*Jurnal Mekanikal*
*Dec 2017, Vol 40, 01-11*

# Manufacturing and Testing of Briquetting Fuel from Palm Oil Mill Waste

Jessica Lee Pei Chen and Farid Nasir Ani*

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
Johor, Malaysia

## ABSTRACT

*Tropical countries are producing a great amount of biomass from cultivation of crops and plants. One significant biomass is from the oil palm plantation where its availability is from the oil palm mills. Unburned biochar from oil palm shell and fibers are taken from the boiler pits and are separate for briquette production. The production of briquette using a mould and a press machine compresses the mixture of biochar and binder. An experimental study on the variation of height of briquette with the ratio of biochar to binder of 80:20, 70:30 and 60:40 were investigated on the burning rate, burning time and the maximum stove temperature when the stove airflow is fully open and half open. The results show that briquette with the lowest density and the highest height give the best burning quality with the total burning time (TBT) of 30 to 40 minutes, maximum normalized burning rate (NBR) of an average of 102% mass loss/min with the maximum temperature of approximately 260°C.*

**Keywords:** *Biomass, biochar briquette, briquetting machine, clay*

## 1.0 INTRODUCTION

Nearly half the world's population, almost all in developing countries cook using biomass solid fuels [1]. Especially remote rural communities that have no access to fuels such as liquid petroleum gas (LPG) and who depend substantially on burning collected local biomass for their energy needs [2]. Direct burning of biomass emits substantial amount of pollutants including respirable particles, carbon monoxide, nitrogen and sulphur oxides which may cause health hazards and increased greenhouse gas emission [1].

Densified biomass, also known as briquette, has been found to be a solution to these problems. It can provide an alternative household solid clean fuel and is eco-friendly [3]. Biomass residues from agriculture and industry can be found in abundance in many parts of the world, for example in Malaysia there are significant quantities of residues left over from palm nut processing [4, 5]. Fortunately for Malaysian, Malaysia's palm oil industry generates a significant amount of biomass, which the government feels should be put to better use rather than just be left in the field as fertilizer. For a long time, planters would spread the biomass that is left over after palm oil has been extracted from the oil palm fruit bunches, as a form of cheap soil conditioner.

*Corresponding author: farid@mail.fkm.utm.my

However, the Government believes such low-value material could be put to better use rather than just be left to decay in the field, even though it still serves a useful function. There is now a concerted effort to push for a more thoughtful utilization of biomass, and the most concrete manifestation of this was the unveiling of the National Biomass Strategy 2020. According to the National Biomass Strategy 2020, Malaysia's palm oil industry produced over 83 million dry tonnes of solid biomass in 2012 [6]. This volume is projected to increase to 85–110 million dry tonnes by 2020. For this experiment, the oil palm's biomass that have been converted to biochar during the incomplete combustion process in the boiler and obtained from a palm oil mill in Sg. Kachur, Johor.

There are basically three types of briquette shapes, the lump type, the log type and the cake type. This study shows the production of cake type briquette using the briquetting mould that has been designed and fabricated. The briquettes were produced using the press machine. Briquettes were burned and experimental results and data were analyse to study the effects of the height of briquette with briquette composition of 70% biochar and 30% soil clay on the normalized burning rate, total burning time and briquette maximum temperature. Also, the effect of composition of briquette using soil clay as binder with height of 50mm ± 2mm on the burning rate, burning time and briquette maximum temperature with two different airflow rates. Briquettes are made cylindrical with parallel holes which make this looked like beehive [7]. Briquettes can range from 30mm to 200mm in diameter and 50mm to 400mm in length [8]. The holes of the cylindrical briquettes provide an insulated combustion zone resulting in less heat transfer by radiation to the surroundings from this surface. This produces higher temperatures within the hole compared to the outer briquette surface which is in contact with the atmosphere [9]. The Legacy Foundation, suggest that the best shape to make a briquette is a cylinder with a central hole, commonly known as a holey briquette [10]. They suggest that the central hole acts as an insulated combustion chamber as well as a 'mini-chimney', giving a draught to drive the combustion and that its presence greatly improves the performance of the combustion compared to not having a hole. Another explanation that has been suggested to explain the difference in NBR, is a chimney effect, where the presence of the central hole draws more oxygen by natural convection causing a hotter burn and a faster rate [11]. The central hole effectively provides an insulated combustion zone. Less heat transfer by radiation to the surroundings from this surface produces higher temperatures within the hole compared with the outer briquette surface, which is exposed to the ambient radiant field.

