Physical Characteristic of Briquette Charcoal Derived from Carbonization of Food Waste via Microwave Technique

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***Abstract*— Food waste disposal at the landfills is a crucial problem to government and people in Malaysia since the landfills is unable to support big amount of food waste anymore. An alternative solution is by transforming the food waste into beneficial product such as briquette charcoal using microwave pyrolysis technology. This research investigates the potential of solid char from food waste to become briquette charcoal with addition of binder. The main objective in this study is to investigate the effect of binder and blending ratio on briquetting ability of food waste charcoal in terms of the physical characteristic and energy content. Microwave pyrolysis method was used to convert food waste into fully pyrolysed solid char under parameter: 30 minutes of radiation time, 1000 W microwave power, 200 ml/min nitrogen flow and mass loading of 200g. Binders involve in this research are starch and carboxymethyl cellulose (CMC). A good quality of charcoal briquette has capability to withstand impact during packaging, handling and transportation. Standard physical characteristic that were tested for briquette includes moisture content, compressive strength and impact resistance. Calorific value of briquette was studied to analyze energy content in the briquette. Thus, briquette charcoal with 10% CMC (S3) is the most ideal to become a quality briquette due to its suitable calorific value (21.171 MJ/kg), moisture content (6.2312%), compressive strength (0.813 MPa) and impact resistance (99.81%). This finding is beneficial for briquette industry in the development of green product using biomass, but further research is essential before production of briquette take place.**

***Keywords*— Briquette, Food waste, Microwave pyrolysis**

I. INTRODUCTION

Recently, green technology is vital to Malaysia since environmental issue keep blooming throughout the years. Pollution rapidly occurs from land, water to the air due humans act. Common environmental deterioration in this country are Deforestation and landfill.

Landfill in Malaysia become a crucial environment issue because of improper municipal solid waste (MSW) management since a long time ago. According Fauziah et al.,[1], disposal of MSW into the landfills is more than 10.40 million tonnes annually. MSW can be classified into two categories which are organic and inorganic. Example for organic materials are food waste and wood waste. About 50% of MSW comes from food waste that are disposed at the landfill sites as stated by Nadzri et al.,[2].

Food waste can be defined as food that is lost uneaten or throw away throughout food supply chain. Typical disposal of food waste is at landfill. However, this method causes a lot of environmental issue which are greenhouse effect, soil pollution and air pollution. Continuation of these unsolved problem, many research have been developed technology on converting waste product into useful product that not harmful to the environment. One of greatest innovation is microwave pyrolysis whereby organic and inorganic waste transformed into three phase; solid char, liquid and gas.

According to Fernandez et al.,[3], microwave heating has the ability in reducing waste volume, energy saving, rapid heating and low pollution compared to conventional heating. As indicated by Januri et al.,[4] microwave pyrolysis is great method to treat kitchen waste since it can handle high moisture content waste. Hence, it is important to conduct research on production of solid char from food waste via microwave pyrolysis to study its potential as charcoal briquette product.

This study is mainly about investigating the effect of binder and blending ratio on briquetting ability of food waste charcoal in terms of the physical characteristic and energy content. The sample will undergo carbonization process via microwave pyrolysis, mixing, briquetting and drying. Binders involve in this research are starch and carboxymethyl cellulose (CMC). Physical tests will be conducted on the charcoal briquette are moisture content, compressive strength and impact resistance. Thus, the ideal binder with blending ratio can be determined at the end of the research.

II. METHODOLOGY

A. Sample collection and preparation

Food waste was collected from restaurant in Seksyen 7, Shah Alam. It was collected and kept in a sealed plastic bag to reduce contamination of microorganisms in the food waste. Time of collection was about 3 days to prevent the waste from being rotten which may affect the experimental result of this research. Food waste consist of vegetables, rice, egg, fish and chicken meat. The proportion of the food waste were 1/3 of rice, 1/3 of vegetables and 1/3 of meat/egg/fish.

B. Binder for briquette

A binder is used to ensure strong structure of charcoal briquette produced by increasing charcoal adhesion. Binder used for briquetting food waste char are starch and carboxymethyl cellulose (CMC). Starch is a well-known binder in charcoal briquette industry while CMC is a new potential binder to be tested for this industry. Percent of each binder are 5%, 10%, 15% to the food waste char. The effect of different binder and blending ratio on the physical properties of charcoal briquette will be studied in this research.

