



UNIVERSITI PUTRA MALAYSIA

***DEVELOPMENT OF PORTABLE BIODIGESTER FOR HOUSEHOLD
BIOGAS PRODUCTION***

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**A PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF
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ABSTRACT

Biodigester is a structure called bioreactor or anaerobic reactor which provides the reaction of microbial digestion and fermentation into biogas under anaerobic condition. It is a system that helps in optimizing the biogas production from food waste for a low-cost renewable energy. Basically, it takes influent feed such as food waste and produce methane rich biogas and nitrogen rich fertilizer as effluent. In fact, the digestion and fermentation time is depending on the type of feed input and the condition parameters of bacteria used.

The design of portable household biodigester should meet the required specifications which include the absence of water or gas leakages, high corrosion resistance, low cost and affordable, easy to be manage, simple maintenance and accessible to both small and large scale production.

Portable biodigester for household use was invented as a system to converting food waste into biogas as the main product and effluent liquid as the second product. The system comprises of a tank divided into two compartment as the main component for anaerobic digestion. The biogas produce is store at the upper part of the tank with extended storage create by a floating lid that can move up and down based on amount of biogas available and the biogas can be discharge through a biogas port at the top of the floating lid. A water-jacketed is designed at the outer part of the tank to create a brier to the biogas from release out and complete the float mechanism of floating lid. The system also equipped by a pair of impellers that connected to the floating lid by a rod and a nut which can increase the production rate of biogas. The impeller rod is guide by a plate to avoid it from tilting. The influent port is connected to the bottom of main part which is work as a feeding port to the system while for the effluent port,

it is connected into the second part of the tank with design of S-shape to avoid the biogas produce from release out through the effluent port. The system is placed above a stand support that comprise of 4 castor wheel to help in portability of the system.

The performance of the portable biodigester is tested to observe the efficiency of mixing process inside a portable biodigester. The performance test done by run the portable biodigester for 10 days with mixing process by a pair of impeller and mix the food waste sample inside the portable biodigester 2 minutes per day for 10 days. The test was continued by another 10 days without mixing to observe the performance. The biogas produce each day was recorded by a wet gas meter. As results, the biogas produce during mixing process is 45% higher compare to biogas produce when non-mixing. Total solid content and chemical oxygen demand of food waste and effluent sample was analyse to observe the anaerobic digestion efficiency inside the portable biodigester. The total solid removal during mixing process was 94% compare to during without mixing 96%. The COD removal during mixing was 91% compare to without mixing which is 95%.

ABSTRAK

Biodigester adalah struktur yang dikenali sebagai bioreaktor atau reaktor anaerob yang memberikan reaksi pencernaan mikroba dan fermentasi ke dalam biogas dalam keadaan anaerobik. Sistem ini membantu mengoptimalkan pengeluaran biogas dari sisa makanan untuk tenaga yang boleh diperbaharui dengan kos rendah. Pada dasarnya, ia mengambil makanan yang berpengaruh seperti sisa makanan dan menghasilkan biogas yang kaya dengan metana dan baja yang kaya dengan nitrogen sebagai produk pengeluar. Sebenarnya, masa pencernaan dan penapaian bergantung kepada jenis input makanan dan parameter bakteria yang digunakan.

Reka bentuk biodigester isi rumah mudah alih harus memenuhi spesifikasi yang diperlukan termasuk bebas daripada kebocoran air atau gas, ketahanan kakisan tinggi, kos rendah dan berpatutan, mudah dikendalikan, penyelenggaraan sederhana dan mudah menghasilkan pengeluaran berskala kecil dan besar.

Biodigester mudah alih untuk kegunaan isi rumah diciptakan sebagai sistem untuk menukar sisa makanan menjadi biogas sebagai produk utama dan cecair efluen sebagai produk kedua. Sistem ini terdiri daripada tangki yang terbahagi kepada dua petak sebagai komponen utama untuk pencernaan anaerob. Hasil biogas disimpan di bahagian atas tangki dengan penyimpanan yang diperpanjang dibuat dengan penutup terapung yang dapat bergerak naik dan turun berdasarkan jumlah biogas yang ada dan biogas dapat dikeluarkan melalui salur biogas di bahagian atas penutup terapung.

Jaket air dirancang di bahagian luar tangki untuk membuat penyekat biogas dari terlepas keluar dan menyelesaikan mekanisme pengapungan penutup terapung. Sistem ini juga dilengkapi oleh sepasang pendesak yang terhubung di penutup biodigester dengan batang dan skru yang dapat meningkatkan kadar pengeluaran

biogas. Batang pendesak dipandu oleh piring untuk mengelakkannya daripada condong. Port influen dihubungkan ke bahagian bawah bahagian utama yang berfungsi sebagai port penyusunan ke sistem sementara untuk port efluen, ia disambungkan ke bahagian kedua tangki dengan reka bentuk S-bentuk untuk mengelakkan pengeluaran biogas dari pelepasan keluar melalui port efluen. Sistem ini diletakkan di atas sokongan pendirian yang terdiri daripada 4 roda kastor untuk membantu dalam kemudahan sistem.

Prestasi biodigester mudah alih diuji untuk melihat kecekapan proses pencampuran di dalam biodigester mudah alih. Ujian prestasi dilakukan dengan menjalankan biodigester mudah alih selama 10 hari dengan proses pencampuran oleh sepasang pendesak dan mencampurkan sampel sisa makanan di dalam biodigester mudah alih 2 minit sehari selama 10 hari. Ujian ini dilanjutkan selama 10 hari lagi tanpa mencampurkan untuk melihat prestasi. Hasil biogas setiap hari direkodkan oleh meter gas basah. Hasilnya, hasil biogas semasa proses pencampuran adalah 45% lebih tinggi berbanding dengan pengeluaran biogas ketika tidak mencampurkan. Jumlah kandungan pepejal dan permintaan oksigen kimia sisa makanan dan sampel efluen dianalisis untuk melihat kecekapan pencernaan anaerob di dalam biodigester mudah alih. Keseluruhan penyingkiran pepejal semasa proses pencampuran adalah 94% berbanding semasa tanpa pencampuran 96%. Penyingkiran COD semasa pencampuran adalah 91% berbanding tanpa pencampuran iaitu 95%.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Biodigester is a structure called bioreactor or anaerobic reactor which provides the reaction of microbial digestion and fermentation into biogas under anaerobic condition. It is a system that helps in optimizing the biogas production from food waste for a low-cost renewable energy. Basically, it takes influent feed such as food waste and produce methane rich biogas and nitrogen rich fertilizer as effluent. In fact, the digestion and fermentation time is depending on the type of feed input and the condition parameters of bacteria operate at. Moreover, it also reduces the greenhouse gases emission which potential to treat our environment by global warming. This is because some of the total amount of food waste can be transfer into the biodigester and methane gas produced by anaerobic digestion is being trapped without having to release it to an open area.

The design of portable household biodigester should meet the required specifications which include the absence of water or gas leakages, high corrosion resistance, low cost and affordable, easy to manage, simple maintenance and accessible to both small and large scale producers. Thus, family can also generate their

own biogas which can replace the fossil fuels especially for cooking without the exposure to respiratory disease, eye irritation and other diseases. This is because biogas does not produce smoke that appears as black soot that can enter the lungs and cover the kitchen walls.

Biogas technology offers multiple benefits in many factor including health, food, agriculture, energy, environment, and sanitation. Biogas technology, known as biofuel production process through fermentation of biological wastes, is a well-established technique to improve lives, livelihoods, health, and ecosystem. This invention generates a large revenue opportunity that supports the socioeconomic development in rural areas. Biogas can be used as substitute of natural gas in many different purposes. Recently, biogas is widely used in combined heat and power plants (CHPs) where it replaced oil and gas.

In an age of worrying climate change and looming fossil energy decline, the benefits of biogas are obvious. It is a renewable energy source with zero net greenhouse emissions. And yet its potential not recognized. A portable biodigester could provoke a domestic green energy revolution in a few years ahead, so here we proposed a portable biodigester for a better world. Thus, this invention would be a first step to open Malaysian people to grab benefit from the food waste rather than making our environment worst.

1.2 Problem statement

AD is likely to be one of the most promising technologies for converting organic waste in the absence of oxygen into bioenergy, including methane-rich biogas (Nguyen et al., 2014) and fertilizer products (Peres et al., 2019). A biodigester is used to provide a system in producing biogas from organic waste. Nowadays, various type of biodigester have been introduced around the world but very little of them is built specifically for household use. Some household biodigester that have been introduced have limitations such as short lifespan, leakage of gas, fluctuate production of gas and high construction cost due to difficulty to install and getting spare parts. Thus, some of manufacturing company take some efforts to produce simple design of biodigester with low construction cost.

EZ-Digester is an example of biodigester that is portable and above ground floating dome type digester that is quick and simple to install. The EZ-Digester which is manufactured in South Africa can provide enough biogas for households used to cook for approximately 2 hours a day. However, the EZ-Digester has the limitation of inefficient agitation of the substrate which affects its biogas production. The only possible solution of agitation can be achieved by the upward and downward motion of the gas holder.

Moreover, Agama fixed dome is also another example of household biodigester by South Africa which having the same limitation which is the absence of an agitation device. This inefficient agitation of the substrate is a significant factor affecting biogas production (Mutungwazi, Mukumba, & Makaka, 2018). Thus, we propose a new design of biodigester with portable, easy to install and handle and built with locally available material including an impeller that can improve inefficient agitation from

current design. Our new design concept of biodigester can be used for household to produce biogas that can be replace cooking gas up to 30%.

1.3 Objective

The objective of this project are:

- i. To develop a concept and fabricate a portable biodigester for household biogas productions.
- ii. To evaluate the performance of a portable biodigester.

1.4 Scope of study

The scope of study of this project is include the invention of this portable biodigester usages for household use. Besides, the machine could be used for processing food waste into biogas use to replace cooking gas which is considered as green energy that can help in conserve our environment. The product from anaerobic digestion also can be use as fertilizer in form of liquid and solid. The liquid fertilizer can be collect by the effluent discharge while the sludge produce can be collect after desludging process.

Moreover, mixing process is one of the main focus in this study. Mixing process in a biodigester will help in increasing contact time between the microorganism and the substrate (food waste). Thus a comparison between mixing and non-mixing is necessary to improve anaerobic digestion in a portable biodigester.

CHAPTER 2

LITERATURE REVIEW

2.1 Food waste

“Food waste (FW) is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed of (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded at sea)” (Branka et al., 2019). Previous studies have shown that food material wasted at the early of food processing such as post-harvest and production is referred as food losses while food products discarded during consumption and marketing is known as food waste. Some others definition on food loss and waste is explain in Figure 2.1. This biodegradable waste discharged from various sources including processing industries and households are becoming a serious problem around the globe due to the increase of the world population.

Table 2.1: Definitions of food loss and waste (Ishangulyyev, Kim, & Lee, 2019)

Concepts	Definitions
Food Loss (by FAO)	Decrease in weight (dry matter) or quality (nutritional value) of food that was originally produced for human consumption
Food Waste (by FAO)	Food appropriate for human consumption being discarded, whether after it is left to spoil or kept beyond its expiry date
Food Waste (by FUSIONS EU)	Any food and its inedible parts, removed from the FSC to be disposed (including composted, crops ploughed in or not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea) or recovered
Food Loss (by High Level Panel of Experts)	A decrease, at all stages of the FSC prior to the consumer level, in mass of food that was originally intended for human consumption, regardless of the cause
Food Waste (by High Level Panel of Experts)	food appropriate for human consumption being discarded or left to spoil at consumer level—regardless of the cause
Food Loss and Waste (by United States Department of Agriculture)	FW is a subcomponent of FL and occurs when an edible food goes unconsumed. The food which is still edible at the time of discard is considered as food waste

FAO: Food and Agriculture Organization; FUSIONS EU: Food Use for Social Innovation by Optimising Waste Prevention Strategies EU; EU: European Union; FSC: food supply chain; FW: Food Waste; FL: food loss.

In 2017, studies of Paritosh, et al. are well documented and acknowledged that food waste incinerated into landfills may be increase in next 25 years due to economic

and population growth. Thus, it also increases carbon footprint that contribute greenhouse gas emissions by accumulation of 3.3 billion tonnes carbon dioxide into the atmosphere every year. Besides, a large number of existing studies in the broader literature have examined that generation of food waste effectuates an impact in environmental spheres such as soil depletion and soil contamination. Furthermore, social effects are related with the ethical behaviours of residence whereby excessive resource consumption of food by consumer.

Moreover, it is reported that approximately 1.3 billion tons of edible food which is one third of all produced foods is wasted every year to feed nearly 2 billion people of 2 100 kcal per day of a good diet (Conrad, et al., 2018). As global food demand continues to rise through population and consumption growth, the average of food waste also predictable to be drastically increased in the future (Sharma et al., 2019). Furthermore, a unique food culture of diversity and tastiness food in Malaysia had turning it into a waste culture due to the poor planning and bulk purchasing of food according to the lifestyle, education, family composition and socioeconomic which then create a critical environmental, economic and natural resource impacts. According to Solid Waste Corporation of Malaysia (SWCorp), it showed that approximately 15 000 tonnes food waste being disposed daily in Malaysia with 3 000 should not have been discarded. A substantial portion of food waste thrown into landfills is converted into greenhouse gas (GHG) and methane which threat our global 25 times higher compared to carbon dioxide. Conventionally, food waste incinerated into the landfills with an open area may cause severe health and environmental issue as it decomposes faster with a higher methane yield. Table 2.2 shows sources of food waste in Malaysia.

Table 2.2: Food waste generated in Malaysia (Abd Razak, 2017)

Estimated food waste generated in Malaysia	Generation rate		
	(tones/day)	(tones/year)	Percent
Sources of food			
Household	8,745	3,192,404	38.23
Wet and night markets	5,592	2,040,929	24.50
Food courts/restaurants	5,319	1,941,608	23.35
Hotels	1,568	572,284	6.87
Food and beverages industries	854	311,564	3.41
Shopping malls	298	108,678	1.30
Hypermarkets	291	106,288	1.28
Institutions	55	26,962	0.32
Schools	45	21,808	0.30
Fast food/chain shops	25.21	9,064	0.26
Total	22,793	8,331,589	100

In order to provide a solution to the food waste problem, it is necessary to overcome food waste with reliable methods and not to underestimate the problem. The discarding of food is a problem that can be largely solved by educating consumers and changing their drive when it comes to the generation of waste, while establishing a disposal system for this type of waste. The establishment of an efficient bio-waste management system, which includes food waste, is a necessity for environmental protection, for the more efficient use of resources, as well as for economic and social benefits (Branka et al., 2019).

2.2 Anaerobic digestion

Food waste that contains total solid and biochemical methane potential (BMP) is a highly desirable substrate for anaerobic digestion due to its biodegradability and high nutrient contents. Anaerobic digestion (AD) that converting organic waste into bioenergy is considered to be green energy and attractive solution for food waste management as it is environmentally friendly and less harmful to the nature. AD is a

complex biochemical process that combines chemical and physicochemical reactions in series, involves different microbial species that potentially treat organic waste, and produces renewable energy (Perrot & Subiantoro, 2018). AD by using food waste can act as feedstock to produce bioenergy, such as biomethane (Zhao et al, 2019), biohydrogen (Yasin et al, 2013) and bioethanol (Hafid et al, 2017).

The process of anaerobic digestion consists of hydrolysis, acidogenesis, acetogenesis and methanogenesis process which then produce products such as methane and carbon dioxide, collectively called as biogas. Large polymer molecules in food waste are broken down by hydrolase into monomeric units during hydrolysis stage and this product will then undergo acidogenesis stage whereby it is fermented to volatile fatty acids along with carbon dioxide, hydrogen and ammonia. During acetogenesis process, acetogenic bacteria converts the acid phase products into acetates and hydrogen which later being fermented by reducing carbon dioxide to produce biogas in methanogenesis stage as shown in Figure 2.2.

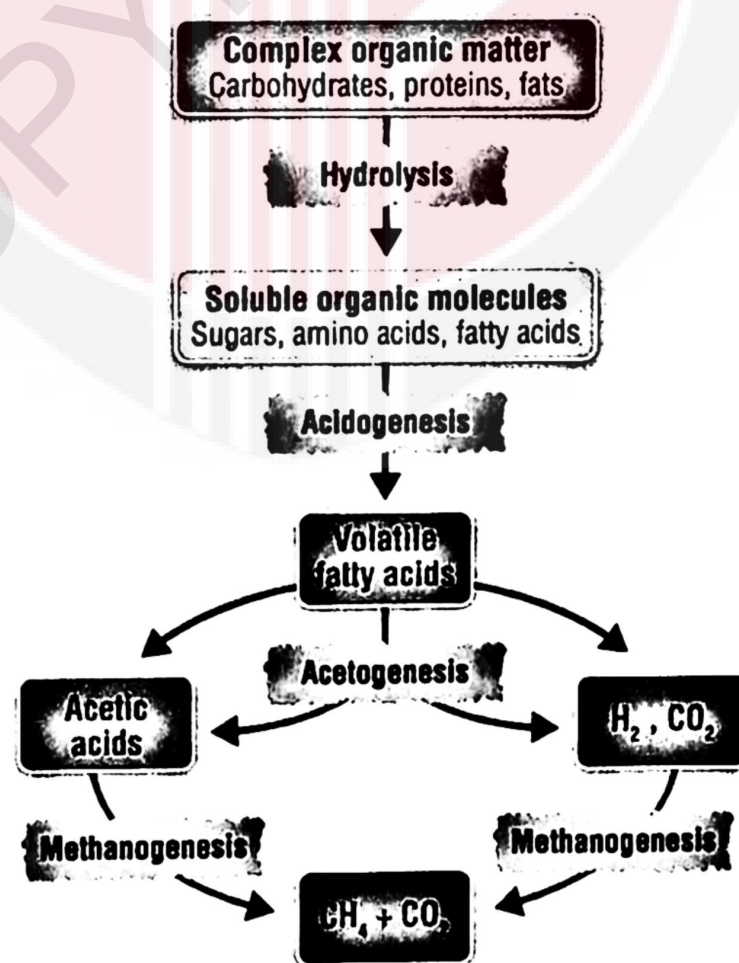


Figure 2.1: Biological process of anaerobic digestion (“Managing Digester Feedstocks,” 2016).

Thus, AD is a potential biotechnology to treat food waste for both energy and resource recovery. Energy recovery and utilization from solid waste presents a significant role in primary energy saving and waste reduction. Food waste (FW) is the potential source anaerobic digestion because of its composition and moisture as well as for biogas production via fermentation, which has an additional benefit of improving waste management practice and energy conversion (Zhang et al., 2019).

A series of recent studies has indicated that advantages of AD include the production of renewable energy, reduction of greenhouse gas emissions (compared to landfill), reduction water pollution and generation of a significant source of income. Biogas consists of 60–70% methane and 30–40% carbon dioxide, and digestate consists of water and nutrient-rich biosolids that can be filtered and used as fertilizer or soil conditioner. Thus, prior research suggests that anaerobic digestion is a better alternative than landfilling catering waste as it significantly reduces the volume of food waste and allows the production of these useful products. However, catering waste is one of an excellent candidate for anaerobic digestion because of its high moisture and high organic matter content. (Tayyab et al, 2019). Figure 2.3 shows a summary on how anaerobic digestion can give many benefit to the environment and consumers.

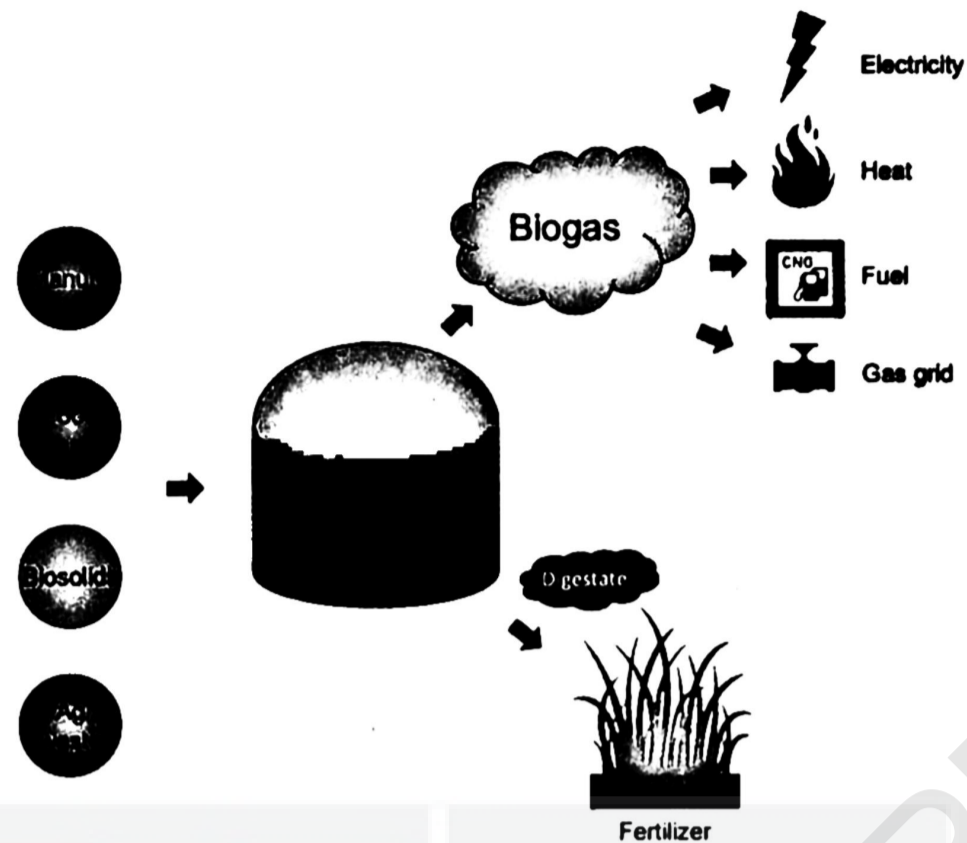


Figure 2.2: Benefits of anaerobic digestion (Juliana, Ashish, & Ajay, 2018)

In China, there is no full scale developed and operational anaerobic food waste digestion plant yet but there are over 20 national projects under development phase comprising anaerobic digestion and composting of main substrates of food waste, manure and municipal solid waste (Christian and Dubendorf, 2007). In spite of many development project of food waste anaerobic digestion in India, most of the projects have been hampered due to technical failure, poor management and incomplete regulation and policy (Christian and Dubendorf, 2007).

2.2.1 Inoculum

Inoculum is use of microorganism culture which is inoculated into a growth medium or in other word, it is a microorganism use as starter to create an environment suitable for fermentation process. Preparation of inoculum requires collecting the species in an ideal condition compatible with inoculation into cultured cells, culture of tissues, media, and fermentors. Typically, the prime objective is to obtain a high degree of viable biomass in an acceptable physiological state for use as an inoculum (Sood,

Singhal, Bhat, & Kumar, 2011). According to Dhamodharan, Kumar, and Kalamdhad (2015) five different livestock dungs which is poultry dung, goat dung, cow dung, piggery dung and rhinoceros dung were experimented to observe the best inoculum. The results indicated that cow dung inoculum were more suitable for the anaerobic digestion of food waste than other livestock dungs. Reactors inoculated with cow dung achieved higher methane production and volatile solids degradation. Thus, we were using cow dung as our inoculum.

2.2.2 Factor affecting anaerobic digestion

The biogas production is influenced by many factors, of which the temperature of the anaerobic digester process, hydraulic retention time, mixing rate, organic loading rate and pH are the example. Depending on the reaction medium temperature, certain groups of microorganisms are stimulated, while others are inhibited (mesophilic bacteria require an optimal temperature around 35°C, and the thermophilic bacteria require an optimal temperature around 55°C) inducing various degrees of organic material biodegradability, the maximum being reached at 55°C, influencing the quantity and quality of biogas production. Apart from temperature, the qualitative and quantitative influence over the biogas production is determined by the biodegradable organic matter content of the raw material subjected to the microorganism's action, by the C/N ratio, sublayer pH etc. These parameters could be controlled via appropriate design and mixing regime of the fermentation process (Arapatka, 1994).

Besides, the optimal range of pH to obtain maximal biogas yield in anaerobic digestion is 6.5–7.5, the range is relative wide in the plant scale and the optimal value of pH varies with substrate and digestion technique (Liu, Yuan, Zeng, Li, & Li, 2008).

