existing plant and practices [8].

This paper presents work done in developing a bench scale biomass torrefier to produce samples of torrefied biomass to be used for further fuel characterization studies such as gross calorific value (GCV), proximate and ultimate analyses. Torrefaction process occurs in an inert environment at a temperature between 200 °C to 300 °C [9, 10]. Previous work on torrefaction on Malaysian biomass had been done using thermogravimetric analyzer (TGA) or tube furnace apparatus as the torrefier. Such apparatus can only torrefy small amount of biomass, a maximum of 5g, at a time which produce insufficient sample size for further characterization studies. Torrefying several times to produce
enough samples not only is time and energy consuming, it can also lead to a heterogeneous sample when recombined. Hence the work presented in this paper was to develop a bench scale torrefier that could handle a larger biomass sample size.

2. Methodology

2.1. Bench Scale Torrefier

A domestic 1600W electric oven was selected as a base for the torrefier due to its built-in heating elements and a basic temperature controller housed in a safe, working enclosure. The 20-litre oven is also large enough to accommodate a sizable sample of biomass. Another advantage of the domestic oven is that it has a rotating mechanism built in which was later modified as an agitator for the biomass sample. The oven has a maximum temperature rating of 250 °C but it was found to be consuming too much time to reach this temperature. Insulation using aluminium lined ceramic fibre improved this, managing to achieve over the 300 °C upper temperature limit. It was also found that the basic bimetal temperature switch could not maintain a steady temperature required for torrefaction. A temperature microcontroller with fuzzy logic control is used to replace the bimetal switch. The fuzzy logic reduces the heating time and control the supply current to heating element to reduce the temperature fluctuation as shown in Figure 1. Biomass sample is placed in a reactor made of a thin-walled aluminium container sealed with aluminium tape. Figure 2 shows the schematic of the bench scale torrefier highlighting the modifications done to the oven.

![Figure 1. Temperature response comparison between standard oven and modified oven.](image1)

![Figure 2. Modifications to 1600 W electric oven.](image2)

2.2. Torrefaction Experiment and Analyses

Pelletized empty fruit bunch (EFB) was used for the torrefaction experiment. The EFB pellets were sourced from palm plantations and commercially pelletized at Tanjung Karang, Selangor. The pellets were of 8mm in diameter with a moisture content range of between 15% – 18%. A sample of raw pellets was sent for GCV and proximate analyses at a certified laboratory.

A sample of approximately 200g of EFB was placed in the reactor for a single run of the torrefaction experiment. The aluminium tape seal was visually checked to make sure the tape was fixed securely. The torrefier was preheated at 20 °C min⁻¹ until 250 °C was reached. This temperature is held for 5 minutes to achieve uniform condition inside the torrefier. The reactor was rolled a few times slowly to make sure the sample inside the reactor is distributed evenly. The reactor was placed inside the torrefier using the agitator rotating latch. Close the door, turn on the agitator and set the timer to one hour. As the time reached one hour, the agitator switch is turned off, and the reactor was taken out. The reactor was then left cool naturally to temperature less than 50 °C. The torrefied sample
was removed from the reactor the weight was recorded. The sample was then kept in an airtight glass bottle and sent to the certified lab for GCV and proximate analyses. The ratio of calorific value, $CV_{ratio}$, mass yield, $Y_{mass}$ and energy yield, $Y_{energy}$, were then defined by (1), (2) and (3) respectively based on equations suggested by Bridgeman et al. [11].

$$CV_{ratio} = \frac{GCV \text{ after torrefaction}}{GCV \text{ before torrefaction}} \quad (1)$$

$$Y_{mass} = \left(\frac{\text{Mass after torrefaction}}{\text{Mass before torrefaction}}\right) \times 100 \quad (2)$$

$$Y_{energy} = CV_{ratio} \times Y_{mass} \quad (3)$$

3. Results and Discussion
The GCV for raw EFB was 17.5 MJ/kg and increased to 18.82 MJ/kg after torrefaction which gives a $CV_{ratio}$ of 1.08. This value is found to be slightly lower than other previous work. Comparison of proximate analyses on dry basis before and after torrefaction showed a slight decrease in volatile matter, slight increase in fixed carbon content and insignificant change in ash content. Table 1 summarises the proximate analyses results.

Observation of the torrefied samples showed that it has changed to a very dark brown, more easily breakable and homogeneous in terms of appearance and brittleness as shown in Figure 3. Figure 4 shows the mass yield and energy yield after torrefaction of EFB. Both values showed a decrease with mass yield slightly being lower than energy yield as expected with torrefied biomass. The result was also reflected in the small increase in $CV_{ratio}$ value.

These changes from both observation and analyses confirmed that torrefaction occurred, although in a mild form. This could be due to the densely packed particles of the pelletized EFB slowing heat transfer throughout itself. A higher rate of torrefaction would be achievable by increasing the reactor’s temperature or prolonging the residence time similar to previous work on biomass pellets [12]. This can be easily set using the installed microcontroller. Additionally, no ash was found in the torrefied sample indicating that combustion did not occur in the reactor.

|                  | Raw (%) | Torrefied (%) |
|------------------|---------|---------------|
| Volatile matter  | 77.74   | 76.36         |
| Fixed carbon     | 15.66   | 17.02         |
| Ash              | 6.60    | 6.62          |

Table 1. Proximate analysis results of EFB.

![Figure 3. Comparison of (a) raw and (b) torrefied EFB.](image)

![Figure 4. Mass and energy yields of torrefied EFB.](image)

4. Conclusion
A bench scale torrefier was successfully developed from a domestic oven for use to study biomass upgrading by torrefaction. It has been proved that it can be used to produce relatively large,
homogenous sample of torrefied fuel. Mild torrefaction of pelletized EFB was achieved, confirmed by both physical observation and analytical results. The result showed that torrefying at 250 °C for one hour has increase the GCV by a factor of 1.08 and slight decrease in volatile matter and increase in fixed carbon content. Mass yield was lower than energy yield, similar with other previously reported work on torrefying biomass. The bench scale torrefier was also able to torrefied the sample evenly.

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