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THE EFFECT OF TORREFACTION ON OIL PALM EMPTY FRUIT BUNCH PROPERTIES USING MICROWAVE IRRADIATION

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ABSTRACT

In this study, torrefaction via microwave irradiation was introduced towards oil palm empty fruit bunches (EFB) samples. The samples was fed into the alumina type crucible inside the microwave with the power input limit at 385W. Experimental was carried in non-oxidative atmosphere at 50 ml/min continous flow of nitrogen gas into the torrefaction system. The effects of main parameters from temperature, residence time were studied towards mass yield, energy yield, proximate analysis and hydrophobicity percentage.

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Result revealed the increased of energy value up to 22.4MJ/kg for torrefied samples, whereby from proximate analysis mark the increased of fixed carbon percentage whilst volatile matter decreased. Torrefaction products also shows the ability of reducing of moisture uptake up to 60%, which is prudent the good grindability.

Keywords: microwave reactor; oil palm empty fruit bunch (EFB); torrefied samples.

1. INTRODUCTION

Currently, fossil fuels are the primary sources as cheap energy that powers our modern industrial civilization [1]. The other problem with fossil fuels is that they will soon run out and considerable not a good thing [2]. According to the global problem associated with the intensive use of fossil fuel have increased the interest in the use of renewable fuel worldwide, and Malaysia is blessed with widely availability of such renewable resources from biomass [3]. There are better in financial gains and other advantages when used as a fuel for renewable energy power generation. The rapid consumption of fossil fuel needs an alternative replacement and the developed nations mostly are pursuing the development of biomass as an alternative method of power generation. Biomass energy or bioenergy is the largest and the most important one that has been employed in worldwide including in underdeveloped, developing and developed countries [4].

Biomass can be lignocellulosic or non-lignocellulosic material. Lignocellulosic biomass has the potential to produce sustainable clean-green energy and other bio-based materials. Compared to coal, reported by [5] the low bulk density, high moisture content, degradation during storage and low energy density of raw lignocellulosic biomass are challenges in generating agricultural residues as a cellulosic feedstock. The lignocellulosic biomass has difficulty to store and also grinding into small particles. However, there is solution of all this weakness of lignocellulosic biomass which is through the pre-treatment of biomass. Torrefaction is one of the solution methods [4].

Torrefaction of lignocellulosic biomass has attention interest because of its potential to overcome the disadvantages of current biofuel. Torrefaction improve the biomass properties to be used as energy. In [7] mentioned that torrefaction improve grinding properties of biomass. The fuel characteristics make such as fixed carbon and heating value, closer to coal. Torrefied particles are brittle which is easy to grind with less energy consumption. The torrefaction able to increase 40% the calorific value of the biomass. However, about more than 50% of weight was lost from the biomass. Torrefaction can enhance the hydrophobic properties of biomass which can be stored even in an open environment [8]. The lignocellulosic biomass structure is damaged especially on hemicellulose from torrefaction so that the grindability of biomass is improved significantly. In other hand, the advantages torrefied biomass is suitable to be co-fired or co-gasified with coal [9-10].

Torrefaction of various types of biomass by electrical heating method (conventional method) has been discussed in literature. Previously, conventional heat methods comes from external firing like tube furnace, fluidized or fixed bed reactor which normally consumed a long heating duration and severe energy consumption that results in low quality products. The reaction is usually carried out at 200-300°C and the heating rates are usually kept below 50°C/min with the heating of the biomass takes place from the surface to the inside of the particle through conduction, convection and radiation and therefore higher heating rates may result in shorter processing time and also result in incomplete reaction [11] In contrast to this, in microwave, heating takes place at a molecular level and volumetric heating is achieved [12]. Because of the difference in how heat being generated, microwave heating has many potential advantages in processing materials. Microwave heating is a selective, rapid, uniform, and energy-saving method without direct contacts with the heated materials [11]. Only few studies have been done for torrefaction of oil palm wastes and microwaved-assisted using statistical approach is undoubtedly novel in this area.

Present paper focuses on the characteristics of torrified samples production from oil palm EFB via microwave-assisted based on torrefaction process in the absence of oxygen. The effect of holding temperature, residence time on the torrefaction mass and energy yield were investigated. The correlations among parameters were analysed using statistical software. The moisture uptake percentage was also been addressed as it is an advantage for storage purpose.

2. METHODOLOGY

2.1. Materials

Oil palm EFB were taken from local oil palm mill in FeldaKemahang at Jeli, Kelantan, Malaysia. Fresh oil palm EFB samples collected were undergoes sun-dried for 2 days to dry-off the moisture content. Then, samples were grounded using rotating grinder and sieved progressively under finer screen into < 500 µm particle size. Therefore, it will be kept for 24 hours at 105°C before further process in order to minimal the moisture content. Only 10g was used for each batch processing inside the microwave reactor.

2.2. Methods

In this study, the microwave system with 2.45GHz with the maximum power level 700W was modified as shown in Fig. 1. The microwave system [25] setup consisted of nitrogen gas tank, torrefaction chamber (alumina crucible) and power modulator (proportional-intergral-derivative controller (PID) with type-K thermocouple). Hollow tube made of ceramic (internal diameter (ID): 30 mm) as housing was coupled with two aluminium (ID: 4 mm) for inlet nitrogen gas and outlet gas from torrefaction chamber. In order to obtain the process effect, torrefaction chamber from alumina cylindrical crucible (at ID: 71 mm and length 114 mm) in purity of 99.6% was manned for this purpose. The heating source (magnetron power) was modulated using PID, so it could work in on-off mode to achieve the desired temperature in torrefaction chamber. Data logger was used to ensure all the intrinsic temperature was kept profile. Input power of 385W (medium level) was selected for further experiments. Effect of such various residence time (15 and 30 min) and holding temperature at 200, 240, 280 and 300°C were chosen for further analysis. All experiments were duplicated to determine the range and deviation between the results.

