THE EFFECT OF VARIOUS CARBONIZATION TEMPERATURE AND DURATION ON THE FOOD USING MICROWAVE FOOD WASTE CARBONIZER

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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LIST OF ABBREVIATIONS

ΔU	Change in internal energy
q_{syst}	Heat transfer to the system
q_{surr}	Heat transfer to the surrounding
C_{cal}	Heat capacity of the calorimeter
ΔT	Change in temperature
q_{fuel}	Energy content of fuel
q_{paper}	Energy content of paper
$q_{fuse\ wire}$	Energy content of fuse wire
C_{pwater}	Specific heat capacity for water
T_{corr}	Corrected temperature
m_w	Mass of water
m_{ew}	Mass of water equivalent
m_{fuel}	Mass of fuel
Q_{fuel}	Heating value of fuel
m_{paper}	Mass of tracing paper
Q_{paper}	Heating value of tracing paper
$\Delta L_{fuse\ wire}$	Change in length of fuse wire
$Q_{fuse\ wire}$	Heating value of fuse wire
T	Temperature
t	Time
$l_{initial}$	Initial length of fuse wire
l_{final}	Final length of fuse wire
V	Volume

ABSTRAK (BM)

Sisa makanan merupakan salah satu cabaran yang dihadapi oleh dunia ini. Sisa makanan juga merupakan sejenis biomas yang boleh menjadi sumber yang berharga apabila ia diuruskan secara munasabah dan berkesan, kesan buruk terhadap alam sekitar juga akan dikurangkan. Terdapat banyak cara untuk merawat sisa makanan, salah satu cara ialah karbonisasi mengunakan gelombang mikro. Karbonisasi mengunakan gelombang mikro adalah salah satu proses termokimia baru di mana biomassa disinari dengan gelombang mikro dan biomas akhirnya akan diubah menjadi sumber lain seperti arang atau biogas. Dalam kajian ini, suhu 260 ° C - 340 ° C dan tempoh pengkarbonan selama 30 minit dan 1 jam akan digunakan.

Sebuah ketuhar gelombang mikro telah diubahsuai dan digunakan untuk menjalankan karbonisasi dan kentang digunakan sebagai spesimen untuk eksperimen. Produk terbentuk dari suhu dan tempoh karbonisasi yang berbeza diperhatikan dan dibandingkan. Kebanyakan kentang masa pengkarbonan selama satu jam adalah berkarbonasi sepenuhnya manakala untuk tempoh 30 minit, kentang tidak berkarbonasi sepenuhnya. Selain itu, nilai pemanasan untuk produk dianalisis dan dibandingkan. Nilai-nilai pemanasan meningkat apabila suhu karbonisasi meningkat.

ABSTRACT

Food waste is one of the challenges faced by the world's food system. Food waste is also a type of biomass which can become a valuable resource when it is managed reasonably and effectively, whilst reducing the impact on the environment. There are many ways to treat the food waste, one of the method is microwave carbonization. The microwave carbonization of biomass is one of the novel thermochemical process in which biomass is irradiated with microwave and the biomass eventually will convert to other resources such as biochar or biogas. In this study, temperature of 260° C - 340°C and carbonization duration of 30mins and 1hour will be used.

A microwave oven has been modified and is used as a carbonizer to conduct the experiment and potatoes are used as specimen for the experiment. The products formed from different carbonization temperatures and durations are observed and compared. Most of the potatoes of one-hour carbonization time are fully carbonized whereas for those of 30 mins duration, the potatoes were not fully carbonized. Besides that, the heating values for the products are analyzed and compared. The heating values calculated show an increasing trend as the carbonization temperature increase.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Biomass carbonization is one of the thermo-chemical process to decompose biomass with heat in the absence of oxygen. It is divided into 4 stages. In the first stage, biomass is heated to completely remove the water inside the cell and the water will transformed into non-pungent and non-harmful vapor. In the second stage, the volatiles are removed by heating the biomass and the hemicelluloses will fully decomposed. The yield from this stage is of pale gray color consisting of CO, CO_2, acetic acid, and methanol. Thirdly, the derived biomass will convert into char. The biomass will undergo self-decomposition through the endothermic reaction. The celluloses in the will decompose rapidly. Then, lignin decomposes at a certain temperature. Beyond certain temperature, biomass will fully convert into char. In the final stage, tar is removed to improve the char quality. Although biomass becomes char after approximately 400 °C, high quantity of tar will remain in the char. Tar will causes the char to be of low quality and, once burned, changes into benzopyrene and dibenzanthracene, both of which are dangerous to health. Therefore, char can be dried at high temperature for a period of time to remove tar [1].

The microwave carbonization of biomass is one of the novel thermochemical process in which biomass is irradiated with microwave. The microwave carbonization process has more advantages compared to traditional carbonization process, such as uniform internal heating biomass, ease of control, and saving of time and heat energy. As such, the microwave carbonization is therefore adopted by industries. The microwave heating causes the heat to originate from inside the materials and migrates outward. Recent research studies on the thermochemical process of biomass with the application of microwave heating have been reported and the research results suggest that this heating method is suited to distributed conversion of large biomass particles [2-5].