Next, mixing process in a biodigester will help in increasing contact time between the microorganism and the substrate (food waste). But, mixing process have their limitation, the mixing should not disturb the anaerobic digestion process. Thus, some evaluation needed to find out optimum mixing condition for a biodigester. Hydraulic retention time (HRT) is closely related to the amount of substrate that can be handled per unit time (Kim, Cha, & Kim, 2013). HRT is calculated by dividing digester volume (litre) by the feed volume (litre/day) (Gould, 2015). As an important controlling parameter, hydraulic retention time (HRT) has an influence on not only pH but also some other internal environment factors in the anaerobic digestion processes (Shi, Li, Leu, & Antwi, 2016). Lastly, Organic loading rate (OLR) also play an important roles toward anaerobic digestion rate. OLR defines the amount of substrate fed in the bioreactor per working volume per day (VS/L/d) (Wainaina, Awasthi, Horváth, & Taherzadeh, 2020). OLR can affect the acidogenic phase in a number of ways. As an example, operating at high OLRs can potentially raise the concentration of the VFAs as a result of the higher availability of organic nutrients (Wainaina et al., 2020).

2.3 Biogas as a renewable energy

The biogas (CH_4) is a feed-stock for electricity generation and could be used as flammable fuel for cooking and heating purposes (Khanal, 2008). Capturing and utilizing methane is important in contributing to CH_4 emission reduction and as a renewable energy source (Atelge, 2018). Biogas is a gas mixture, mainly consisting of 65% methane and 35% carbon dioxide, resulting from the biological process of anaerobic digestion of various organic materials. The percentage of methane in biogas will vary depending on the process conditions and the type of organic matter fermented

between 55% and 80%. Biogas also contains very small quantities of other gases such as: hydrogen sulphide, nitrogen, oxygen, water steam etc.

2.4 Type of biodigester

2.4.1 Fixed-dome

The fixed dome biodigester, also known as “Chinese” or “hydraulic” digesters are the most common design developed and applied in China for the biogas production (Santerre & Smith, 1982). It is called fixed-dome because of its upper part(dome) is built-in together with the body part which cannot be move or separated. The dome is mostly made of granite, sharp sand, iron rods, and cement. Some of the essential consideration of design includes local climate, the volume of waste and the water required for everyday input into the anaerobic digester. The bottom part of the digester includes a biosolid layer, and a liquid layer above the biosolids (Uche et al., 2020). Fixed-dome plant has an inlet chamber feeding into the digester which is topped by a dome expansion chamber with a gas release point to discharge biogas produce. A slurry outlet from the digester can feed into a tank, providing high-quality fertiliser. The organic matter feeds into the main tank through the feeding port as shows by arrows in Figure 1. Then, biogas produce is transfer into the gas storage through the upper part of the main tank. An effluent port is collecting liquid which can be used as liquid fertilizer. Figure 1 shows how the system works.

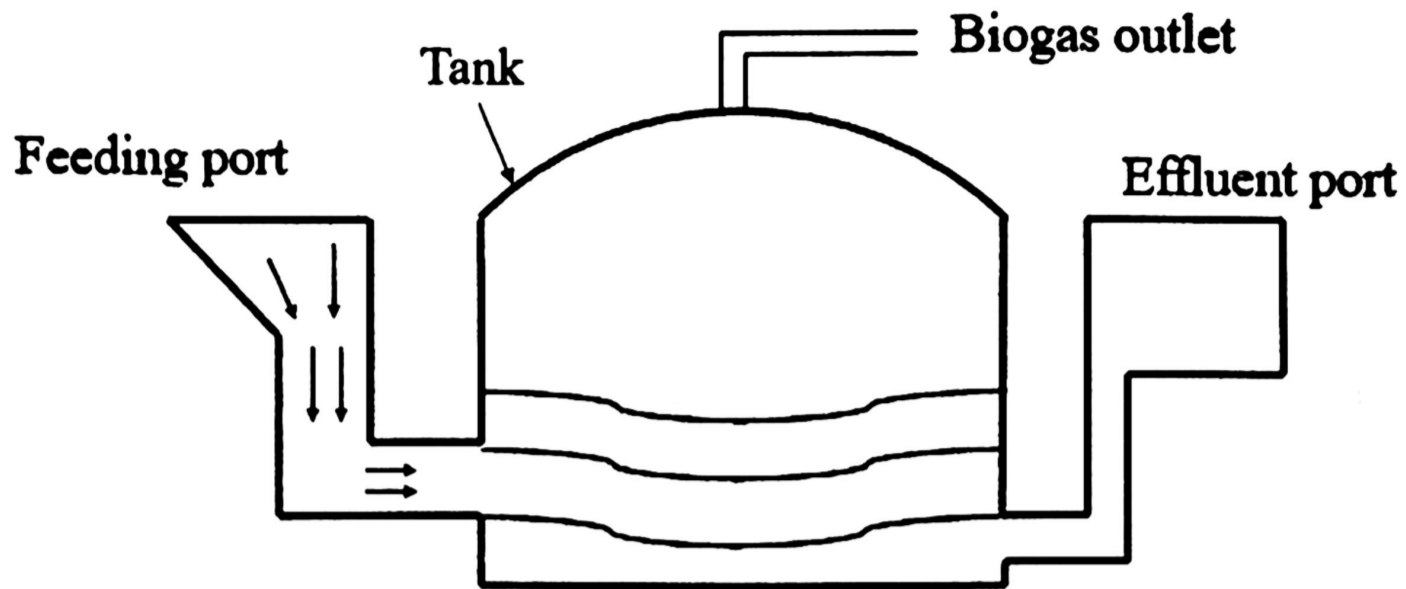


Figure 2. 3: Sketch of fixed-dome biodigester (Rajendran et al., 2012)

This design usually uses plastic-based material to avoid the material rust or reacting with the organic matter. Thus, it has a low cost to be built due to the type of material used and simple design. Moreover, the fixed dome design on the upper part helps it to lengthen the operational life of this biodigester as it has no moving parts for gas utilization. The risk of cracking and porosity due to the hydrostatic pressure between the lower and upper part of the dome can be reduced by using special sealants with gas-tight properties. However, this fixed-dome biodigester is less effective as the gas pressure will fluctuate substantially depends on the invisible volume of biogas stored and this design also lack of agitation action that causing slower anaerobic digestion reaction which directly effect on amount of biogas produce. Besides, a laboratory experiment was observed that in digester bottle the biomass and water get separated after some time and made the 2 unusual layers. The biogas gets trapped in the layer of biomass which as the result of it the whole mass transfer in the digester was not uniform. The agitation can help in proper mass transfer by uniform distribution of mixture inside the digester. It facilitated in uniform distribution of temperature (Kaur & Kumar, 2017).

2.4.2 Floating Drum

Khadi and Village Industries Commission (KVIC) is the name for floating drum biodigester design which developed in 1962 (Figure 2). Even though the design is quite old, it is still acceptable and is being used in Indian community until this new era (Ishmael et al, 2014). Floating drum digester is an innovation design from the fixed-dome biodigester. The fermentation chamber also acts as the holder unit for gas in this system also called as a gasholder which provides more spaces to store a certain amount of biogas with constant pressure. For this design, mild steel is commonly not being uses to create the gas holder thereby making it less costly and not prone to corrosion. The fixed dome type could last longer than the floating drum (Nkoi, Lebele-Alawa, & Odobeatu, 2018). The volume of stored biogas visible directly as the drum will rise when biogas collected and moves down when it is consumed. The floating gasholder floats in the water-jacketed compared to the fermented slurry to provide more aesthetic appearance and prevent stuck of the substrate especially with high solid content. The dark colour painted on the floating drum may help in the higher biogas production due to the high temperature. This is because high temperature improves the bacterial action on organic materials which also helps to reduce the chemical oxygen demand (COD) of waste to be used as fertilizer. A central guide constructed inside biodigester to prevent the floating drum from tilting when a maximum amount of biogas stored. At the beginning of operation, we eliminate air trapped in gas holder to minimize the risk of explosion. The air if allowed, aids combination of methane and oxygen which is an explosive mixture and can cause serious hazards when accidentally exposed to spark or fire (Ononogbo, 2015). The main system works similar to the fixed-dome biodigester design but more efficient as it provides larger space for biogas

storage. Some disadvantage of this design is it may be having high cost compared to the fixed-dome type.

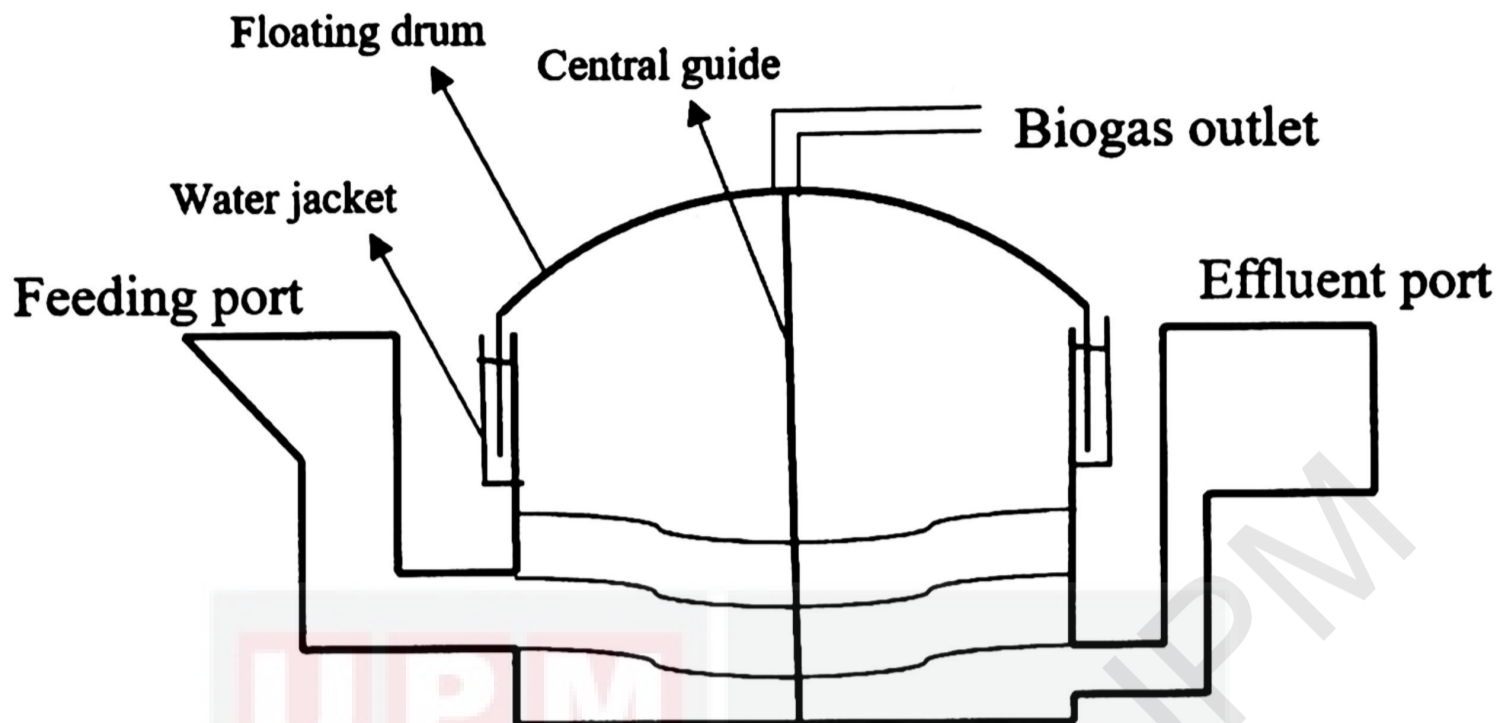


Figure 2. 4: Sketch of the floating drum biogas digester (Rajendran et al., 2012)

2.4.3 Low-Cost Polyethylene Tube Biodigester

Low-Cost Polyethylene Tube Biodigester was applied in Bolivia (Peru, Ecuador, Colombia, Centro America and Mexico). The tubular polyethylene film is bent at each end around a 6 inch PVC drainpipe and is wound with rubber strap of recycled tire-tubes. With this design, an air tight tank is obtained to provide a system for anaerobic digestion. The amount of biogas produced is to a large extent dependent on the outside temperature and placing the digesters in a non-shaded area is preferable. It is possible for using a transparent material but be sure to cover the tube with a non-transparent material or to build a roof over the digester in order to avoid algae formation due to direct sun exposure (Eckerwall, Jansson, & Larsson, 2015). In general, this design is much simpler to be construct compare to fixed-dome and floating drum which indirectly reduce the cost. The system works the same as before which having feeding port, effluent port and biogas outlet as shows in Figure 3.

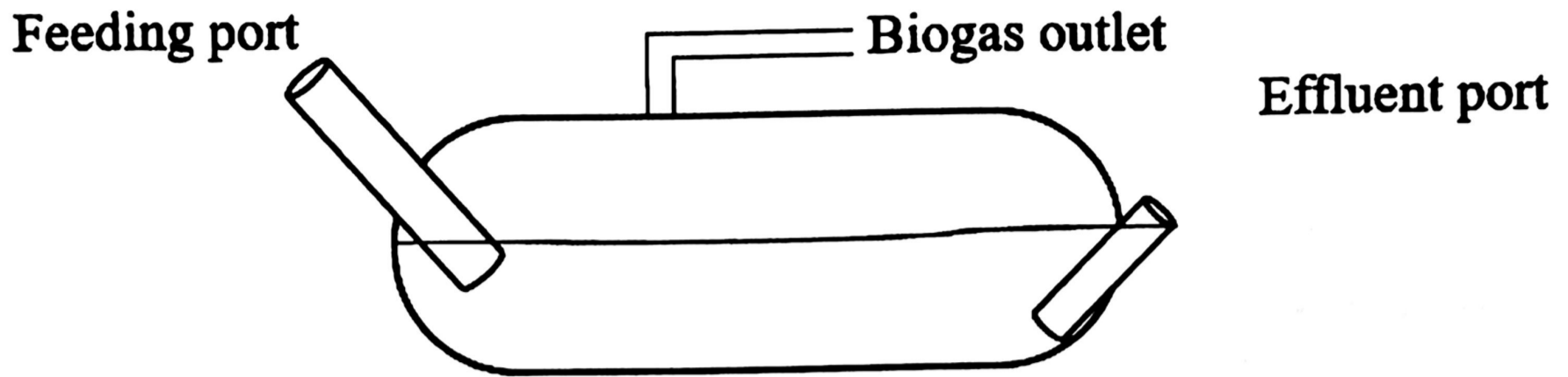


Figure 2. 5: Sketch of low-cost polyethylene tube digester model (Ferrer et al., 2011)

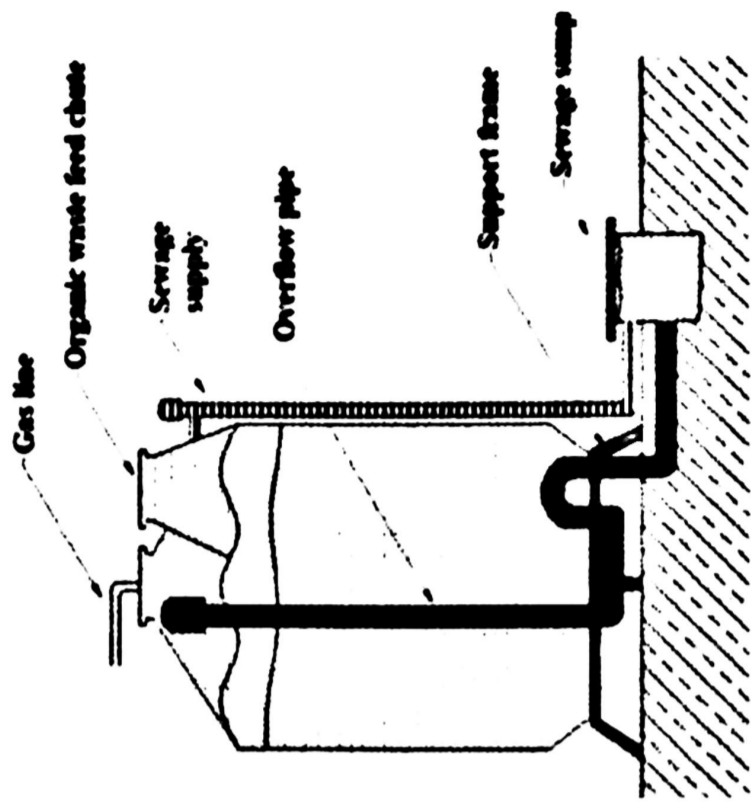
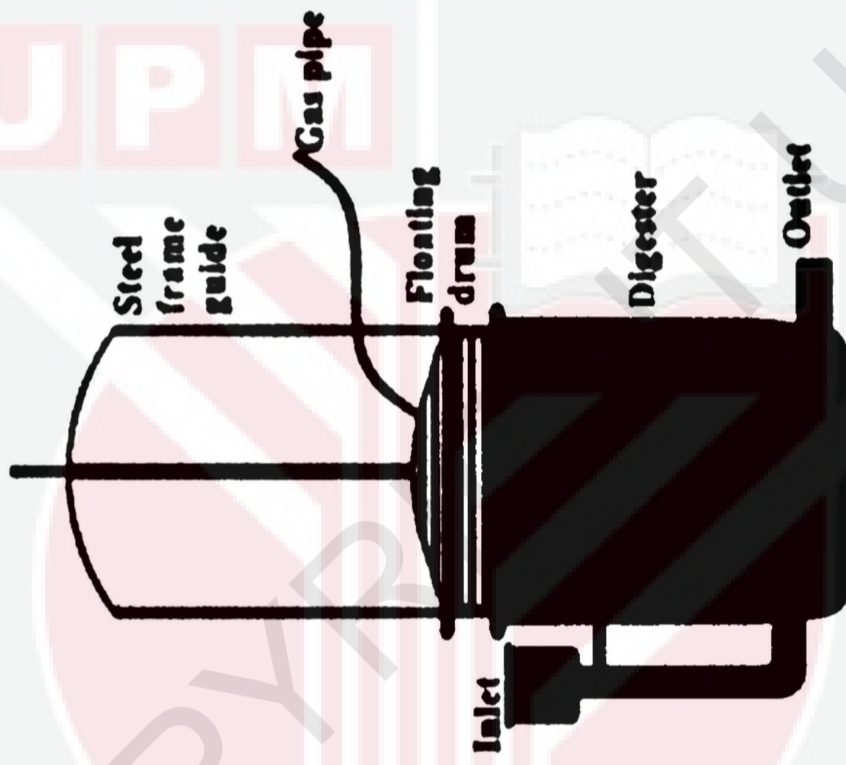
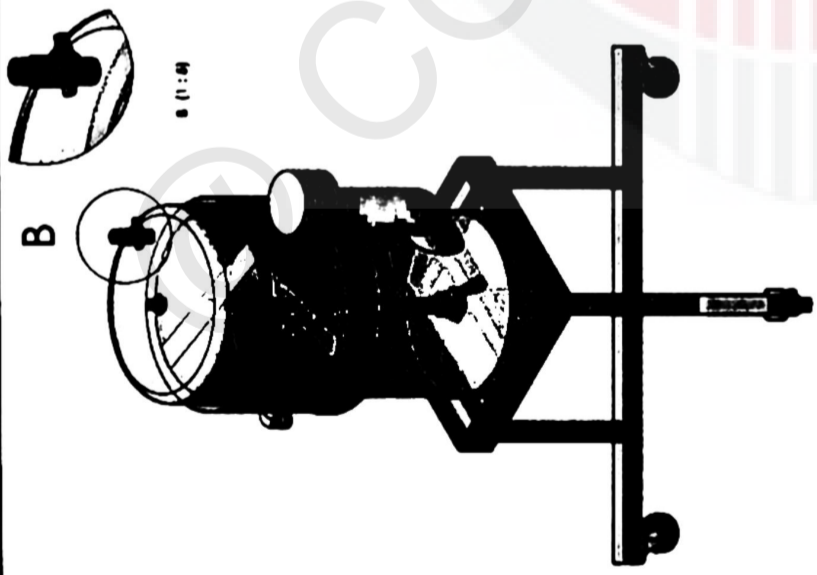
One of the 6 inch PVC drainpipes uses as the inlet of feeding and the other one as the outlet of the slurry. A hydraulic level in the tube digester is set up by the level of the effluent port. The quantity of added prime matter (feeding organic) should have the same quantity of fertilizer leave by the outlet (Low-Cost Polyethylene Tube Digester, 2016). Some main advantages of this design is include low cost, fast payback, simplicity and positive effect on pollution (An, Preston, & Dolberg, 1997). However, this design has a serious limitation on life span, gas pressure and gas production as it depends on the ambient temperature.

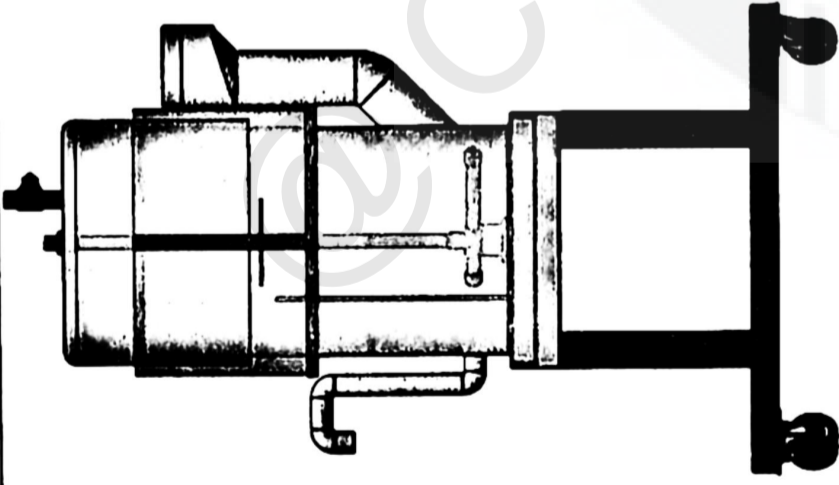
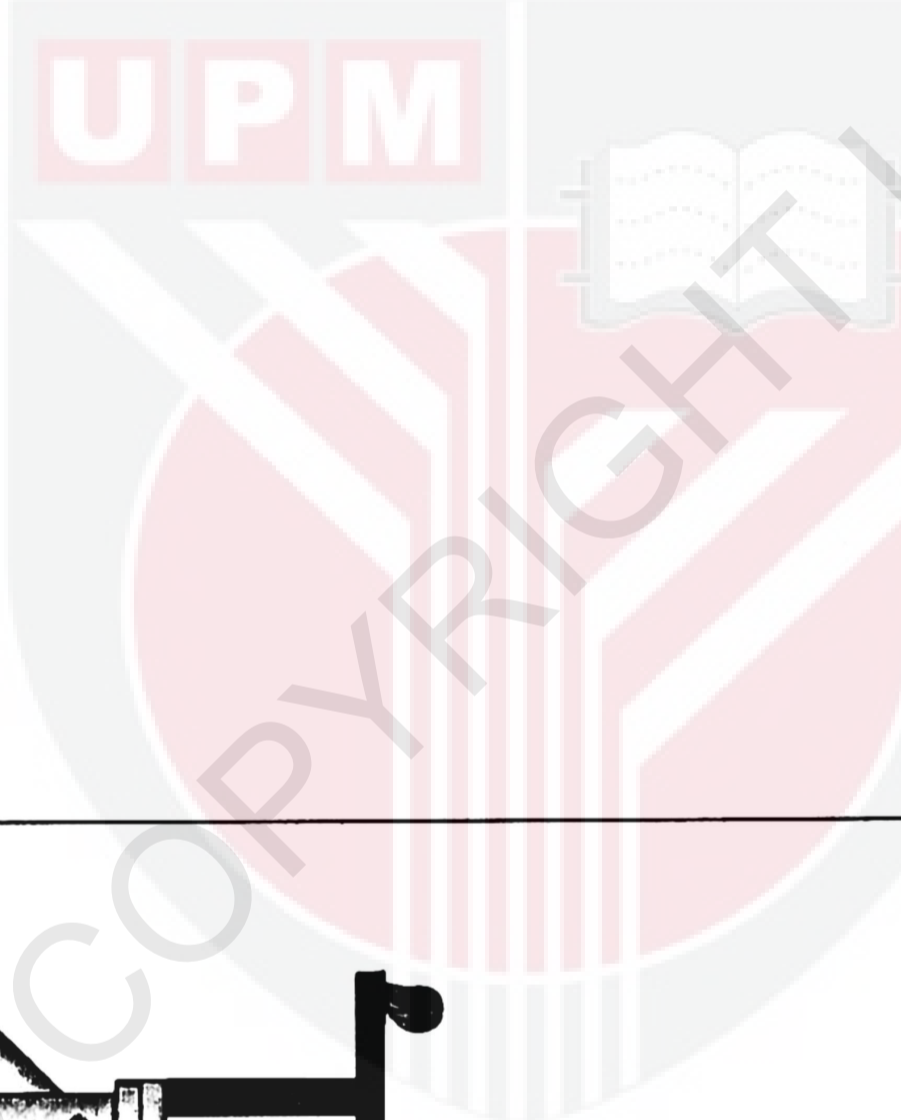
2.5 Prior art

Prior art is design that has been disclosure to the public in any form about the invention. Prior art does not need to exist physically or be commercially available. It is enough that someone, somewhere, sometime previously has described or shown or made something that contains a use of technology (Office, n.d.). In this project, prior art done related to biogas production from food waste, organic material and agriculture waste.