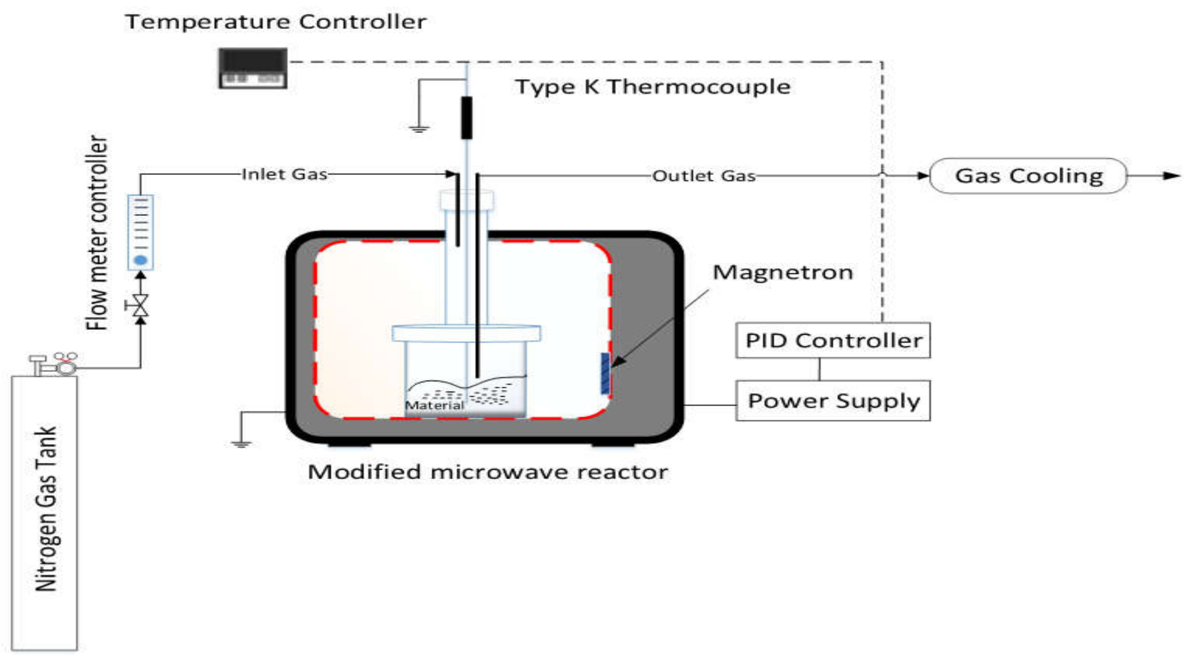

Fig.1. Schematic diagram of modified microwave reactor for torrefaction process

2.3. Proximate and Calorific Value Analysis

The raw and torrefied oil palm EFB were underwent the proximate analysis in order to characterize the biomass (dry basis). It can determine three categories in such of volatile, ash and fixed carbon content carried out by electric furnace. Moisture content is obtained by using moisture analyser by having the biomass into the oven at 105°C at 180 min to remove the moisture. The test procedures ASTM D3175 and ASTM D3174 were used to determine the volatile matter and fixed carbon content respectively. The sample (1 g) was placed and heated up to 900°C for 7 min in closed crucible to prevent oxidation. The weight loss is calculated and represent as volatile matter. The remaining sample was then combusted in 3 hours under temperature of 815°C. Weight loss is calculated as fixed carbon while ash content can obtained simultaneously. The following equation been used for proximate analysis which is Equation (1) for moisture content; Equation (2) for volatile matter; Equation (3) for ash content and Equation (4) for fixed carbon.

$$\text{Moisture content (MC) in dry basis} = (W_i - W_f)/ W_f \times 100 \quad (1)$$

$$\text{Volatile matter (VM)} = (W_i - W_f)/W_i \times 100 \quad (2)$$

$$\text{Ash content (AC)} = \frac{\text{Weight of ash}}{W_f} \times 100 \quad (3)$$

$$\text{Fixed carbon} = 100 - (MC + VM + AC) \quad (4)$$

where Wi is the initial dry weight of sample and $W_f$is the final dry weight at every stage respectively.

The samples were then undergoing investigation for calorific value using adiabatic bomb calorimeter (model 1013-B Yoshida Seisakusho). This test is important to reflect the effect of microwave heating in order to enhance the biomass energy content. The standard test method (ASTM D2015) was used with initially the sample approximately 1 g was put into the chamber, inducing high pressure into 30 bar and connected fuse wire. Heat generated in the chamber is defined as the total heat liberated by the complete combustion of the sample. This particular value is determined by measuring the heat removed when cooling [24] the products of combustion to a standard reference temperature. The deviation of initial and final temperature accordance of heat release was recorded as a function of T_i and T_f. The following Equation (5) was used to determine the lower heating value (LHV).

$$LHV_{sample} = \frac{\Delta H_{water} x (m_{water}) x \Delta T}{(m_{sample})} - Lh_{vap}, H_2O \qquad (5)$$

where$m_{water}$is 2.74kg, deviation temperature, $\Delta T = T_f - T_i$, heating value of water, ΔH_{water} = 4.18kJ/kg and latent heat of vaporization water, $Lh_{vap,} H_2O$ = 2260kJ/kg (at 100°C).

