Elucidating on Time and Temperature Effects on Torrified Moldy Bread

Muhammad Iqbal Ahmad [1*], *Ain Zulaikha* Zuhairi[1], *Mohamad Faiz* Mohd Amin[2], *Mohd Sukhairi* Mat Rasat[2], and *Mohd Mahadzir* Mahmood[3]

[1]Faculty of Bioengineering and Technology, Universiti Malaysia Kelantan, Jeli Campus,17600 Jeli, Kelantan
[2]Faculty of Earth Science, Universiti Malaysia Kelantan, Jeli Campus,17600 Jeli, Kelantan
[3]Centre for Mechanical Engineering Studies, Universiti Teknologi MARA, Cawangan Pulau Pinang, Permatang Pauh Campus, 13500 Pulau Pinang

Abstract. Waste-to-energy is the preferred solution, according to the waste management hierarchy considering landfill waste disposal may not be the most effective method of waste usage. Torrefaction of kitchen waste to produce higher-quality solid fuels is an effective option with lower temperature requirements than pyrolysis and gasification. By addressing the problems, the fuel quality in terms of high heating value can be investigated. Also, the torrefaction parameters, temperature and time, can be examined on the fuel performance. The moldy bread undergoes torrefaction by torrefying it in the furnace with temperatures of 200, 250 and 300°C, respectively, with 15, 30, 45 and 60 mins of processing times. With increased torrefaction temperature, the mass dropped while the higher heating value (HHV) increased. The rise in carbon content also enhanced the torrefied moldy bread's fuel properties. Also, this is because the primary components of the moldy bread, particularly hemicellulose, have significantly decomposed. Therefore, processed temperature of 300°C at elevation time of 45 min produced tremendous gain than other parameters observed.

1 Introduction

As stated by Abdul Samad et al. [1], throughout 2000 and 2015, Malaysia's population risen from 23.49 to 30.65 million, respectively. Municipal solid waste (MSW) production is increasing in sync with population expansion. According to Malaysian MSW generation research, total daily MSW generation reached 29,711 ton/day in 2012, with an estimated total of 36,165 ton/day by 2020. Due to the vast MSW generation rate, improper MSW disposal is a critical aspect of environmental and sustainable development. How et al. [2] stated that biomass conversion into value-added biofuels and biochemicals was not a novel concept in Malaysia due to many agricultural wastes. Biomass proved to be a viable sustainable feedstock for energy and chemical synthesis. Recognizing this opportunity, the Malaysian government took significant steps by enacting a series of environmentally focused laws and regulations. These measures played a crucial role in advancing the biomass industry, as the

---

* Corresponding author: iqbal@umk.edu.my

government made substantial investments in research and development, as well as the commercialization of biofuel and biochemical conversion technologies.

According to the waste management hierarchy, Kuo et al. [3] mentioned that preventing waste production is the preferred solution. Nevertheless, landfill waste disposal is the least preferred alternative. Considering landfill waste disposal may not be the most effective method of waste usage, waste-to-energy is a trend right now. Torrefaction (low-temperature thermal treatment) is one approach for waste conversion of biomass (as an energy source). While Al-attab and Zainal [4] concluded that the management of kitchen wastes from houses, which is growing in line with the population, is a serious global issue, releasing greenhouse gases and demanding big landfill locations. With its acidic character, high moisture level, and organic components, kitchen wastes represent a large portion of municipal solid waste. The greenhouse gas emission from kitchen waste decomposition and the transmission of diseases through insects and rodents are two primary environmental disadvantages of traditional kitchen trash disposal to landfills. As a result, one of the realistic alternatives has been proposed: kitchen waste management through conversion into valuable products. Torrefaction of kitchen waste to produce higher-quality solid fuels is an effective option with lower temperature requirements than pyrolysis and gasification.

2 Material and Methods

2.1 Materials

Moldy breads were collected from kitchen waste from food processing industries around Jeli, Kelantan. Before characterization and torrefaction process, the bread was cut and weighed uniformly which is 10 g for each slice for the samples. Then the bread dried in the drying oven. The bread slices were lined in a single layer of aluminium foil and dried in about 70 to 75□C oven for 1-2 hours.

2.2 Preparation and Characterization of Torrified Moldy Breads

Torrefaction took place in a laboratory-scale furnace (Carbolite Gero, CWF1300) with maximum power output was 2.7 kW. The experiment involved weighing moldy bread placed in a ceramic container, which was then sealed with a lid to create a controlled and inert environment. The lid was positioned to allow flue gases and water vapor to exit. Chosen operating furnace temperature at 200, 250, 300, 350°C, respectively, with different time's parameters including 15, 30, 45, and 60 minutes for each tested sample. The higher temperatures were utilized to determine the maximum temperature at which torrefaction is suitable for treating the moldy bread in terms of energy produced.