Clay is widely available at almost no cost in many areas. A briquette can contain about 15% of clay. Clay does not add to the heating value of the briquette [12]. Chin and Siddiqui carried out an experiment on briquettes at modest pressures of 5±7 MPa so that the briquettes could be pressed manually using a hand press and states that the greater the quantity of binder used in the manufacturing, the greater the resulting stable briquette density, durability and sheer strength of the briquettes. For this experiment, clay soil is used as binder [13]. Chin and Siddiqui also proposed a relationship between the dwell time or hold time and the combustion rate of a briquette where valid up to the maximum dwell time for the most stable briquettes. The dwell time remains constant throughout the study. Choosing a hold time of greater than 40 seconds, means, that there does not need to be any more rigorous control of this variable to manufacture briquettes of repeatable density [14]. The effect of pulp moisture content on the briquettes' final density was minimal since the compressed water was squeezed out until an equilibrium reaction force is attained at a particular pressure. After forming, the briquettes were oven dried at 105°C to reach 0% moisture content [15].

## 2.0 METHODOLOGY

### 2.1 Biochar and Binder

The unburn biochar of the oil palm shell and fibres were taken from the oil palm mill boiler's pits and was separated using a sieving process. The clay soil was used as the binder for the briquette, it was dried and sieved to remove unwanted materials.

### 2.2 Stove

Traditional clay stove was used in the experiment. The airflow door is at the bottom side of the stove which allows the air flow during the burning of briquette. The door was either fully open or half open during the burning experiments. The inner dimension of the stove affects the dimension of the briquette as the briquette produced need to fit appropriately in the stove. The stove's grate is located 7 cm from the inner base of the stove with a diameter of 14.5 cm.

### 2.3 Briquetting Mould

The briquetting mould plays a significant role in the briquette production during the compression process as it gives the shape of the briquette. The briquette mould was fabricated using high tensile steel. The briquetting machine consists of four parts, the top plate (a), bottom plate (b), main cylinder (c) and the base plate (d) as shown in Figure 1. The briquette's diameter is 140 mm, which reassemble the cake type briquette. The plate thickness is 10 mm and consists of 25 holes of 15 mm diameter to fit the 25 bars from the base plate.

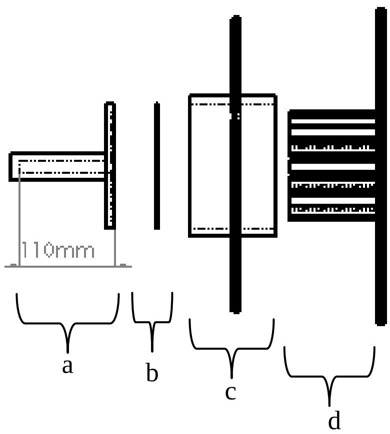



**Figure 1**: Fabricated briquetting machine

### 2.3 Composition and Height of Briquettes.

The effect of composition or the weights of bio-char to binder ratio of briquettes were investigated. The binder that was used throughout the experiment was the filtered clay soil. The data for analysing the NBR, TBT and maximum temperature of briquette are obtained through the burning test. The weight ratio of the bio-char to binder of 80:20, 70:30 and 60:40 were fixed. The other fixed parameters for this study were, the height of briquette (~50 mm), die compression pressure of 7 MPa and dwell time of 10 minutes.

In the second study, the effect of height was investigated, the amount of weight of the final mixture that is poured in the briquetting machine for compression plays the role in resulting different heights of the briquette. The burning test was carried out to study its effects of burning rate with fully open airflow setting. The fixed parameters for this study are, the weight ratio of bio-char to binder which was set at 7:3, die compression pressure of 7 MPa and a dwell time of 10 minutes.

## 2.4 Procedures

The production of briquette was carried out by mixing the biochar and binder with a control amount of water which is then poured into the mould. It was then placed under the press machine with a constant pressure of 7.0 MPa and a dwell time of 10 minutes. The briquette was then removed from the mould and oven dried for 24 hours at 105°C to achieve the lowest moisture content [15]. Once the briquette was dried, it is ready for the burning test to obtain the NBR, TBT and maximum temperature. Thermocouple and mass balance were connected to the data logger as shown in Figure 2. A fire starter was lighted above the grate and the briquette was placed slowly above it. A thermocouple was placed at 50 mm above the centre of the briquette [16]. The temperature and mass loss were recorded at every minute interval till the recorded temperature decreases to 100 °C.