1.2 Project Background

Wasted food is one of the challenges faced by the world's food system. Food waste can be described as food materials produced for human consumption but left uneaten, either lost or discarded throughout the food supply chain, from farm to fork. It is organic waste discharged from various sources including food processing plants, and domestic or commercial kitchens, cafeterias and restaurants [6]. Other terms can be used interchangeably, such as food loss, biowaste, and kitchen waste [7]. Malaysian generate 38,000 tonnes of waste per day and around 15,000 of the waste are food waste, 3,000 tonnes the food waste are still edible which mean still fit for consumption and should not have been discarded [8]. The study also found that a household of five spent an average of 210 USD a month on food and that a quarter of that food was wasted during preparation, cooking and usage.

However, food waste is also a type of biomass which can become a valuable resource when it is managed reasonably and effectively, whilst reducing the impact on the environment [9]. There have been many studies on treatment of municipal solid waste. Food waste also one of the municipal solid waste but it has the feature of high moisture, salinity, organic and oil content, which requires different methods of treatment from the normal municipal solid waste [10]. Landfill is a traditional treatment method to treat the waste but it has the disadvantages of requirements on large area of land and will release large amount of greenhouse gas. At present, landfilling is the main method of waste disposal in Malaysia. This method is expected to reduce to 65% in 2020 (Waste Management Policy of Malaysia 10th Plan, 2010 to 2020).

Diverting food waste from landfills will not only conserve limited landfill space, but also help to reduce greenhouse gas emissions [11]. Carbonization is one of the treatment that can divert the food waste from landfill. Carbonization is a thermochemical process also called pyrolysis which is the breakdown of complex substances into simpler ones by heating. Carbonization is the term used when complex carbonaceous substances such as food waste are broken down by heating into elemental carbon and chemical compounds which may also contain some carbon in their chemical structure [12]. The carbonized residue remain after the carbonization process is called biochar. The biochar resulting from the carbonization of food waste contained higher energy content (> 25 MJ/kg) compared to the food waste, so the biochar can be use as fuel [13].

1.3 Problem Statement

Food waste problem show an increasing trend in recent years. Food waste will eventually end up in landfills produce a large amount of methane which is a more powerful greenhouse gas than CO_2. Composting the food waste is one of the way to treat the food waste but it take a very long time and will produce unwanted odor. Microwave carbonization is a good way to treat the food waste as it takes shorter time to treat food waste and will not produce any odor.

1.4 Objectives

Microwave carbonization is a good way to treat the food waste as it can convert the food waste to biochar which has a high energy content that can use as fuel. In this project, a microwave food waste carbonizer will be developed. The following are the objectives of the study.

1. To design and develop a microwave food waste carbonizer.
2. To investigate the effect of the temperature and carbonization time to the product formed.
3. To determine the heating value for the product formed.

CHAPTER 2

LITERATURE REVIEW

2.1 Biomass

Food waste is a type of biomass which are organic materials derived from living organisms which mainly consist of carbon, hydrogen and oxygen. All water and land-based vegetation and tress, or virgin biomass, and all waste biomass such as municipal solid waste, municipal bio-solids (sewage) and food wastes are examples of biomass materials. By using biomass fuel instead of fossil fuel to as fuel to generate energy, the greenhouse gas emission and harmful emission such as oxides of nitrogen and oxides of sulfur from the combustion will be reduced [14].

According to the Key World Energy Statistics 2017, in 2015, biofuels and waste (9.7%) is the fourth largest energy supply after oil (31.7%), coal (28.1%) and natural gas (21.6%) [15]. Together with its potential to be processed into different energy carriers, it has become the largest and most important renewable energy option at present. Utilizing waste biomass for biochar production is a reasonable option as these waste feedstocks do not have any economic value [16]. Biomass possess the potential to substitute fossil fuels but several properties of biomass materials have restraint its utilization as the main energy source.

According to Table 1, in the untreated form, biomass has relatively low energy density and high moisture content compared to fossil fuel. To generate the same amount of energy from fossil fuel, massive amount of biomass will be needed [18]. High moisture and volatile matter content are the main disadvantages of burning biomass, as these lead to poor combustion efficiency and high harmful emissions when directly combusted [19].

Table 1: Elemental analysis raw biomass and biochar of kitchen waste and raw potato [17]

Sample of raw biomass	Kitchen waste		Raw potato	
	dried sample	original sample	dried sample	original sample
Water (% wt.)	0.00	72.85	0.00	76.80
Ash (% wt.)	3.07	0.83	4.61	1.07
Carbon (% wt.)	46.22	12.55	41.21	9.56
Hydrogen (% wt.)	6.92	1.88	6.39	1.48
Nitrogen (% wt.)	2.39	0.65	1.40	0.32
Sulphur (% wt.)	0.00	0.00	0.00	0.00
Oxygen (% wt.)	41.40	11.24	46.39	10.76
HHV (MJ/kg)	19.46	4.94	16.78	4.35
LHV (MJ/kg)	18.36	2.75	15.69	2.15
Sample of biochar	Biochar of kitchen waste		Biochar of potato	
	dried sample	original sample	dried sample	original sample
Water (% wt.)	0.00	2.76	0.00	4.40
Volatile matter (% wt.)	–	69.17	–	48.34
Non-volatile matter (% wt.)	–	26.55	–	45.41
Ash (% wt.)	1.56	1.52	1.93	1.85
Carbon (% wt.)	68.86	66.78	68.79	65.77
Hydrogen (% wt.)	7.98	7.76	5.09	4.87
Nitrogen (% wt.)	1.31	1.28	2.53	2.42
Sulphur (% wt.)	0.19	0.19	0.12	0.12
Oxygen (% wt.)	19.39	18.86	21.41	20.47
Chlorine (% wt.)	–	0.85	–	0.10
HHV (MJ/kg)	–	28.57	–	26.00
LHV (MJ/kg)	27.57	26.58	25.97	24.82