Compositional analysis of the hydrochar was achieved through proximate analysis in thermogravimetric analysis (TGA). It provides data on the moisture content, volatile matter, fixed carbon, and ash content of both the torrified moldy bread and the raw feedstock. A METTLER TOLEDO Simultaneous Thermogravimetry (TGA) Analyzer with sub-microgram resolution across the whole measurement range of characterisation was used to assess the samples. A standard method (ASTM-E870-82) for proximate analysis of 10 mg samples was employed in this study. The TGA curve allows for the determination of the percentage composition of moisture content, volatile matter, and ash content, with fixed carbon content being calculated as the remaining component. Apart the fixed carbon yield (FCY%), used to quantify the effectiveness of the carbonization process [5].

$$Fixed\ carbon\ yield\ (FCY\%) = MY\% \times \frac{Fixed\ carbon\ of\ solid\ fuel\ (\%)}{100 - Ash\ of\ raw\ biomass\ feedstock} \qquad (1)$$

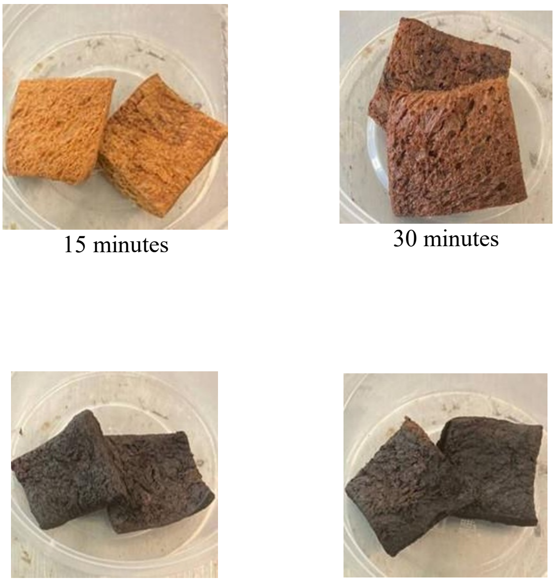
A Parr Instrument bomb calorimeter (model 6200) was employed to ascertain the high heating value (HHV) of both the untreated and torrefied samples. 10 mg of weight sample was employed to the adiabatic calorimeter with the four times repetitions. The data acquired has a substantial influence on the characteristics of the fuel. The direct cause of changes in fuel characteristics is the breakdown of hemicellulose [6]. EDR is the ratio of the heating value of dried solid fuel produced to that of dried raw moldy bread. Hence, the Energy yield (EY%) can be computed employing the subsequent equation, as described by [7].

$$Energy\ yield\ (EY\%) = MY\% \times EDR \qquad (2)$$

3 Results and Discussion

3.1 Appearance and Fuel Properties

As shown in Figure 1, image of moldy bread and torrefied versions of the samples exhibit colour variations, particularly darker colour samples as time and temperature increase. As the temperature of torrefaction increases, mouldy bread's colour changes from white with yellowish spots to black. During the torrefaction process, the hemicellulosic and partial cellulosic components of the moldy bread experienced thermochemical degradation, leading to the observed alterations in colour. This finding is consistent with others that use other carbohydrate sources and fibres [8].



15 minutes

30 minutes

45 minutes

60 minutes

Fig. 1. Processing time (minutes) samples of torrified moldy bread at 250ºC torrefaction process

Proximate analysis is used to ascertain how the products are distributed when the samples are heated under circumstances [9]. Proximate analysis stands as a paramount method for characterizing biomass when contemplating thermal conversion processes. This requires calculating the moisture, ash, volatile matter, and fixed carbon concentrations in the raw and treated fuel [10]. These data are essential for understanding the effects of moisture, volatile matter, and fixed carbon on the sample's structure and combustion behaviour. Consequently, elevated moisture levels lead to slower combustion, while high ratios of volatile matter to fixed carbon signify greater fuel reactivity [11].

Table 1 shows the percentage of moisture, volatile matter, fixed carbon and ash content of each tested terrified samples. It shows that the correlation between torrefaction temperatures and times approached increases the percentage of moisture in coal from torrefied moldy bread. While the ash rate is unstable, it is already in the lowest weight. The difficulty that may cause the instability was the fine particle size, frictional nature, and high temperature, making fly ash a challenging substance to manage reliably. Thus, the breakdown of ash and subsequent removal of the material minimises the number of hazardous substances that emit into the environment. A solid fuel should have low moisture content, volatile matter, and high fixed carbon content. This leads to an efficient combustion, thus producing high combustion energy and low harmful emissions. This causes efficient combustion, increasing combustion energy and less hazardous pollutants [12].