Patent requirements	CURRENT TECHNOLOGY	PRIOR TECHNOLOGY	PRIOR TECHNOLOGY
	Portable biodigester for household use	EZ-digester	Agama fixed dome digester

Drawing



			
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<p>Novel process/product</p>	<p>This invention is designed to providing an environment for anaerobic digestion of food waste with main desire product is biogas. The biogas produces are used to replace cooking</p>	<p>Ez- digester is one of floating dome biodigester type but redesigned to be portable and able for household use. It is equipped with floating dome that</p>	<p>Agama fixed dome digester is plastic roto mould digester which uses the operating principle of the traditional fixed dome digester. There</p>
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	<p>gas. Main target for this invention is for household use. The biodigester design in small scale to make it suitable for household use. The main tank is designed to have two compartment where each of the compartment store sludge and liquid product. Sludge compartment also is the main part of the biodigester where anaerobic digestion reacts. During the reaction, an impeller used to stir the food waste feed to increase the contact time of microbial population and available substrate. The anaerobic digestion producing biogas as main product will be going up to the upper part of the tank. A jacketed at outer main tank is fill by the water to help lid of the tank to float and preventing biogas from escape. The lid (floating part) will be push up by the biogas produce creating more spaces for biogas storing.</p>	<p>able to move forward to make bigger space for biogas storing. The floating dome is connected by a gas pipe to transfer the biogas produce for consumption. A steel frame guide is designed to avoid the floating dome from tilt. Organic waste is added through the inlet and stay in the tank for anaerobic process and discharge through the outlet.</p>	<p>were two inlets to the tank which is one for organic waste and the other one connected straight to the sewer system. The waste in added will fill the tank until it reaches a certain level that overflow the waste into a sewage sump by a pipe. The pipe is designed with a S-shape at a point to avoid biogas getting flush out together with the overflow waste. Biogas produce from the anaerobic process in the tank is transfer out by a gas line at the top part of the tank. This design also supplies gas at variable pressure which is a limitation.</p>
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Inventive step	<p>1. Food waste is feed to the main tank through the hopper of the influent port.</p> <p>2. The main tank is transparent and air tight which allow the consumer to monitoring the process occur inside the main tank while providing an ideal space for the food waste to undergo anaerobic digestion.</p> <p>3. The tank is divide into 2 part by a divider to keep potential substrate (food waste) at bottom of main part while the liquid sample will overflow into the second part.</p> <p>4. Water jacketed is the second tank at the outer part is fill with water to help the floating lid float while preventing biogas produce from release out.</p> <p>5. A pair of impeller that having different length use to stir and spread the bacterial population to the available substrate (food waste) which can increase biogas production rate is connected to the center of floating lid</p>	<p>1. Organic kitchen waste is added into the main tank through the inlet</p> <p>2. The main tank is air tight which provide an ideal space for the food waste to undergo anaerobic digestion.</p> <p>3. NA</p> <p>4. Water jacketed fill with water to help the floating lid float while preventing biogas produce from release out.</p> <p>NA</p>	<p>1. Organic waste or wastewater from the sewage system is added into the main tank through the inlet port</p> <p>2. The main tank is air tight which provide an ideal space for the food waste to undergo anaerobic digestion.</p> <p>NA</p> <p>NA</p> <p>NA</p>
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	by a nut which will rotate based on the floating lid rotation.		
	6. A guide plate use to guide the impeller rod to stay at the center of the tank and avoiding the floating lid from tilting.	6. Steel frame guide use to make sure the floating drum is not tilting.	NA
	7. The floating lid is the third tank placed in inverted position use to create more spaces when it is pushed upward by the biogas produce from anaerobic digestion process.	7. The floating lid is pushed upward by the biogas produce by the anaerobic digestion process.	7. Biogas produce by the anaerobic digestion process is discharge through a pipe line to a storage tank.
	8. Biogas produce will stay at the top of the main tank and can be release out through the biogas port which is located at the top of the floating lid.	8. Biogas produce will stay at the top of the main tank and can be release out through the gas pipe which is located at the top of the floating lid.	8. Biogas produce instantly flow to the biogas storage through the gas line continuously.
	9. S-shape effluent port help to prevent biogas from release through the effluent port while releasing the liquid sample when the liquid sample in second part reach same level as the effluent port.	9. Sample is remove through a simple outlet pipe at the bottom part when the process ended.	9. S-shape overflow pipe use to prevent biogas from release through the effluent port while releasing the liquid sample at the top of the tank when it is reach a certain level.

Industry application	For household gas production	For household gas production	For household gas production
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2.6 Review of food digester machine in market

There are some food digester machines that available in the market that functioning to digesting the household food waste. Most of them are only converting food waste into a product that can only use for bio fertilizer but some of the food waste digester targeting biogas production for cooking fuel. Commonly, they required electricity to operate and need bigger space.

For the time being, there has been lack of development of commercialize of biodigester for household use in our country. There are few food digesters in the market but they not fabricated in the Malaysia.

2.6.1 HomeBiogas 2.0

The product is made from flexible digester tank. It is constructed for the purpose of digesting food waste and storing biogas for cooking fuel. Besides, the HomeBiogas 2.0 also create a fertilizer outlet as the product from food waste digestion. The main tank has volume 1300 L to place food waste and 700 L to store biogas before use for cooking. The total size needed to place HomeBiogas 2.0 is 115 cm x 205 cm x 125 cm. Figure 2.1 shows the view of the HomeBogas 2.0.

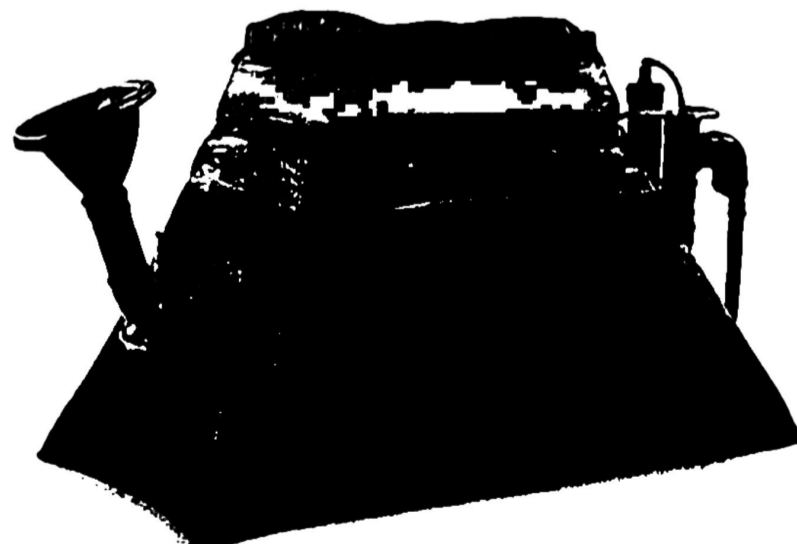


Figure 2. 6: Overview of HomeBiogas 2.0

The disadvantage of this product is it cannot operate in smaller spaces. This product are not very recommended to use at flat or condominium as it required large area. Besides, the system also does not have impeller or stirrer to help anaerobic digestion process.

2.6.2 BioHiTech Seed®

BioHiTech Seed is a product that invented a machine to composting food waste into before it discharges into the sewer line. The process involve is adding food waste throughout the day. Then, aerobic digestion technology uses a proprietary blend of microorganisms to naturally break down food waste into liquid form. Once food waste is completely broken down it is safely discharged as wastewater through any standard sewer line. Figure 2.2 shows the view of the BioHiTech Seed.



Figure 2. 7: Front view of BioHiTech Seed.

The disadvantage of this product is it required electricity to operate. Moreover, this product only focussing to discharge food waste instead using for many other valuable purposes.

2.7 Design summary

Identifying the problem is the most important part in designing a machine. From the problem, the possible conceptual design will develop to solve the problem. According to Edjabou, Peterson, Scheutz and Astrup (2016), 183 ± 10 kg of food waste per year collected from 1474 households is being dumped together with other solid waste which can cause the undesired smell and pollute our environment. The waste in the landfills and the use of undigested waste as fertilizer will contribute to land and underground water pollution. Thus, it is considered a threat which can be the largest source of methane emissions to the environment. Based on this problem, several designs of innovative biodigester had been proposed as a strategic plan to overcome the future challenges of food waste locally and globally. Thus, from these improved designs of the biodigester, it will benefit both humans and the environment by producing digested liquid fertilizer and capturing methane to produce biogas through anaerobic digestion.

In order to have an overview and more understanding on a biodigester, a visit to Biomass Technology Center, UPM has been made to acknowledge the function and properties of digester besides getting a closer look of the biogas pilot plant. The pilot plant consists of three main sections such as food grinder, anaerobic digester, and gas storage balloon. The 15 m^3 green anaerobic digester as being shown in Figure 3.2 used organic waste from restaurants as an indicator to evaluate biogas generation. Water and cow dung as an inoculum to the reaction is filled into the digester with a 1:1 ratio to approximately 50% of its volume. The biogas produced is then channeled through the piping system and stored in a gas storage balloon. Biogas is an alternative method as a substitution gas for household cooking and produces electricity by using a gas engine.

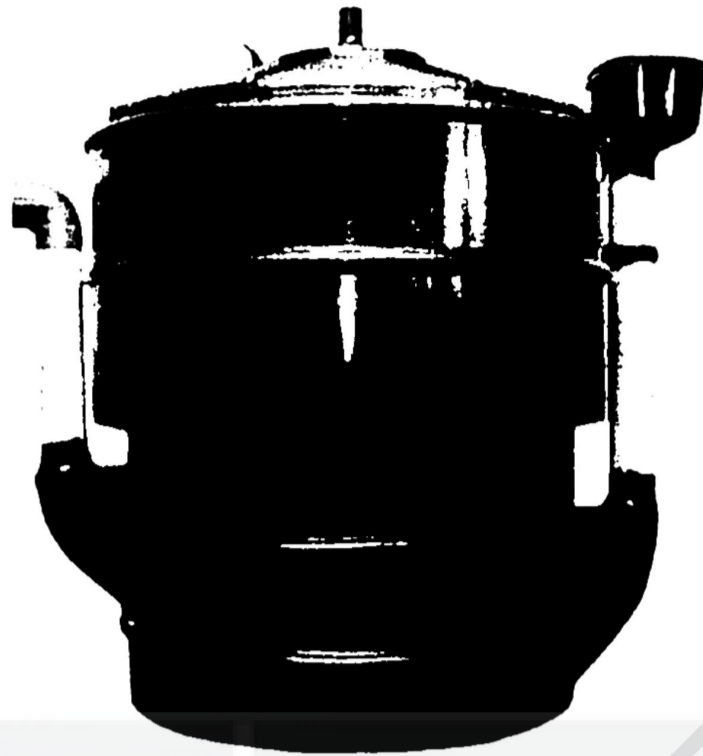


Figure 2. 8: Design of floating dome biodigester in Biomass Technology Center, UPM

However, the big size of this green digester which can be fed up to 15 m³ of organic slurry is not very helpful for the neighbourhood as it is not portable and can only be in a fixed location. It is also a high maintenance digester where the floating dome may be tilting due to the absence of the frame. Thus, a few design concept of household portable biodigester is drafted to overcome the problem. These modifications of existing biodigester are needed to fit into the modern era which craves better portability, safety, and efficiency. The design specifications are then finalized and the compartment parts of the machine are identified for understanding machine

mechanism. All the specifications may concentrate on the economic and safety aspect through its structure strength, durability, and flexibility to withstand different weather conditions.

Next, the information on prior art through patent search is compared. The main purpose of the searching is to make sure the conceptual design propose is not similar to the previous design. The advantages and disadvantages of the current machine studied to give idea generation of better conceptual design as discussed in section 2 which focused on the construction and structure of innovated portable biodigester.

Thus, from the information and idea, a new design concept of a portable biodigester for the household is designed to solve the problem. The possible conceptual design was then transformed into visualized reality using Solidwork 2019. All the conceptual design then compared against one other based on certain criteria. The best design then continued to the next stage of development which is performance testing. Performance testing will analyse the conceptual design and determine either it is the best design or need some improvement.

CHAPTER 3

METHODOLOGY

3.1 Flow Diagram of the design process

In this chapter, the methodology of the design flow of portable biodigester will be discussed. The methodology summarized in a flow diagram as a guideline to complete the project. In order to propose a new design concept of a portable biodigester, some consideration, innovation, and hypothesis are discussed and tested to make sure the design of the machine is meet the objective of this project. The following Figure 3.1 shows the flow diagram of the design process.

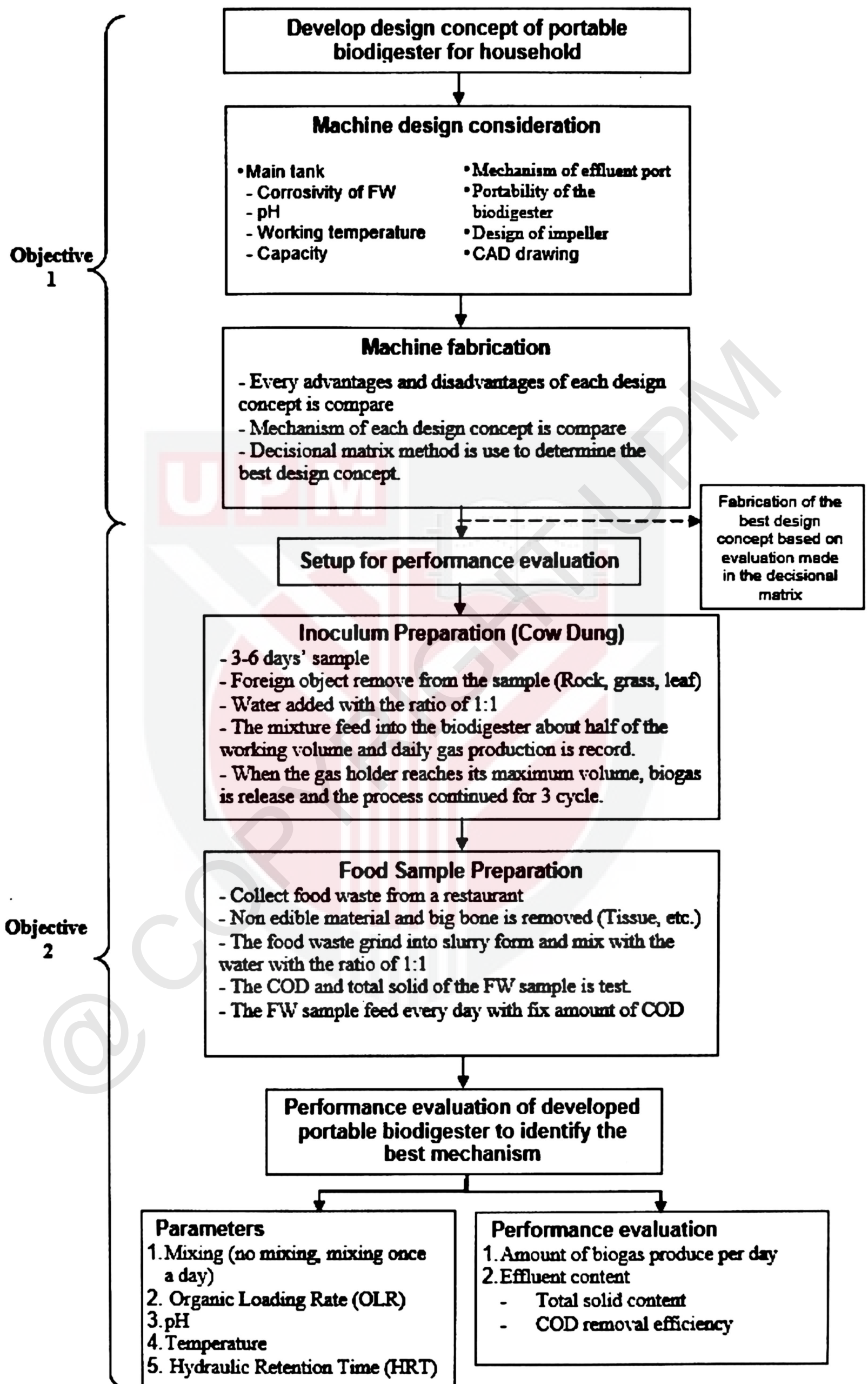


Figure 3. 1: Project flowchart

3.2 Conceptual design

The general objective of this research project was to design and fabricate portable biodigester for household biogas production. The innovation on the design of this portable biodigester was conducted in an organized and systematic methodology to ensure the end product can be competitive in the domestic market and well accepted by the citizen.

There are three drawing concepts were developed in considering the need of portable biodigester. These designs were the initial ideas on how the machine will look like. After the evaluation and screening process, the best design was selected for fabrication. The details and explanation of the requirement for conceptual design are shown in Table 3.1 below.

Table 3. 1: Requirements of conceptual design

Requirements	Details
Problem statements	Food waste dumping gave a bad effect on the environment and human health while food waste actually can be a potential source for producing biogas which green energy and can give benefit as alternative cooking gas.
Objective of the project	The propose conceptual design is to generate ideas for a portable biodigester that can be used as household biogas production
Originality of the idea	Observing and knowledge on existed portable biodigester and other equipment components that had the potential to solve the problem. Also comparison with prior art past patent
Knowledge and drawing concept	Knowledge of drawing and Autodesk software
Drawing explanation	All components in the drawing should be details and explain to having a better understanding of how each component work

3.2.1 Conceptual design 'A'

Concept design A comprise of a tank, feeding port, effluent port, floating lid and water tank. This concept design A is design to be square shape because of it can optimize the space usage to place the biodigester compare to circular shape. The feeding port connected to the bottom part of main tank as shown in Figure 3.2. Food waste sample added through the feeder fill the main tank until a certain then discharge through the effluent port. The water-tank is designed to support the weight floating lid and preventing biogas from release to the surrounding. Next, the floating lid will provide more spaces to store biogas produce by move forward. The more biogas produces, the higher pressure that will move the floating lid upward. At the top of the floating lid, a valve is design to allow the biogas to be discharge. The advantages of this design are it simple to fabricate and low maintenance as it requires less components. The disadvantage of this design is it not have a mixer that can help in increasing anaerobic digestion rate. This is because, the square shape floating lid make it not possible to be rotate which mean the mixer also is not possible to be rotate.

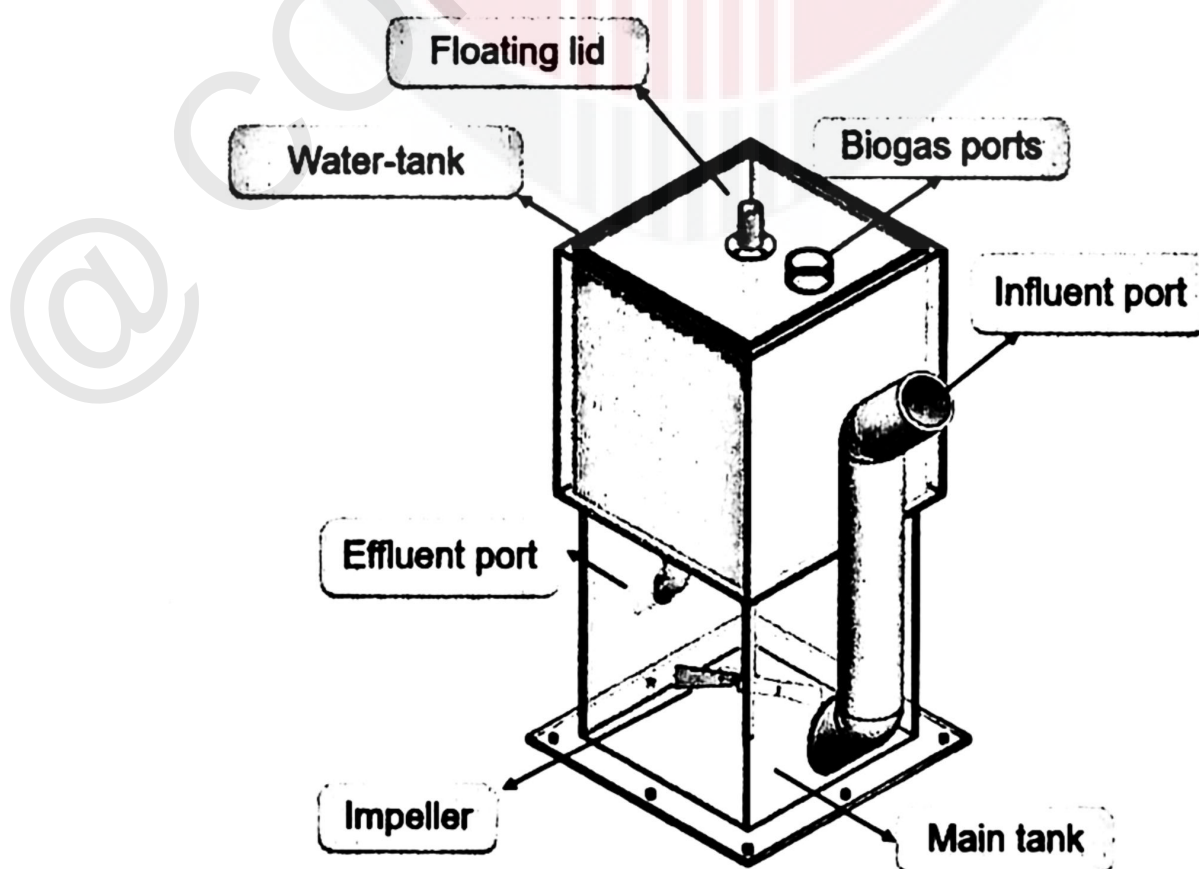


Figure 3. 2: 3D view of concept design A

3.2.2 Conceptual design 'B'

Design B comprise of a tank, water tank, floating lid, impeller, influent port, and effluent port. In concept design B, the square tank changed into a circular tank where it is designed to join together with an impeller as shown in Figure 3.3. A circular shape helps to make the floating lid to be able being rotate which directly rotating the impeller and mixing the food waste sample inside. In general, this design is using 3 different tanks, one main tank to store FW sample and second tank is the floating lid to store the biogas while the third one is water tank fill with water to support the floating lid. The advantage of this design is it has a mixing mechanism that can help to accelerate the digestion rate. However, this design was found out to have a disadvantage which is biogas produce maybe release through the effluent port. This is because there was no physical barrier to block the biogas from release to the surrounding. Thus, the biogas store on the upper part of the tank will be release out when the pressure inside is higher than pressure at the outside.