HHV – higher heating value; LHV – lower heating value

2.2 Thermochemical Conversion Process

Thermochemical processes depend on the relationship between heat and chemical action as a means of extracting and creating products and energy. A variety of biomass resources can be used to convert to liquid, solid, and gaseous fuels with the aid of thermochemical, conversion processes. There are few types of thermochemical conversion processes. Pyrolysis is one of the thermochemical conversion process. Pyrolysis is the endothermic decomposition process of biomass materials without air or oxygen into fuel. Gas, liquid and solid products will have produced during the decomposition process. The liquid product produced is called bio-oil which can be used in applications similar to those of petroleum oil. The gas product is a mixture of mainly CO, H_2, CO_2, and some low molecular weight hydrocarbons. The solid product is a carbon-containing residue or char. Carbonization is the conversion of biomass into carbon or a carbon-containing residue through pyrolysis or destructive distillation.

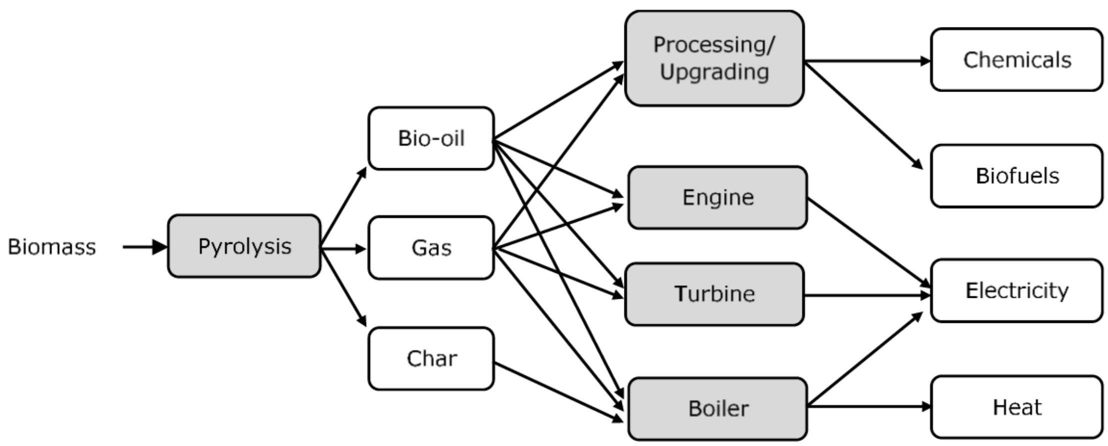


Figure 2.1:Pyrolysis products and their applications. Adopted from [20].

2.3 Microwave carbonization

The microwave carbonization of biomass is one of the novel thermochemical technologies in which biomass is irradiated with microwave. As opposed to conventional carbonization, microwaves penetrate the walls of the heating container and heat the material directly. With conventional carbonization, the wall of the container is heated first before the material gets heated through conduction or convection and this results in heat and energy loss [21]. The microwave carbonization process offers several advantages over the traditional carbonization process, some of which include uniform internal heating of biomass particles, ease of control, and saving of time and heat energy.

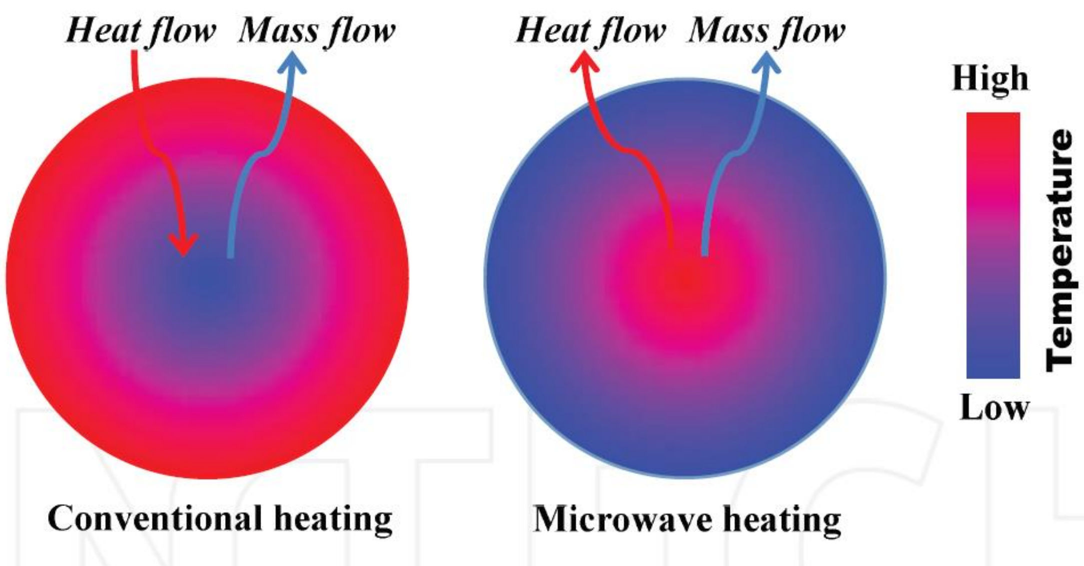


Figure 2.2:Schematic diagram of temperature distribution, heat transfer, and mass transfer in the conventional heating. Adopted from [22]

