PERFORMANCE STUDY OF
KITCHEN WASTE CARBONIZER

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PERFORMANCE STUDY OF

KITCHEN WASTE CARBONIZER

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DECLARATION

This work has no previously been accepted in substance for any degree and is not being concurrently in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF SYMBOLS

M	Mass
%	Percentage
kg	Kilogram
kg/s	Kilogram per second
kg/m^3	Kilogram per cubic meter
ρ	Density
m	Meter
m/s	Meter per second
mm	millimeter
kW/h	Kilowatt per hour

LIST OF ABBREVIATIONS

KWC	Kitchen Waste Carbonizer
MSW	Municipal Solid Waste
GHG	Greenhouse Gas Emission
WTE	Waste-to-Energy Technologies
LFGRS	Land Gas Recovery System
FW	Food Waste

KAJIAN PRESTASI

KARBONIZER SISA DAPUR

ABSTRAK

Terdapat banyak sisa makanan yang dihasilkan dari kantin, restoran, asrama dan hotel. Sisa-sisa ini dibuang ke dalam tong sampah dan dilupuskan di tempat pembuangan sampah. Transformasi sisa dapur yang tidak diingini menjadi produk akhir karbon berharga dapat dicapai oleh penguraian termokimia bahan organik menggunakan karbonizer sisa dapur. Produk akhir boleh digunakan sebagai bahan bakar tanpa asap gred tinggi untuk memasak dan pemanasan rumah serta baja untuk tumbuh-tumbuhan. Untuk melakukan itu, kandungan lembapan dan bahan tidak menentu dalam sisa mesti dihapuskan. Tesis ini mengkaji ciri bahan bakar sisa dapur pada suhu tindak balas yang berbeza di dalam kapal reaktor dan masa digunakan.

PERFORMANCE STUDY OF

KITCHEN WASTE CARBONIZER

ABSTRACT

There are many food waste generated from canteens, restaurant, hostels and hotels. These wastes being thrown away into the rubbish bin and disposed in landfills. The transformation of the unwanted kitchen waste into a valuable carbon end product can be accomplished by the thermochemical decomposition of organic materials using kitchen waste carbonizer. The end products can be used as high grade smokeless fuel for cooking and household heating as well as fertilizer for plants. In order to do that, the moisture content and volatile matter within the waste must be eliminated. This thesis examines the fuel characteristic of kitchen waste at different reaction temperature in the reactor vessel and time being used.

CHAPTER 1

INTRODUCTION

1.1 Research background

In general, solid waste is disposed in landfills which is considered the cheapest option available to handle the waste in large quantity as compared to incineration and composting. This current practice poses a serious problem on the environment and public health. Main source of waste production are by human activities itself. One of the major failure facing by sustainable development in Malaysia's population is Municipal Solid Waste disposal itself. Malaysian population has been increasing every year. In line with the rapid population growth, the generation of municipal solid waste (MSW) also increases. Because of the enormous rate of MSW generation, MSW disposal becomes one of the major environmental and sustainable development issues.

The current concerns of the world in the energy sector are to reduce dependency on fossil fuels and achieve a sustainable and renewable energy supply. Over the past decades, the importance of biomass as fuel has increased. Biomass is a primary form of renewable that is expected to be fully exploited and used, transforming fuels into an important source of energy in the upcoming years. Biomass abundance is widespread in comparison with available non-conventional sources of energy such as nuclear, wind, hydro and solar. Biomass is considered carbon neurtal, as net carbon emissions from biomass are zero.

Kitchen waste carbonizer is an innovtive technology designed to treat all types of organic waste materials with a high level of humidity, such as kitchen waste, agricultural waste without drying beforehand. Due to its high carbon content, which is commonly wasted through disposal in landfills, enormous quantities of kitchen waste can be a source of energy. These wastes can be converted into useful energy source by carbonizing, crushing and briquetting to form solid fuel with commercial value or as cooking fuel, barbeque and domestic heating.

1.2 Problem statement

Poor management system in food waste has resulted in disposal into the landfill sites as it is the largest source for greenhouse gas (GHG) emission. The food waste treatment facility in Malaysia is extremely limited. There are arguments against incineration and concerns from local communities about the environment impact of incinerators in Malaysia. An alternative footprint is essential for dealing with the problems of food waste for the local communities and the nation, as well as putting these unwanted food waste into useful and value-added resources for the other application such as biofuels production.

