

The production of charcoal normally involves the heating of the biomass raw material at temperatures between 300°C-500°C, in which volatiles are emitted and removed during the process (Payakkawan *et al.*, 2014). The carbon content is thus enriched, and an initial porosity and some ordering in the carbon structure is formed. Theoretically, during the carbonisation, the temperature rises to approximately 275°C and the gas yield increases. At this point, external application of heat is no longer required because the carbonisation reaction becomes exothermic. Once the temperature reaches around 350°C, exothermic pyrolysis ends, and the heat is again applied to remove less volatile tarry materials. Charcoal has many end uses such as for the production of activated carbon, agronomic soil remediation and as bio-coal for the fuel industry. Currently, it is produced using conventional processes such as the drum kiln or pit kiln methods. Many of these systems are not environmental-friendly and very time consuming. MPOB previously introduced a number of technologies on carbonisation namely the hollow plinth furnace system (Astimar *et al.*, 2011), Taki carbonisation system (Astimar *et al.*, 2012) and continuous carbonisation system (Astimar *et al.*, 2015). All the systems are equipped with smoke treatment systems, which treat the smoke before being emitted and in the process produce a by-product called wood vinegar. However, the challenge is high energy consumption and the long period of the processes.

The microwave assisted hydrothermal method has gained interest lately as an innovative approach for carbonisation. Besides being known as a 'clean technology', this method can carbonise materials at lower temperatures at 200°C-300°C (Guiotoku *et al.*, 2009; Chen *et al.*, 2012; Payakkawan *et al.*, 2014), and at faster rate.

## THE SYSTEM

The schematic design of the microwave system with a size of 0.42 m<sup>3</sup> was fabricated using stainless

steel as shown in *Figure 1*, and is installed with three magnetrons of 2 kW capacity each. From the optimisation process, about 30 kg of palm kernel shells (PKS) can be loaded into the reactor. Prior to the carbonisation, the process materials have to be free from impurities such as metal components. Therefore, screening of the PKS using a metal detector and separator is vital prior to the carbonisation process. The carbonisation process is started by switching on all the three magnetrons until the reactor temperature has reached the set value at 250°C. After that, all the magnetrons are automatically shut down and the self-sustained carbonisation was generated by the exhaust fan. A magnetron stirrer was used to ensure that hot air generated from microwave radiation was evenly distributed throughout the biomass. Two k-type thermocouples are installed inside the reactor positioned at different heights, *i.e.*, T1 (0.2 m) and T2 (0.4 m). The whole process of microwave heating from start-up until carbonisation of PKS took about 8 hr. Since this is a batch process, the carbonised samples will only be ready to be taken out after the temperature reached below 50°C.

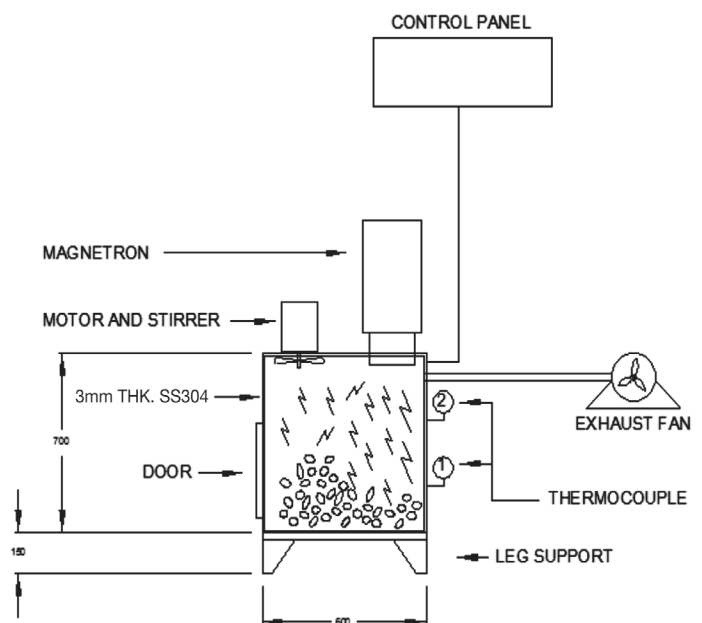


Figure 1. Schematic diagram of the microwave carbonisation system.

## THE CARBONISATION PROCESS

The changes in the measured mean temperature of PKS charcoal under the microwave carbonisation system are shown in *Figure 2*. The PKS were heated up by three microwave radiation sources until the reactor temperature reached the set temperature of 250°C (*Figure 2*). Temperatures inside the microwave reactor were seen to slowly rise through the process and peak around 250°C-275°C, when the exothermic reaction occurs and the gas yield increases. Once the temperature reaches around 300°C-350°C, exothermic pyrolysis ends, and the process of removal of less volatile tarry materials is continued until optimised and the temperature will start to cool down. Comparison of proximate and ultimate analysis results of PKS charcoal from microwave carbonisation as compared to that from conventional carbonisation (Rugayah *et al.*, 2014) are shown in *Table 1*. Moisture content was found to be quite low suggesting vigorous removal of moisture by the microwave radiation during the carbonisation process. Meanwhile, the percentage of fixed carbon was quite optimum with low ash content, as compared to charcoal from the conventional process. This may be due to the theory that the microwave radiation enhances the drastic removal of moisture and other volatile matter while dissolving the inorganic material in the moisture, leaving more stable carbon with less ash-forming minerals (ElaiGWU and Greenway, 2016). Overall, the characteristics of the charcoal from microwave process are comparable to that of charcoal from the conventional method.

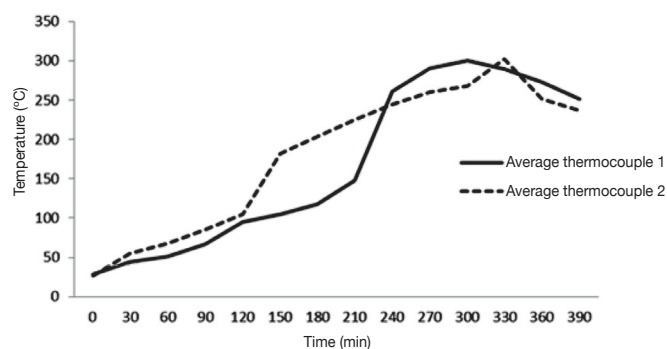


Figure 2. Profile of temperature vs. time during carbonisation of PKS using microwave reactor.

TABLE 1. PROXIMATE AND ULTIMATE ANALYSIS OF CHARCOAL FROM OIL PALM SHELL

Analysis	OPS	
	Microwave	Conventional*
Proximate (wt%)	Ash	3.37
	Fixed C	67.19
	Moisture content	0.59
Ultimate (%)	C	61.41
	H	3.30
	N	0.59
	S	0.04

Source: \*Rugayah *et al.* (2014).

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