2.4 Microwave Absorbers

The pyrolytic process can be enhanced by adding microwave absorbers such as carbon materials or metal, metal oxides or hydroxides. The microwave absorber used as additives together with the subject materials to initiate the pyrolysis process. The function of the microwave absorber is to absorb microwave energy and then dissipates the heat energy, this will cause the temperature inside the reactor and the surrounding material increase until it is sufficient to pyrolyse the substrate. Hu et al. compared the use of several catalysts such as activated carbon, CaO, SiC and biochar from and reported lowest solid residue production with activated carbon while highest solid residue with the biochar [23]. FAISAL et al. compared the difference configuration and different composition of the microwave absorbers and reported that the configuration and the composition of the absorbers will affect the yield of the product. [24]

Several factors will affect the pyrolysis product yields and quality and these include the characteristic of the food waste such as type, size and moisture content, microwave conditions such as power, time and temperature and type of microwave absorbers used.

CHAPTER 3

METHODOLOGY

3.1 Microwave Oven

The microwave oven is use to provide the microwave for the carbonization. The model of the microwave oven used was Samsung ME711K. A reactor was designed and fabricated so it can fit into the chamber of the microwave. Thus, the dimension of the microwave needed was measured.

A hole that fit the to the cover pipe was drilled to remove the volatile.

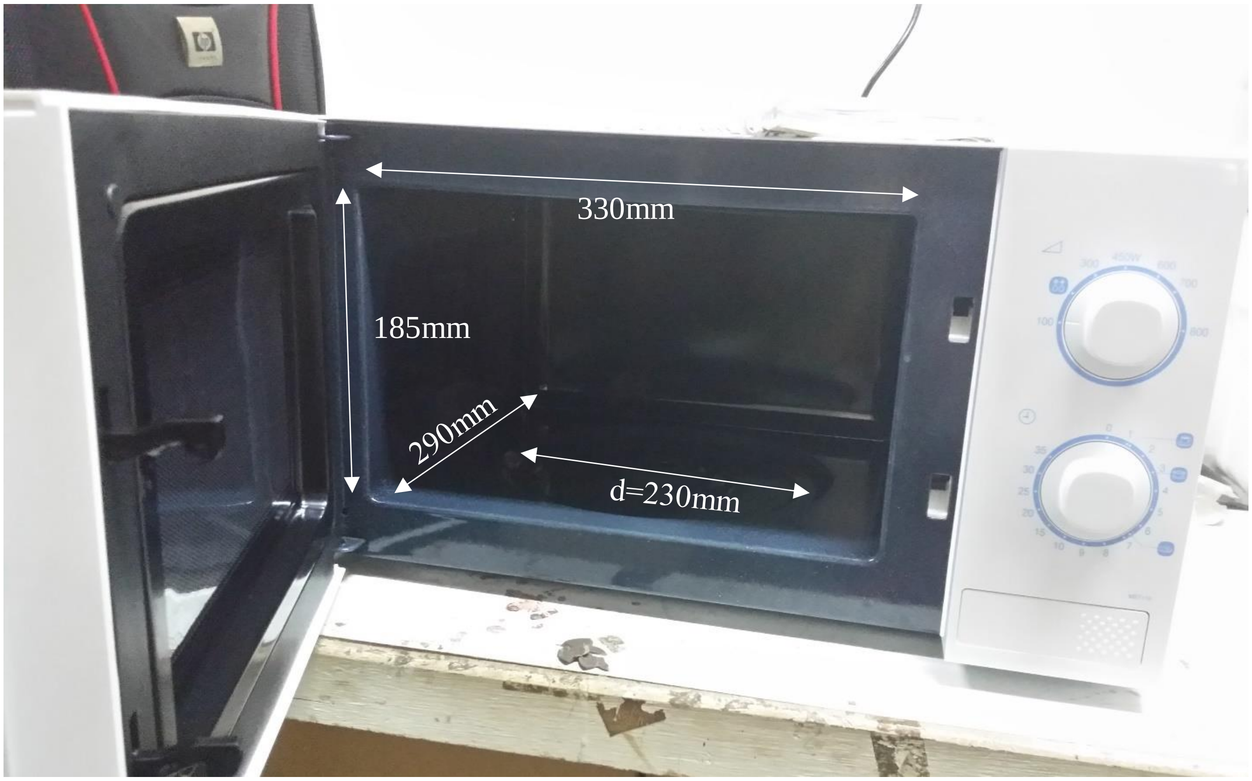


Figure 3.1: The microwave oven used for the experiment

3.2 Reactor

The materials use to design the reactor is very important. The material used must be transparent to microwave (low loss materials), such as fused quartz, some glasses, some ceramics and etc. This is because the materials will not absorb of reflect the microwave, this can prevent the energy loss and take longer time to finish the process.