1.3 Objective

A kitchen waste carbonizer has been designed to carbonize various kitchen waste. Generally, explicit objectives have been defined to support better understanding in the carbonization process. These objectives are:

1. To study the performance of the kitchen waste carbonizer.
2. To study the effectiveness of an afterburner.

1.4 Scope of work

A kitchen waste carbonizer has been developed to carbonize various food waste. This project aims to convert the food waste into char through the process of carbonization. Types of wastes that will be converted into char are various food waste collected from the cafeteria. Carbonization process will be conducted at different parameters. Parameters that being used is different temperature and different time. Besides, an afterburner has been developed to eliminate smoke remove from reactor vessel.

1.5 Outline of Thesis

This thesis consists of five chapters which are the introduction, literature review, methodology, results and discussions and the conclusions. The first chapter describes the introduction of the project starting with the project backgroud, problem statement, objective and scope of work.

Second chapter cover on the literature review. It is describes the related research from the journal, website, article and book. This chapter overview of the municipal solid waste (MSW) generation, waste-to-energy (WTE) technologies and food waste as biomass fuel.

In the third chapter “Methodology”, it was explaining the method and process required to be following to complete this project. Methods in interpreting the findings are also discussed in order to clarify the flow of this project.

In chapter four “Results and Discussions”, it presented the results and the findings of the study. Besides, this chapter also explain the problems face during running the experiment.

All the findings are summarized in the “Conclusions” chapter. This chapter also outlines several recommendations for further development and improvement on the design. Suggestion for future inventor also provided within the chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Municipal Solid Waste

Increase in population has led to an increase in consumption pattern, thus causing an enormous amount of waste generated in households. In Malaysia, household wastes contribute majorly towards municipal solid waste being produced. In 2005, the waste generate amounted to 19,000 tons per day. The recycling rate is 5%. In the next eleven years, in 2016, the quantity of waste was 38,200 tons per day and the recycling rate is 17.5%. The main component of the waste generated is food waste that is 45% high in organic compounds. This rate can lead to MSW generation of 31,000 tonnes per day in 2020[1].

According to Housing and Local Government Minister Zuraida Kamaruddin, waste separation and recycle rate is only at 24% while the remaining 76% goes to the landfill. As landfilling is currently the ultimate waste disposal method that can handle majority of waste ends at landfill sites with many types of materials. According to the company's solid waste management and public cleansing, there are only 14 sanitary landfills all over the country. 161 landfills are still in operation while 141 are closed. Therefore, other ways need to be taken to treat this waste. Waste-to-energy technology can treat the municipal solid waste.

2.2 Waste-to-Energy (WTE) Technologies

In recent years, considerable efforts have been devoted to developing waste-to-energy (WTE) technologies that can reduce the volume of waste and mitigate its negative effects on the environment. Urbanization and population growth have led to increased volumes of waste. Globally, the volume of waste is increasing faster than the rate of urbanization. WTE technology directly converts the energy content of waste into steam or electricity[2]. It is cost-effective, with an energy cost of approximately 10% of that of solar energy and 66% of that wind energy[3].

Waste-to-energy emerged as a promising alternative to deal with the waste generation problem and a potential renewable energy source for Malaysia. WTE has been employed in Malaysia for decades and executed for biomass accessible from agricultural waste and forestry residue such as palm oil biomass, paddy straw and logging residues[4]. WTE is classified before disposal into landfill, after waste reduction, reuse and recycle materials[5]. WTE approaches can be categorized into three types, which are thermal treatment, biological treatment and landfill[6]. Choices for thermal treatment of WTE to generate electricity and heat include waste incineration, gasification and pyrolysis. Biological treatment of WTE comprise of anaerobic digestion with the yielding of biogas. Landfill equipped with methane gas restoration system can also produce electricity and heat via turbine. A brief explanation on each WTE technology will be explain in section 2.2.1 to 2.2.5.

2.2.1 Waste Incineration

Waste incineration is a primary approach of waste treatment technology that transform biomass to electricity. The feedstock is used in combustion process, which react with excess oxygen in a boiler or furnace under high pressure. End product derived from combustion of waste is the hot combusted gas, which mainly composed of nitrogen (N2), carbon dioxide (CO2), waster (H2O, flue gas), oxygen (O2) and non-combustible residues[7].