Using the torrefaction output, the sample was then measured the following Equation (6), (7) and (8).

$$Y_m: \frac{\text{Weight of mass after torrfaction}}{\text{Mass of raw EFB}} \qquad (6)$$

$$CV_R: \frac{\text{CV of sample after torrefaction}}{\text{CV of raw oil palm EFB}} \qquad (7)$$

$$Ye: Y_m \times CV_R \qquad (8)$$

where$Y_m$is mass yield, CV_R is ration of calorific value and Y_e is energy yield.

2.4.Hydrophobicity Analysis

Poor absorption and drying tends to have longer storage and on that hydrophobicity test was carried out to torrefied oil palm EFB. To compare the hydrophobicity of the torrefied biomass material, approximately 0.5g of biomass (particle size < 1 mm) were immersed in deionised water at room temperature for 12 hours. The hydrophobic nature was evaluated based on the state of the biomass after this period and by determine the degree of water uptake. Equation (9) is manned for moisture uptake calculation.

$$\text{Moisture uptake} :[((W_f - W_i)/ W_f) \times 100] \qquad (9)$$

where, W_i = Initial weight and W_f = Final weight

3. RESULTS AND DISCUSSION

3.1. Mass Yield

The mass yield of torrefaction products is shown in Fig. 2. Solid fraction (bio-char) yield decreases with an increase of torrefaction temperature. In trend of results, mass yield also decreased with increased of residence time and the holding temperature. It might explain the severity of thermal exposure would lead to extend further the decomposition of oil palm EFB. Higher weight loss at 30 min was obtained comparable to 15 min residence time. Meanwhile, the highest mass yield value for oil palm EFB torrefied is achieved at 83.8% in 15 min while 72.9% at 30 min residence time at low holding temperature (200°C). On the other hand, the mass yields gradually decrease over the range of microwave temperature. Increasing the microwave temperature increases the heating exposure during torrefaction process, thus results in secondary cracking and depolymerisation occurs between 225°C and 325°C for hemicelluloses [13].

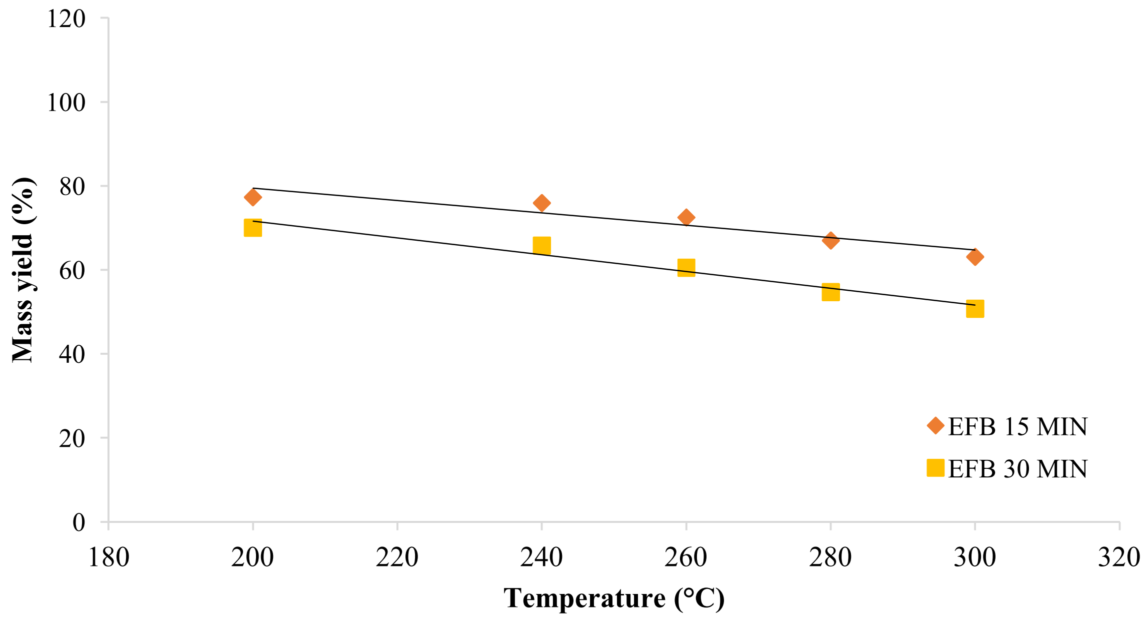

Fig.2. Effect of holding temperature and residence time on the mass yield

3.2. Proximate Properties

The proximate properties revealed oil palm EFB value in different categories which is moisture content (6-8%), volatile matter (85-73%), fixed carbon (6-22%) and ash (0.25-0.96%)

as illustrated in Fig. 3 and 4. Based on the result, raw oil palm EFB exhibits the highest moisture content 8.1%. Moisture content expressed as the quality of water per unit mass of dry solid. The amount of moisture in biomass is reflecting the handling and storage conditions. The highest volatile matter content was attained 82.01% at holding temperature of 200°C in 15 min residence time, while lower content as 72.88% at holding temperature 300°C in 30 min residence time. These trends shown the effect of decreasing residence time and temperature might approach the increasing of volatile matter contents. The reported by [14] high volatile matter content biomass and low char content makes biomass a highly reactive fuel giving a faster combustion rate during the volatilization phase than other fuels such as coal. Besides that, according to [15] reported that the biomass was decomposed into volatile gases and solid char during this process. Typically, biomass has high volatile matter content which is more than 80% compared to coal which had low volatile matter content which is less than 20%. Therefore, lower volatile content matter might closer the torrefied biomass to coal.