In the first design, the materials use for the cover and reactor are clay. Glass tube was used to remove the volatile matter to avoid from damage the microwave oven

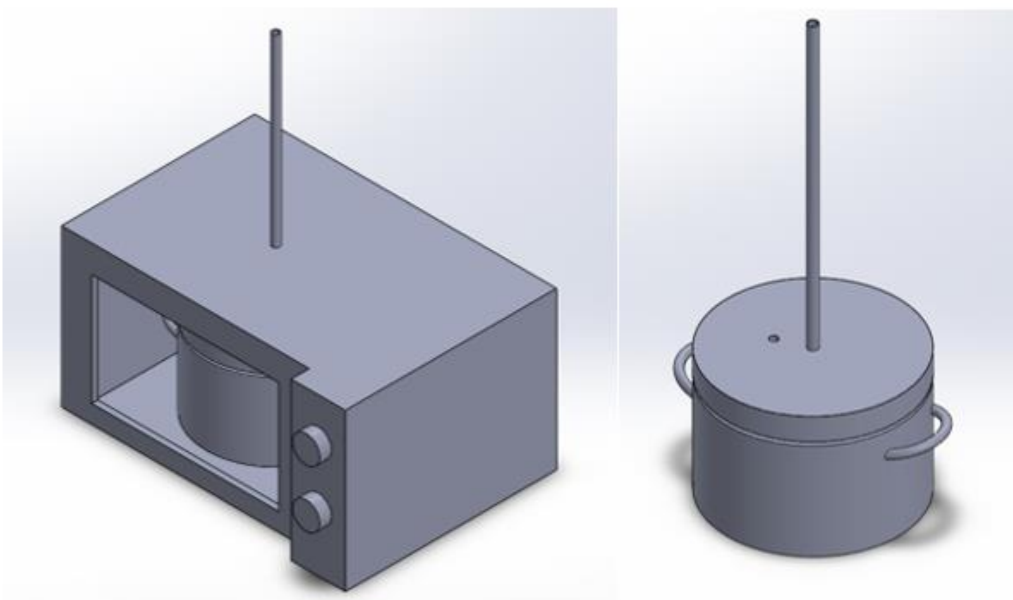


Figure 3.2: The Solidworks design of the clay reactor (with and without microwave)

The thickness of the clay is hard to control, if the thickness is too thick, the reactor will be very heavy, if the thickness is too thin, the reactor will crack and damag easily under high temperature in the microwave oven.

The second option is using glass. Ceramic glass will not break easily, it is transparent to the microwave and can withstand high temperature. The material for the cover of the reactor need to be identified as the material need to

1) withstand high temperature,
2) will not react with the microwave to produce spark
3) can drill a hole easily on the surface

The glass cover for the ceramic glass shown in Figure 3.3 was not used as the cover for the reactor because a hole is very hard to drilled on a glass, the glass will break upon drilling. Besides that, a pipe is hard to attach to the cover to remove the volatile. Aluminum was used as the cover for the reactor as aluminum because it is light and it can withstand high temperature. Besides that, a hole also can be drilled on the aluminum easily.