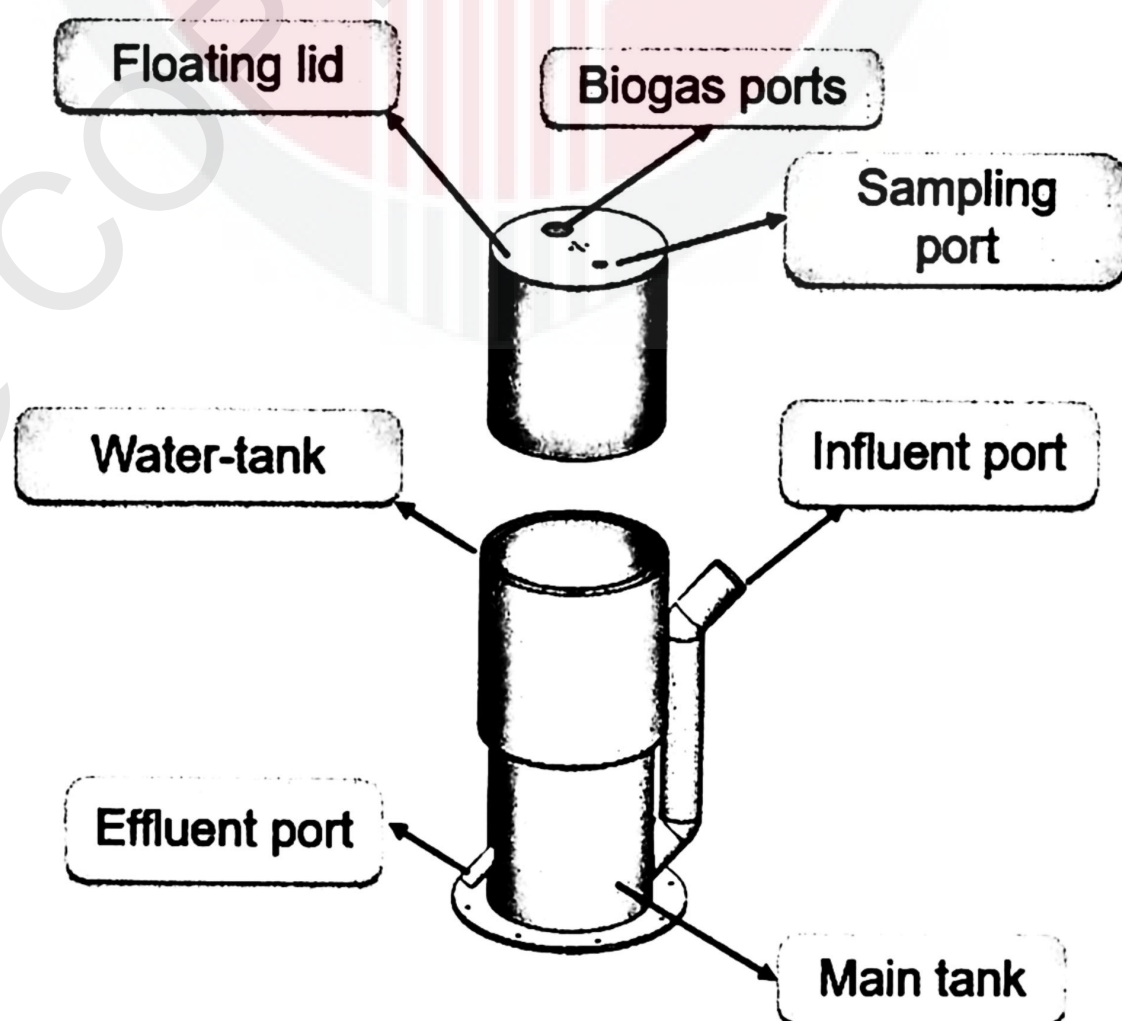


Figure 3. 3: 3D drawing of concept design B

3.2.3 Conceptual design 'C'

Design C is improved from designed B where the main tank is designed to be divided into two compartments. The design comprise a tank divide into two compartment, water tank, floating lid, impeller, guide plate, support stand, influent port, and effluent port as shows in Figure 3.4. The main part will be much bigger than the second part. The FW sample added through the influent port will be going to the bottom of the main part until it reaches the same level as divider then, it will overflow into the second part. The second part of the tank is connected with the effluent port. When the FW that overflows from the main tank reaches the same level as the effluent port, it will be discharged. The FW sample in the second part will block the biogas from flush out through the effluent port. This design improves the disadvantage from the design B which is biogas produce will not be release through the effluent port. Besides, the mixer is designed to be 2 different length impeller (refer sub-section 3.3.5) to ensure the FW sample is mixed well. Moreover, 2 guide plate is designed to guide the impeller and prevent the floating lid from tilting. Lastly, the biodigester is more efficient and easy to move around with the presence of stand support include 4 castor wheels. One disadvantage of this design is it has more components thus fabrication cost is higher than design A and B due to it having more components compare to design A and B.

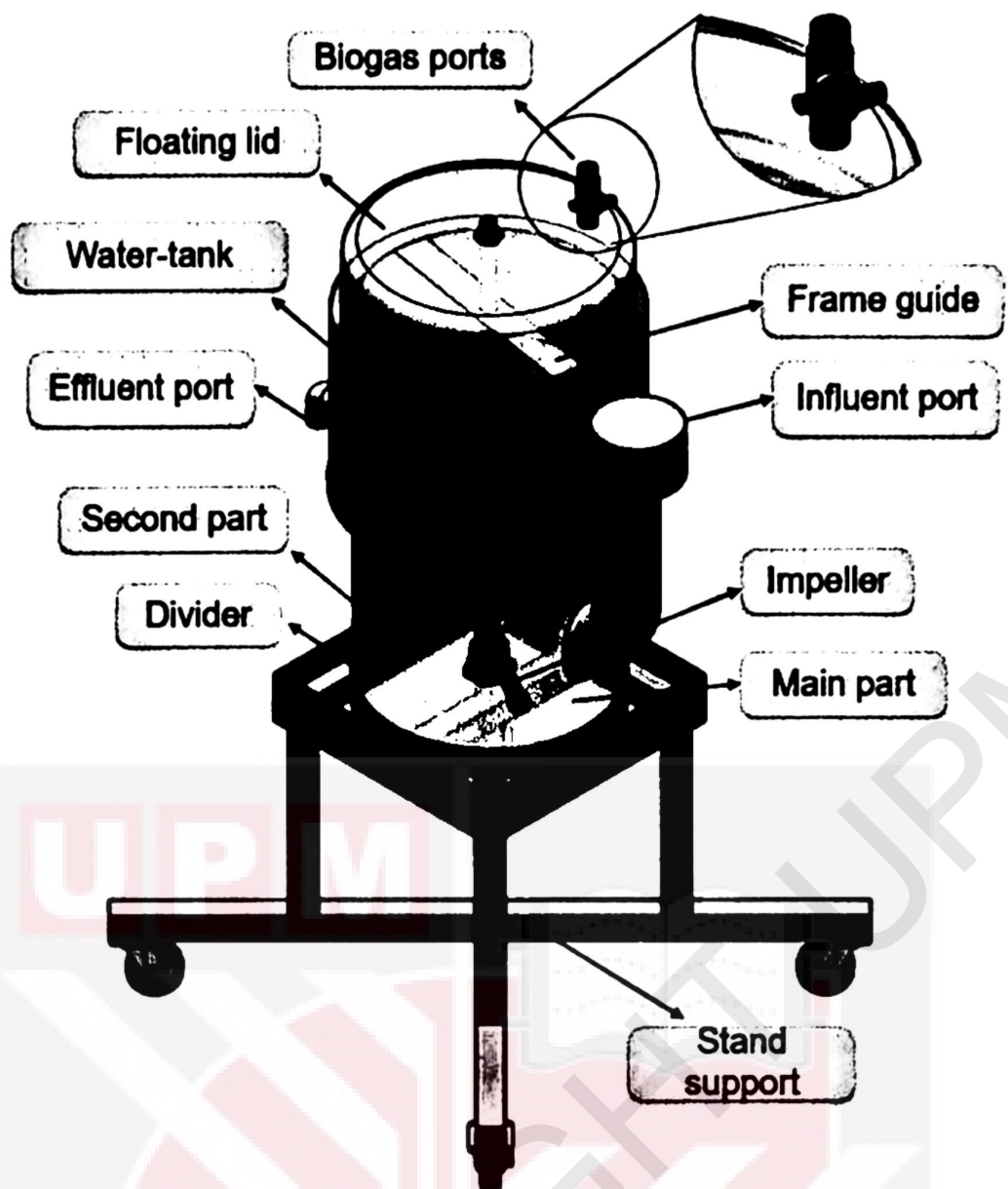


Figure 3. 4: 3D view of the concept design C

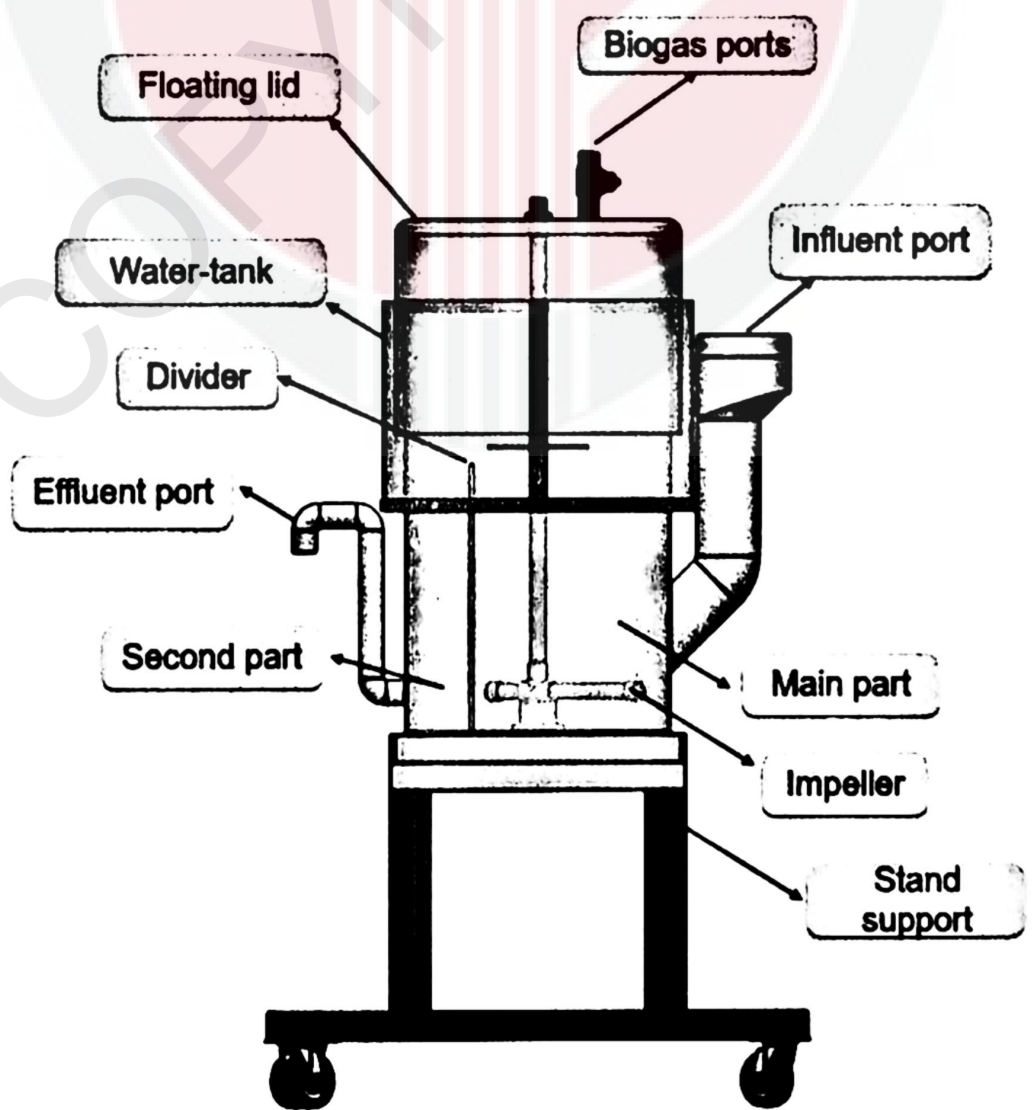


Figure 3. 5: Side view of concept design C

3.2.4 Conceptual evaluation and selection

From the three concept designs that were developed and introduced before, the best design needs to be selected for the fabrication. Therefore, a structured method of concept design selection was conducted. There are two steps of concept selection where the first step is to eliminate the product concept idea generated from many to a relative few that will be additional refinement. Secondly, the remaining concept designs evaluate to select the best concept design. Some selection criteria and the description used for concept screening and scoring are shown in table 3.2 below.

Table 3. 2: Description of the criteria used in conceptual designs evaluation

No	Criteria	Description
1	Ergonomic	The machine should consider the most comfortable positions when handling the machine.
2	Effectiveness	The effectiveness of the mechanism use and probability of failure
3	User friendly	The machine should be convenient to use especially aspect of operation handling
4	Maintenance	Parts of the machine can be reached or detached easily for cleaning purpose
5	Lifecycle	The machine should resist corrosion and able to use it for a long period.
6	Size/portability	The size of the machine aims to be lightweight, compact and easy to transport.
7	Affordability	Material cost, manufacturing cost and assemble cost must be affordable for the targeted customer.
8	Safety	The machine must be safe to be handled by operator/user which means safety features should be installed at potential hazardous parts.
9	Productivity	Hours of operation and the production of biogas rate
10	Exterior design	Exterior design that can attract the customer

3.2.5 Concept screening

Pugh Concept Selection was used for evaluating and selecting the best concept design.

Pugh Concept Selection Method is a quantitative technique used to rank the multidimensional options of an option set. This method frequently used in engineering for making design decisions but also possible to be used for rank investment options, vendor options, product options or any other set of multidimensional entities. A basic decision matrix consists of creating a set of criteria upon which the potential design can be decomposed, scored, and summed to get a total score which then can be ranked (“PRODUCT DESIGN DEVELOPMENT : Pugh Concept Selection Method,” 2013). The description of each step is shown in Table 3.3.

Table 3. 3: Steps in Pugh concept selection method

Step	Explanation
Criteria development	A list of criteria needed for selection is developed.
Design concept	Original design concepts are brainstormed. All concept should be compared at the same perspective of generalization and in similar language
Evaluation scoring	One of the concepts will be used as a datum. Each design concept is discussed and evaluated against the datum. For every comparison, the product should be evaluated as being better (+), same (=), or worse (-). For rating purposes, +1, 0 or -1 can be used to represent (+), (=) and (-) respectively.
Total score	The total score of the evaluation is calculated by the total positive number deduct the negative number. The total score should not be taken as an absolute decision-making to choose the final design, but as a guidance only. The top two scores should be choosing for the next stage.

Design concepts A, B, and C were tabulated in a spreadsheet and compared using the decisional matrix concept screening method. Design A was chosen as a

datum, which means it is a reference for comparing. The highest two scores with a positive overall score were chosen for the next stage.

Table 3. 4: Comparison of design concept using the decisional matrix method

Criteria	Design concept		
	A	B	C
Ergonomic	D A T U M	=	+
Mechanism		+	+
User friendly		=	+
Maintenance		-	-
Lifecycle		=	=
Size/portability		=	+
Affordability		-	-
Safety		=	+
Productivity		+	+
Exterior design		+	+
Pluses		3	7
Minuses		2	2
Total score		1	5

Based on Table 3.4, concept design C ranked first while design B in the second place therefore they will proceed for the next stage.

3.2.6 Concept scoring matrix

An evaluation matrix can also include an importance weight and the ratings of the concepts have a numerical scale, the matrix. Scoring is the more careful analysis of relative few concepts to choose a single concept which can make product success is possible. Table 3.5 shows the steps and explanation of the concept scoring matrix.

Table 3. 5: Steps in concept scoring matrix (Kosky, Balmer, Keat, & Wise, 2013)

Step	Explanation
Identify the evaluation criteria	List of criteria for design scoring matrix will be the same as in the design selection matrix
Weight of evaluation criteria	Weight values are determined to each evaluation criteria to represent its relative importance to the overall success of the design. The larger the weight, the more important is the evaluation criteria. Though not a mathematical necessity, it is preferable to define the weights such that their sum is equal to 1.
Assign values to each concept	Each concept is scoring by a value between 0 and 10 according to how well it satisfies the evaluation criteria under consideration. The values are assumed to have the following interpretation: 0- Very bad 5- Average 10- Very good
Overall value	For each concept-criterion combination, the product of the weight and the value is calculated and recorded. After these calculations are completed, the overall value (OV) is computed for each concept using the following expression: $OV = \sum_{n=1}^N (W_n V_n)$ <p>Where W_n = Weighting for n criteria V_n = Rating of concept for n criteria N = Number of criteria</p>
Result interpretation	The highest overall value indicates which design is best. Selected conceptual design is fabricated and performance evaluation is done. The design may be modified to improve its performance.

Based on the previous stage, design B and C are chosen for the concept scoring matrix. All the criteria for design selection were weight based on their importance and significance. The highest score concept design chosen for the next steps. Table 3.6 shows the selection of the design concept using the scoring matrix method.

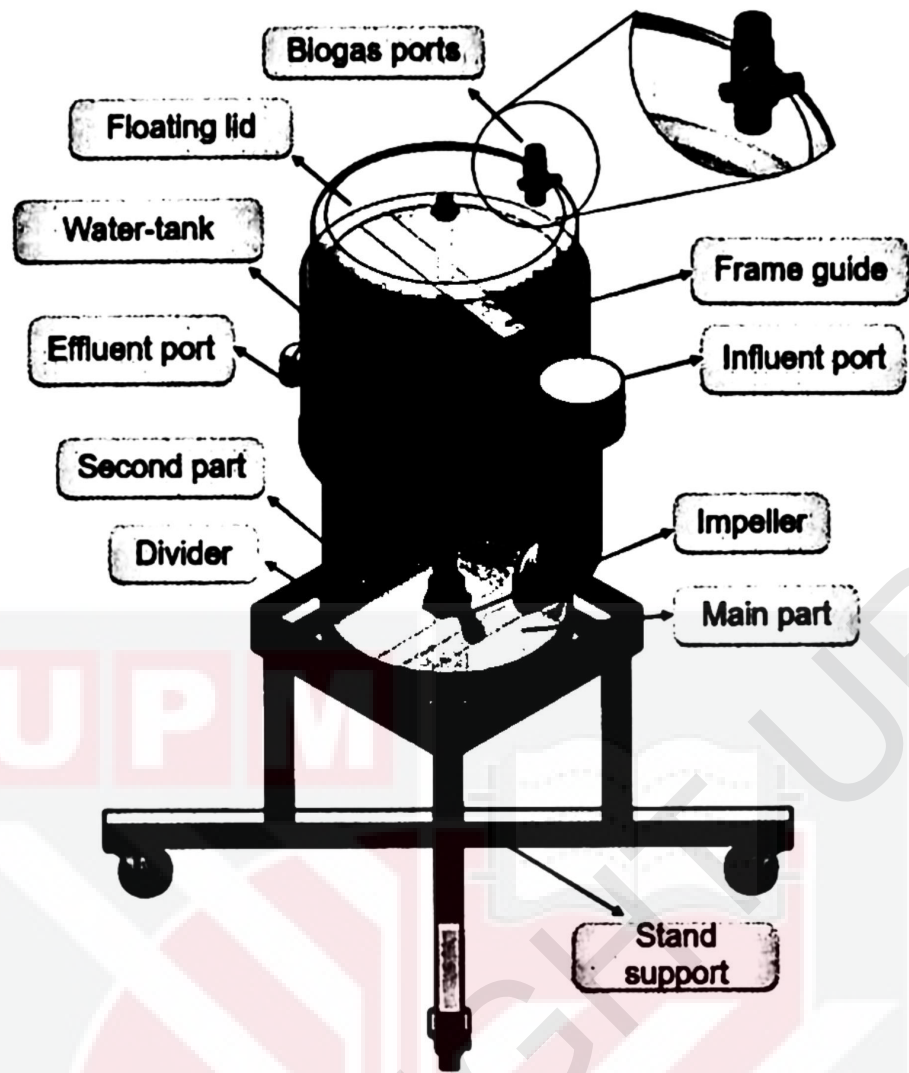
Table 3. 6: Selection of the best conceptual design using concept scoring

Criteria	Weight (Decimal)	Design concept			
		B		C	
		Rating	Weighted score	Rating	Weighted score
Ergonomic	0.13	3	0.39	8	0.14
Mechanism	0.15	4	0.60	9	1.35
User friendly	0.12	3	0.36	9	1.08
Maintenance	0.08	5	0.40	5	0.40
Lifecycle	0.10	6	0.60	8	0.80
Size/portability	0.05	4	0.20	9	0.45
Affordability	0.07	7	0.49	5	0.35
Safety	0.10	6	0.60	9	0.90
Productivity	0.15	6	0.90	7	1.05
Exterior design	0.05	3	0.15	9	0.45
Overall value		4.69		6.97	
Rank		2		1	
Continue to next stage		No		Yes	

Concept C has a higher overall value compared to the concept B. Thus, concept design C is selected as the final concept design. The best conceptual design of portable household biodigester is refined and improved using Autodesk software.

3.3 Construction and structure of portable biodigester

a)



b)

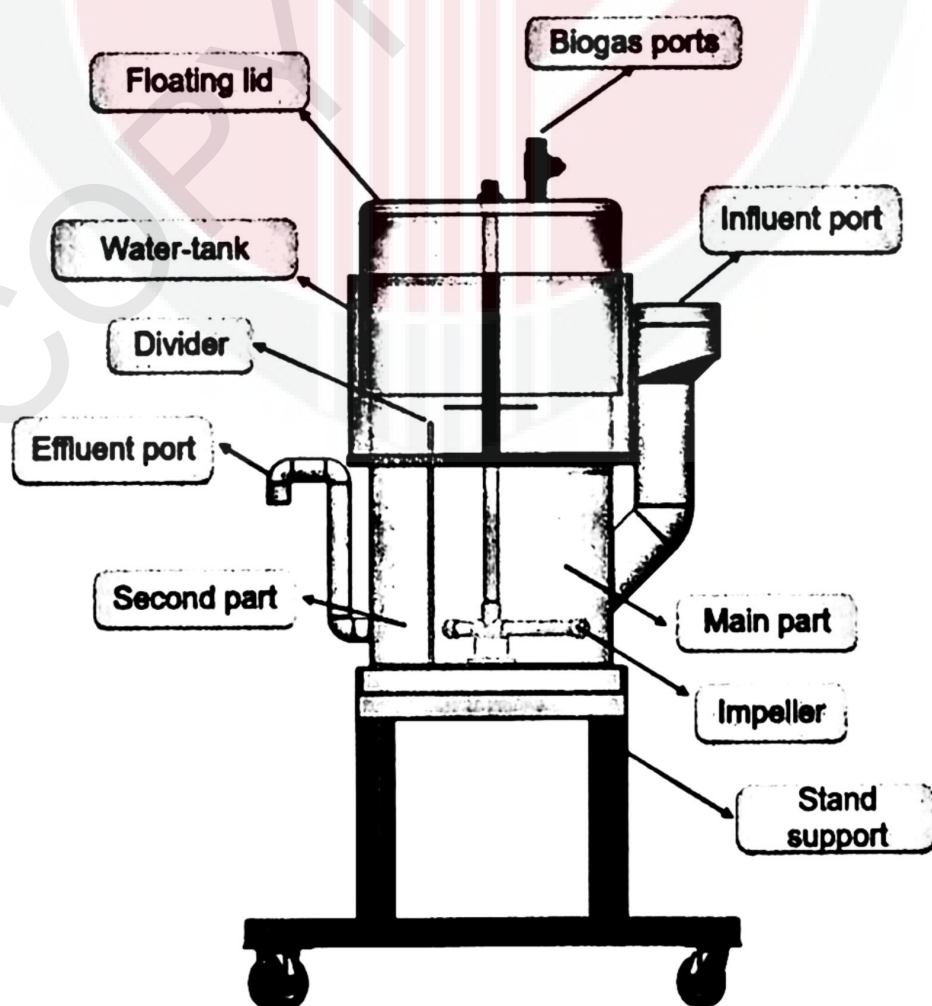


Figure 3. 6: View of (a) isometric view and (b) side view of fully assemble portable biodigester machine with the label of components

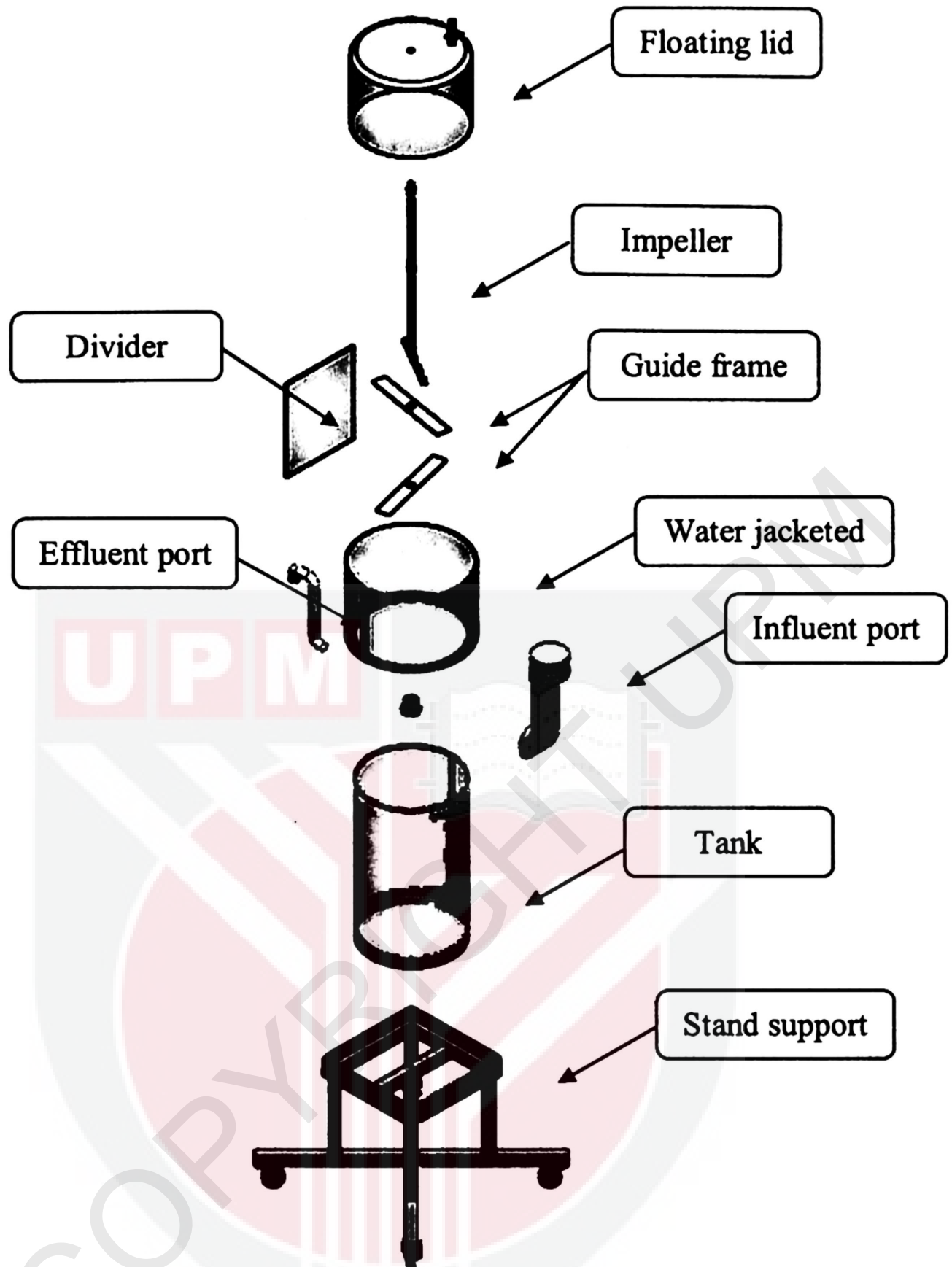


Figure 3. 7: Exploded view for each component in the portable biodigester.