On the other hand, the highest ash content in torrefied oil palm EFB was attained 1.08% and the lowest was 0.2% while 1.04 and 0.25% for 30 and 15 min residence time respectively. In the trends of recorded result the percentage of ash content increased when the temperature and residence time increased. Meanwhile, higher ash content attributes to lower calorific value. As reported by [16] said that the non-combustible component of biomass was found to be 2.6% known ash.An impurity of ash that will not burn, fuels with low ash content are better suited for thermal utilisation than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency.Biomass ash does not contain toxic metals like coal ash. Ash composition is important to prevent the corrosion. The combustion temperature significantly affects the total yield of ash from biomass.

Another parameter is fixed carbon which observing in raw and torrefied oil palm EFB. The trends observed the highest value are 8.25 and 17.89 % in raw and 30 min of residence time. In counterparts at 15 min residence time shown the value varies from 9.59 to 17.7 % at 200 to 300°C torrefaction holding temperature. Therefore, more time necessary needed rather than desired various holding temperatures to improve the heating value. As predicted, the increases of temperature and residence, the fixed carbon will definitely increase. The fixed carbon is the fraction that remaining after releases of volatiles, keep out the ash and moisture contents. Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning [16]. Carbon content is physically approach by effect of heating source and it would attribute the changes of heating value. Thus, higher carbon content will have a higher heating value.

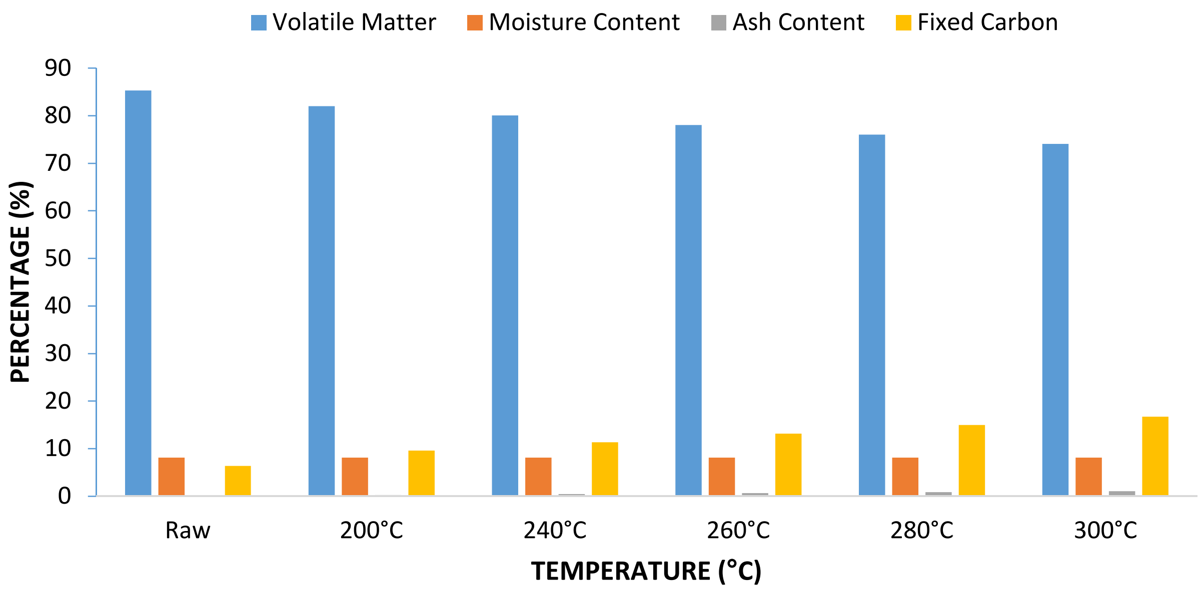

Fig.3. Proximate properties for oil palm EFB in 15 min torrefaction residence time

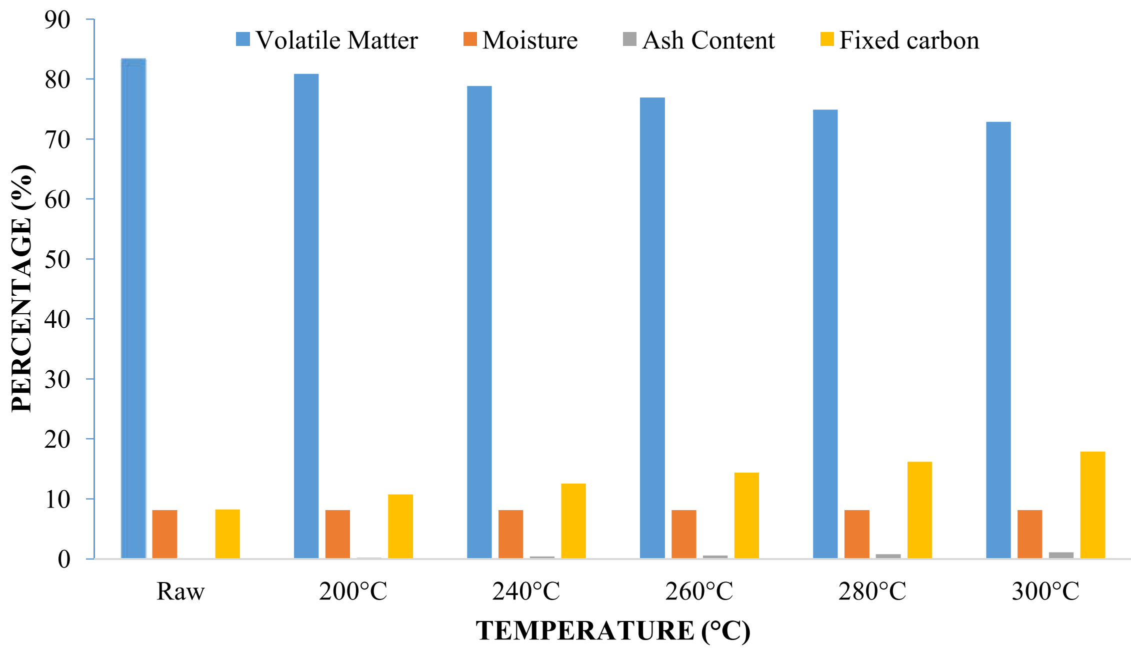

Fig.4. Proximate properties for oil palm EFB in 30 min torrefaction residence time