Production of hot flue gas will enter the heat exchanger as hot stream to generate steam from water. Generation of electricity occurred in the steam turbine through the Rankine cycle. Single steam cycle basically only produces electricity, whereas cogeneration of steam and electricity requires an extracting steam cycle. Prior the combustion of waste, preparation work and processing such as drying is necessary to remove high moisture content of the waste. Combustion process normally requires temperatures between 850°C to 1100°C.

2.2.2 Gasification

Gasification is the transformation of solid waste into fuel by gas-forming reactions. Gasification is regarded as “indirect combustion” with the partial oxidation of waste in the presence of an oxidant amount lesser than that required for stoichiometric combustion[8]. Minimum operating temperature for gasification is 1100°C. Products of the gasification process generally include ash, hydrogen, carbon, nitrogen, sulphur, methane and oxygen, where specific products depend on type of raw materials used.

In the process of gasification, waste is combusted under regulated amount of oxygen to supply sufficient heat for the predominantly syngas reaction, in operating temperature range of 780°C to 1650°C. Syngas is sent to power generation plant to generate steam and electricity. Solid by-products of the gasification are known as char and contain mainly of carbon and ash. The by-products are then undergo the second gasification process using steam and oxygen which provides the necessary heat energy for the former processes.

2.2.3 Anaerobic Digestion

Anaerobic digestion is a highly promising and environmental-friendly technology for processing organic waste and organic wastewater[9]. Anaerobic digestion is a natural biodegradable process, where organic matters degraded by microorganisms in the absence of air. Four key biological and chemical stages involved in anaerobic digestion, which are hydrolysis, acidogenesis, acetogenesis and methanogenesis[10]. In hydrolysis, complex chain of organic waste is disintegrate into basic structural molecules.

The biological process of the acid genesis stage leads to further breakdown by acid fermentative bacteria of the remaining components. Gases such as carbon dioxide (CO2), methane (CH4) and ammonia (NH3) are produced at this stage. The acetogenesis in which the simple molecules created by acetogens are further digested to produce mainly acetic acids, along with carbon dioxide and hydrogen. Methanogenesis is the end of the anaerobic digestion stage, where methanogens bacteria convert the intermediate products into carbon dioxide (CO2), methane (CH4) and water.

2.2.4 Pyrolysis

In general, pyrolysis is defined as a process of thermal degradation of the waste under an inert atmosphere, the total absence of air that produces recyclable products, such as char, oil and combustible gases. In a pyrolysis-involved process, energy can be obtained in a cleaner method compared to traditional municipal solid waste incineration plants as lower amounts of nitrogen oxides (NOx) and sulphur oxides (SOx) are formed as a result of the inert atmosphere.

The important operating parameters such as heating rate, final temperature and residence time in reaction zone able to influence the pyrolysis behaviours and the end products[11]. Optimization of process parameters and conditions can yield either a solid char, gas or liquid product (oil), which makes pyrolysis reactor as an effective waste-to-energy convertor.

However, pyrolysis do have its disadvantages, such as product stream is more complex than for many of the alternative treatments and product gases cannot be vented directly to the atmosphere without further treatment due to high concentration of carbon monoxide (CO).

2.2.5 Land Gas Recovery System

Landfilling can be regarded as WTE technology when the site is equipped with a methane recovery system and utilized for energy generation. High percentage of biodegradable matter with high moisture content is well-suited for landfill gas recovery system. LFGRS helps in mitigation of greenhouse gas emissions from waste through the conversion of CH4 to CO2 and makes this system a significant measure for successful waste management.

2.3 Food Waste as Biomass Fuel

The occurrence of food waste (FW) has become an issue of global concern these days. Industrialization and unsuitable waste management result in the accumulation of large quantities of kitchen and food waste. Even developed countries are trying to find a suitable solution for management of this food waste. Food waste is one of the major components of municipal solid waste. Collection, storage and inappropriate segregation are the main concerns that limit proper conversion of waste. Food waste are generated during production, handling, storage, processing and consumption[12].

Food waste contains high content of organic components such as carbohydrates, proteins, lipids, and organic acids which makes it a reasonable feedstock for cultivating microorganisms[13]. Diversion of food waste from landfills has been a major concern for the world in recent decades, as food waste is the largest proportion of municipal solid waste. Dumping food waste into a landfill is tantamount to waste a valuable resource. Food scraps capable of generate renewable energy, as fertilizer for soil enhancement and as animal feed when properly processed.