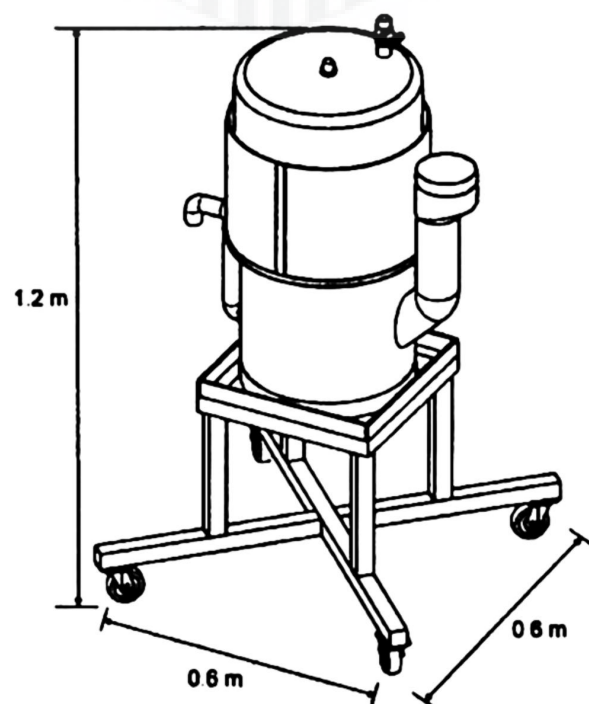


Figure 3. 8: Dimension of the portable biodigester

Figure 3.6 above shows the portable biodigester that is developed by using Autodesk software 2019. The main components of the innovation are the tank with a divider, water tank, floating lid, impeller, guide plate, influent port, and effluent port. In general, portable biodigester is design based on 3 different size of tank. First tank is used to place FW waste feed by through the influent port. The second tank is the floating lid to store the biogas while the third one is water tank fill with water to support the floating lid. Figure 3.7 shows the schematic diagram of main tank (bottom), second tank (outer tank at upper part) and third tank (middle tank at upper part or floating lid). The dimension of the machine is 0.60 m (length) x 0.60 m (width) x 1.20 m (height) as shows in Figure 3.8. The detailed each component's operation system will be discussed in detail in the further section.

3.3.1 Main tank and water-tank

The tank used for portable biodigester is one of the most important components. This is because the tank is filled with the FW sample and where the anaerobic digestion reacts take place. The tank is devided into 2 part by a divider which name as main part and second part as shows in Figure 3.9. The main reason why the tank is divide into two part is to avoid the fresh FW sample from flush out through the effluent part. The FW sample feed through the influent port is going to the bottom of the main part of the tank. The sample feed will reach its maximum volume and overflow to the second part of the tank. Further explanation is explain in sub-section 3.4. Any leakage due to overpressure occurs on the tank may affect anaerobic digestion may be affected which is indirectly affecting the biogas production. Thus, the tank use should have the durability to avoid any unnecessary event. The selection of material used for the tank is due for some reasons which are:

- **Corrosivity and pH** - Corrosivity of the sample used for the biodigester is important to be determined to make sure the correct material use for the biodigester. According to (Valdez, Schorr, Stoytcheva, Zlatev, & Carrillo, 2012) food usually will having a pH range between 2.0 to 7.0 which means it is acidic and may causing corrosive to the metal surface. Besides, the use of corrosive material such as mild steel could affect the reaction in the biodigester. so, material used for surface contact to the food waste should be non-corrosive material such as stainless steel or plastics.
- **Working temperature** - The portable biodigester is operating at environment condition which temperature range between 24 °C to 36 °C while anaerobic digestion reaction in the tank having an optimum temperature of around 35°C.

Based on 2 criteria needed above, acrylic is one of the best materials that can be used for the tank and water jacketed. According (Induflex, n.d.) acrylic can withstand maximum temperature up to 80 °C and down to -40 °C. Besides, acrylic is non-corrosive material and transparent which can help us in observing the reaction occur in the tank.

For the sizing of the tank, the common diameter of the cylindrical acrylic tank in the market is 360 mm. To make sure the tank is stable, the maximum working capacity will be having a length to diameter ratio of 1:1. Thus, the height of the working volume should be around 360 mm, which can store about 29 liters of food waste samples in the main part of the tank. In order to round off the volume of the main part to 30 liters, the height of the main part will be 362 mm. Meanwhile, the volume of the second part of the tank is designed to be a quarter of the main part which is about 7.5 liter. Meanwhile, the upper part of the tank will store the biogas produced.

The volume of each part can be calculate from the formula below:

$$\text{Area of second part (white region)} = \frac{100}{360} \pi r^2 - \frac{1}{2} \times \text{length} \times \text{width}$$

$$\text{Area of main part (blue region)} = \pi r^2 - \text{area of second part}$$

$$\text{Volume of second part} = \text{Area of second part} \times \text{height}$$

$$\text{Volume of main part} = \text{Area of main part} \times \text{height}$$

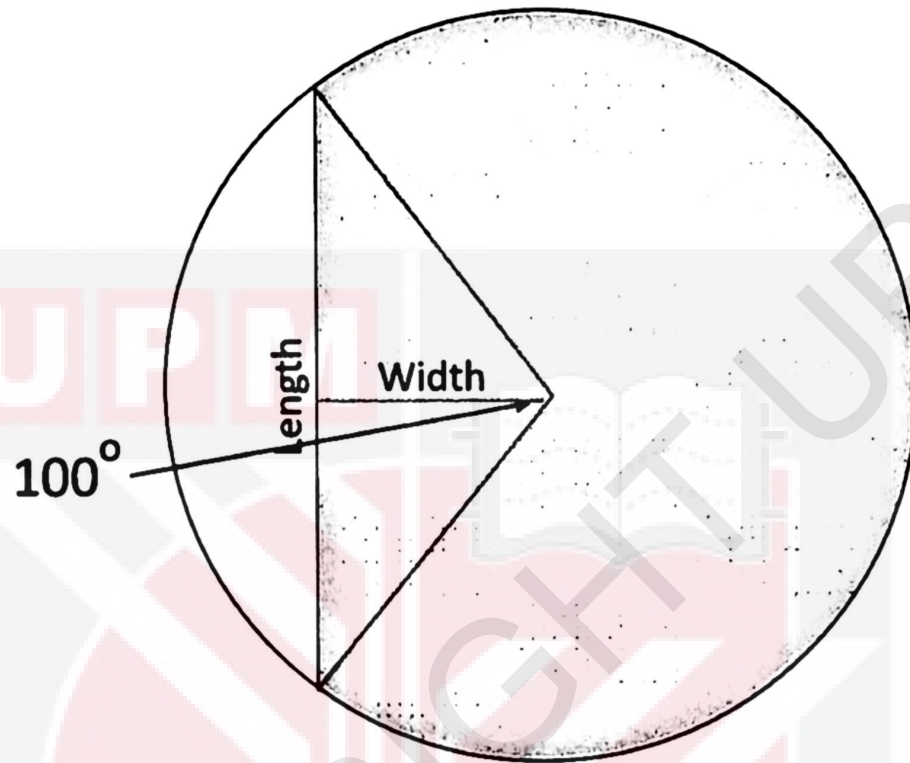
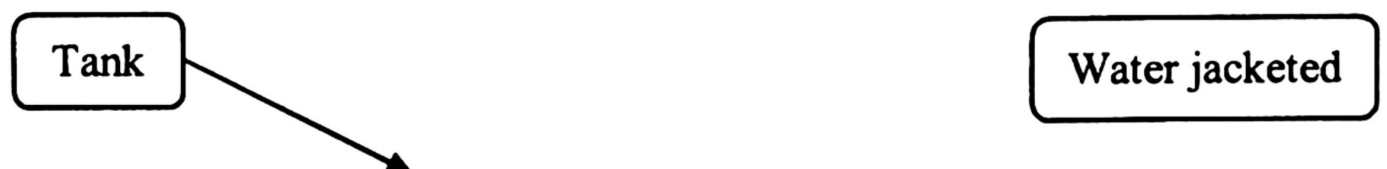


Figure 3.9: Area of main (blue) and second part (white).

In addition, at the outer part of the tank, water jacketed fill with water is design to support a floating lid and at the same time blocked biogas from released to the environment. The material used is also acrylic to make sure observation toward reaction in the main tank is clear. The dimension for the water jacketed is had a diameter of 420 mm and a height of 284 mm as shows in Figure 3.10.



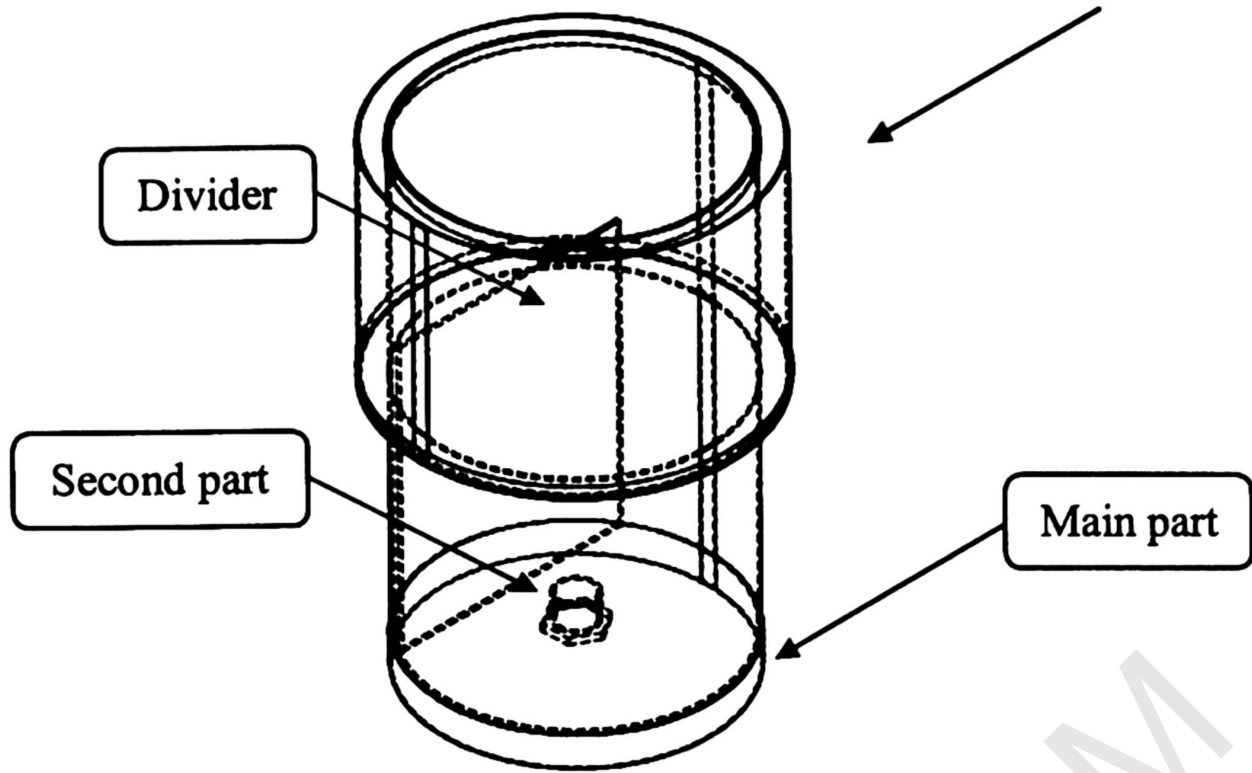


Figure 3. 9: Schematic diagram of water jacketed and main tank

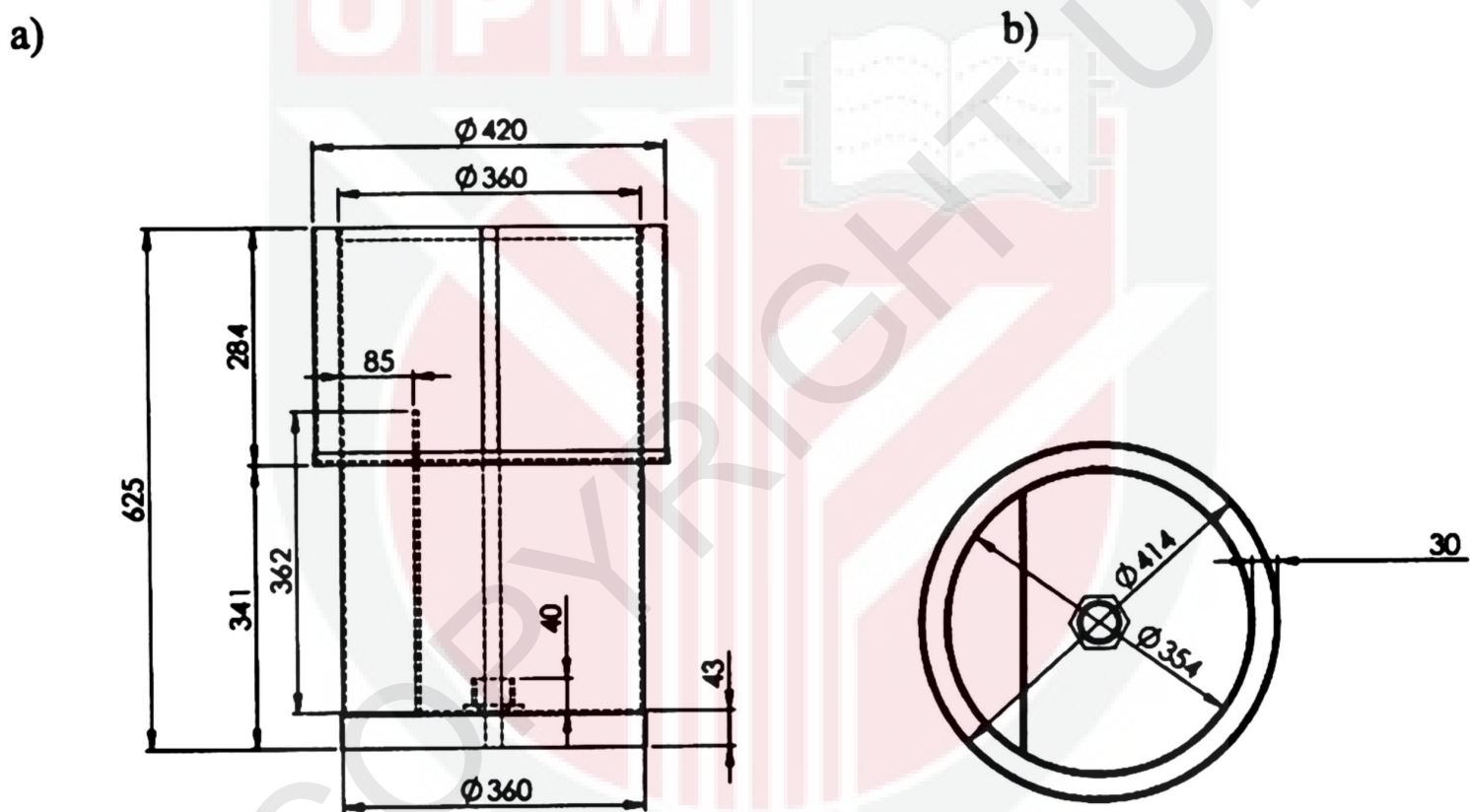


Figure 3. 10: (a) Schematic diagram of the tank and water jacketed from the side view. (b) Schematic diagram of the tank and water jacketed from the top view

3.3.2 Influent port

The influent port is where the FW sample is feed and it is connected to the bottom of the tank. Figure 3.11 shows that the schematic diagram of the influent port while figure 3.13 shows the real view of influent port. The type of material used for this influent port is Polyvinyl chloride (PVC) which is non-corrosive material. Besides,

PVC is more flexible and has many choices of shape rather than acrylic. The diameter of the influent port is 85 mm with a hopper to make sure the FW sample feed is not scattered during the feeding process. The dimension of influent port is shows in Figure 3.12 below.

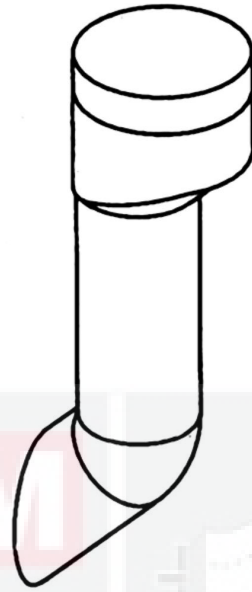


Figure 3. 11: Schematic diagram of the influent port

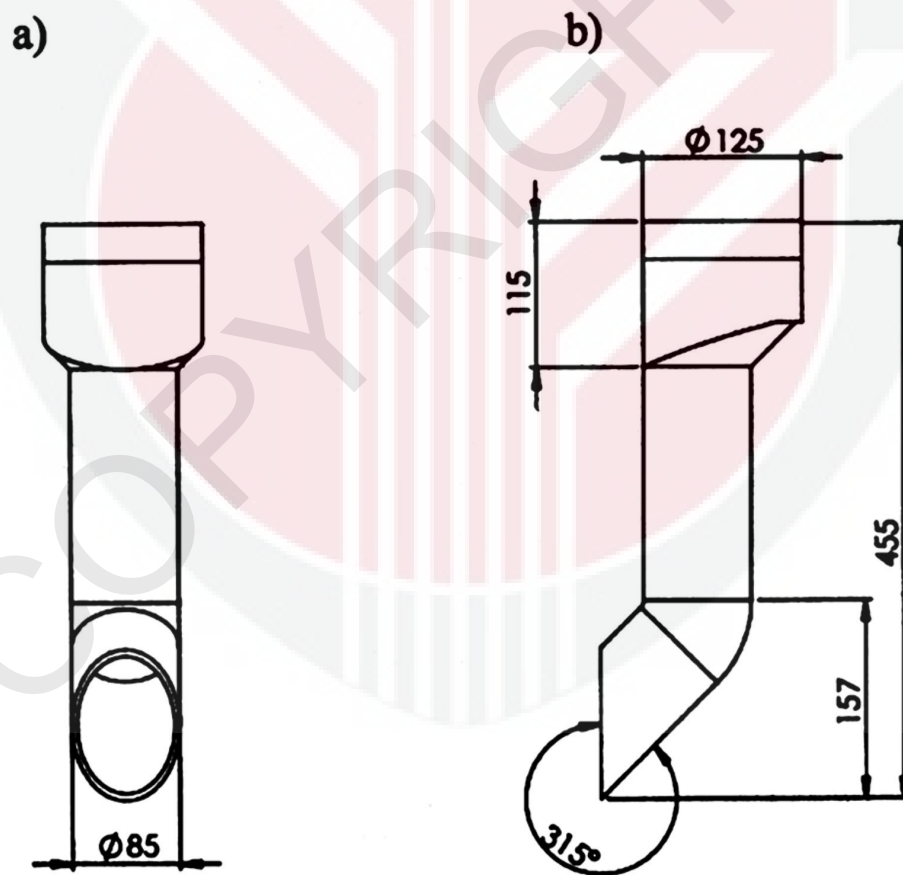


Figure 3. 12: (a) Schematic diagram of the influent port from the front view. (b) Schematic diagram of the influent port from side view



Figure 3. 13: The real view of influent port

3.3.3 Effluent port

The FW sample from the second part of the tank is connected to an effluent port. Figure 3.14 shows the schematic diagram of the effluent port. This effluent is function to discharge the FW sample from the second part. A mechanism is developing to make sure the FW sample is discharged when the FW sample in the second part is reaching the same level as effluent port while avoiding the biogas from release out by designing the effluent to be S shape. Thus, Polyvinyl chloride (PVC) is one of the best choices of material selection because it is easy to be connected and non-corrosive. The diameter of the effluent port is 32 mm with a height of 272 mm as shown in Figure 3.15. Figure 3.16 shows the real view of effluent port.

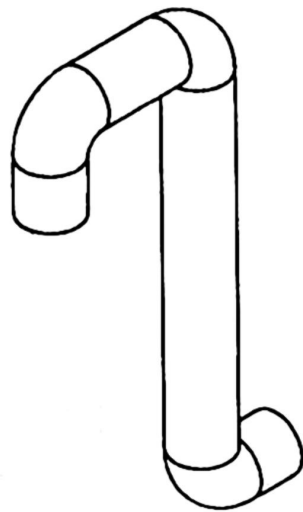


Figure 3. 14: Schematic diagram of the effluent port

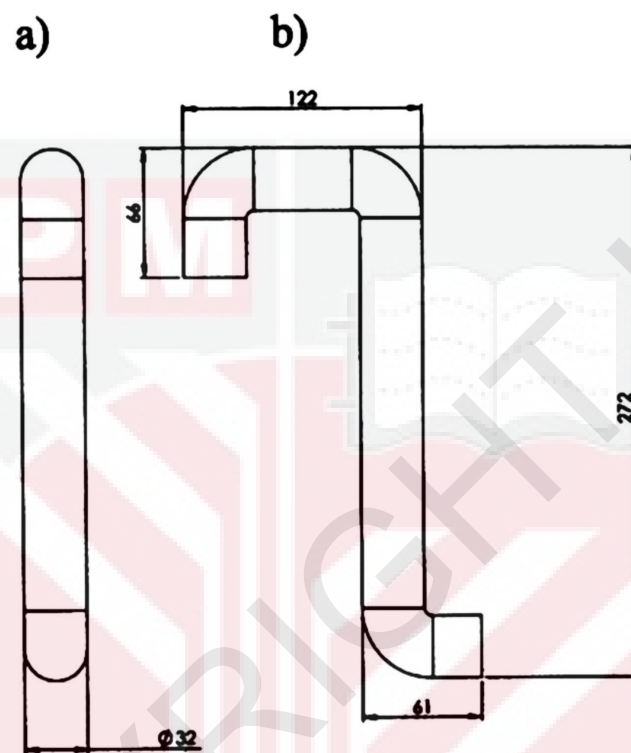


Figure 3. 15: (a) Schematic diagram of the effluent port from the front view. (b) Schematic diagram of the effluent port from the side view



Figure 3. 16: The real view of effluent port

3.3.4 Floating lid

The biogas produced from the anaerobic digestion in the portable biodigester needs spaces to be stored. Thus, a floating lid (Figure 3.17) is designed to be floating in the water jacketed part and can move upward to create more space to store biogas. The floating lid is the middle tank at the upper part. The position of the floating lid is determined by the amount of biogas produced. The more biogas is produced, the higher the floating lid moves upward until it reaches its maximum level, which is about a 30% increment. Figure 3.19 shows the minimum and maximum level of the floating lid. If biogas is still produced when the floating lid has reached its maximum level, the pressure from the biogas will force it to be released out through the water.