3.3. Calorific Value

The standard measurement of energy content in fuel is heating value, sometimes called the calorific value or heat of combustion. In order to discuss more specifically, the calorific value yield of torrefied sample are plotted against torrefied temperature as shown in Fig. 5. The calorific value was attained at 20.4 and 22.4MJ/kg in 15 and 30 min residence time respectively. In the trends of result shown calorific value of oil palm EFB is coherent with the factor of residence time and holding temperature as reported by [17-18]. The increase in the calorific value is due to decrease in the moisture content and an increase in the carbon content of the samples. As expected, the fixed carbon also shown similarity trends correspond to the increasing of calorific value.

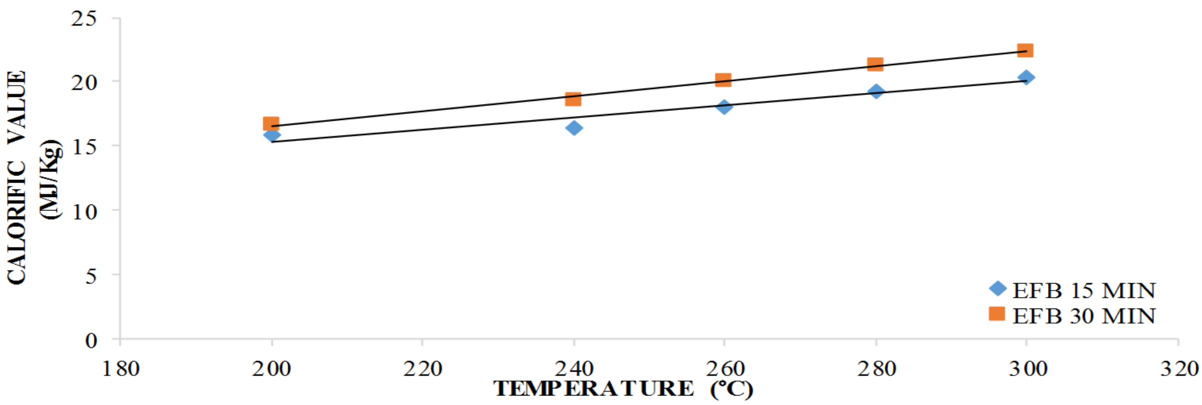

Fig.5. Calorific value in 15 and 30 min torrefaction residence time

3.4. Energy Yield

Equation (8) was used to define the energy yield of various range temperature of torrefied oil palm EFB. As reported by [19] said that parameters such as the energy yield, the composition of the torrefied products and the calorific value must be considered to obtain the optimum torrefaction temperature. The energy yields of oil palm EFB are slightly decreased from 78% to 54% depending on the residence time as shown in Fig. 6. The same trend goes for both parameters with the longer residence time would have low energy yield. The difference value in residence time mainly based on poor mass yield and it also exhibit moisture loss during the treatment.

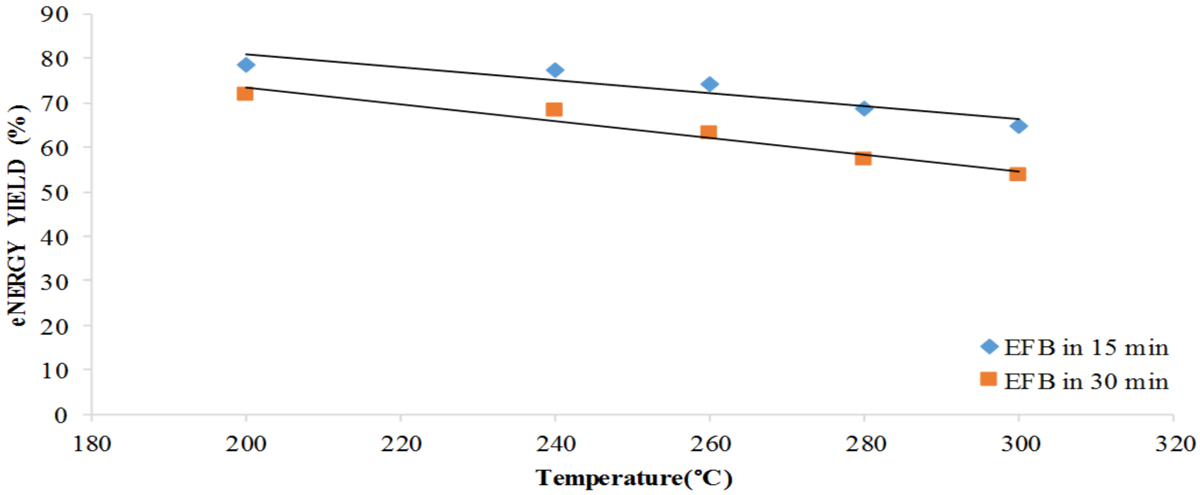

Fig.6. Energy yield at various temperatures in 15 and 30 min torrefaction residence time

3.5. Hydrophobicity Properties

From these studies, torrefaction was proven to improve the physical properties of a biomass by increasing its hydrophobicity. Based on torrefaction treatment, the higher water uptakes was recorded at holding temperature 200°C in 15 min residence time while the lowest water uptakes was at holding temperature 300°C in 30 min residence time as shown in Fig. 7. The hydrophobic behaviour of oil palm EFB was observed higher at all test conditions rather than torrefied material. The moisture absorption capacity in biomass of its hemicellulose constituent is highest. This show a good agreement with [20], torrefaction was involved to near-complete breakdown of hemicellulose, the process makes biomass hydrophobic. This was another special feature of torrefaction that it reduces the hygroscopic properties of biomass. Therefore, when torrefied biomass is stored, it absorbs less moisture than that absorbed by fresh biomass. Besides that, torrefaction improves the water repelling characteristics of biomass through the elimination of hydroxyl groups responsible for hydrogen bonding with water molecules and the generation of a non-polar, hydrophobic compound [21].