Figure 3.3: The Ceramic glass

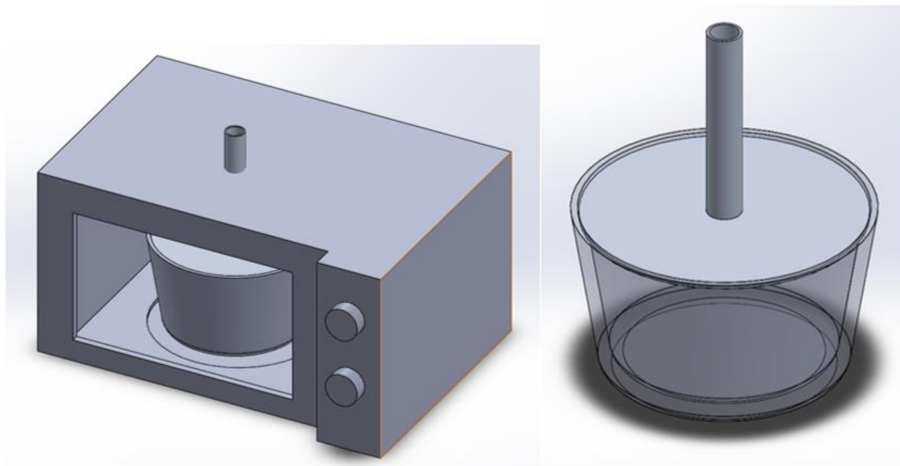


Figure 3.4: The Solidworks design of the glass reactor and the cover

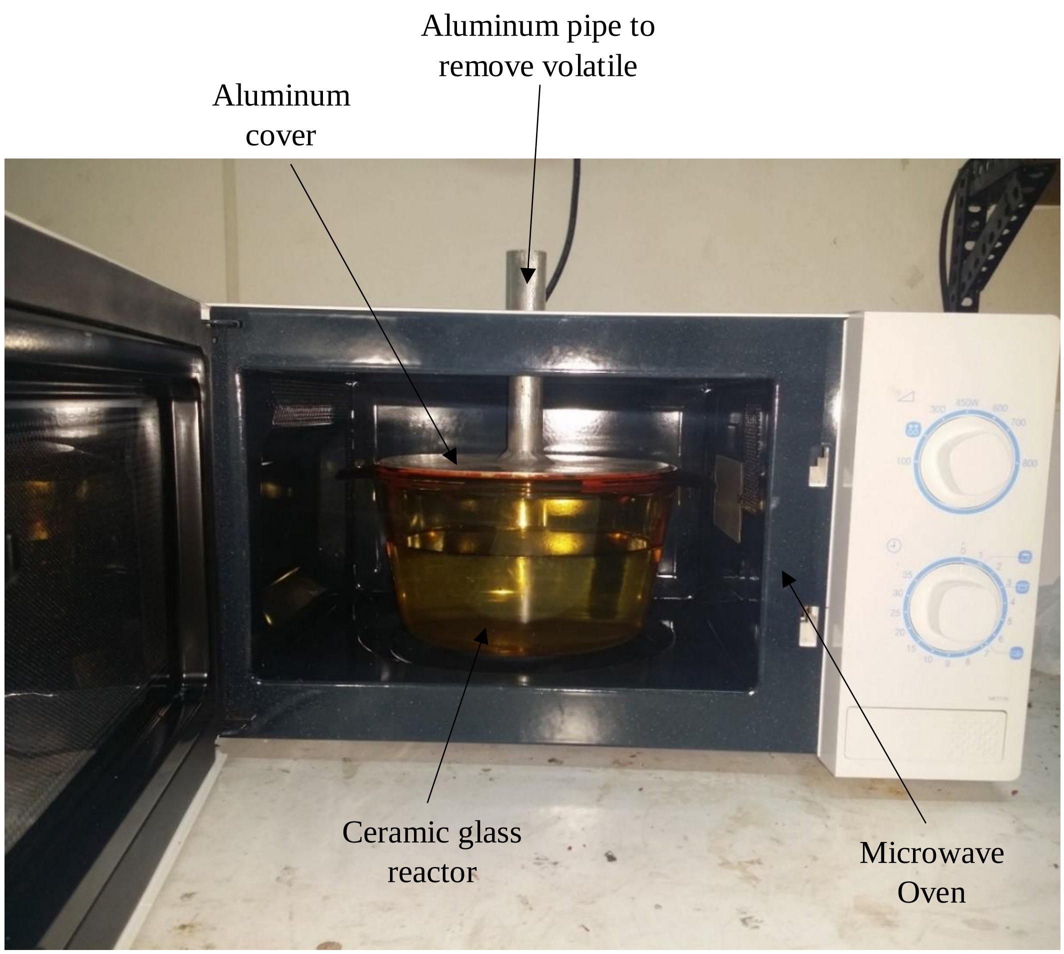


Figure 3.5: The set-up of the carbonizer

3.3 Absorber Materials

Microwave absorber were used to initiate and enhance the pyrolysis process. Activated carbon will be selected. This is because it can be mixed with the biochar and reuse.

3.4 Configuration of the food

The intimately mix configuration will be used in this experiment, this is because this configuration will produce higher yield of biochar compare to the layered configuration.

3.5 Carbonization of Sample

The sample used was potato. The potato was cut into five pieces of small size sample with dimension of 30 mm x 30mm x 5mm. Activated carbon that microwave absorber was put into the reactor. The 5 pieces of sample were put into the reactor and mix together with the microwave absorbers. A thermocouple connected with the thermometer was used to measure the temperature of the microwave absorbers. The reactor with cover was put inside the microwave oven. The microwave oven was turned on. The temperature of the microwave absorber was monitored, when the temperature is approaching the desired temperature, the power of the microwave oven was lowered. The samples were carbonized for a certain time (30 minutes or 60 minutes). After the times was up, the reactor was cooled down for 10 minutes to prevent high temperature difference between the ambient temperature and temperature inside the reactor that will cause thermal shock and break the reactor. After 10 minutes, the samples were taken out from the reactor.

