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# Torrefaction of Empty Fruit Bunch (EFB) fibres adopted in modified microwave

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**Abstract.** Thermochemical pre-treatment process was implemented within the torrefaction temperature to improve the empty fruit bunch (EFB) fibers material, further exploiting for low rank solid energy material purposes. Modified microwave was introduced as a heat source chamber using the irradiation wavelength, with the mild exposure of atmospheric air in the system. The study involved such parameter of (i.e. heating rate and temperature) in which has influenced the process yield. Therefore, a regulated power input within 100 to 700 W was capped to access the effect toward samples and alumina crucible prepared. Based on this study, the 385 W of power selection was made with bound consideration of formation thermal shock at a constant nitrogen supply as inert gas during the heating process. The yield of compound constituents from this treatment also been discussed.

## 1. Introduction

Fuel is defined as a burned substances used as a source of heat (energy) by which it is undergoing combustion to release heat [1]. Increasing demand for energy causing a considerable risk of fuel depletion, causing an increase in crude oil's price. The rapid growth of development in population and industrialization will be causing energy demand to be increased [2]. The total exploitation of fossil fuel declines in large-scale industrial development, causing an increase in environmental pollution [3]. This situation may worsen the environmental issues such as economic activities and rapid climate change. Continuous consumption of fuels makes them unable to be used as they act as a limited resource nowadays [4]. Renewable energy also is a perfect solution to promote sustainable development so that global warming will not be going rampant. Increasing non-renewable resource consumption had contributed to the global climate changes [5].

Oil palm (*Elaeis guineensis*) is biomass energy that generates a lot of lignocellulosic by-products. Malaysia is one of the leading producers of oil palm in the world [6]. The tremendous amount of biomass generated from the oil palm industry will be a waste if it is not appropriately utilized [7]. Half of the wastes from the oil palm industry was from empty fruit bunch (EFB) [8], and another half were



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from mesocarp fibre (MF) and palm kernel shell (PKS) [9]. Due to EFB abundances, it was suitable to be used as biomass compared to oil palm fronds (OPF) and oil palm trunks (OPT) [10]. Thus, the exploitation of EFB for energy sources is one option and merit for renewable energy applications. Gasification and incineration are promising methods to produce the thermal output via partial or complete combustion from raw biomass. Therefore, this study investigates the prior treatment for EFB in the torrefaction process as feed materials for further thermal processing.

## 2. Methodology

### 2.1 EFB Fibres

Oil palm EFBs were collected from a local oil palm mill at Jeli, Kelantan. Fresh oil palm EFB samples collected were undergoing sun-dried for 48 hours to dry off the higher moisture content (approximately 30-40%). The samples have later been grounded into a particle size of  $< 500 \mu\text{m}$  by applying the grinding. All the obtained particles were screened to separate the oversize and undersize particles, whereby the unwanted material has been removed. Prior to batch processing in the microwave chamber, the EFBs were kept for 24 hours in the storage oven to have minimal influence from atmospheric condition moisture.