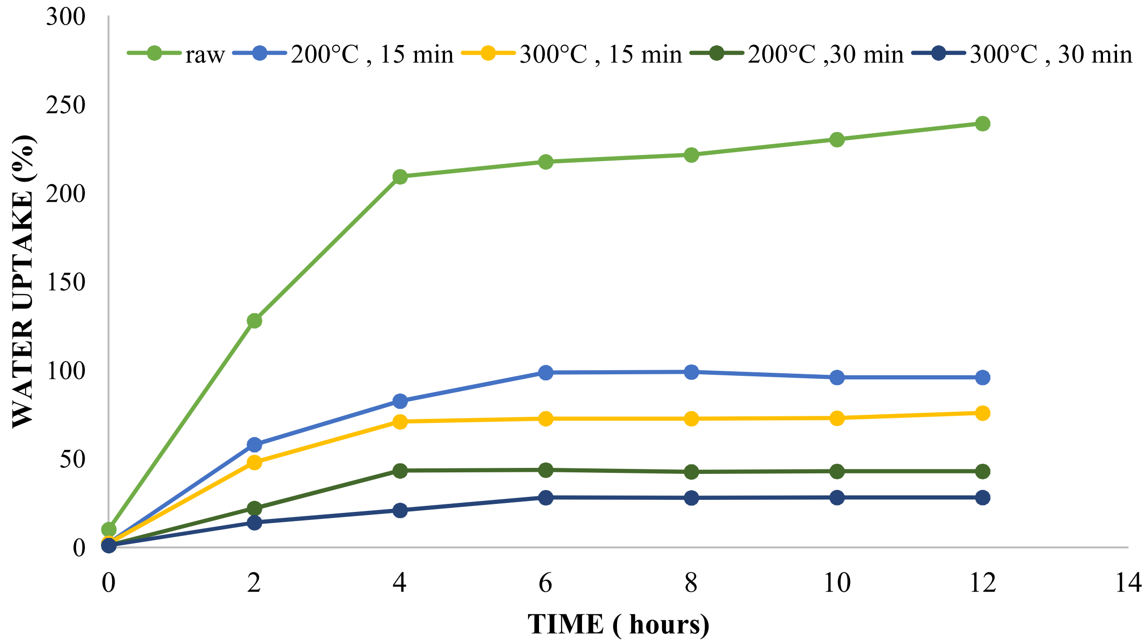

Fig.7. Immersion test on oil palm EFB treatment on 15 and 30 min torrefaction residence time

3.6. Correlation Coefficient

For further analysis to determine the existing relationship between independent and dependent variable, correlation coefficient analysis was conducted.

Table 1. Correlation coefficient analysis of tprrefied oil palm EFB

	Holding Temperature	Residence Time	Volatile Matter	Ash Content	Fixed Carbon	Calorific Value
Holding Temperature	1	-	-0.872**	0.965**	0.973**	0.462*
Residence time		1	-0.457ns	0.061ns	0.688**	0.803**
Volatile matter			1	-0.905**	-0.953**	-0.760**
Ash content				1	0.734**	0.496**
Fixed carbon					1	0.862**
Calorific value						1

Notes: **Correlation is significant at $p \leq 0.01$; *Correlation is significant at $p \leq 0.05$; nsNot significant

Based on Table 1, holding temperature was positively correlated (r = 0.462) at significant ($p \leq 0.05$) towards calorific value.Meanwhile, for residence time towards calorific value, it shows the similar trend (positive correlation) with r = 0.803 at $p \leq 0.01$. This indicates calorific value of torrefied oil palm EFB increased with the increment of holding temperature and residence time. According to [22], the nature of biomass or its high heating value (HHV) as fuel is a combined effect from moisture content, volatile content, ash content and fixed carbon. For determination of the relationship between these variables, the readings of proximate properties obtained were examined based on their impact towards calorific value. Based on the correlation coefficient analysis in Table 1, volatile matter was negatively correlated (r = -0.760; $p \leq 0.01$) with the calorific value. This indicated that the higher volatile matter of torrefied oil palm EFB resulting lower its calorific value. The relationship between volatile matter and calorific value is illustrated in Fig. 8.