The floating lid has a diameter of 382 mm and a height of 290 mm as shown in Figure 3.18(b). The space that can store biogas when the floating lid is at its bottom level is 38 litres, while at the maximum level it can store about 48 litres of biogas. Acrylic is also used for the material of the floating lid to avoid corrosion when in contact with water and because of its transparent characteristic that can help in the observation process as shown in Figure 3.20. Besides, a biogas port with a valve is created at the upper part of the floating lid to release biogas when it is needed to be consumed as a cooking fuel. A hole in the middle of the floating lid will be connected with the impeller.

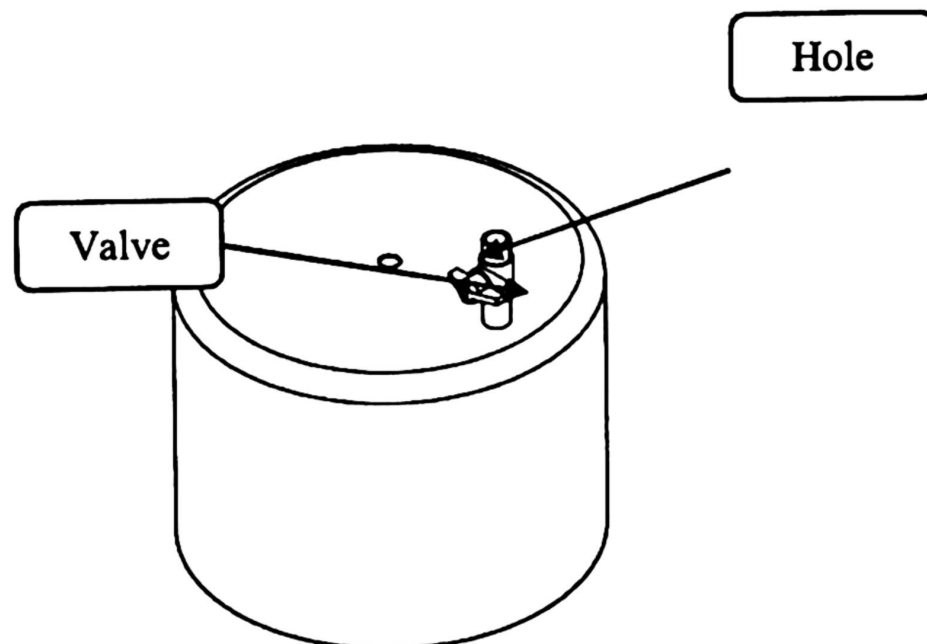


Figure 3. 17: Schematic diagram of the floating lid

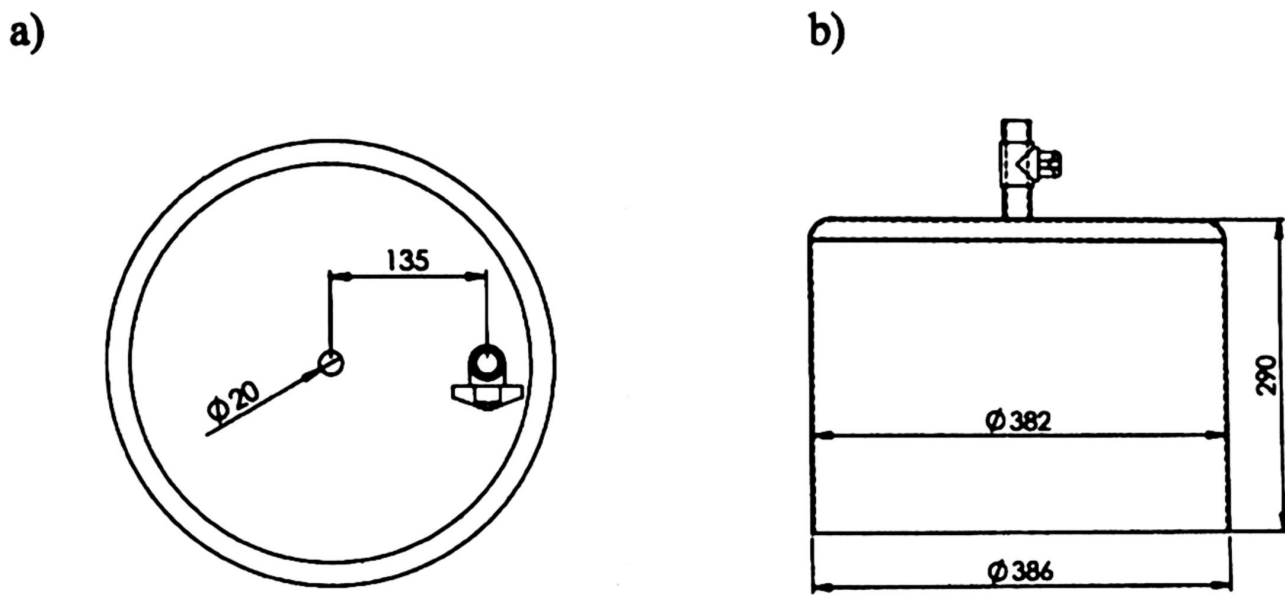


Figure 3. 18: (a) Schematic diagram of the floating lid from the top view. (b) Schematic diagram of the floating lid from the side view

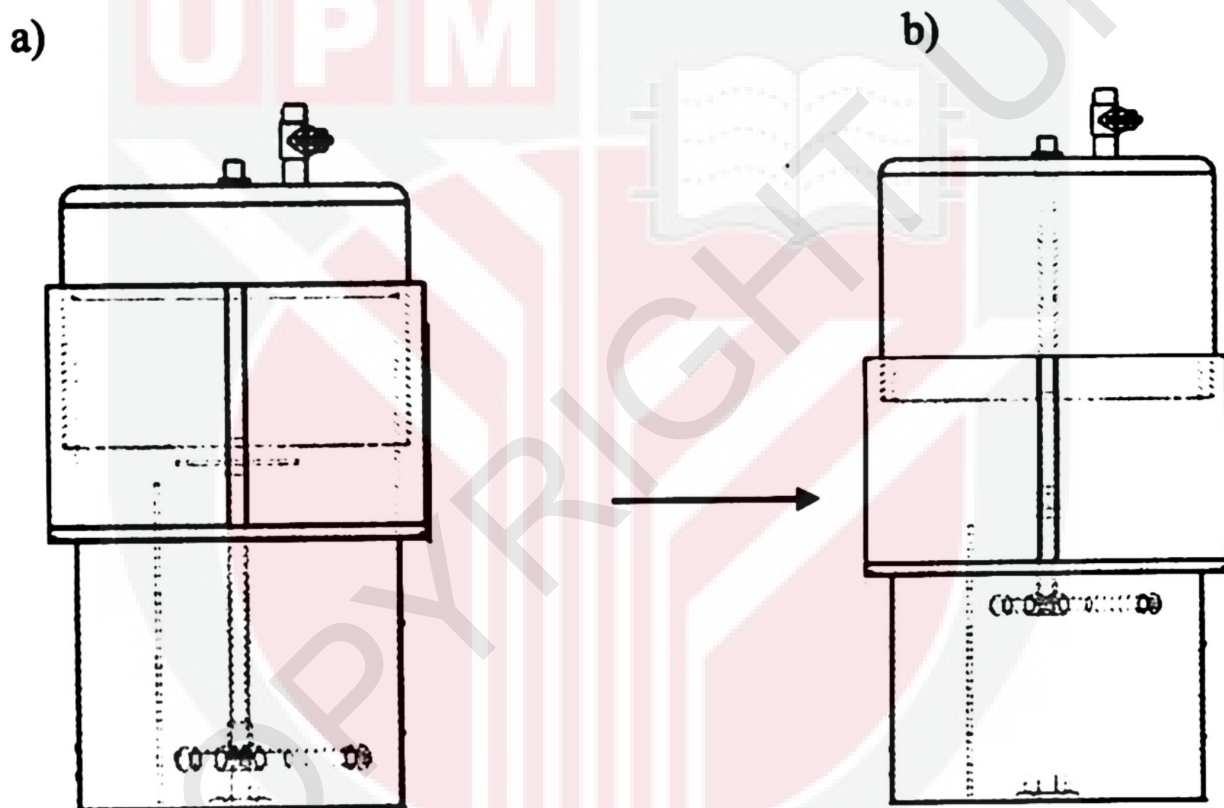


Figure 3. 19: (a) The minimum level of floating lid. (b) The maximum level of floating lid.

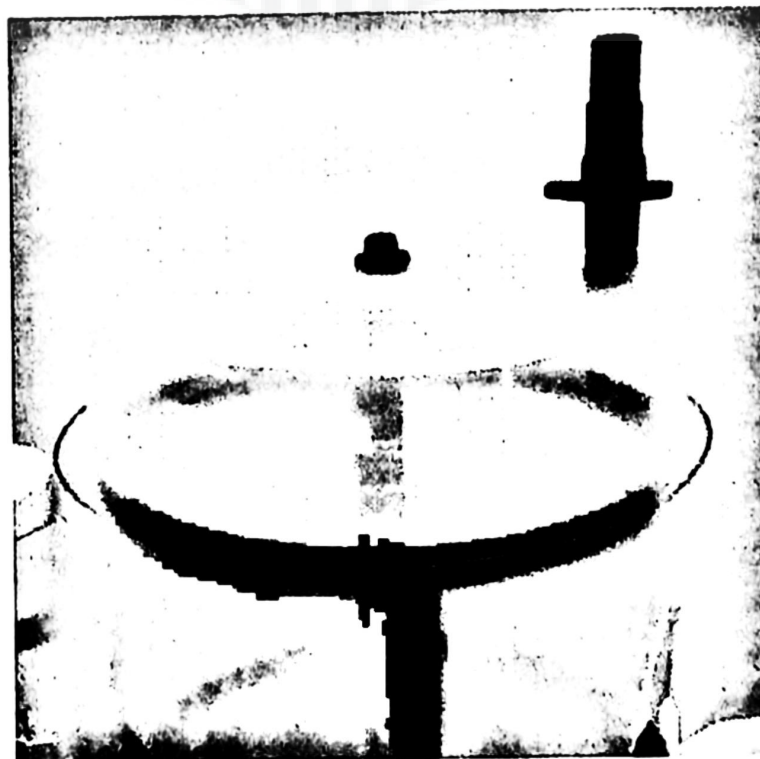


Figure 3. 20: The real view of floating lid

3.3.5 Impeller

An impeller as being shown in Figure 3.21 is designed to intermittently mix the fermentation solution to accelerate the digestion rate and increase the contact time between the bacteria culture and the substrate (food waste). It plays significant role in attaining mixing homogeneity and mixing time. The type of impeller used will affect the flow in the biodigester which will affect the rate of anaerobic digestion. As shown in Figure 3.22, the impeller used is built with the 2 cylindrical impellers of different lengths, 77.5 mm and 162.5 mm to make sure the system totally mixes while not creating turbulent flow toward the FW solution. Figure 3.23 shows the impeller is fixed with the floating lid which means the impeller will be move when the lid is rotated. The impeller should be anticorrosive type of material as it will submerge in the FW sample. The upper part of this anticorrosive impeller is attached with the floating lid by a nut. The bottom part of 2 cylindrical impellers is responsible for mixing efficiency where agitation happens to move the slurry. The diameter of the impeller is 20 mm and a height of 650 mm as shown in Figure 3.22 while Figure 3.24 shows real view of impeller.

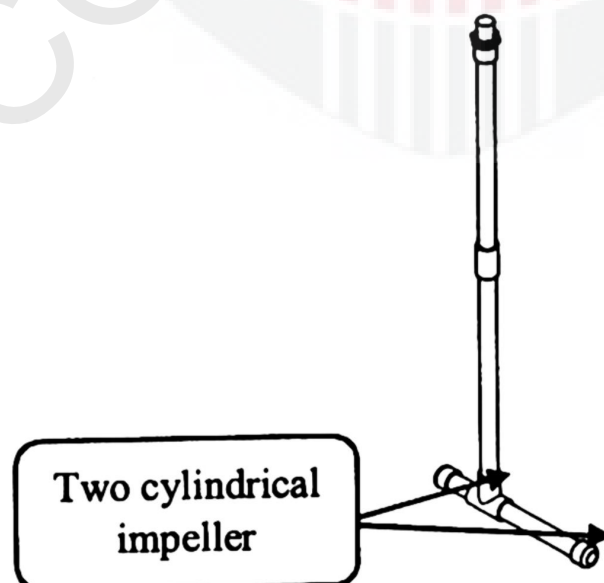


Figure 3. 21: Schematic diagram of the impeller

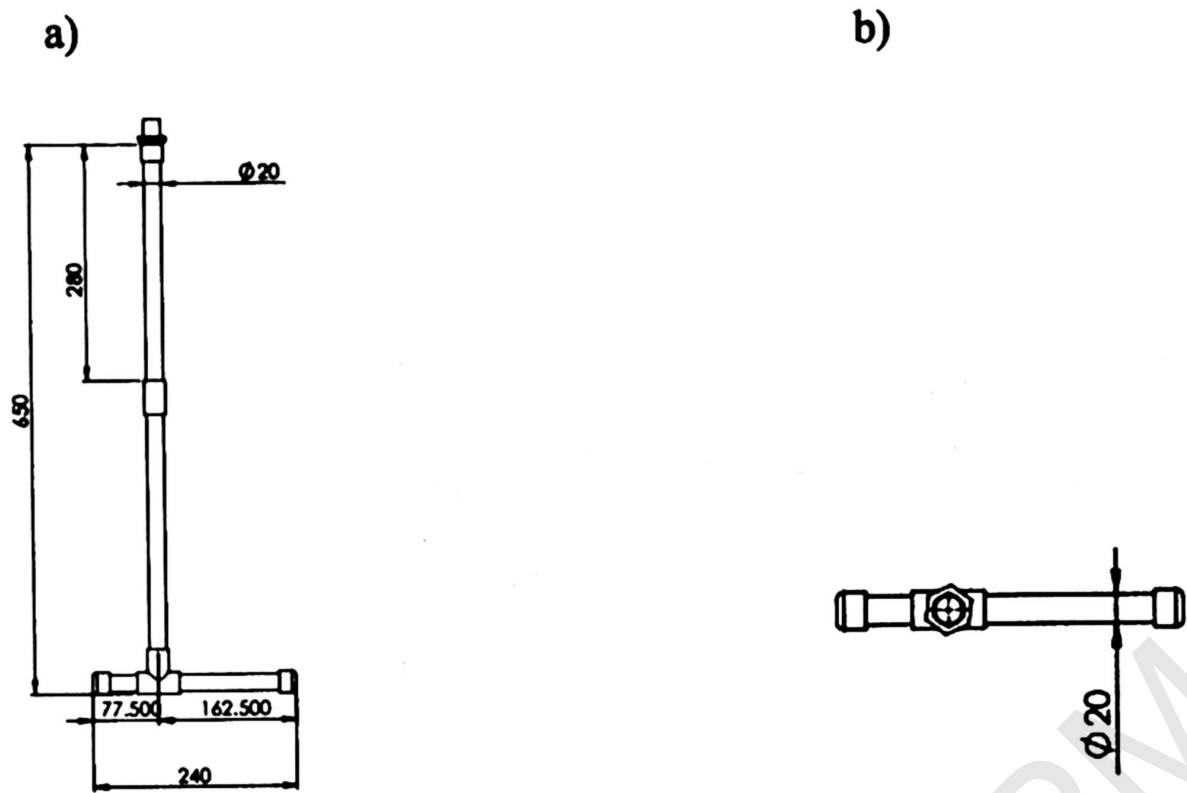


Figure 3. 22: (a) Schematic diagram of the impeller from the side view. (b) Schematic diagram of the impeller from the top view

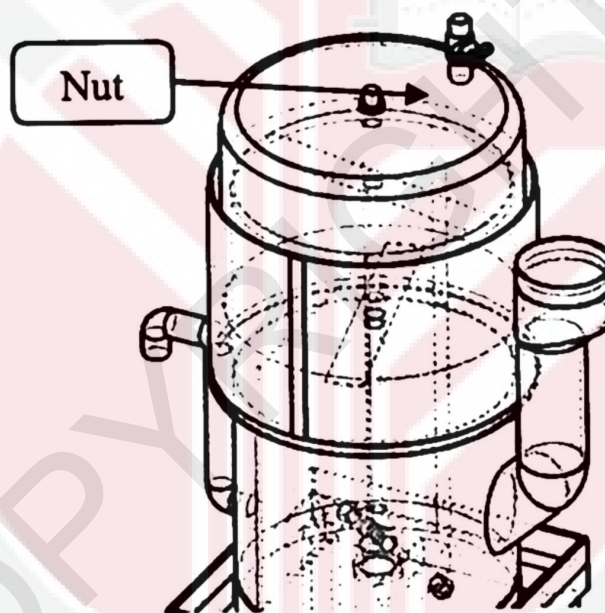


Figure 3. 23: The position of nut to make the impeller fix with the floating.

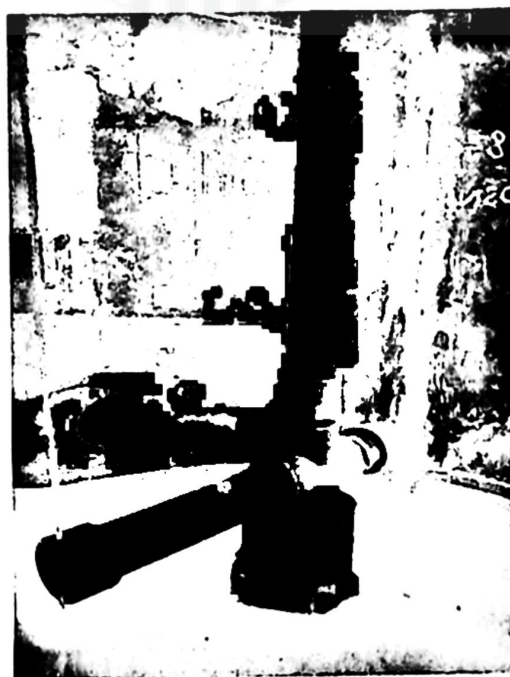


Figure 3. 24: The real view of impeller

3.3.6 Guide plate

Biogas produce in the portable biodigester will force the floating lid to be move upward. There is possibility the floating lid may be tilt from the water jacketed. Besides, the impeller could break during the mixing process due to turbulent flow. Thus, two guide plates is design to guide the impeller fix in its position and at the same time avoiding the floating lid from tilting. Figure 3.27 shows the position of guide plate in the portable biodigester tank. A hole in the middle of guide plate enable the impeller to moving up and down freely without tilting as shows Figure 3.25.

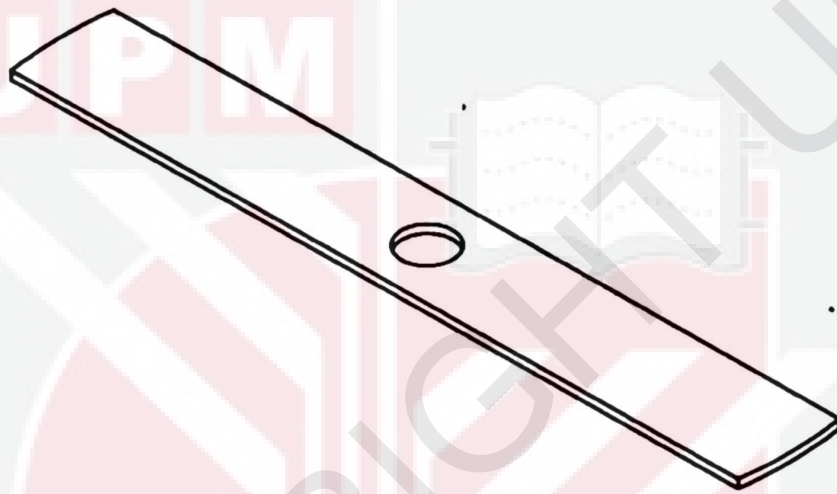


Figure 3. 25: Schematic diagram of the guide plate

a)



b)

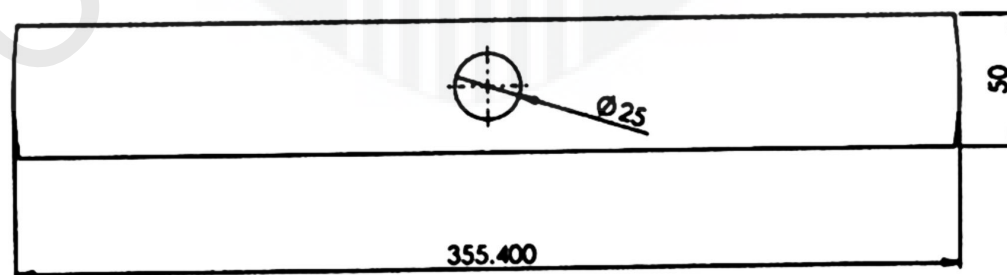


Figure 3. 26: (a) Schematic diagram of the guide plate from side view. (b) Schematic diagram of the guide plate from side view

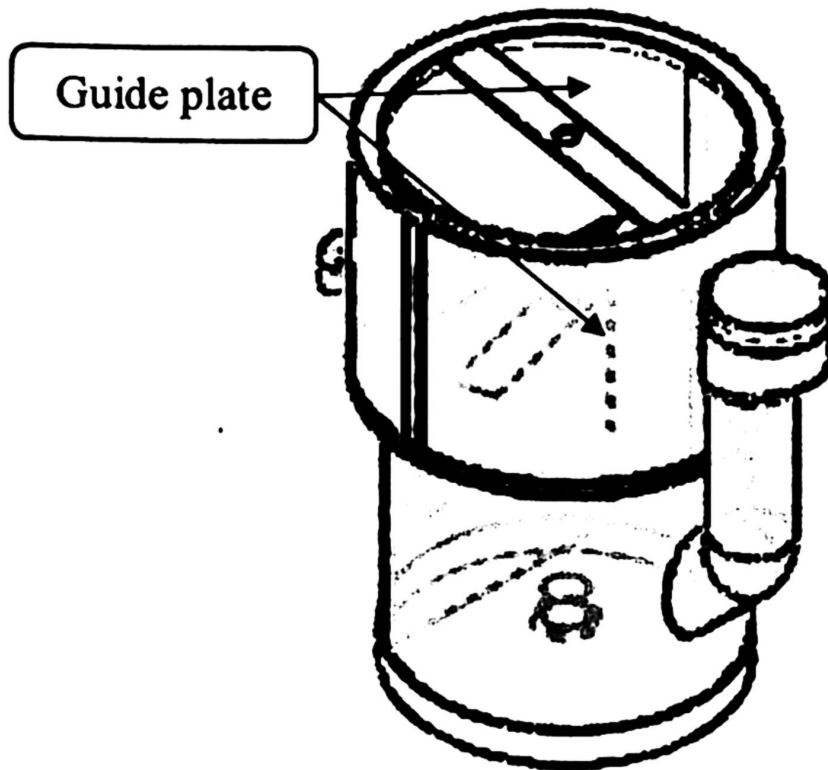


Figure 3. 27: The position of guide plate in the portable biodigester.

3.3.7 Stand support

Portability is one of the main highlights of this portable biodigester. Thus, stand support as shown in Figure 3.28 is design to support the biodigester and make it easier to be transported with the presence of castor wheels. Besides, comfortability when handling a machine is one of the important characteristics to make it is more user friendly. Thus, this stand support level up the biodigester to be higher and allows the portable biodigester handling to be more comfortable. The material used for the stand support is steel to make sure it can withstand the load from the whole biodigester tank. The steel is painted to avoid rusting. The height of the stand support is 505 mm with a wide of 600 mm as shown in Figure 3.29. The real view of stand support shows in Figure 3.30.