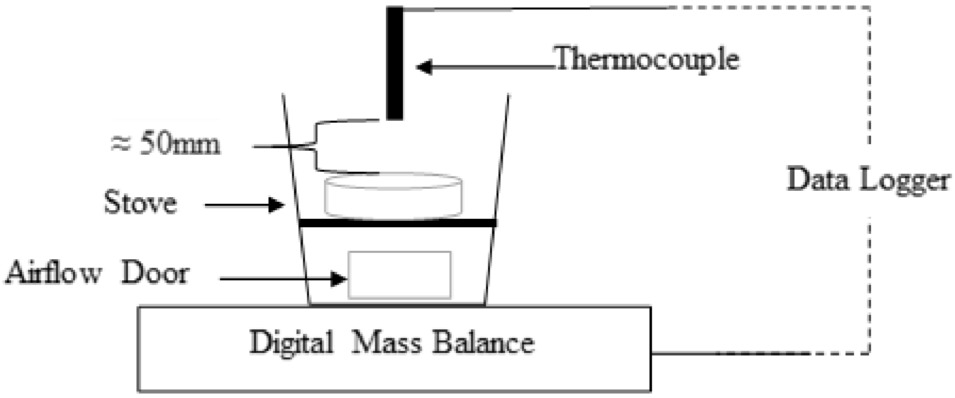



**Figure 2**: Schematic diagram of burning test

## 2.5 Calculation and Measurement

A stereometric method based on Rabier *et. al*. (2006), was used to determine briquette density. In this stereometric method, the briquettes were weighed using a mass balance, which had a precision of ± 0.01 g and the height of each briquette was measured in four positions (90° to each other around the sides of the briquette).

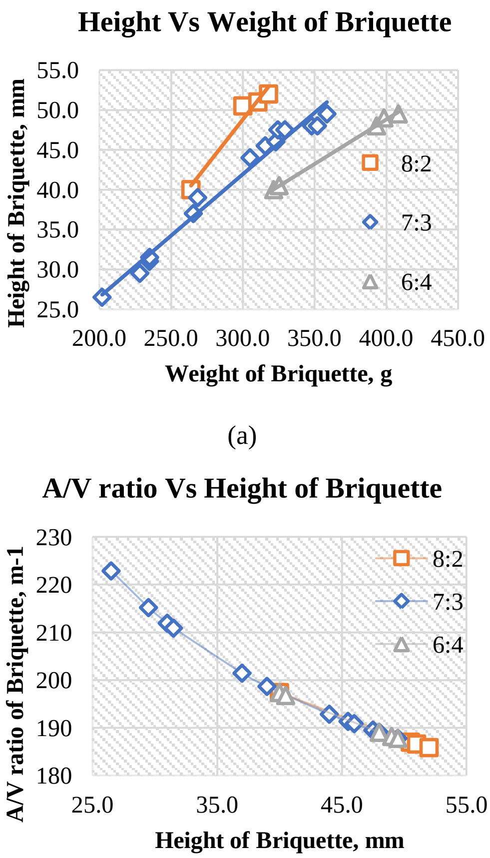
The volume and area with the average measurement of briquette was then calculated and the density was then determined. The total burning time is the time taken to burn whole briquette from 100% initial weight to the maximum weight loss [7]. There are three distinct phases of burning. Phase (1) is the ignition phase, phase (2) the steady state flaming combustion phase and phase (3) when the flame dies [15]. The normalized burn rate (NBR) can be calculated during the second burning phase by determining the gradient of the face which is the percentage loss of the initial briquette mass against time as shown in Equation (1).

$$Normalized\ Burn\ Rate = \frac{Percentage\ of\ Initial\ Mass\ Loss}{Time\ Taken} \quad (1)$$