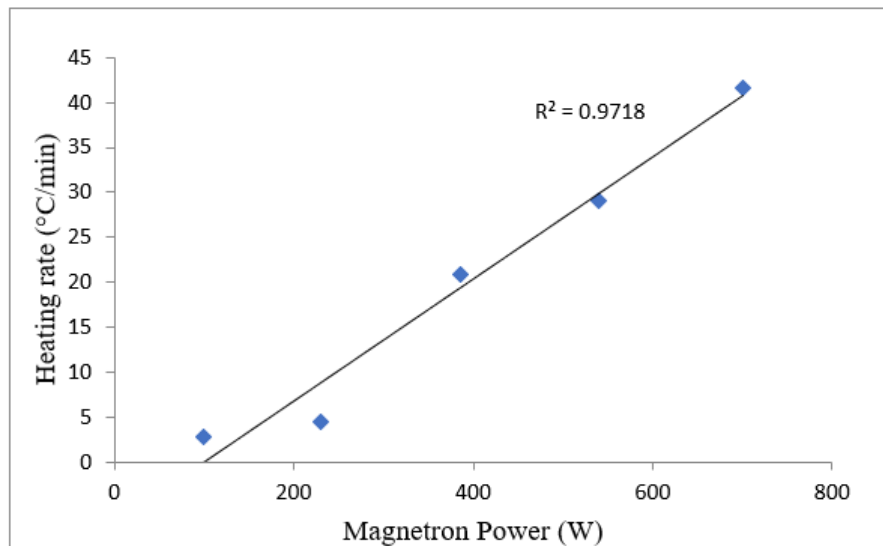
### 2.2 Modified Microwave Setup

In this study, the torrefaction process was carried out in the modified microwave with a similar setup [11] & [12], as a heat chamber. The physical add-in components consist of the nitrogen gas supply, inlet/outlet gas port, power supply, alumina crucible, temperature, power, and flow meter controller. A commercial microwave system of 2.45 GHz with the maximum power level 700W was considered. Then, grounded fibres were fed into a crucible in the microwave chamber with a mild oxygen presence, considering the continuous purged of nitrogen gas in a 20 ml/min scale during the process cycle. Prior to the cycle run, the chamber was heated up and kept stable for at least 10 minutes. Then, several parameters that affect the formation of torrefied EFB by using the microwave were investigated. Chamber temperature was configured around (200 to 300) °C at a constant heating rate of 10 (°C/min) to avoid the microcrack on the alumina crucible (samples holder). In addition, the involved controlled parameters as such of power supply, heating rate and temperature were discussed in this paper. The heating source (microwave power) was modulated using PID; hence it performs with on-off mode to sustain at desired torrefaction temperature. A data logger was used to store the intrinsic temperature of samples in the chamber.

## 3. Result and discussions

### 3.1 Effect on the selection of power input level

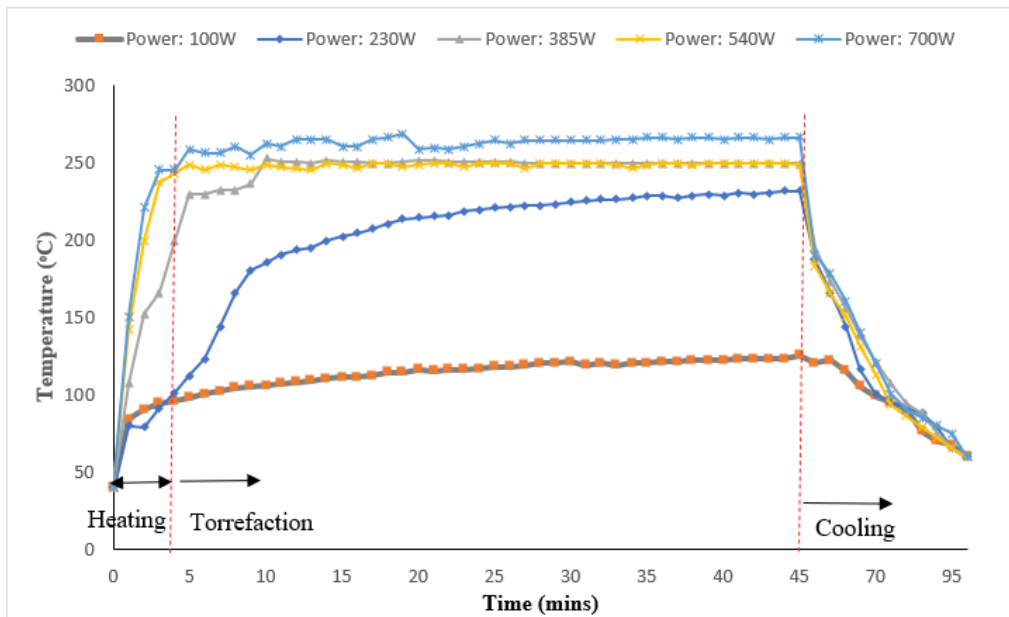
The result of the heating rate of samples size of  $< 500 \mu\text{m}$  that handled batch processing using different power input levels was shown in Figure 1. In general, the heating rate in the microwave chamber can be described as an ability of sample preparation to increase temperature per minute during the heating process. In this study, the heating rate is the relation to the microwave magnetron power selection [13]. Thus, the heating rate trend increases drastically when the power input increases. In comparing 100 and 700 W, the heating rate produced was 2.86 °C/min and 41.60 °C/min, respectively. The trends also observed the linear relation at all cases with the closes of 0.9718. Thus, this shows the ability of the used microwave to produce the amount of targeted heating rate.