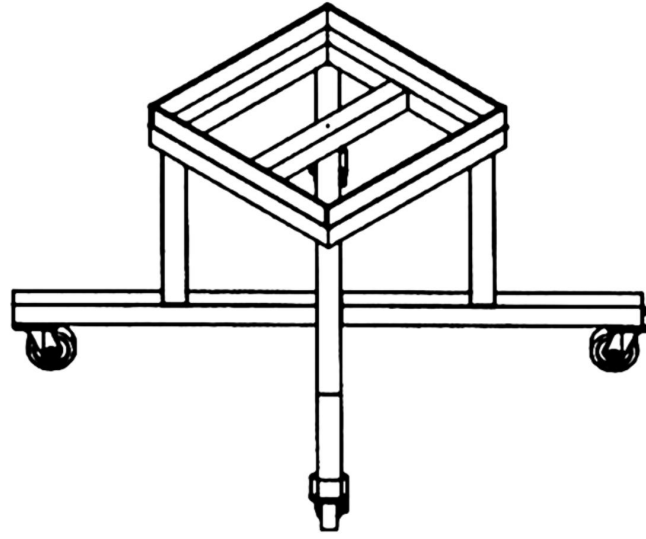


Figure 3. 28: Schematic diagram of the stand support

a)

b)

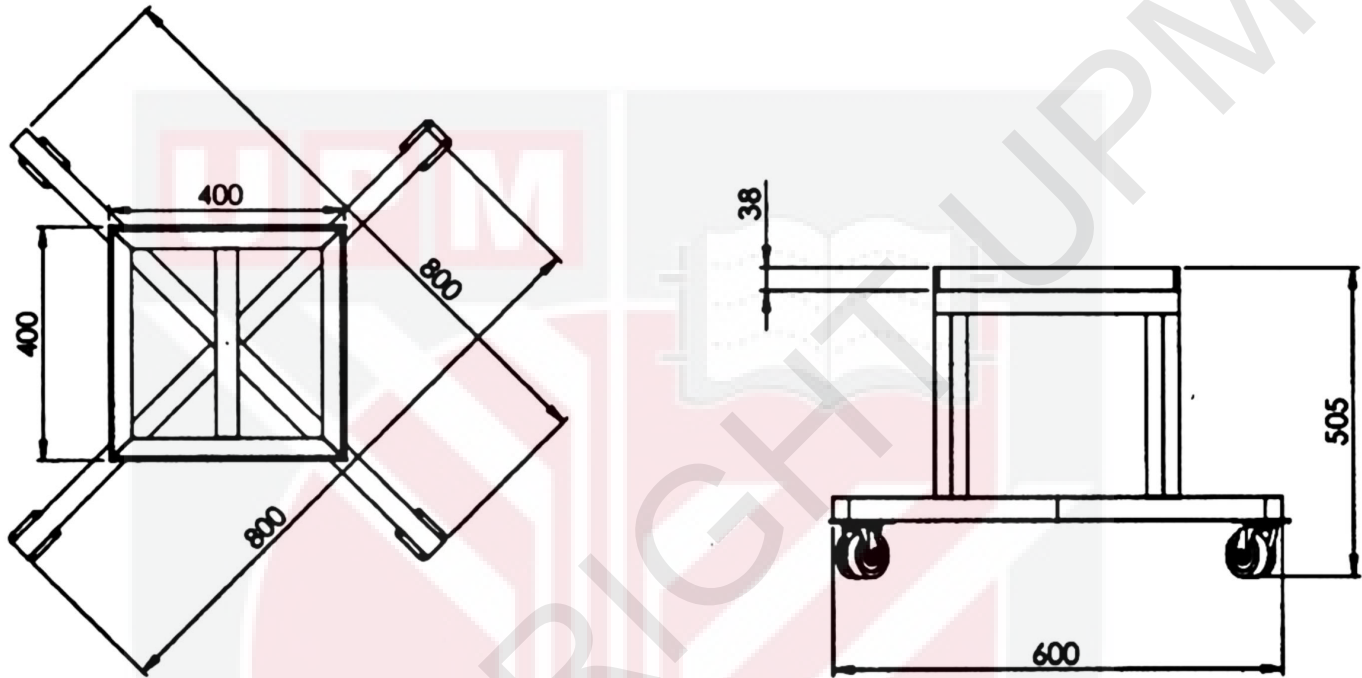


Figure 3. 29: (a) Schematic diagram of the stand support from the top view. (b) Schematic diagram of the stand support from the side view



Figure 3. 30: The real view of stand support

3.4 Sample preparation

3.4.1 Inoculum preparation

In general, portable biodigester basically used to convert food waste into 2 main products which are biogas and liquid fertilizer by the anaerobic digestion process. Cow dung is one of the main substances used as a starter (inoculum) for the anaerobic digestion process. It is a potential organic matter that can help in providing anaerobic conditions in a system. For an optimum reaction rate, cow dung should not be too fresh or too old, cow dung that has been dump for 3 to 6 days should be fine to be used as inoculum.

In order to prepare the inoculum, 15 kg of cow dung is collected from Cattle Farm at Taman Pertanian Universiti (TPU). Raw cow dung sample is shows in Figure 3.31(a). The cow dung needs to be free from any foreign matter (rock, grass, leave, etc.) to get the best result. The total weight after clearing the foreign matter is about 13.3 kg.

a)

b)



Figure 3. 31: (a) Raw cow dung sample from TPU cattle farm. (b) Cow dung sample after clean from foreign matter.

Next, water is added with the ratio of 1:1 with cow dung and mixed well together as shows in Figure 3.32 make the total weight of the inoculum to be 26.6 kg (Zulkifli et al., 2019). An approximate 24 kg of the mixture is then added to the main part of the tank while the rest mixture, 2.6 kg added into the second part. The floating part of the biodigester is turned several times once a day to stir the impeller which allows the inoculum to mix well. The biogas production is observed every day by mark on each time the floating part rises as shows in Figure 3.33. The biogas generated is flushed out through the biogas port into the surrounding for three cycles to acclimatize the inoculum to ensure the anaerobic condition in the digester. After the acclimatization process completed, the reactor was ready to be feed with FW as the main substrate. The number of days needed for completing each cycle recorded.



Figure 3. 32: Cow dung sample after water added.



Figure 3. 33: The level of floating lid rise is mark every day.

Process flow for inoculum preparation



Raw cow dung sample



Clean cow dung sample



Water added with ratio 1:1



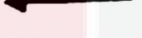
The biodigester is placed at the normal environment



The mixture is added into the both



The mixture is added into the biodigester



The floating lid at its minimum level



The floating lid at its maximum level

3.4.2 Food waste preparation

Food waste sample is collected from a restaurant in Sri Serdang every week. Then, any foreign matter or inorganic matter needs to be separate from the food waste before continue with the next steps. Next, food waste is ground using a grinder (meat mincer, RC, Taiwan) into a smaller size (slurry) to increase the surface area of the substrate and the rate of digestion by the microorganism. Lastly, water is added with the weight ratio 1:1 and mixed well before it is ready to add to the system. Water addition is necessary to fulfil the need of water molecules to support the hydrolysis reaction and acetogenesis stage. At the stage of hydrolysis, hydrolytic microbes exist in the system will degrade complex organic compounds in the form of polymers into monomers which is insoluble compounds and smaller molecular weights (Putri, Saputro, & Budiyo, 2012).

The substrates will be feed into the influent ports and go to the bottom part of the main tank as shows in Figure 3.34(a). Food waste sample will stay in the main part and reaches the maximum level of the main tank as shows in Figure 3.34(b). Next. it will overflow to the second part and until reach the same level with the effluent as shows in Figure 3.34(c). Then, the FW sample will be discharged through the effluent port as Figure 3.34(d).

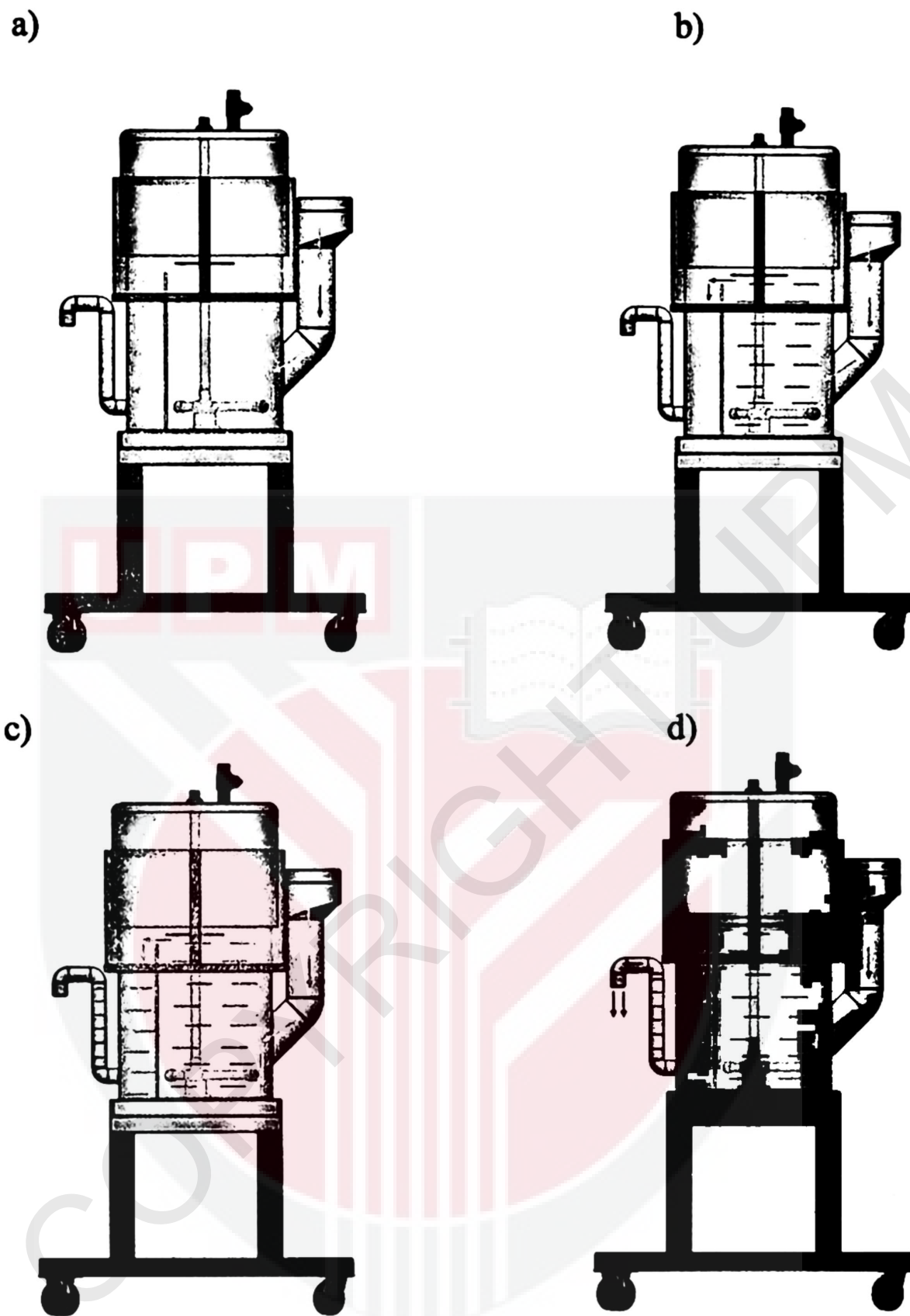


Figure 3. 34: The flow of the process in the biodigester

3.5 Parameters affecting performance evaluation

The parameters that can affect the anaerobic digestion include pH, temperature ($^{\circ}\text{C}$), hydraulic retention time (HRT) (day/L), organic loading rate (OLR) (gVS/Ld), and mixing method in the biodigester. We need to ensure that the working pH in the biodigester is in the range of 6.5 - 7.5 in which it is the optimum pH for anaerobic

digestion (Liu et al., 2008). Thus, a pH meter (PB-10, Sartorius, Germany) is being used to measure the pH value every day. The outdoor surrounding is selected to do the performance evaluation where it will be exposed to the environment temperature. A digital thermometer is used to determine the temperature in the biodigester every day. For a hypothesis, if it is a rainy day, the temperature will drop which directly affect the temperature in the biodigester to drop accordingly while for a sunny day, the temperature will be high, means the temperature will be fluctuate according to environment condition. For the HRT and OLR, it is set to be 30 days and 277,000 VS/l/day. The HRT is set to be 30 days to avoid microbes culture flush out if the HRT is lower than 30 days. HRT is the working volume of the portable biodigester per volume feed per day. Based on the HRT of 30 days and 30 litre working volume, 1 litre food waste need to be feed every day and to set the OLR value, a COD analysis to a FW sample is done to get the OLR value per 1 litre FW. Next, the mixing method of the biodigester will be set with 2 different condition which are mixing once a day and without mixing.

3.6 Performance test of the machine

A performance test is done to detect the weaknesses and advantages of the machine based on some parameters that can affect the anaerobic digestion in the biodigester.

3.6.1 Amount of biogas produce per day

The amount of biogas (litre) that able to be produced per day is one of the main parameters that determine the performance of a biodigester. The evaluation was begun by feeding the FW sample into biodigester with a constant volatile solid value which is 277,000 VS/l per day by mixing and without mixing. Biogas production is measured

every day for 10 days for each variable. A wet gas meter (W-NK, SHINAGAWA, Japan) is used to measure the volume of biogas produce. The set-up for measuring the volume of biogas is shown in Figure 3.35. A tube is used to connect the biogas port to the wet gas meter. When the valve on the biogas port is opened, the biogas will be forced into the wet gas meter. The meter indicator on the screen will show the value of biogas being transferred into the wet gas meter in liter and m³. To get the value of biogas produce per day, the value on the meter indicator after the biogas transfer need to be minus to the value before the biogas is transfer into the wet gas meter. Figure 3.36 shows the meter indicator on the wet gas meter. The amount of biogas produce per day for the two variables is recorded and compared.

Amount of biogas produce per day =

Value on the indicator before biogas transfer (litre)

– Value on the indicator after biogas transfer (litre)

Equation 3.1



Figure 3. 35: The set-up for measuring the amount of biogas produce using a wet gas meter.

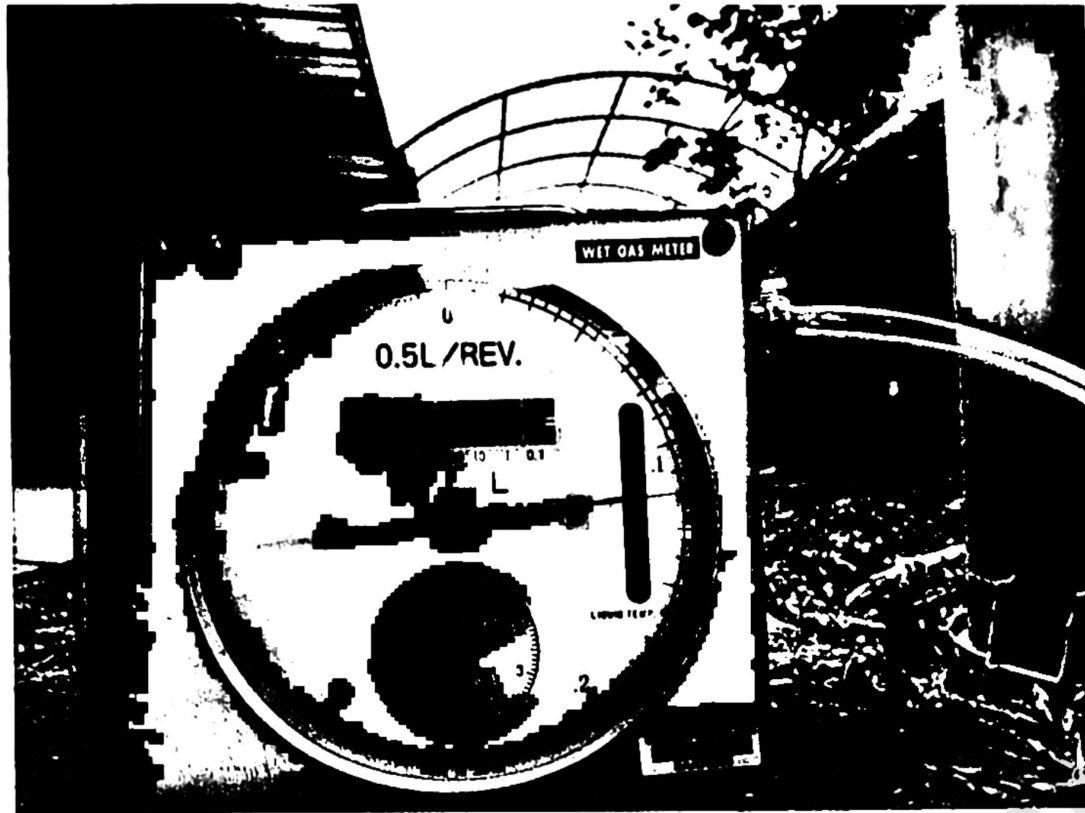


Figure 3. 36: The wet gas meter use for measuring biogas produce.

3.6.2 Effluent content

3.6.2.1 Total solid content (TSC)

Total solid content of a sample also indicates its moisture content. For the total solid content, the sample of food waste and effluent is taken for analysis. The sample was measured to be approximate 5 mg and added into a crucible. The sample then was heated into an oven for two hours at 105°C. The sample was then cooled in desiccator and weighed. The cycle of drying, cooling, desiccating and weighing was repeated until a constant weight was obtained.

Calculation:

$$\text{mg total sold/L} = \frac{(A-B) \times 1000}{\text{sample volume, mL}}$$

where:

A = weight of dried residue + crucible, mg

B = weight of dish, mg

$$\text{Total solid content removal} = \frac{\text{TSC of food waste} - \text{TSC of effluent}}{\text{TSC of food waste}}$$

3.6.2.2 COD removal efficiency

The organic matter concentration in the sample is measured by indirect methods, and the most common is the measurement of the chemical oxygen demand (COD). The COD is the measure of the amount of oxygen needed to chemically oxidize a determined amount of organic matter, quantifying, therefore, the total organic material present (Tommaso, 2011). The anaerobic digestion process will convert the organic matter into biogas. The lower the COD value in the effluent sample, the higher the efficiency of the biodigester system.

During the test done on the method in sub-topic 3.6.1, 50 ml of FW sample discharge through the effluent port is collected every 4 days for each variable using a falcon tube. From the effluent sample, 2 mL is added in COD digestion vials (HACH) and digested at 150 °C then measured with spectrophotometer DR3900. The COD value is recorded and compared with the COD value of FW sample feed into the portable biodigester (Zulkifli et al., 2019).

$$\text{Chemical Oxygen Demand removal} = \frac{\text{COD of food waste} - \text{COD of effluent}}{\text{COD of food waste}}$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Machine design

Figure 4.1 below shows the portable biodigester for household use. The dimension of the machine is 0.60 m (length) x 0.60 m (width) x 1.20 m (height). The machine is support by a portable stand which make it easier to be move and provide a comfortable height to be handle by an average height person.

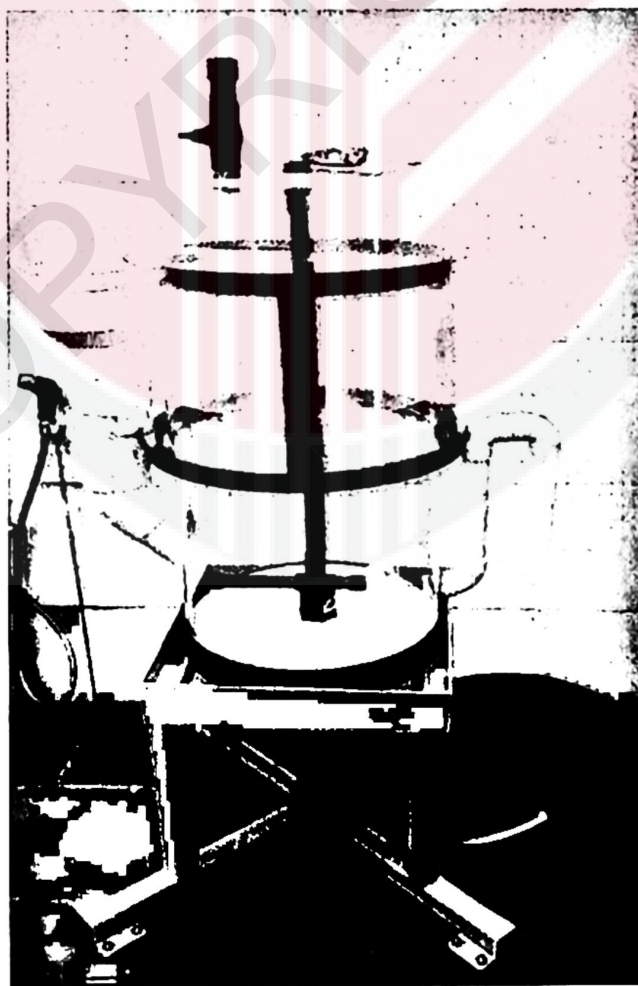


Figure 4.1: Portable Biodigester for Household use.

Portable biodigester for household use is a fully manual which is needs an operator or user to feed the food waste into the influent port manually. Influent port is where the food waste is feed to the main tank of the machine for fermentation process. The influent port is included with a hopper to make sure feeding process more efficient. It is connected to the main tank where the anaerobic process was occurring. The main tank is divide into two compartment by a divider in mean to hold the solid on the main part while allow the overflow the treated effluent to the another compartment. This is important process to make sure only liquid sample is remove through the effluent port. The sludge will stay at the bottom of main tank and remove once a while during maintenance. The volume of main part and second part was calculated below:

$$r = 177 \text{ mm}$$

$$\text{length} = 218 \text{ mm}$$

$$\text{width} = 109 \text{ mm}$$

$$\text{height} = 362 \text{ mm}$$

$$\begin{aligned} \text{Area of second part} &= \frac{100}{360} \pi (177 \text{ mm})^2 - \frac{1}{2} \times 218 \text{ mm} \times 109 \text{ mm} \\ &= 1.546 \times 10^4 \text{ mm}^2 \\ &= 0.01546 \text{ m}^2 \end{aligned}$$

$$\text{Area of main part} = \pi r^2 - \text{area of second part}$$

$$= \pi (177 \text{ mm})^2 - 1.546 \times 10^4 \text{ mm}^2$$

$$= 9.842 \times 10^4 \text{ mm}^2 - 1.546 \times 10^4 \text{ mm}^2$$

$$= 8.296 \times 10^4 \text{ mm}^2$$

$$= 0.08296 \text{ m}^2$$

$$\text{Volume of second part} = \text{Area of second part} \times \text{height}$$

$$= 1.546 \times 10^4 \text{ mm}^2 \times 362 \text{ mm}$$

$$= 5.6 \times 10^6 \text{ mm}^2 \times \frac{1 \text{ litre}}{1 \times 10^6}$$

$$= 5.6 \text{ litre}$$

Volume of main part = Area of main part x height

$$= 8.296 \times 10^4 \text{ mm}^2 \times 362 \text{ mm}$$

$$= 30 \text{ litre}$$

Food waste sample in the main tank will be spread homogenously by an impeller which can increase contact time between bacteria culture and substrate (food waste). The impeller is connected to the floating lid. The impeller also can move vertically according to the position of floating lid. The impeller rod is guide by a plate to make sure the floating lid is not tilting and make sure the impeller stays at the centre of the tank. Anaerobic digestion in the main tank producing biogas which then the biogas will collect at the upper part of the main tank. When the amount of biogas increase, it creates a pressure that push floating lid to move upward. The floating lid is float in a water tank fill with water. The water also acts as a sealer that prevent the biogas from release out and create air tight condition inside the main tank which is needed for anaerobic digestion.

Table 4.1: Summary of all parts in banana slicer machine

Parts or components	Description
Influent port	Built with hopper for receiving food waste sample and pass to the main tank.
Biogas port	For biogas release valve.
Effluent port	For discharging liquid sample from the second part
Divider	Divide the first main tank into two compartment.
Main part	Receiving food waste sample from the influent port and space for anaerobic digestion to occur.

Second part	Receive liquid sample that overflow from the top of main part.
Impeller	To introduce mixing for homogenous mixture of bacteria and substrate .
Water tank	Work as a water sealer to prevent the biogas from release out and help the floating lid to float.
Floating lid	The third tank placed in inverted position use to create more spaces when it is pushed upward by the biogas produce from anaerobic digestion process
Guide frame	To guide the impeller rod from tilting.
Stand support	To support the whole system and enable the system to be move easily.

4.2 Machine operation

The standard operating procedure for this biodigester is quiet simple where it is not required any special training and it is can be done manually. Figure 4.2 show the flowchart of machine operation.