Using food waste as a biomass fuel not only retains limited landfill space, but can reduce GHG emissions. Methane is a powerful GHG with a 25 times greater warning potential compared to carbon dioxide. Suprisingly, there has been little discussion of the issue of food waste as a solid fuel. Initially, diversified food waste is treated using biological approaches such as anaerobic digestion and composting.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will focus and explain about the details of the experimental rig that have been done and an equipment used during the carbonization process. Besides, this chapter also provides a clarification of materials preparation. This study plans to develop a carbonizer system to manage the kitchen waste generated through carbonization at different temperature and time. In addition, this project need to study on the effectiveness of an afterburner in order to eliminate the smoke produce by the reactor during running the carbonizer.

3.2 Feedstock

Kitchen waste sample that being used in this study was gathered from the Lembaran cafeteria and Pusat Islam as shown in Figure 1.1 below. Waste that being collected comprise of a mixed composition of bones, fish, meats, rice, fruits, vegetables and grains. The raw waste was classified to remove packaging and non-degradable materials. For example, non- degradable materials being state is plastic bags, straws, cans and glass bottles. Waste that being collected weight 15 kg and 20 kg for each run.

Figure 1. 1 : Feedstock

3.3 Kitchen Waste Carbonizer

The experimental rig of the kitchen waste carbonizer is a single step pyrolysis reactor comprising of two electrical heater bands. The process is a batch type process, having a handling capacity up to 20 kg by weight of waste. In order to monitor and control the temperature of the reactor chamber, a programmable temperature controller was installed.

Kitchen waste carbonizer comprised of a series of components such as reactor vessel, loading port, thermocouple, heater band, control panel, motor and exhaust pipe afterburner as shown in Figure 1.2 below. The reactor vessel is where the feedstocks are fed for the process of carbonization. The feedstock is put via the loading port. Thermocouple was installed for temperature sensing within the reactor vessel. Control panel consist of temperature display and 2 button to on and off the heater. Exhaust pipe afterbuner was design and fabricated to eliminate the smoke removes from the reactor vessel.

Figure 1. 2 : Kitchen Waste Carbonizer

3.4 An afterburner for exhaust pipe

An afterburner being installed at 100mm diameter pipe. This pipe has been design and fabricate as shown in Figure 1.3 below. This pipe consist of spiral inside the pipe. The use of this afterburner is to eliminate smoke that being remove from the reactor vessel. The temperature that being set is 700°C, 800°C and 900°C.

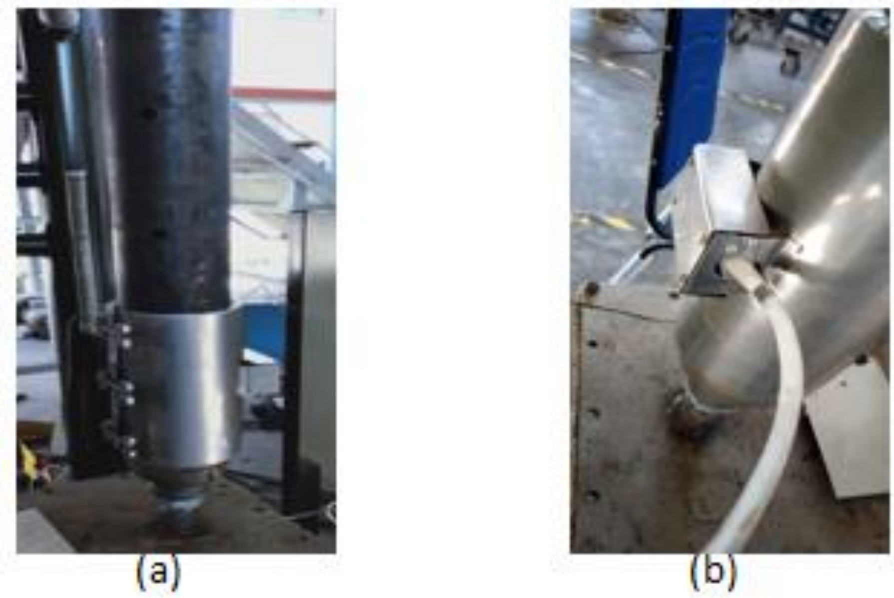


Figure 1. 3 : Afterburner (a) Front view (b) Side view

3.5 Fabrication of spiral inside exhaust pipe

This spiral has been design and fabricated as shown in Figure 1.4 below. Length of this spiral is 200mm. The outer diameter of this spiral is 94mm and inner diameter is 35mm. One end of the rod being closed to ensure that smoke did not moving through it.