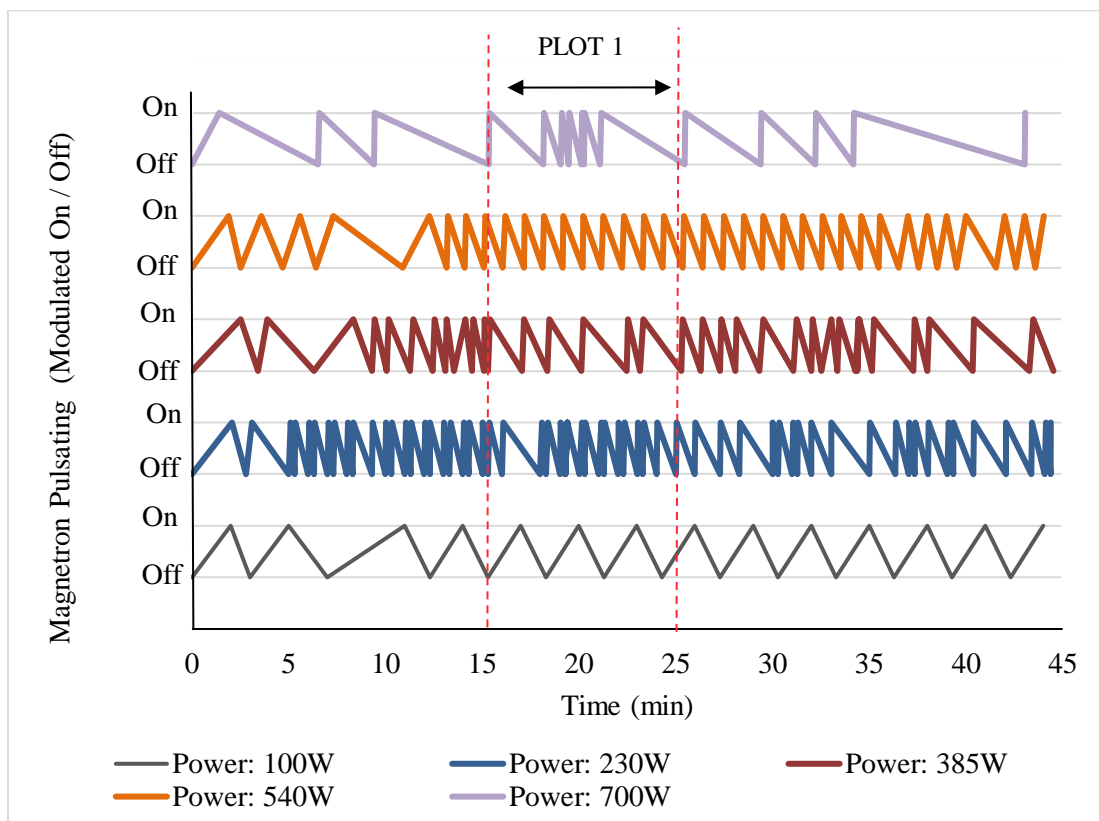
**Figure 1.** Heating rate using different magnetron power input on tested EFB samples in size of < 500  $\mu\text{m}$ .

The intrinsic of EFB fibres temperature across the process times at various input power were displayed in Figure 2. Three stages are commenced from the process trends, slow temperature-rising, a rapid temperature-rising phase, and a slow temperature-reduction [14]. As for 385, 540 and 700 W power input, a slow mode of temperature rising was traced with regards from 1 until 10 minutes, followed with homogenous temperature along 5 to 45 minutes (desired torrefaction temperature) and progress with reduction or cooling state. When the power at a low level (i.e., 100 and 230 W), the temperature trend only experience two steps: slow temperature rising then followed with the temperature-reduction state as witnessed of low heating rate. Low power input may infer insufficient thermal capability to produce a desired torrefaction temperature, therefore inducing low heating value of output products [13]. Homogenous torrefied EFB fibres were obtained at a power level above 230 W, promote the degradation of samples at the desired temperature. The less uneven temperature on this stage credits a potential for chosen power level to treat the samples.

Graph of pulsating magnetron as in Figure 3 was plotted to show the operating of PID controller frequencies. In this section, the pulsating of electrons has been released from the magnetron according to power selection. A consistent gap of the peak in plot one was produced in 100 W, resulting from the frequent minimal release of electrons at respective torrefaction time. This situation occurs due to low thermal output released inside the chamber, as observed in low-temperature samples in Figure 2. In contrast, electrons power were perceived more rapid in frequency for 230 W, yet not still manage to obtain the desired in short durations. As for 385 W and 540 W power output, the consistency of magnetron pulsating was observed, respectively. Hence, the tabulation of the desired temperature has shown more homogenous after 5 minutes of operating. As for this, torrefied EFB fibres will gain more uniformity than a low level of power output. On the other hand, 700 W showed a massive gap for the electrons pulse released, which was not ideal due to the torrefaction process as the temperature trends surpass the desired temperature. As far as the alumina crack is concerned, higher power output trends (i.e. 700 W) must be avoided.