Table 1. Proximate analysis derived from torrefied mouldy bread

Sample Temperature/Time	% of moisture (M)	% of volatile matter (VM)	% of fixed carbon content (FC)	% of ash (A)
200/15	1.9	80.81	13.9	3.39
200/30	2.3	79.91	13.2	4.59
200/45	4.0	78.05	16.2	1.75
200/60	2.2	81.55	14.1	2.15
250/15	3.8	78.58	13.6	4.02
250/30	2.7	79.34	15.3	2.66
250/45	5.6	76.62	16.2	1.58
250/60	3.4	74.46	19.1	3.04
300/15	3.9	84.4	9.9	1.80
300/30	3.6	83.49	9.2	3.71
300/45	2.0	79.19	16.0	2.81
300/60	1.9	81.27	15.4	1.43

The mass yield (MY%), fixed carbon yield (FCY%), energy densification ratio (EDR), and energy yield (EY%) of the torrefied, moldy bread were all shown in Table 2. A critical factor in determining the amount of usable solid fuel recovered after thermochemical treatment is mass yield (MY%). It is described as the mass of dried solid fuel produced as a proportion of the mass of dried raw biomass. Higher mass yield suggests that most of the treated solid residue is recovered as fuel. On the other hand, the fixed carbon yield (FCY%) has quantified the carbonisation process's effectiveness in higher temperature with longer processing time. Also, better fuel qualities in the sample are indicated by a higher EDR rating.

Table 2. Fuel properties derived from torrefied mouldy bread.

Sample Temperature/Time	**MY (%)**	**FCY (%)**	**EDR**	**EY (%)**
200/15	96	13.35	0.36	34.56
200/30	92	12.15	0.47	43.24
200/45	88	14.26	0.42	36.96
200/60	86	12.13	0.48	41.28
250/15	84	11.43	0.55	46.20
250/30	82	12.55	0.46	37.72
250/45	81	13.12	0.67	54.27
250/60	79	15.09	0.62	48.98
300/15	74	7.31	0.53	39.22
300/30	72	6.63	0.62	44.64
300/45	68	10.88	0.81	55.08
300/60	65	10.01	0.72	46.8

3.2 Effect towards high heating value (HHV)

Figure 2 shows the HHV of torrefied moldy bread that ranged from 7.71 to 24.2 MJ/kg with the severed condition, had the highest value of HHV. Results showed that the physiochemical properties of the moldy bread significantly change due to the torrefaction process. The reason comes in when water is released and the reactive hemicellulose fraction is further broken down, resulting in a loss of mass but a gain in calorific values [13]. With increased torrefaction temperature, the mass dropped while the higher heating value increased. Also, the torrefied moldy bread's fuel properties were also enhanced by the drop in oxygen content and rise in carbon content. It was discovered that the ideal moldy bread torrefaction conditions were 300°C and 45 min of time.

Moreover, torrefaction induces a significant disruption of O-H and C-O bonds, leading to torrefied biomass with a higher proportion of C-C and C-H bonds, resulting in increased energy production during the bond-breaking process. Oxygen content within lignocellulosic biomass plays a crucial role in combustion, yet excessive oxygen content can have a detrimental impact by reducing the High Heating Value (HHV). Lignocellulosic biomass typically contains a higher oxygen content. Therefore, torrefaction pretreatment plays a pivotal role in substantially improving the HHV by eliminating undesirable elements (H and O) from the torrefied solid [14].