# 3.0 RESULTS AND DISCUSSION

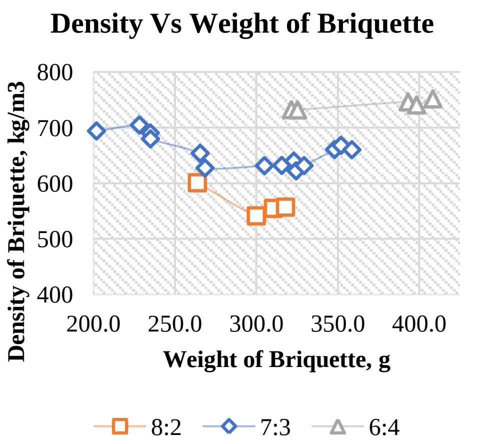
## 3.1 Characteristics of Briquettes

A total of 23 sample briquettes were produced. The area and volume of briquette were calculated to obtain the area/volume (A/V) ratio. Based on the A/V ratio against height of briquette as shown in Figure 3(a), it could be seen that as the height of the briquette increases the A/V ratio of briquette decreases. Similar finding was obtained by Chaney *et al.* [15]. Thus, the A/V ratio is inversely related to the height of briquette. The height of the briquette is related to its weight where the height of briquette is linearly proportion to the weight of the briquette. As the weight of the briquette increases, the height of briquettes increases as well, as shown in Figure 3(b). Therefore, the height of the briquette can be controlled by manipulating the weight of the mixture during the production stage. The density however does not have any linear or proportional relationship to the weight nor the height of briquette as shown in Figure 4 (a). Density against weight and height of briquettes as given in Figures 4(a) and 4(b) respectively, show that briquettes with higher content of soil clay have higher density. This is because of clay soil are heavier than biochar. The result showed the briquette composition of B:C = 6:4 have the highest density, followed by B:C = 7:3 and finally B:C = 8:2.

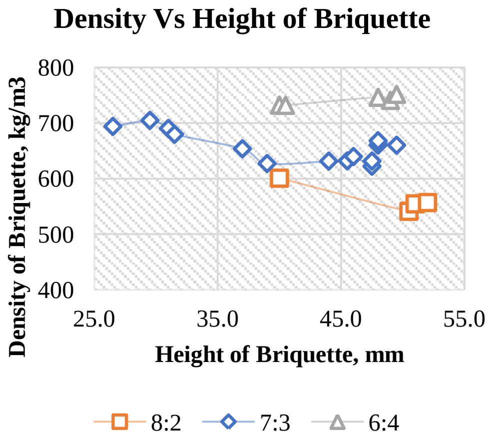



(b)

**Figure 3**: (a) The A/V ratio of briquette against height and (b) The height of briquette against weight of each briquette with its respective compositions of B:C = 8:2, B:C = 7:3 and B:C = 6:4



(a)




(b)

**Figure 4**: The density of briquette against (a) weight of briquette and (b) height of briquettes with its respective compositions of B:C = 8:2, B:C = 7:3, and B:C = 6:4.

### 3.2 Effect of Weight Ratio of Bio-Char to Binder of Briquette

Five samples with height of briquettes of 50 mm ± 2 mm were burned accordingly and the data were recorded. Table 1 and Figures 5 and 6 show that briquette with the lowest density or highest content of biochar which is the briquette composition of B:C = 8:2 produce the highest NBR and maximum temperature followed by briquette composition of B:C = 7:3 and B:C = 6:4. These are confirmed by Mandal *et al*. [16] where the samples with the highest NBR are the samples with the lowest density, highest char content and the lowest clay soil content. Higher NBR and temperature give lower TBT.

There is some differences in the burning quality as shown in Figure 5 for briquette composition of B:C = 6:4 as compared to the other two compositions. This is due to the high content of clay soil which affects the combustion for higher density briquettes. This slows the process of burning in the first ignition phase and took a significant longer time for the combustion phase. This is agreeable with Mandal *et al*. [7], where the slow propagation of combustion through the briquette mass and less availability of oxygen led to slow burning of the briquettes of higher density

Figures 5 and 6 indicate that when only half air flow is allowed; decreasing airflow, decreases the NBR and the maximum temperature achieved. This eventually increases the TBT. This is the result of lesser oxygen available for combustion causing the briquette to not reaching its optimum burning quality.