**Figure 2.** Temperature profiles bound with different microwave power.

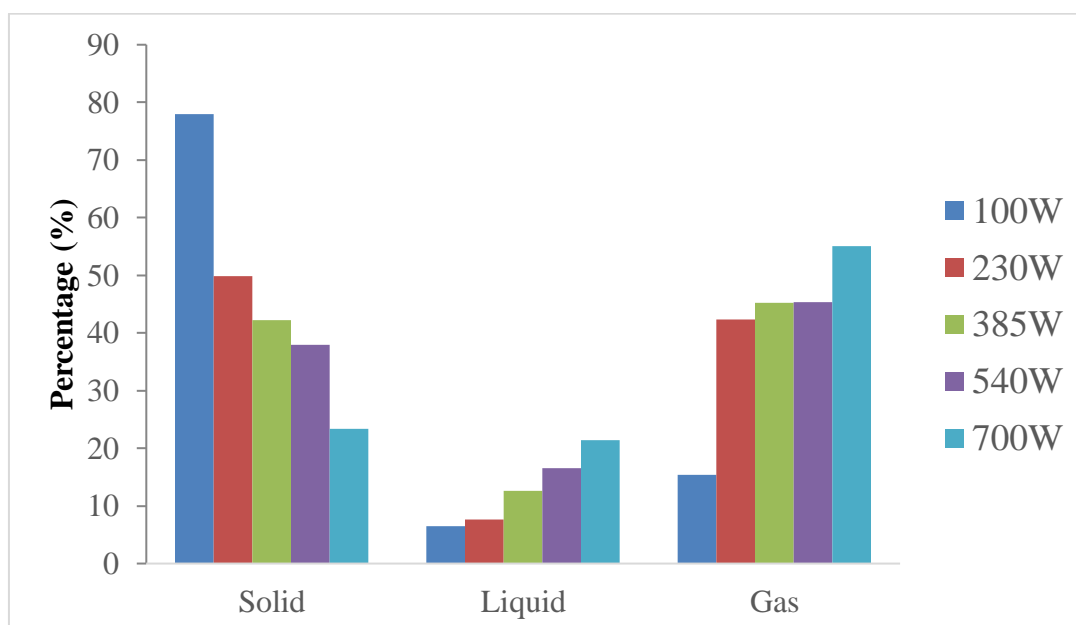


**Figure 3.** Magnetron effect on power selection.

Figure 4 shows the yield percentage of solid, liquid and gas at the ends of the torrefaction process with the different microwave output power levels. In general, selection of power, therefore, influenced the fraction of the final percentage of the EFB fibres constituents (i.e. solid, liquid and gas) as the factor

of different heating characteristics. The solid and liquid fraction was determined from weight changes by comparing the onset value before and after the cooling process.

Meanwhile, the gas fraction was subsequently measured from the by-product of the liquid fraction after the process [15]. In this study, the findings on 540 W for 45 minutes thermal treatment can have in approximately 35 % of the remaining solid, which is closely aligned to the previous research [16]. An increase of power input inside the oven chamber would definitely reduce the weight percentage of solid (torrified) from the observation trends. This is due to due to the evaporation of moisture content and slight decomposition of cellulose, hemicellulose and lignin inside the sample [3]. Also, it potent to increase the condensable product as the power input goes increased. A similar situation is observed on liquid and gas fraction, with a higher remaining percentage reflecting from 100 to 700 W. The highest percentage of remaining gas obtained around 50% at 700 W, where the lowest rate was 10% that used 100 W of power. In the torrefaction process, the primary traced gasses formed were carbon dioxide (CO<sub>2</sub>) and carbon monoxide (CO), hydrogen and methane [11].



**Figure 4.** Effect rate of power on the fractional output.

#### 4. Conclusions

The conclusion of this study may draw some consideration of input power level, magnetron pulsating and fractional output from EFB fibres. It is shown that 385 W, the middle operating power level, has the opportunity to promote homogenous trends of intrinsic temperature in the tested samples. As for this, pulsating of magnetron were modulated at middle gap wise of “on and off” behaviour as compared to low and high power level. Poor degradation of samples was recorded at the low power level as witnessed of less reaction as a function of temperature. The usage of 700W power input should be avoided as the impact of thermal on the alumina crucible. Higher output in constituent of gases forms was traced at high power input, promoting the unevenness of the desired temperature. Apart from that, this consideration may help facilitate the shelf life of crucible and cost-effectiveness without sacrificing product outputs. The modified microwave configurations can thermally decompose the EFB fibres to high-end output products for energy purposes corresponding to suitable power input selection.

### Acknowledgements

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