Figure 1. 4 : (a) Spiral and (b) exhaust pipe

Criteration of an exhaust pipe:

M_i = 20 kg
M_d= 4 kg

Moisture content = $\frac{M_i - M_d}{M_i}$ = 80%

Mass of water = 16 kg

Volatile = 70%

Mass of volatile = 70% × 4 kg
= 2.8 kg

Total mass release = 16 + 2.8
= 18.8 kg

Time taken for carbonization ≈ 3 hours

Mass release flow rate = $\frac{18.8}{3 \times 3600}$

= 0.00174 kg/s

ρ = 1 kg/m^3

Volume flow rate = 0.0018 m^3/s

Diameter of pipe = 100 mm

Area = $\frac{\pi D^2}{4}$

= 0.00786 m^2

Velocity of flow = $\frac{0.0018}{0.00786}$

= 0.23 m/s

For 1 second, the particle travels 0.23 m ≈ 230 mm

Residence time for particle in the after burner is 1 second.

3.6 Experimental Methodology

Feedstock is collected as much as 20 kg for each run. To make sure the feedstock is 20 kg, it will be put on the weight scale first. Then, the motor are switched on to move the stirrer for ensuring the feedstock can move inside the reactor. An afterburner at the exhaust was switched on for 30 minute before put the feedstock inside reactor. The feedstock was fed into the reactor chamber by going through the loading port. The cover of loading port then being closed to ensure the reaction happens within the chamber of the reactor.

Heat was supplied to the chamber of the reactor by turning on the heaters. The reactor internal temperature was recorded by installing the thermocouple on the machine. The reactor was heated up to desired temperature which was pre-set before the experiment starts. Once the desired temperature was reached, the temperature will be maintained till the duration of carbonization ends. An amount of time will be given for the machine to cool down before the solid residues left inside the reactor was taken.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Under this chapter, the findings and experimental results are discussed. Kitchen waste carbonizer characteristics and performance have been analyzed. Besides, the performance of an afterburner to eliminate the smoke will be explained. Lastly, the problems that have been faced during doing this project also will be discussed in details. This is due to lack of the result and to improve the kitchen waste carbonizer for future use.

4.2 Results

First experiment was run to see the result for temperature of 400° C. Time taken for heater band to reach 400° C is at 1 hour and 43 minutes. The initial temperature is 37° C. The result for this run is 3.8 kg of char being produced. The picture in Figure 1.5 shown the char being produced. It can be seen by visual that about 50% turn to char nicely.

Figure 1. 5 : Char for 15kg waste

Second experiment was run for 20 kg of kitchen waste. This experiment being run for 1 hour. Char that being produced is 8.55 kg. The picture in Figure 1.6 shown that the quality of char is bad because it did not burn completely. This is due to the temperature did not reach 400°C in 1 hours operating. As shown in Figure 1.6, the temperature at 1 hour is 319°C.