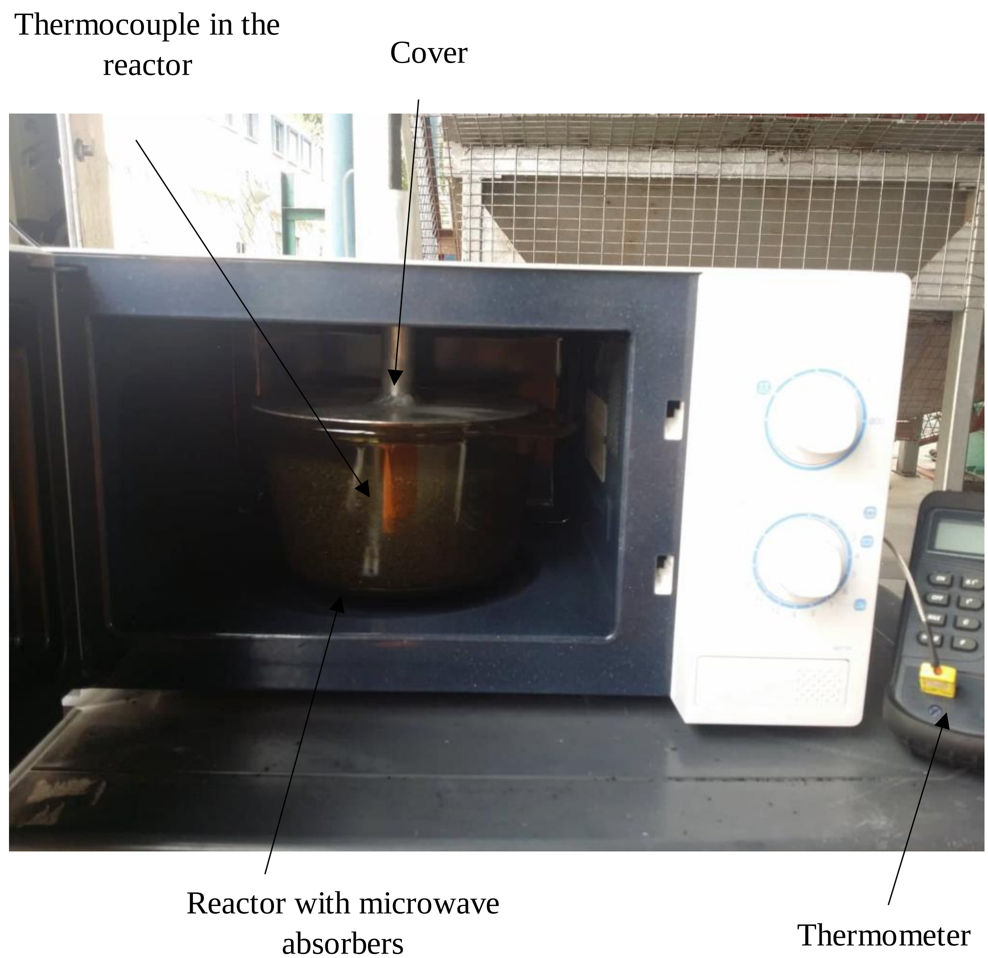


Figure 3.6: The set-up of the carbonizer during experiment

3.6 Bomb Calorimeter

Adiabatic bomb calorimeter will be used to determine the heating value for the product formed. The theory and experimental procedure of the bomb calorimeter can refer to Appendix A.

Figure 3.7: Adiabatic bomb Calorimeter

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Carbonizer

The carbonizer was tested with using different amount of microwave absorbers and potato. The conversion time for the potato into biochar were recorded and tabulated in Table 4.1.

Table 4.1: The converting time for potato to become biochar for different amount of microwave absorbers and different amount of potato at microwave power of 450W

Amount of microwave absorbers	Amount of potato	Converting Time
50% of the reactor	15% of the reactor	60 minutes
50% of the reactor	30% of the reactor	120 minutes
70% of the reactor	30% of the reactor	110 minutes

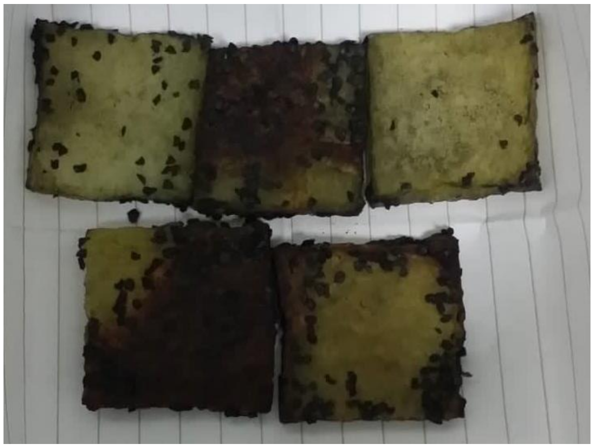
The results show that when the amount of potato increase, the conversion time increase. This is because when the amount of potato increase, microwave penetration depth during intimately mix method will be affected. Besides that, the water inside the potato release to the absorbers and affect the performance of the absorbers. The heat energy dissipated by the absorbers use to remove the moisture on the absorber itself and the potato. The water release by the potato to the surrounding will reduce the temperature of the microwave absorbers, as a result, it takes a longer time to achieve carbonization [26].

While when the amount of microwave absorbers increases, the converting time decrease. This is due to more microwave absorbers will absorb the microwave and more heat will dissipated to surrounding. As a result, it takes a shorter time to fully carbonized the samples

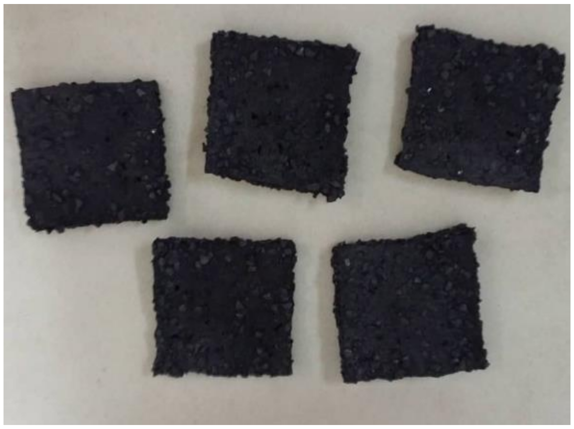
4.2 Product Formed

10 sets of potato samples are carbonized with different duration and under different temperature. The product formed are observed.

Table 4.2: Sample under different temperature and carbonization time

Condition	Sample	Observation
T = 260 °C t = 30 minutes		2 undried samples 1 dried sample 2 semi-carbonized samples
T = 280 °C t = 30 minutes		2 dried sample 3 semi-carbonized sample

T = 300 °C t = 30 minutes		1 dried sample 4 semi-carbonized sample
T = 320 °C t = 30 minutes		1 dried sample 3 semi-carbonized samples 1 fully-carbonized sample
T = 340 °C t = 30 minutes		1 dried sample 2 semi-carbonized samples 2 fully-carbonized sample

T = 260 °C t = 60 minutes		2 semi-carbonized sample 3 fully-carbonized sample
T = 280 °C t = 60 minutes		1 semi-carbonized sample 4 fully-carbonized sample
T = 300 °C t = 60 minutes		5 fully-carbonized sample

T = 320 °C t = 60 minutes		5 fully-carbonized sample
T = 340 °C t = 60 minutes		5 fully-carbonized sample

From the results, there are some brownish samples produced after 30 minutes of carbonization. This mean that the potato was not fully carbonized, the biochar was not fully formed. This is due to the reactor is stationary, and the potato placed further to the magnetron. When the magnetron strike, the activated carbon nearer to the magnetron will absorb the microwave to increase its temperature. The microwave absorbers that are further to the magnetron will receive the microwave slower and will cause the microwave absorbers dissipate the heat slower. As a result, the potato will not receive enough of heat energy to undergo carbonization. For the potato after one hour of carbonization time, almost all the products are black in color. This mean the potato are carbonized, the potato has become biochar.