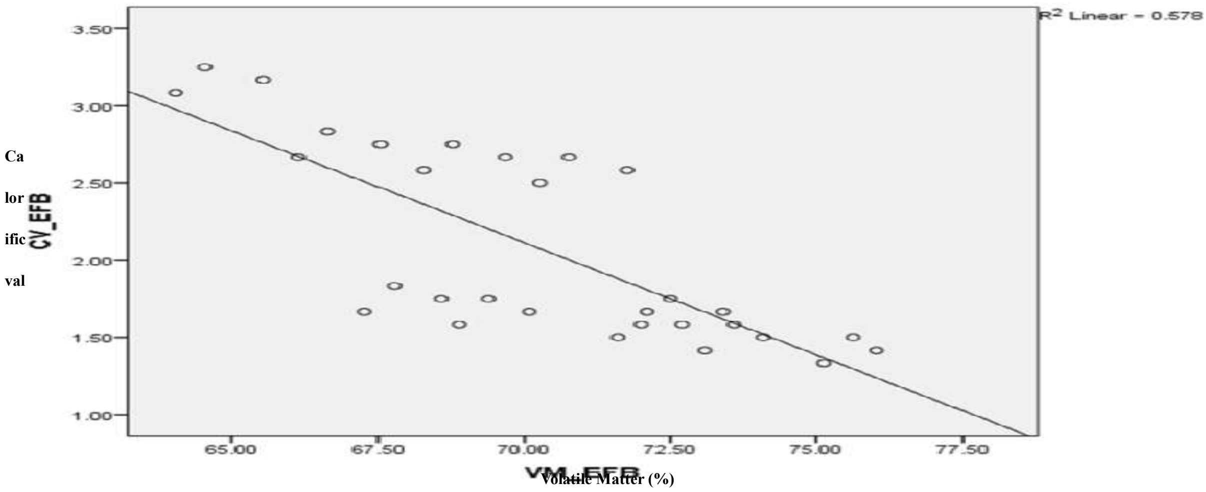

Fig.8. Relationship between volatile matter and calorific value of torrefied oil palm EFB

Besides that, positive correlations ($p \leq 0.01$) were existing among ash content and fixed carbon towards calorific value with r = 0.496 and r = 0.862 respectively. It means that calorific value of torrefied oil palm EFB was increased towards increment of ash content and fixed carbon. Fig. 9 and 10 show the relationship between ash content and fixed carbon towards calorific value respectively.

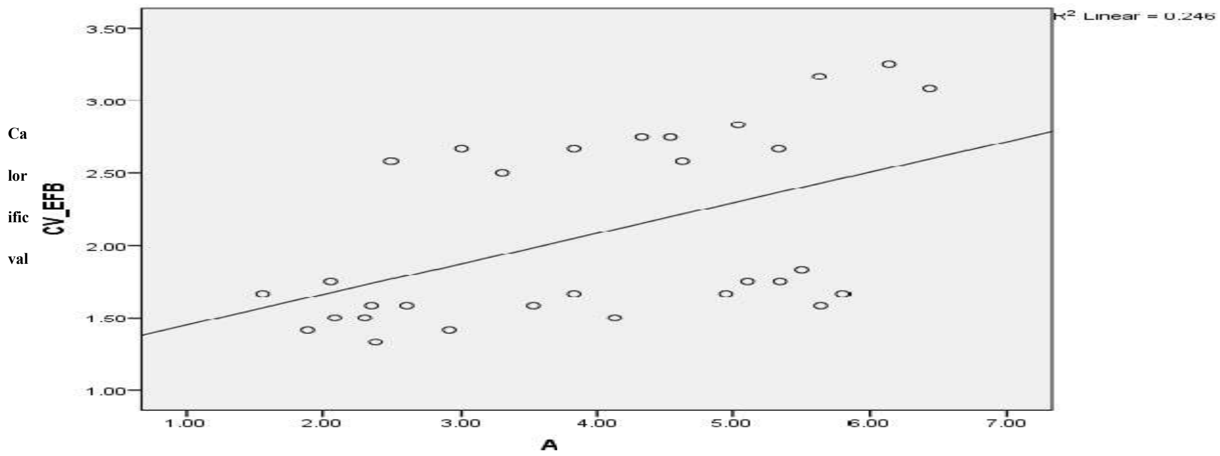

Fig.9. Relationship between ash content and calorific value of torrefied oil palm EFB

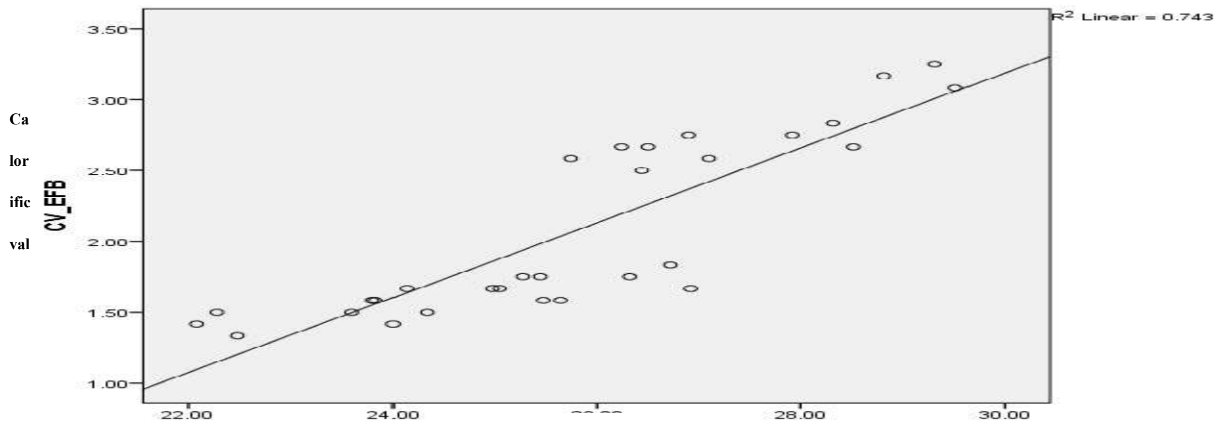

Fig.10. Relationship between fixed carbon and calorific value of torrefied oil palm EFB