**Table 1**: NBR, TBT and maximum temperature for briquette compositions of B:C = 8:2, B:C = 7:3, and B:C = 6:4 and B:C = 6:4 [7]

| B:C | NBR (%initial mass/min) | | TBT to reach 70% initial weight (min) | | Max. Temperature (°C) | |
|---|---|---|---|---|---|---|
| | Full Open | Half Open | Full Open | Half Open | Full Open | Half Open |
| 8:2 | 1.209 | 1.117 | 33 | 39 | 269.3 | 247.7 |
| 7:3 | 0.999 | 0.962 | 37 | 54 | 250.6 | 214.2 |
| 6:4 | 0.138 | - | 57 | - | 176.8 | - |
| 6:4* | 0.706 | - | 40 | - | 572.0 | - |

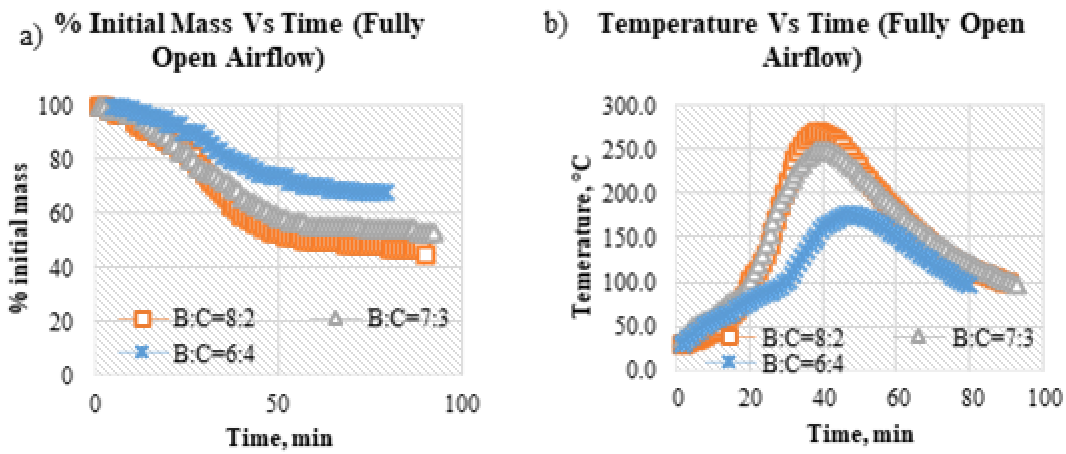
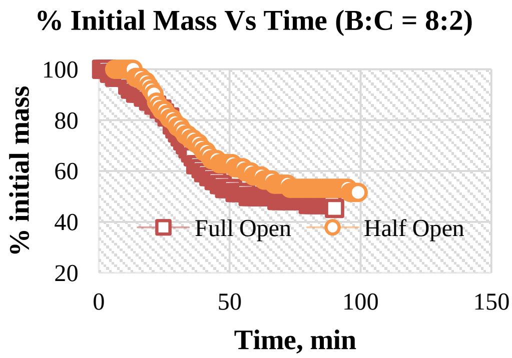
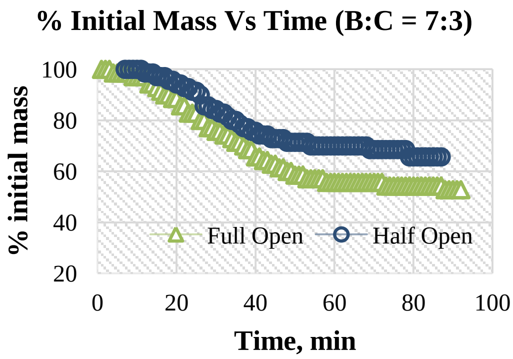



**Figure 5**: (a) The percentage of initial mass and (b) The temperature of briquette for fully open airflow with briquette compositions of B:C = 8:2, B:C = 7:3, and B:C = 6:4.

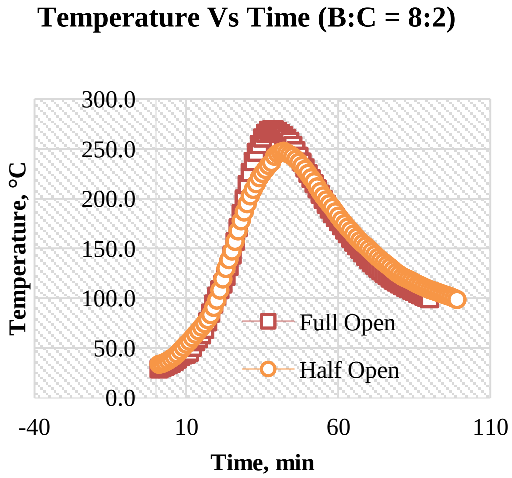



(a)