C. Carbonization

Food waste sample undergo carbonization process to produce char via microwave pyrolysis with condition: 200g sample loading, 1000 W microwave power, 30 minutes of radiation time, and 200ml/min of nitrogen (N_2) flow. Next, the char was grinded into powder using grinder machine for 15 minutes. Fine particles of food waste char have high surface area and give a good structure of charcoal briquetting. A dust mask must be wear during grinding session to prevent the inhalation of fine particles.

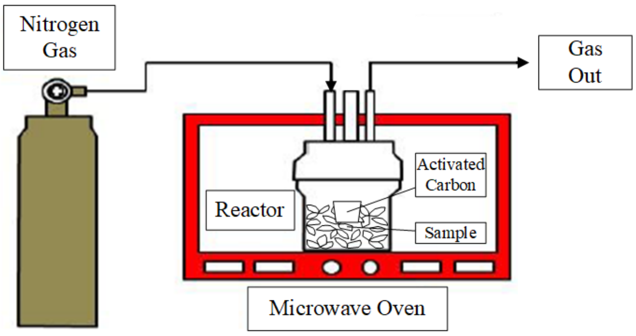

Fig. 1: Experimental setup for microwave pyrolysis process [4]

D. *Mixing*

Adhesion of char was improved by addition of binder. The char powder mixed with different binder and blending ratio. Initially, starch and CMC binder will be mix with food waste char according to their blending ratio. Next, about 50% water/char was added to the sample and stir homogenously. Seven samples mixed char were obtained from this research. Only one sample (S1) does not mix with any binder and remain pure food waste char. Percentage binder used in the mixture are 5%, 10% and 15%.

Table 1: Process parameter of each sample

Sample	**Raw material**	**Type of binder**	**Percentage of binder (%)**
S1	Food waste char	-	-
S2	Food waste	CMC	5
S3			10
S4			15
S5		Starch	5
S6			10
S7			15

E. *Briquetting*

All mixed char samples undergo briquetting process using 20-ton load compression machine. The charcoal briquette was then going for drying process with condition: temperature of the oven was 105°C, drying time was 5 hours. The dried charcoal briquette undergo energy content analysis and physical testing which were moisture content, compressive strength and impact resistance.

F. *Energy content analysis*

Energy content of food waste can be determined by evaluating calorific value. Calorific value is the amount of heat released by complete combustion of a substance. A good briquette charcoal should have high calorific value to ensure sufficient heat produced during combustion process. Seven samples (S1 to S8) were analyzed using bomb calorimeter model IKA WORKS/ C5000 Control Germany D79019.

G. *Moisture Content analysis*

Moisture content is one of important aspect to charcoal quality. Too high moisture will make the charcoal difficult to ignite fire. Moisture content recommended for charcoal briquette is from 5% to 10%. The moisture cannot be too low due to easily fire ignition during processing and transporting the briquette. Moisture content for all samples were analyzed using proximate analysis.

H. *Compressive strength analysis*

This physical test was done using universal tensile testing machine. A charcoal briquette was put onto the provided space for sample of the machine and increasing load was applied at a constant rate, until the sample cracked or breaks. Put the charcoal briquette in its weakest orientation so that the accuracy of this test can be achieved. Standard charcoal briquette in market required a minimum value of 0.375 MPa for compressive strength.

I. *Impact resistance analysis*

Drop shatter test was used to measure the sustainability of charcoal briquette shape towards repeated impact from handling and during transportation. The test started by determining weight of every briquette using weighing balance. Each sample will be dropped repeatedly (2 times) from a height of 2 metres onto a concrete floor. The largest piece of the briquette was then measured. The shattering index of briquette was determined using equation based on ASTM D440-07 (ASTM 2012).

III. RESULTS AND DISCUSSION

A. *Yield of solid char*

Yield of solid char in the process was about 12.16%. The remaining conversion were in liquid and gas form. This finding is similar with previous research done by Januri et al.,[4]. Appearances of fully pyrolysed char was discovered during the experiment. The colour of the char was black, light and porous, not smelly. Contrarily, unpyrolysed char was heavier, orange to blackish colour, and smelly. The unpyrolysed char formed when the radiation time and microwave power is not sufficient to support microwave pyrolysis process. According to Januri et al.,[4] optimum condition for microwave pyrolysis of food waste was 1000 W and 30 minutes of radiation time.