4. CONCLUSION

Torrefaction process using microwave irradiation was proved for biomass upgrading towards energy applications. Result revealed heat irradiation from microwave could improve the physical properties of biomass. In other hand, product, measured in terms of mass yield, energy yield and energy density is influenced by the following parameters including which is holding temperature, type of lignocellulose biomass and residence time. Based on this study, result from proximate properties, calorific value and hydrophobicity extend the validity reason of applying heat source from microwave [23]. The issues highlight of holding temperatures were fuel dependent and therefore the results indicate that careful optimisation is required for all fuel types to maximise the benefits of torrefaction whilst maintaining a good energy yield.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] Ahmad M I, Alauddin Z A Z, Soid S N M, Mohamed M, Rizman Z I, Rasat M S M, Razab M K A A, Amini M H M. Performance and carbon efficiency analysis of biomass via stratified gasifier. ARPN Journal of Engineering and Applied Science, 2015, 10(20):9533-9537

[2] Rasat M S M, Razak W M M, Ahmad M I, Hazim M. Preliminary study on properties of small diameter wild Leucaenaleucocephala species as potential biomass energy sources.ARPN Journal of Engineering and Applied Science, 2016, 11(9):6128-6137

[3] Sirrajudin M S, Rasat M S M, Wahab R, Amini M H M, Mohamed M, Ahmad M I, Moktar J, Ibrahim M A. Enhancing the energy properties of fuel pellets from oil palm fronds of agricultural residues by mixing with glycerin. ARPN Journal of Engineering and Applied Science, 2016, 11(9):6122-6127

[4] Chen W H, Kuo P C. A study on torrefaction of various biomass materials and its impact on lignocellulosic structure simulated by thermogravimetry. Energy, 2010, 35(6):2580-2586

[5] Medic D, Darr M, Shah A, Potter, Zimmerman J. Effects of torrefaction process parameters on biomass feedstock upgrading. Fuel, 2012, 91(1):147-154

[7] Phanphanich M, Mani S. Impact of torrefaction on the grindability and fuel characteristics of forest biomass. Bioresource Technology, 2011, 102(2):1246-1253

[8] Chen W H, Cheng W Y, Lu K M, Huang Y P. An evaluation on improvement of pulverized biomass property for solid fuel through torrefaction. Applied Energy, 2011, 88(11):3636-3644

[9] Strege J, Swanson M, Folkedahl B, Stanislowski J, Laumb J. Fischer–Tropsch catalyst testing in a continuous bench-scale coal gasification system. Fuel Processing Technology, 2011, 92(4):757-763

[10] Ahmad M I, Alauddin Z A Z, Soid S N M, Mazlan M, Yusoff M H. Experimental of wood gasification in suction biomass gasifier. Advanced Materials Research, 2013, 626:1020-1026

[11] Wang M J, Huang Y F, Chiueh P T, Kuan W H, Lo S L. Microwave-induced torrefaction of rice husk and sugarcane residues. Energy, 2012, 37(1):177-184

[12] Satpathy S K, Tabil L G, Meda V, Naik S N, Prasad R. Torrefaction of wheat and barley straw after microwave heating. Fuel, 2014, 124:269-278

[13] Prins M J. Thermodynamic analysis of biomass gasification and torrefaction. Eindhoven: TechnischeUniversiteit Eindhoven, 2005

[14] Koppejan J, Loo S. V. The handbook of biomass combustion and co-firing. Abingdon-on-Thames: Routledge, 2012

[15] Quaak P., Knoef H., Stassen H. E. Energy from biomass: A review of combustion and gasification technologies. Washington DC: World Bank Publications, 1999

[16] Akowuah J O, Kemausuor F, Mitchual S J. Physico-chemical characteristics and market potential of sawdust charcoal briquette. International Journal of Energy and Environmental Engineering, 2012, 3(1):1-6

[17] Zanzi R, Sjöström K, Björnbom E. Rapid pyrolysis of agricultural residues at high temperature. Biomass and Bioenergy, 2002, 23(5):357-366

[18] Nimlos M N, Brooking E, Looker M J, Evans R J. Biomass torrefaction studies with a molecular beam mass spectrometer. American Chemical Society, Division of Fuel Chemistry, 2003, 48(2):590-591

[19] Poudel J, Oh S C. Effect of torrefaction on the properties of corn stalk to enhance solid fuel qualities. Energies, 2014, 7(9):5586-5600

[20] Basu P. Biomass gasification, pyrolysis and torrefaction: Practical design and theory. Massachusetts: Academic Press, 2013

[21] Acharjee T C, Coronella C J, Vasquez V R. Effect of thermal pretreatment on equilibrium moisture content of lignocellulosic biomass. Bioresource Technology, 2011, 102(7):4849-4854

[22] Majumder A K, Jain R, Banerjee P, Barnwal J P. Development of a new proximate analysis based correlation to predict calorific value of coal. Fuel, 2008, 87(13):3077-3081

[23] Muhammad I A, Mohd S M R, Shahril N M S, Mazlan M, ZairiI R, Mohd H M A. Preliminary study of microwave irradiation towards oil palm empty fruit bunchesbiomass. Journal of Tropical Resources and Sustainable Science,2016, 8(1):133-137

[24] Mazlan M, Mohd H M A, Muhammad A S, Mohamad B A B, Mohamad N M, Muhammad I A, Nik A A N Y, Mohammad K A A R, Zairi I R. CFD simulation using wood (cengal and meranti) to improve cooling effect for Malaysia green building. ARPN Journal of Engineering and Applied Sciences, 2015, 10(20):9462-9467

[25] Mohd N K, Moumen I, Muhammad I A, Zairi I R.Computational analysis of air intake system for internal combustion engine in presence of acoustic resonator. ARPN Journal of Engineering and Applied Sciences, 2015, 10(20):9468-9475

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