Figure 1. 6 : Char for 20kg waste

Mass of feedstock : 20 kg
Mass of char produced : 8.55 kg

Time(minutes)	Temperature(°C)
0	26
10	85
20	114
30	284
40	202
50	319
60	319

Table 1. 1 : Data for time and temperature for second experiment

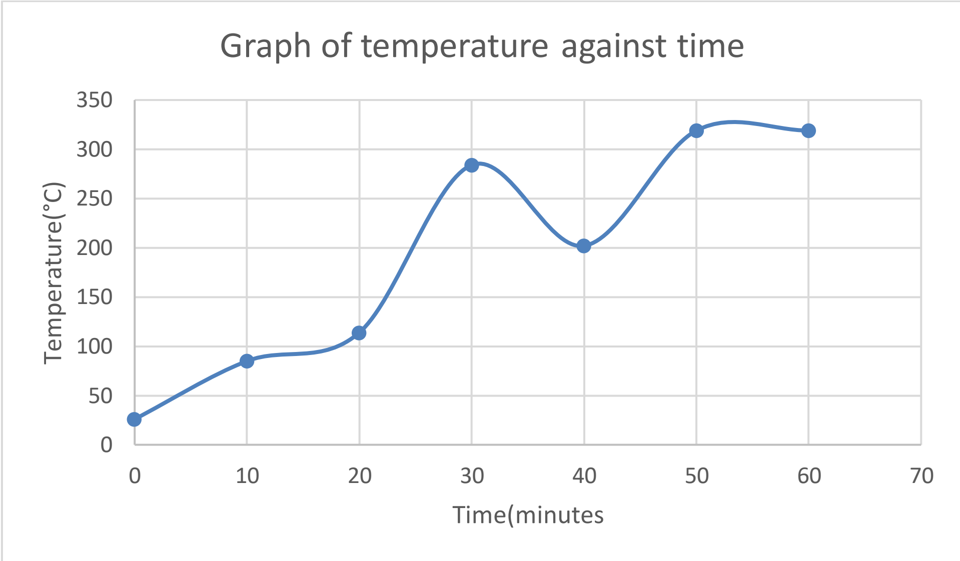


Figure 1. 7 : Graph of temperature against time for second experiment

Third experiment being run for 20 kg of kitchen waste. This experiment different from second experiment because it is run for 2 hour. It can be seen visually from the picture in Figure 1.8 (a) that the char being produced is good. However, the picture in Figure 1.8 (b) shown that the char is not burn completely. This is because the problems that will be explain in Figure 1.15. The weight of the good char produce is 2.35 kg. The weight for the char that did not burn nicely is 3.5 kg.

Figure 1. 8 : Char for 20 kg waste (a) Carbonize nicely (b) Uncompleted carbonize

Mass of feedstock : 20 kg
Mass of char produced : 5.85 kg

Time(minutes)	Temperature(°C)
0	30
45	293
55	317
65	348
75	334
85	362
95	367
105	400
115	391
125	405
135	297
145	227
155	197
165	165
175	136
185	114
195	95
205	80

Table 1. 2 : Data for time and temperature for third experiment

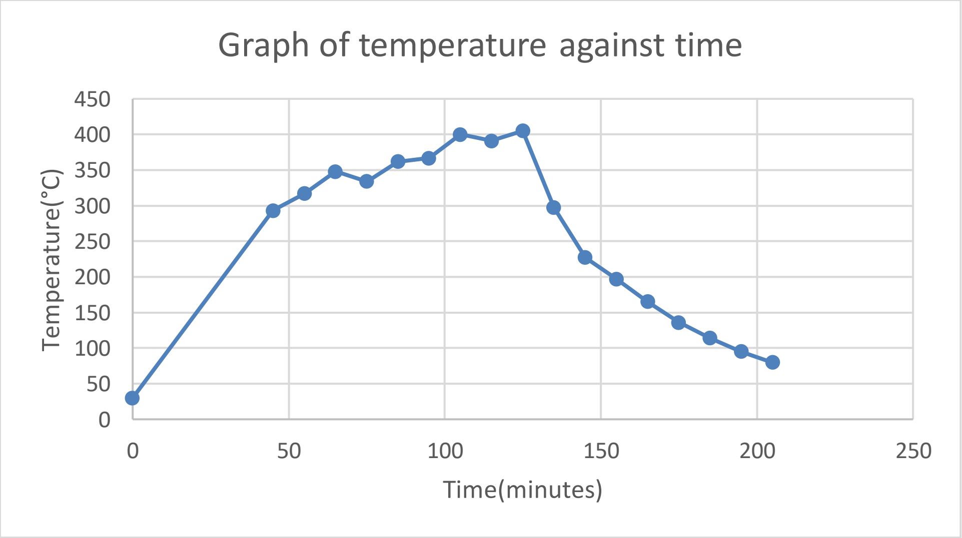


Figure 1. 9 : Graph of temperature agains time for third experiment

The picture in Figure 1.10 shown the afterburner with and without using after burner. It can be seen clearly that by using the afterburner(Figure 1.10 (b)), the smoke being produce from reactor vessel is a little compared to without using it. Thus prove that the afterburner can eliminate the smoke being released from reactor vessel.