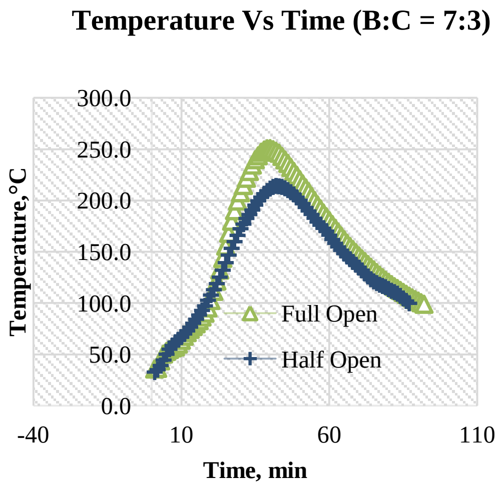



(b)

**Figure 6**: The percentage of initial mass in comparison to fully open airflow and half open airflow for briquette composition of (a) B:C = 8:2 and (b) B:C = 7:3




(a)




(b)

**Figure 7**: The temperature of briquette for fully open airflow and half open airflow considering a briquette composition of (a) B:C = 8:2 and (b) B:C = 7:3

### 3.3 Effect of the Height of Briquettes

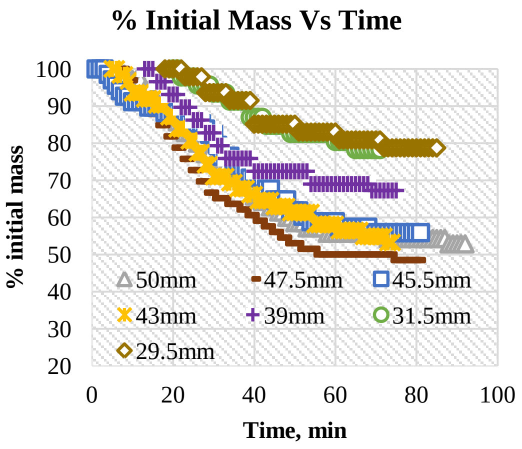
Seven samples with composition of B:C = 7:3 and height of briquette from approximately 29 mm to 50 mm were tested. The effects of height of briquettes have shown that the density of briquettes plays a significant role in burning quality. The effect of density on the burning quality, showing the effect of A/V ratio of briquettes as shown in Table 2 and Figure 3. As shown in Table 2, the value of NBR and maximum temperature of briquette fluctuates with increasing height of briquette. This is because the density is not constant as shown in Figure 4(b). A/V ratio decreases as height increases. However, density fluctuates as height of briquette increases, causing the value of NBR to fluctuate.

**Table 2**: Samples of briquettes with their respective height, density, A/V ratio, NBR, maximum temperature and TBT.

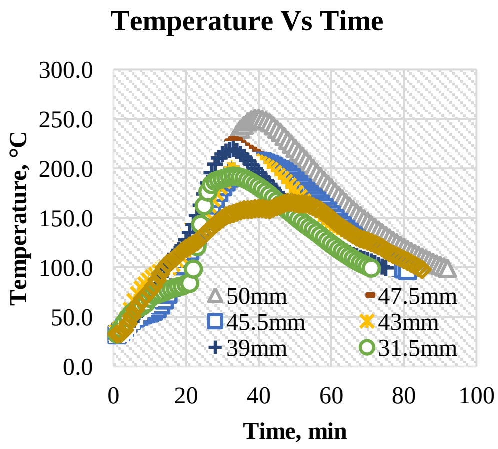
| Sample No | S18 | S4 | S9 | S5 | S 6 | S13 | S20 |
|---|---|---|---|---|---|---|---|
| H (mm) | 29.5 | 31.5 | 39 | 43 | 45.5 | 47.5 | 50 |
| ρ (kg/m$^3$) | 705 | 680 | 627 | 632 | 632 | 622 | 660 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **A/V Ratio ($m^{-1}$)** | 215.202 | 210.898 | 198.688 | 192.861 | 191.362 | 189.511 | 187.810 |
| **NBR (%/min)** | 0.545 | 0.640 | 1.043 | 1.004 | 0.920 | 0.983 | 0.973 |
| **Max. Tem. (°C)** | 165.9 | 192.3 | 219.5 | 207.1 | 207.3 | 229.5 | 250.6 |
| **TBT (min)** | 72 | 60 | 31 | 26 | 31 | 20 | 28 |

Figures 8(a) and (b) show the effect of percentage initial mass and temperature with time. The first shows a downward trend for all briquette heights whereas the latter exhibits a more normal curve characteristic for all heights. Figure 9 depicts the NBR against A/V ratio of briquette for all samples.