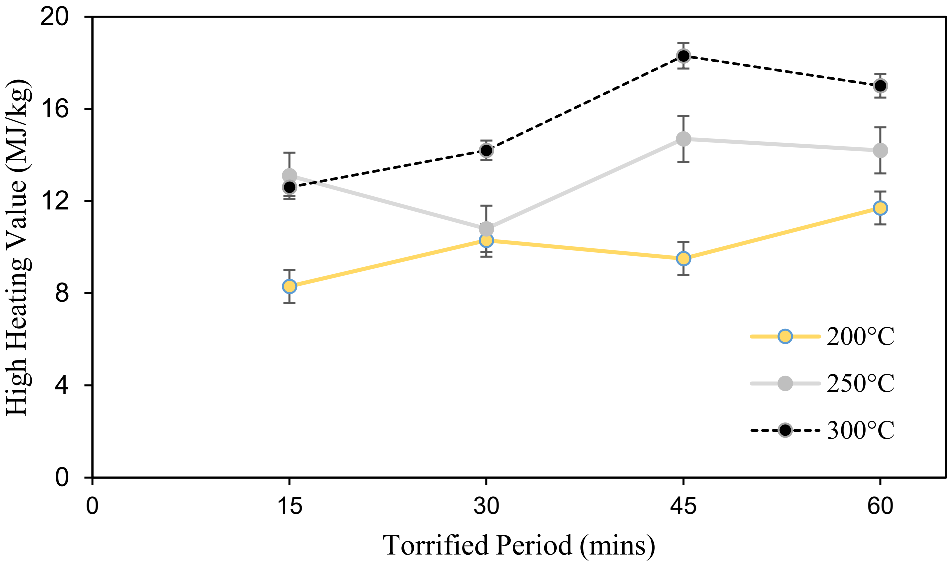


Fig. 2. The High Heating Value (HHV) of tested moldy breads

4 Conclusion

This study draws conclusions about the impact of temperature and duration on the samples, elucidating the compositional and energy characteristics of torrefied moldy bread through the application of standard conventional heating methods. In the proximate analysis, elevating the torrefaction temperature resulted in an increase in fixed carbon and ash content, coupled with a reduction in volatile matter content. The best operating temperature for mouldy bread was determined by the experiment outcomes to be 300°C, which also happens to be the temperature at which heating values increase the most. The 45-minute process period is ideal because the heating value rises the most. Since kitchen waste sources are widely available, torrefaction can be used to enhance and produce new products with increased value using the other wet wastes besides to reducing waste in landfills.

Acknowledgement

The authors acknowledge that this work was financially supported by the Universiti Malaysia Kelantan throughout the UMK Fundamental Grant (R/FUND/A1300/01080A/003/2022/01031).

References

1. N.A.F.A. Samad, N.A. Jamin, S. Saleh. Energy Procedia, **138**, 313-318 (2017)
2. B.S. How, S.L., Ngan, B.H., Hong, H.L., Lam, W.P.Q., Ng, S., Yusup, W.A.W.A.K., Ghani, Y., Kansha, Y.H., Chan, K.W. Cheah, M. Shahbaz. Renewable and Sustainable Energy Reviews, **113**, 109277 (2019)
3. W.C., Kuo, J., Lasek, K., Słowik, K., Głód, B., Jagustyn, Y.H. Li, A Cygan. Energy Conversion and Management, **196**, 525-535. (2019)
4. K.A. Al-attab, and Z.A Zainal. Biomass Conversion and Biorefinery 1-11 (2021)

5. K.Q., Tran, M.Z., Alonso, L. Wang, and Ø Skreiberg, Energy Procedia, **105**, 787-792 (2017)
6. M.T., Islam, J.L. Klinger, and M.T Reza, Chemical Engineering Journal, **452**, 139419 (2023)
7. M.I., Ahmad, M.S.M., Rasat, M.F.M., Amin, P., Elham, M.A., Abas, H. Lateh, and M.A.M Amin, *Torrefaction of Empty Fruit Bunch (EFB) fibres adopted in modified microwave.* In IOP Conference Series: Earth and Environmental Science 42, 1. IOP Publishing (2021)
8. J.S., Tumuluru, B., Ghiasi, N.R. Soelberg, and S Sokhansanj. Frontiers in Energy Research, **9**, 728140 (2021)
9. P. Grammelis, N. Margaritis, and E Karampinis, Solid fuel types for energy generation: Coal and fossil carbon-derivative solid fuels. In Fuel flexible energy generation (29-58). Woodhead Publishing (2016)
10. M.I., Ahmad, M.S.M., Rasat, M.F.M., Amin, P., Elham, H. Lateh, and M.A.M Amin. *Torrefaction of empty fruit bunches (EFB) materials in modified microwave scale reactor*. In AIP Conference Proceedings **2454**, 1. AIP Publishing (2022)
11. M.I., Ahmad, W.N.K.W., Jusoh, Z.I., Rizman, M.S.M., Rasat, Z.A.Z., Alauddin, S.N.M., Soid, M.S.A., Aziz, M.Mohamed, and M.F.M Amin. Journal of Fundamental and Applied Sciences, 9 (3S): 955-968 (2017)
12. S. Basu and A.K Debnath, Power plant instrumentation and control handbook: a guide to thermal power plants. Academic Press (2014)
13. B., Gajera, U., Tyagi, A.K. Sarma, and M.K Jha Fuel Communications, **12,** 100073 (2022)
14. W.H., Chen, C.L., Cheng, P.L. Show and H.C Ong, Fuel, 251: 126-135 (2019)