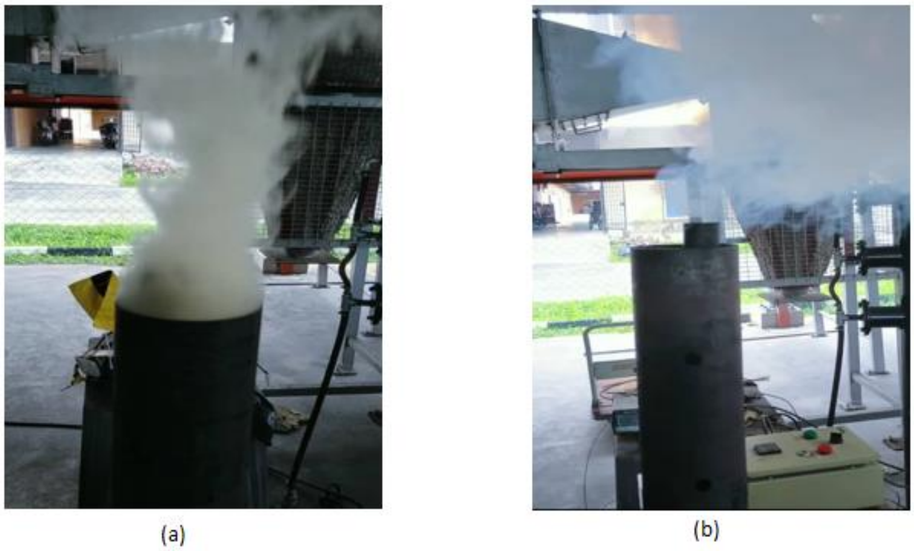


Figure 1. 10 : Exhaust pipe (a) Without afterburner (b) With afterburner

4.3 Mass yield and energy yield

Mass yield and energy yield are used to evaluate the performance of the kitchen waste carbonizer in weight reduction on the raw waste. Formula for the mass yield and energy yield are defined in equations (1) and (2) respectively.

$$\text{Mass Yield} = \frac{\text{Mass of processed waste sample}}{\text{Mass of raw waste sample}} \times 100\%$$

$$\text{Energy Yield} = \text{Mass Yield} \times \frac{\text{HHV of processed sample}}{\text{HHV of raw sample}}$$

First experiment :

Mass Yield = $\frac{3.8}{15} \times 100\%$

$=25\ \%$

Second experiment :

Mass Yield = $\frac{8.55}{20} \times 100\%$

$=43\ \%$

Third experiment :

Mass Yield = $\frac{5.85}{20} \times 100\%$

$=29\ \%$

4.4 Energy consumption

Another crucial assessment of the performace of kitchen waste carbonizer is energy consumption. To determine the energy consumption of a device, the Joulemeter was used. However, due to the need of dismantle the heater bands, the installation of the measuring device on the electrical heaters is unfavourable. Instead, an assumption is made to assess the energy consumption of kitchen waste carbonizer.

Kitchen waste carbonizer specification indicated that 12kW is the rating power for each heater band used. It is difficult to identify the exact energy consumption of the heater bands. Assuming that 60% of the rating power is used for each heater band.

This assumption is made because power will be reduced as the reaction tempe rature has been reached and the heater bands will be supplied with a lower current be low the threshold level. The minimum energy usage recorded was 25.2 kW/h under 3 hours.

4.5 Economic Evaluation

This part of the evaluation examined the costs required for the operation of carbonization. The operating cost corresponds to the energy consumption of the process. Tenaga Nasional Berhad (BHD) reports that tariff rates in Malaysia are 21.8 sen / kW/h for the first 200 kW/h of monthly use. Minimum amount of cost required to treat per batch of waste is RM5.49 at 3 hours, which is equivalent to RM0.27 for per kilogram of waste treatment.

4.6 Problems Faced During Running Experiment

First problems faced during doing this project is the heater band cannot supply desired temperature to the reactor vessel. The desired temperature is 200°C, 250°C, 300°C, 350°C and 400°C.

However, the heater band can only supply temperature until 240°C only. This heater band takes about 3 months to repair by the supplier. This kitchen waste carbonizer can be run in May 2019. This problems really gives big impact because the experiment cannot be run and thus cannot get the data or results for the thesis due to lack of time and other minor problems.