(a)




(b)

**Figure 8**: (a) The percentage of initial mass of briquette against time and (b) The temperature of briquette against time for briquette height between 29 mm and 50 mm

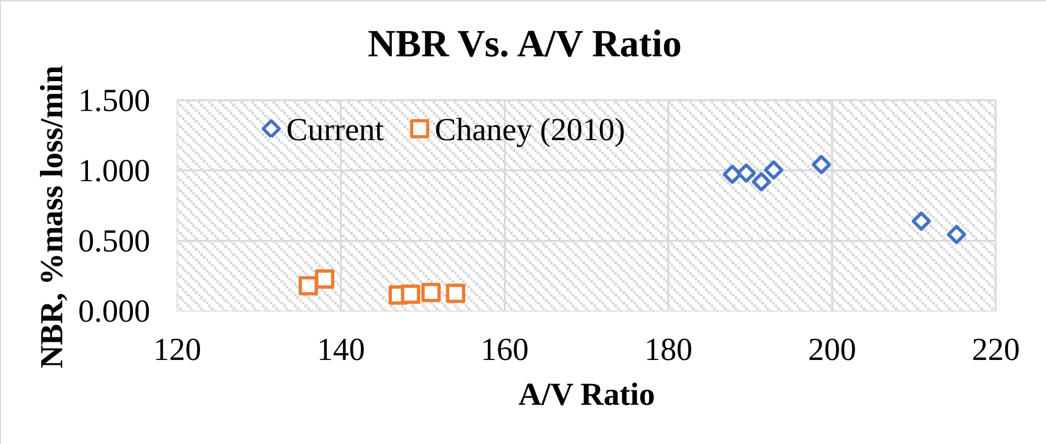



**Figure 9**: NBR against A/V ratio of briquette for all samples

Figure 10 shows the exponential lines of A/V ratio which simplified the data for easier understanding of the density effect on NBR. For briquettes with the highest density with A/V ratio ranges from 213 $m^{-1}$ ±2.5 gives the lowest NBR. The effect of A/V ratio on the burning rate can be seen by the briquettes between density 620 $kg/m^3$ and 640 $kg/m^3$ where A/V ratio range of 196 $m^{-1}$ ±2.5 have lower NBR than A/V ratio range of 190 $m^{-1}$ ±2.5. This is because higher A/V ratios have more percentage of surface area against volume expose for combustion. This is in agreement with Chaney who mentioned that a solid with a large surface area will transfer more heat into the mass which it bounds more quickly than if the surface area with smaller and longer height as more surface is expose for burning [15]. Sample No. 20, with the greatest height of 50 mm produces a high NBR. Though slightly lesser than most of the samples with lower density, it produces the highest temperature between all seven briquettes. This is due to the fact that it is greatly affected by its higher height, where there could be a possible presence of pyrolysis as holes that in turn act as a chimney. As stated by Chaney [9], the greater the height, the lower the proportion of heat radiated to the atmosphere and thus the faster the pyrolysis rate.