B. *Energy content analysis*

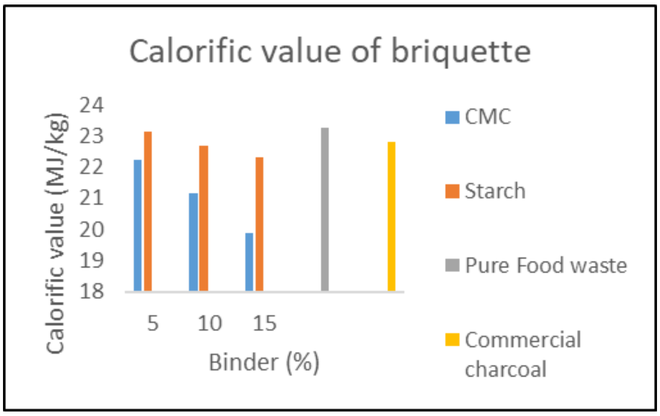

Fig. 2: Calorific value of each sample

Calorific value of each sample was obtained using bomb calorimeter instrument. Calorific value was important in determining amount of heat release per unit mass of the sample. Based on the bar chart in Fig. 2, type of binder and blending ratio indeed affecting the energy value of briquette. Pure food waste charcoal contains higher calorific value than commercial charcoal. This indicates food waste has capacity to become a quality briquette charcoal. However, pure food waste briquette does not have strong physical structure and need a binder that will help in increasing cohesion forces between particles. Cohesion forces between particles makes the briquette appearances stronger.

In terms of binder, both binder showed decreasing in calorific value as percentage of binder increased. Nevertheless, the heating values of each sample was close with commercial carbon. By comparing CMC and starch, starch can be classified as the best binder for food waste since it has higher calorific value than CMC.

Unfortunately, the trend was contradict with research done by Zubairu et al.,[5]. According to Zanella et al.,[6], a lot of substance can become a binder but the materials used must not damage energy characteristic of charcoal briquette, either decreasing calorific value or adding volume of volatile and ash content. Therefore, it can be concluded CMC and starch is not an ideal binder for food waste char because of reducing energy content of briquette but investigation on physical test will testify the overall potential of these binder.

C. Effect of binder type and blending ratio on moisture content

Table 2: Moisture content of briquette sample

Sample	Sample description	Moisture content (%)
S1	FW	8.0060
S2	FW+5% CMC	8.8880
S3	FW+10% CMC	6.2312
S4	FW+15% CMC	9.1469
S5	FW+5% Starch	3.7043
S6	FW+10% Starch	7.3114
S7	FW+15% Starch	6.8149
CC	Commercial charcoal	7.0678

Moisture content was essential in facilitate heat transfer. If the briquette contain too much moisture, it could lead to steam formation and end up with an explosion. According to data presented in Table 2, value of moisture content of briquette was ranging between 3 to 9%. Lowest yield of moisture content was from sample S5 that is 3.7043% while the highest value obtained by sample S4 that is 9.1469%. Both binder, starch and CMC showed inconsistency in moisture content value. However, most of the briquette sample was classified for good quality briquette (5-10% moisture content) as mentioned by Pallavi et al.,[7]. The trend suggested that percentage of binder did not affect the moisture content of briquette. By comparing commercial charcoal with these research samples, it can be concluded that food waste has potential as a feedstock to produce briquette and both binder are good binder.