4.3 Heating Value

After using the bomb calorimeter, the heating value for each sample are calculated and tabulated as shown in Table 4.3. The bomb calorimeter results can refer to Appendix A.

Table 4.3: Heating Value of the sample for different carbonization temperature and time

Temperature (°C)	Time	
	30 mins	60 mins
260	16647.26	16709.37
280	17184.65	17642.38
300	17226.9	20014.71
320	17754.02	22121.2
340	17661.28	23078.91

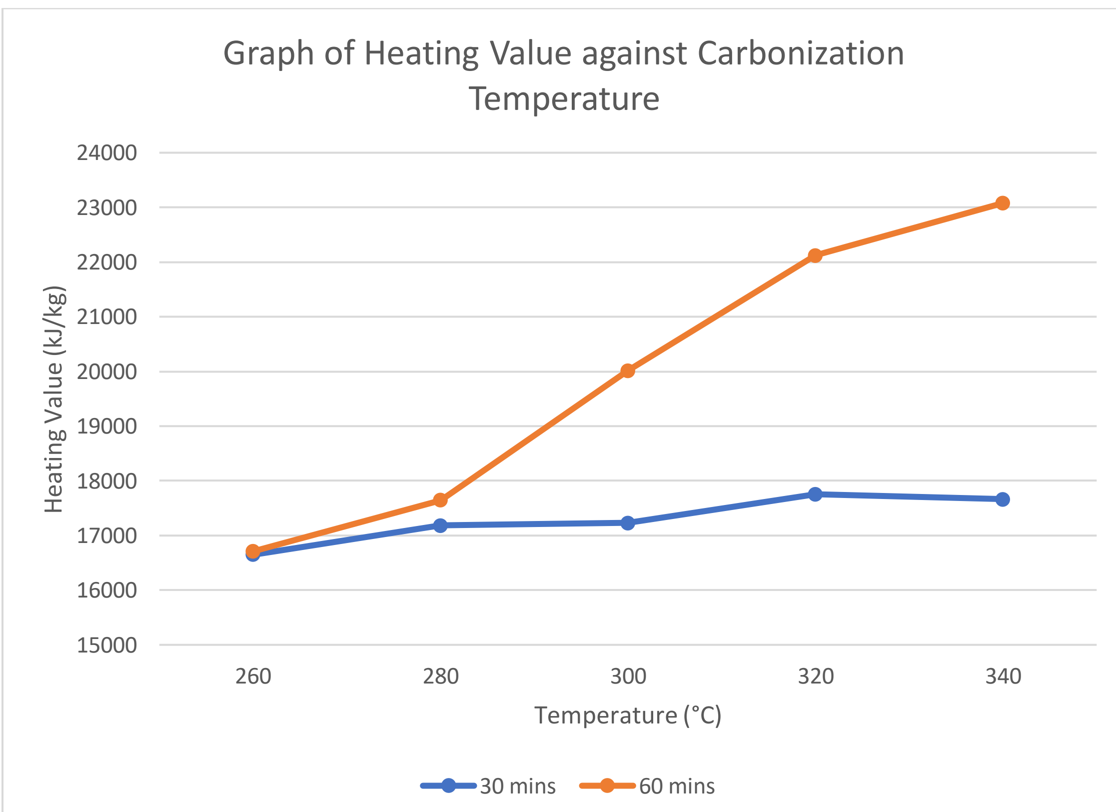


Figure 4.1 Graph of Heating Value against Carbonization Temperature

Based on Table 4.3 and Figure 4.1, the heating value for biochar formed at different temperature and different carbonization time is tabulated and a graph is plotted. From the results, the heating value for the samples show an increasing trend when the carbonization temperature increase from 260°C to 340°C. This is because at higher temperature, the more char is formed [26]. At low temperature, the solid product was not only char formation, but also a mixture of potato and char produced. The higher the heating temperature, the more components of potato are decomposed to be char. Char has a higher carbon content and this will result to higher heating value.

For the sample with 30 minutes of carbonization time, the heating value of the sample with 320°C is higher than 340°C. This maybe due to after took out the sample from the reactor, there will be some activated carbon will stick on the sample. The activated carbon has a high heating value and it did not completely remove from the sample, this will affect the results.

The heating value of the samples with 60 minutes of carbonization time is higher the sample with 30 minutes carbonization time. This is because the samples with 60 minutes of carbonization time almost fully carbonized but the sample with 30 minutes carbonization time not fully carbonized. Fully carbonized sample has higher carbon content which will lead to the higher heating value.

CHAPTER 5

CONCLUSION

5.1 Conclusion

A microwave food waste carbonizer have been developed to carbonize the food waste. Potato was used as food waste to test the function of the carbonizer. The carbonizer was use to compare the product formed by the potato under different temperature and different carbonization duration. When the temperature increases, the more potatoes were fully carbonized and the heating value of the product formed increase.

5.2 Recommendations for future works

The following issues can be focus in the future work

- The design of the carbonizer can be reviewed and redesigned with a more user-friendly design.
- Install the rotating disk to the microwave oven to rotate the reactor so the absorbers and the food waste will receive homogeneous heating and then compare the results with stationary reactor.
- Different type of microwave absorbers can be used and compare.
- Different type of food waste can be used and compare.

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