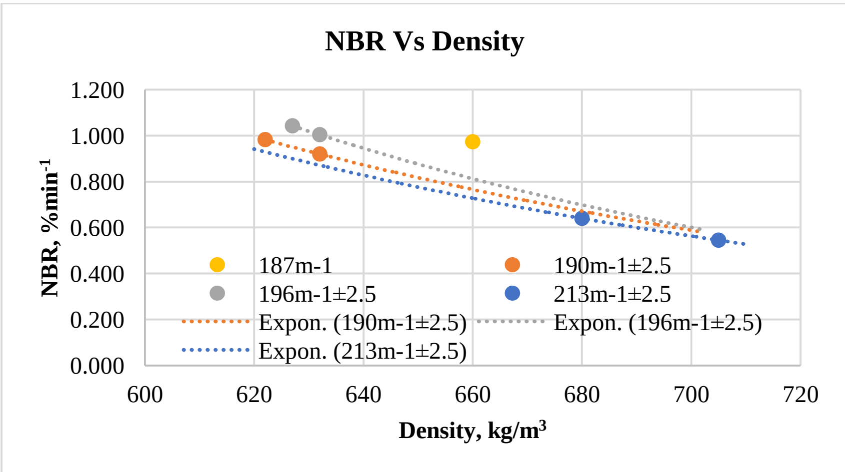



**Figure 10**: NBR against density of briquette of all samples with its respective A/V ratio

## 4.0 CONCLUSION

The experimental study on the production of briquetting fuel from palm oil mill biochar and soil clay as binder using an indigenous briquetting machine has been manufactured. The briquette with the lowest amount of soil clay has the lowest density as soil clay is heavier than biochar, produces the highest NBR, highest maximum temperature, but lowest TBT. Limiting air flow produces longer TBT but decreases NBR, and the maximum temperature. The briquette with higher NBR and maximum temperature could transfer heat at a faster rate and for a longer period. For briquettes, with lower value of density, higher briquette height which has lower A/V ratio produces lower NBR. Lastly, higher briquette height gives higher temperature.

## REFERENCES

1. Bruce N., Perez-Padilla R. and Albalak R., 2000. Bulletin of the World Health Organisation, 78(9): 1078–1092.
2. Amous S., 1999. *The Role of Wood Energy in Africa*, Technical Report, FAO.
3. Grover P.D. and Mishra S.K., 1996. Biomass Briquetting: Technology and Practices, Field Document No. 46, Regional Wood Energy Development Programme in Asia, Food and Agriculture Organization of The United Nations, Bangkok.
4. Ani F.N., 2016. Sustainable Biofuels and Other Related Bio-Products from Palm Cultivations, *3rd International Conference on Mechanics and Mechatronics Research (ICMMR 2016)*, MATEC Web of Conferences, 77, Article No. 11005.
5. Husain Z., Zainac Z. and Abdullah Z., 2002. Briquetting of Palm Fibre and Shell from The Processing of Palm Nuts to Palm Oil, *Biomass and Bioenergy*, 22:505–509.
6. Agensi Inovasi Malaysia (AIM), 2013. National Biomass Strategy 2020: New Wealth Creation for Malaysia’s Biomass Industry Version 2.0.
7. Mandal S., Kumar A., Singh R.K. and Ngachan S.V., 2012. Evaluation of Composition, Burn Rate and Economy Beehive Charcoal Briquettes, *J. Agric. Engg*., 5(2):158-162.
8. Olorunnisola A.O., 2004. Briquetting of Rattan Furniture Waste, *Journal of Bamboo and Rattan*, 3(2):139-149.
9. Chaney J.O., 2010. *Combustion Characteristics of Biomass Briquettes*. The University of Nottingham.
10. Legacy Foundation, 2010. Fuel Briquette Making, A User’s Manual, http://www.legacyfound.org.
11. Legacy Foundation, 2003. Fuel Briquettes-Theory and Applications from Around the World, http://www.legacyfound.org.
12. Zhengzhou Azeus Machinery, 2018. Binder and Additives Selection for Briquetting Plant, http://www.charcoalbriquettemachine.com/Application/binders-for-charcoal-briquettes.html.
13. Chin O.C. and Siddiqui K.M., 2000. Characteristics of Some Biomass Briquettes Prepared under Modest Die Pressures, *Biomass & Bioenergy*, 18:223-228.
14. O'Dogherty M.J. and Wheeler J.A., 1984. Compression of Straw to High Densities in Closed Cylindrical Dies, *Journal of Agricultural Engineering Research*, 29:61-72.
15. Chaney J.O., Clifford M.J. and Wilson R., 2008. An Experimental Study of the Combustion Characteristics of Low-Density Biomass Briquettes, *Procs. of the 3rd Int Conf. on Appropriate Tech*., Kigali, Rwanda, November 12–15
16. Mandal S., Kumar A., Singh R.K., Ngachan S.V. and Kundu K., 2014. Drying, Burning and Emission Characteristics of Beehive Charcoal Briquettes: An Alternative Household Fuel of Eastern Himalayan Region, *Journal of Environmental Biology*, 35:543-548.