D. Effect of binder type and blending ratio on compressive strength

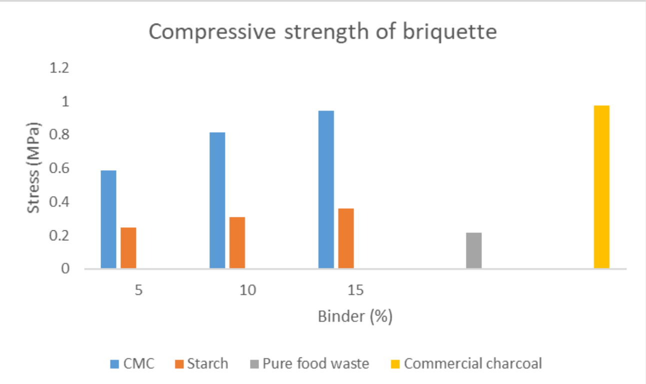

Fig. 3: Compressive strength of each sample

Investigation of resistance to compression of briquette is conducted using universal testing machine. Based on the data recorded in Fig. 3, when the percentage of binder added to briquette increased, the compressive strength of the briquette is increased. This trend is similar with the research done by Zanella et al.,[8]. Pure food waste briquette (S1) have the lowest stress compared to other sample that is 0.215 MPa. This result implied food waste must have a binder to make the briquette stronger. A binder give better adhesion between charcoal particles.

According to the data presented in Fig. 3, CMC provide greater agglomeration between particles than starch. Briquette that contain 5% CMC has stress of 0.585 MPa. Minimum requirement of compressive strength for commercialized briquette is 0.375 MPa [9]. CMC makes stronger shape of briquette than starch and can withstand physical damages during processing, handling and transporting.

Starch did not achieve minimum value of compressive strength with the percentage binder up to 15%. There are a few reasons for the unsuccessful attempt of starch to become binder for food waste briquette. First, unfavorable mixing method of the charcoal with starch. Starch can be mix with charcoal using dry and wet mixing. In this research, dry mixing is applied where water is added after mixing of starch powder and charcoal. Zanella et al.,[6] stated that initial mixing of binder and water provide better homogenization of them, and when combine with charcoal, the mixture reaches particle's pore.

Besides, there is possibility of insufficient amount of starch in the briquette due small portion of starch powder in briquette. However, adding more binder will lead to high cost of briquette production. Addition of other additive may help in producing good quality of briquette with starch. Finally yet importantly, type of starch may become main reason to the low compressive strength of the briquette. Starch used in this research is made of potato soluble. The material may not be suitable with food waste charcoal since many researcher used different type of starch succeed in making starch as a binder. This fact is supported by Borowski et al.,[10], Zanella et al.,[8] and Zubairu et al.,[5].

In conclusion, briquette sample with percentage of 10% CMC (S3) is the most ideal blending ratio in making a quality briquette due to strong compressive strength, cost effective and achieved requirement of commercialized briquette.

E. Effect of binder type and blending ratio on impact resistance

Table 3: Shattering index of briquette

Sample	Weight (gram)		Sh_{in} (%)
	Before dropping	After dropping	
S1	10.54	0.64	6.07
S2	10.96	10.88	99.27
S3	10.74	10.72	99.81
S4	9.34	9.33	99.89
S5	10.16	0.53	5.22
S6	10.15	1.94	19.11
S7	10.43	2.91	27.90
CC	131.77	131.25	99.60

Impact resistance characteristic was a key in production of briquette in terms of handling, storage and transporting. Based on the result obtained in Table 3, briquette sample that mixed with 5% starch had lowest shattering index, which was 5.22%. Highest value for shattering index gained from sample S4 that contain 15% CMC in the briquette.

By comparing starch and CMC as binder, CMC had greater shear strength than starch. High shear strength stipulated that a binder had a good capability to prevent binding substance for breakaway because of some force. This statement is supported by Cahyono et al.,[11]. When comparing briquette sample S3 and S4 with commercial charcoal, it was proven that S3 and S4 sample had better value of shattering index than commercial charcoal. This indicated briquette sample that mix with a certain portion of CMC had potential to become a good quality briquette in the future. Thus, it can be concluded, as percentage binder is increased, shattering index increased, and stronger briquette will be produced.

IV. CONCLUSION

In this study, food waste converted to solid char and mixed with certain binder to produce a briquette sample. The sample is then tested with physical testing to study the ability of the briquette to withstand impact that can make damage to its shape and structure. The physical test including moisture content, compressive strength and impact resistance. Calorific value of briquette is also being studied to analyze energy content in the briquette. In conclusion, biochar of food waste mix with 10% of CMC is the best potential mixture to become a quality briquette due to its strongest physical strength and calorific value. This study of briquette charcoal from food waste should be expand to combustion characteristic area to ensure the capability of the briquette before implementing large-scale production.

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