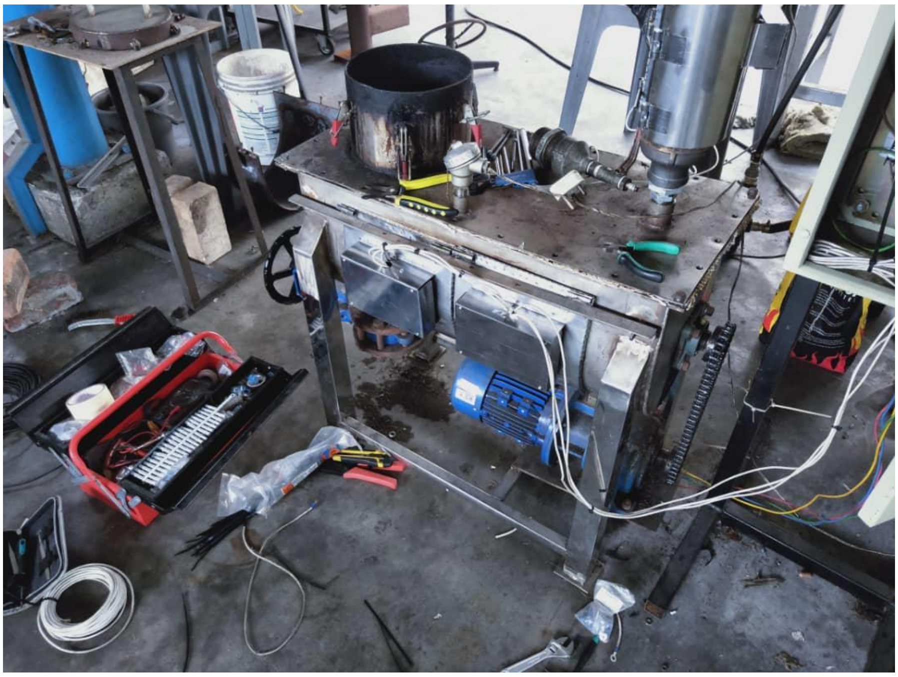
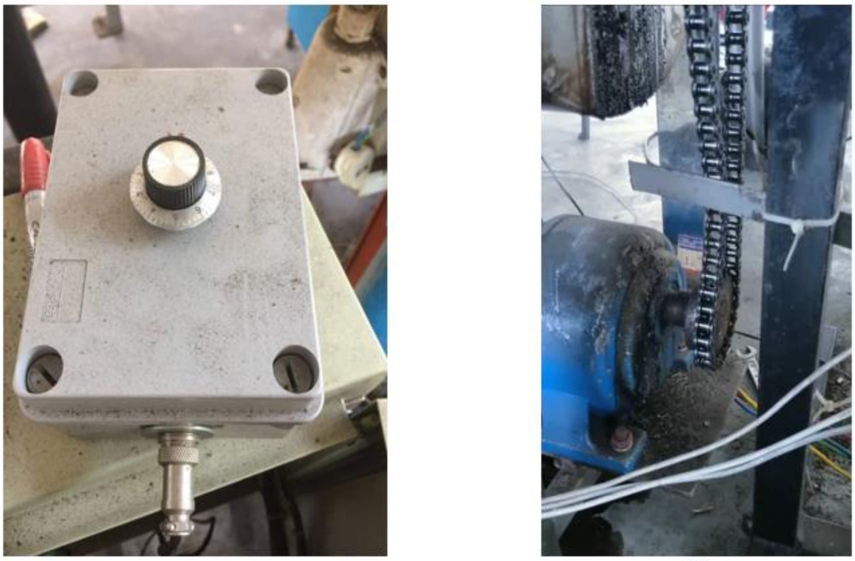


Figure 1. 11 : Heater band

Second problems faced is the motor cannot function well. The motor should move the stirrer inside reactor vessel in two directions automatically. However, it should be done manually. The idea of this stirrer and motor is to move the feedstock inside reactor to the left and to the right in 30 seconds.

Besides, the motor did not attach to the plate nicely due to improper welding. This problems make the experiment difficult to handle because the chain too loose until need to make it tighten by using a plat attached to it.



(a) (b)

Figure 1. 12 : (a) Automatically rotation motor (b) Motor

Next problems is an exhaust hole clogged with tar because the hole is small and an afterburner did not function at that time. The afterburner trip at that time and cannot function.

Figure 1. 13 : Exhaust hole