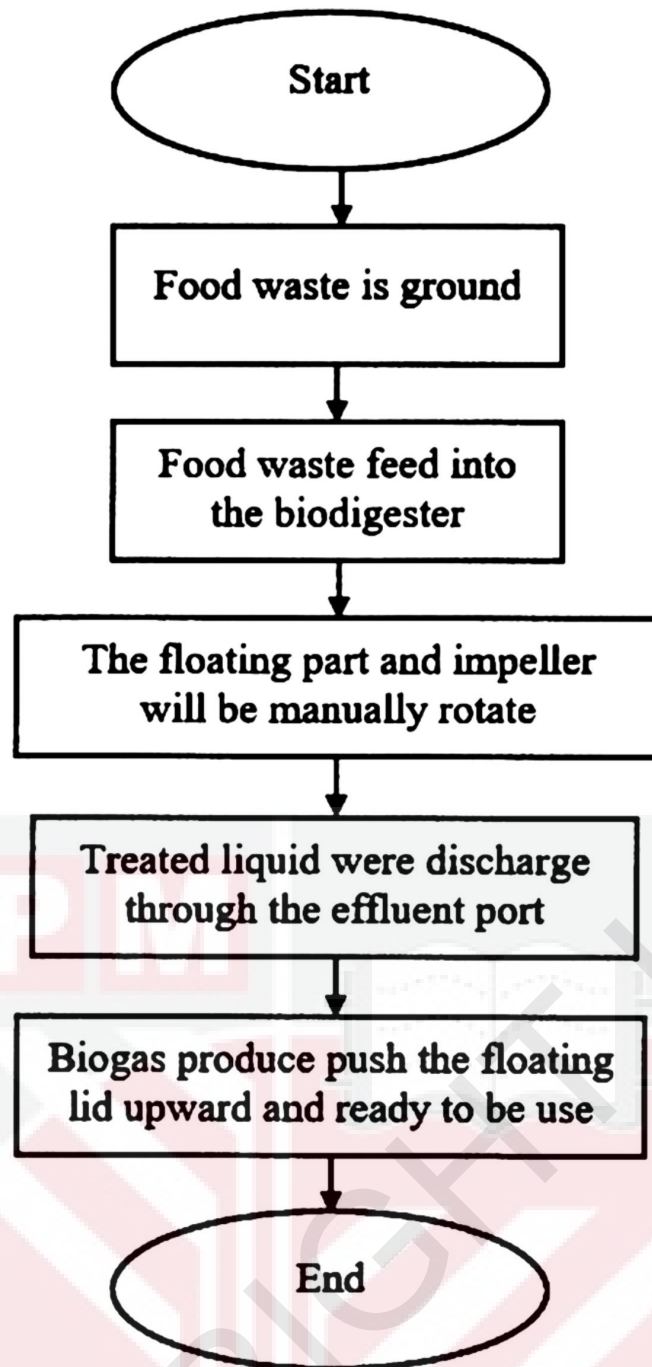


Figure 4.2: Flowchart of the portable biodigester operation

The process begins with the food waste collect and grind by food waste grinder. Ground food waste is then ready to be feed into the digester tank through a feeding hopper at the side of the tank. The floating part and impeller will be manually rotate to introduce mixing for homogenous mixture of bacteria and substrate. Anaerobic digestion process occurred in the digester and produce biogas beside the treated effluent and biomass (sludge). Biogas generated will create enough pressure to push the floating lid upward and at the same time, the impeller simultaneously mixes the food waste. At maximum working capacity, the treated liquid will be overflow to another compartment (second part) and will be discharged as effluent. Sludge

(biomass) produce will be settled at the bottom and biogas produce can be use by simply open the biogas valve at the top of floating lid.

4.3 Bill of material (BOM)

A Bill of Materials (BOM) refers to the inventory of parts, documents, assemblies and subassemblies expected to create a finished product (BOM Management, 2017).

Materials bill can be interpreted as the formula and purchasing list for the finished product being made. It is necessary to produce a precise bill of material, especially for a new product, as it is important that the right parts are accessible when manufacturing the product. Any issues could emerge if the bill of materials were inaccurate which caused manufacturing delay which could cause production to stop (Murray, 2016).

Figure 4.3 is an exploded view drawing that demonstrates the relationship and assembly order of different elements.

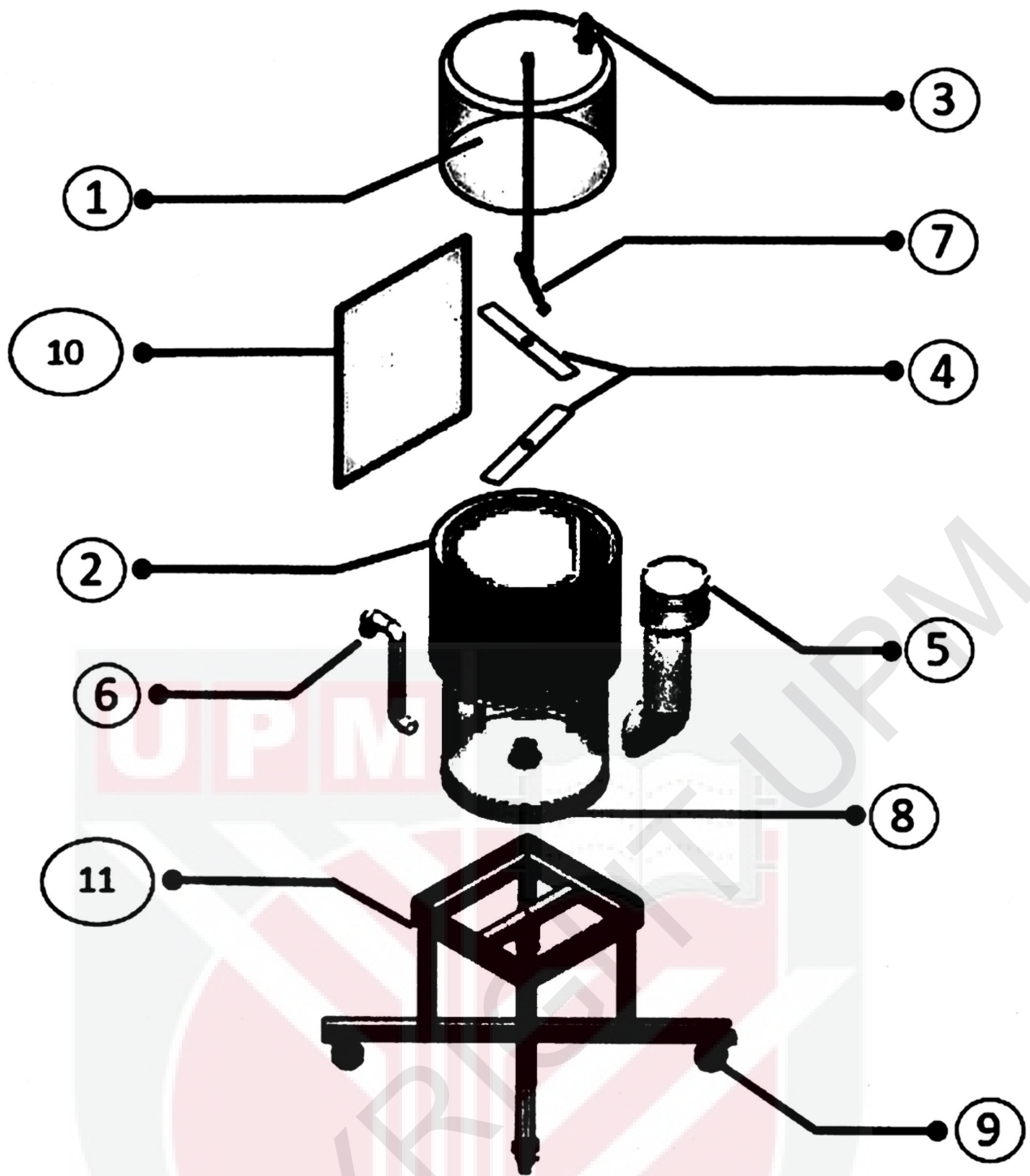


Figure 4.3: Exploded view of the biodigester

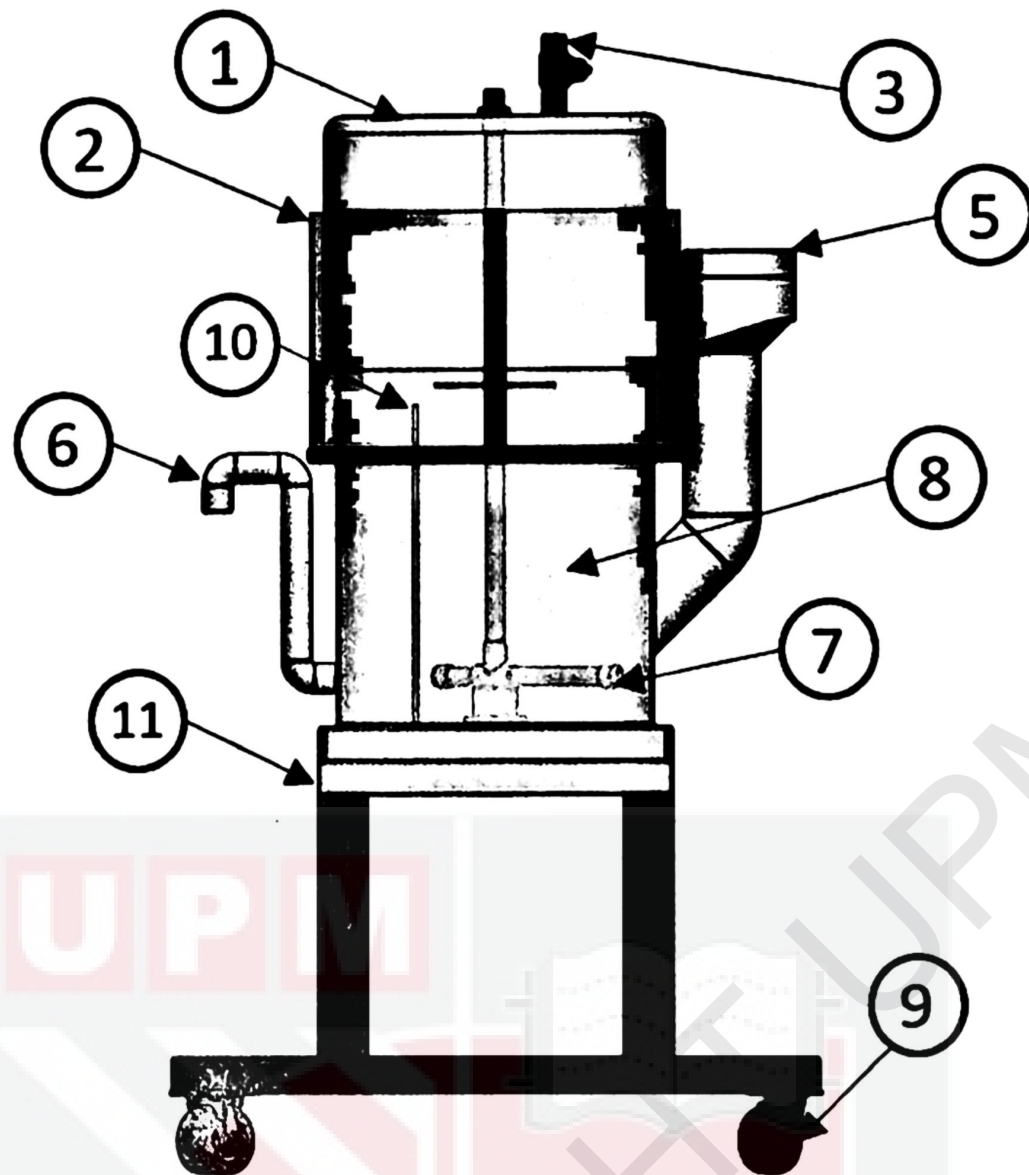


Figure 4.4: Side view of the biodigester

Table 4.2: Bill of material

Item No.	Description	Quantity
1	Floating lid	1
2	Water-jacketed	1
3	Biogas port	1
4	Frame guide	2
5	Feeding port	1
6	Effluent port	1
7	Impeller	1
8	Main tank	1
9	Castor wheel	4
10	Divider	1
11	Stand support	1

4.4 Performance analysis

4.4.1 Amount of biogas produce per day

4.4.1.1 Biogas production during inoculum start-up

Figure 4.5 show the pattern of biogas production in first 23 days of experiment set up. The first 17 days of experiment, the system was only introduced to the cow dung then, the food waste sample was introduced on the day 17 until it fill the maximum working volume on the day 23. From the graph, it shows that low biogas production during first cycle which take about 9 days to fill the maximum volume of biogas storage. This is because the bacteria culture in the cow dung sample is not active and just start to growth in the system. The experiment continued for another two cycle to intermediate anaerobic digestion inside the tank which showing biogas production that was more stable. On day 17, three cycle is complete and biogas production was release daily. Based on the graph, the trend shows unstable trend of biogas production which may because of the new substrate (food waste) introduced to the system. This trend also may have affected by the environment temperature. The temperature is highly influence the anaerobic digestion rate.

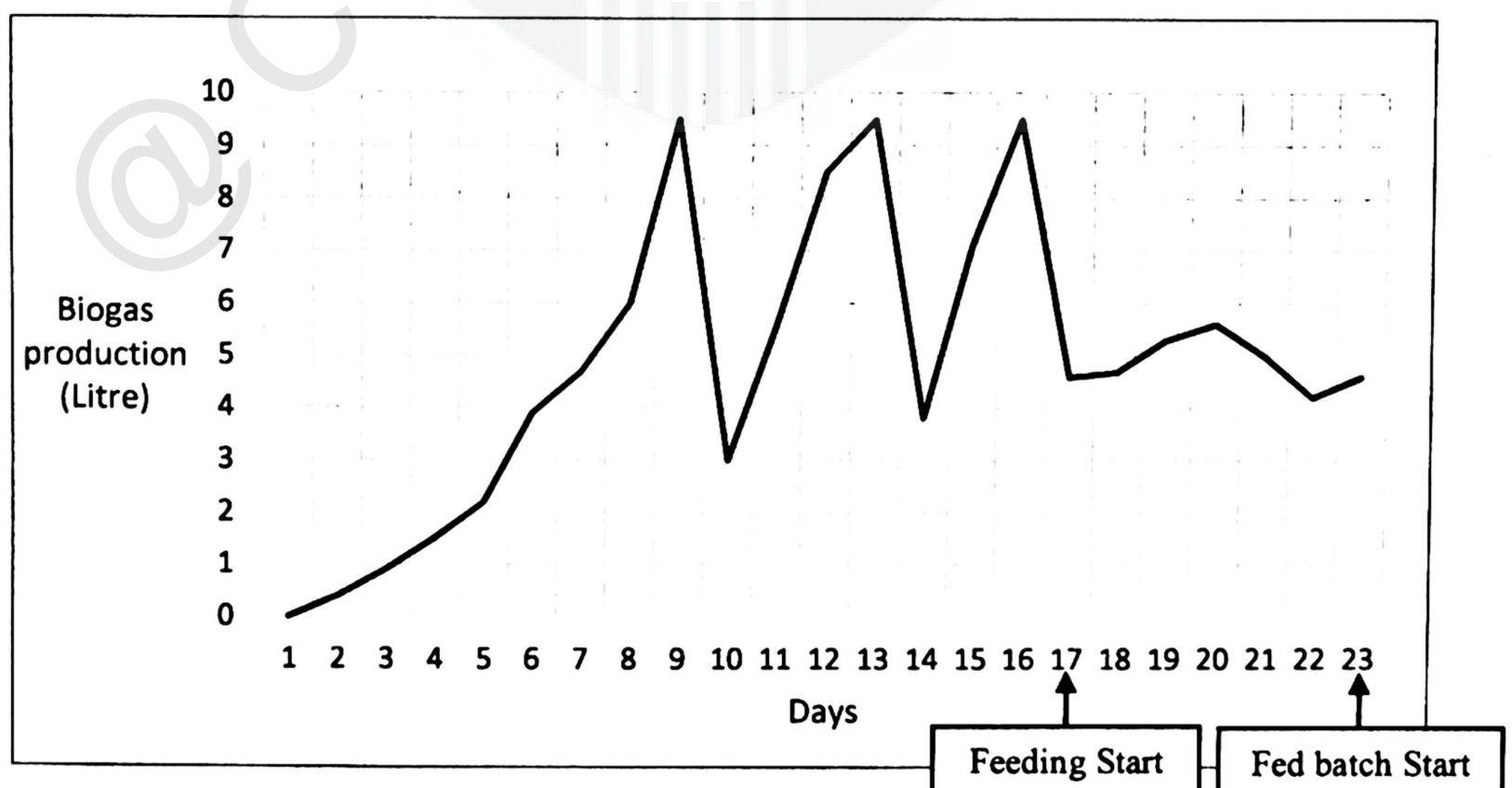


Figure 4.5: Start-up operation of biogas production from food waste.

Figure 4.6 shows the temperature inside the biodigester during the set up period. Based on the Figure 4.6, the trend of biogas production mostly affected by temperature reading on the day. The temperature is highly influence the anaerobic digestion rate. The optimum temperature of the mesophilic digester is 35 °C for the production of biogas. For each 10 ° C fall, the activity and growth rate of bacteria decrease by 50 percent in the mesophilic range (Cioabla, et al., 2012). The food waste sample was reach the maximum working capacity then at day 23 where the effluent start to discharge from the system and experiments started.

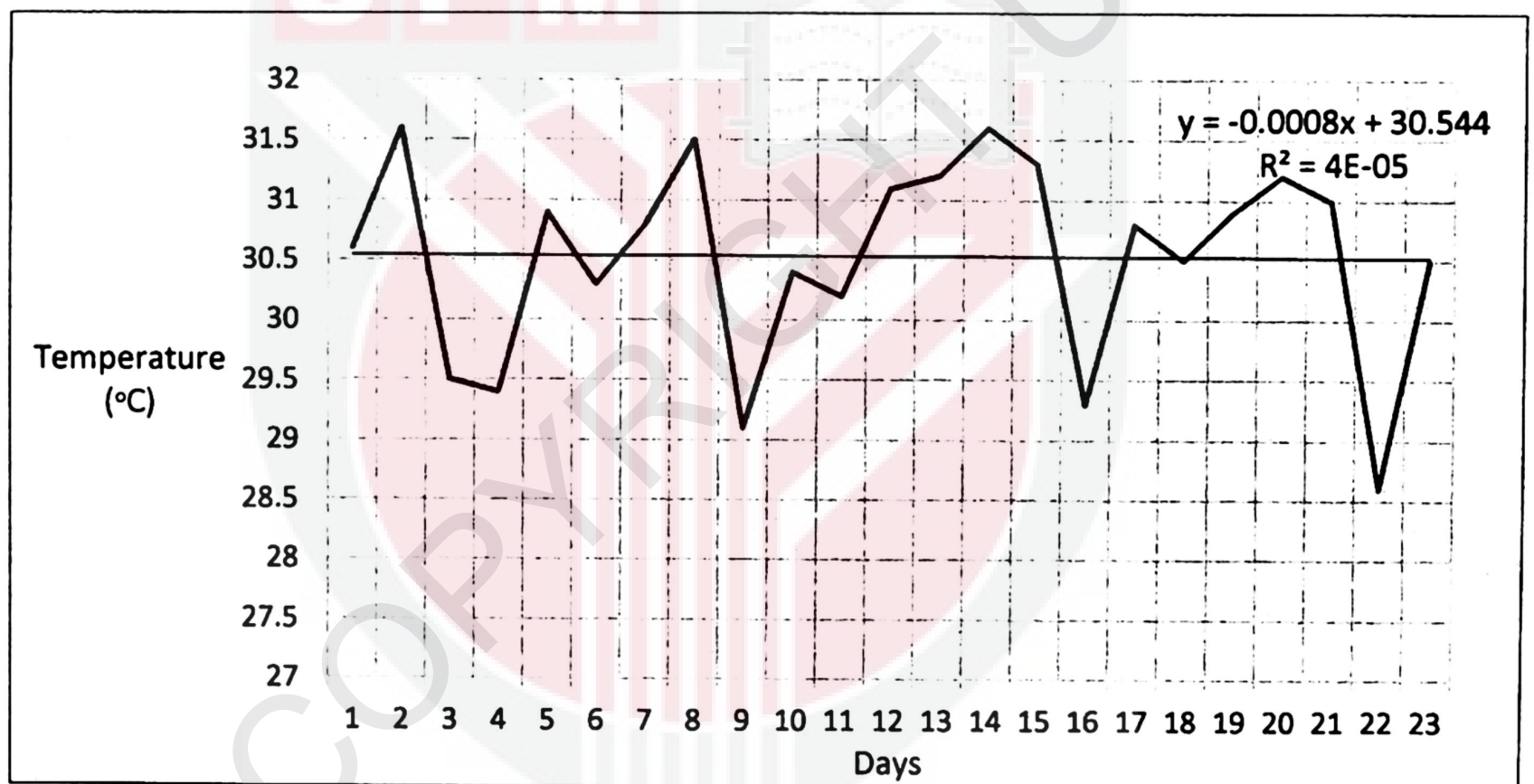


Figure 4.6: Start-up temperature inside the portable biodigester.

4.4.1.2 Effect of Mixing to biogas production

Mixing process is one of the main factor that can boost biogas production where the bacteria culture can reach towards substrate faster when the agitation occurs in the system. Figure 4.7 shows the biogas production daily during mixing for ten days. The floating lid of portable biodigester was rotate to introduce mixing towards the system inside the main tank for two minutes every day. The biogas produces on first five days was lower compare to last five days. Average biogas production during 10

days of mixing was 4.21 litre where this trend of biogas production daily was also affected by the surrounding temperature as temperature is one of main temperature that affecting anaerobic digestion (Arapatka, 1994).

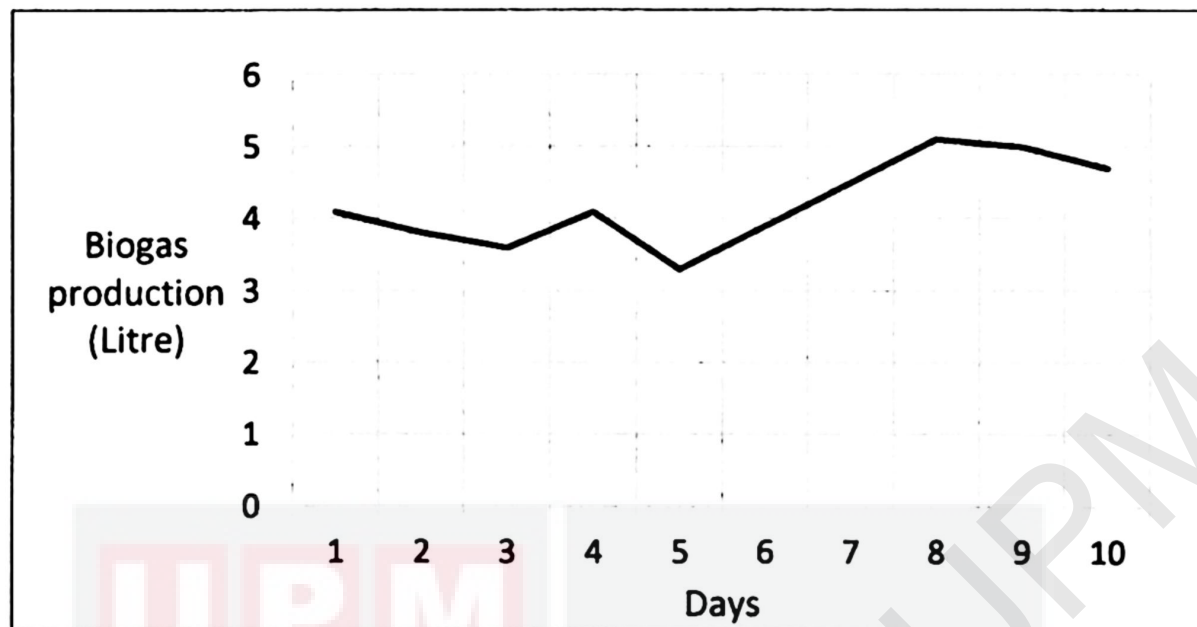


Figure 4.7: Biogas production (litre) from food waste for ten days of mixing.

The reading of temperature inside biodigester was read every day through the influent port of the portable biodigester. As shown is Figure 4.8, the reading of temperature inside the biodigester was fluctuate based on the weather of the day. The reading on day three was 28.5 °C where it was low due to the rainy day. This weather affected the biogas production where the biogas production on the day was 3.8 litre, one of the lowest biogas reading compare to the rest value. However, the temperature reading was not too significantly affecting biogas production ($P > 0.05$).

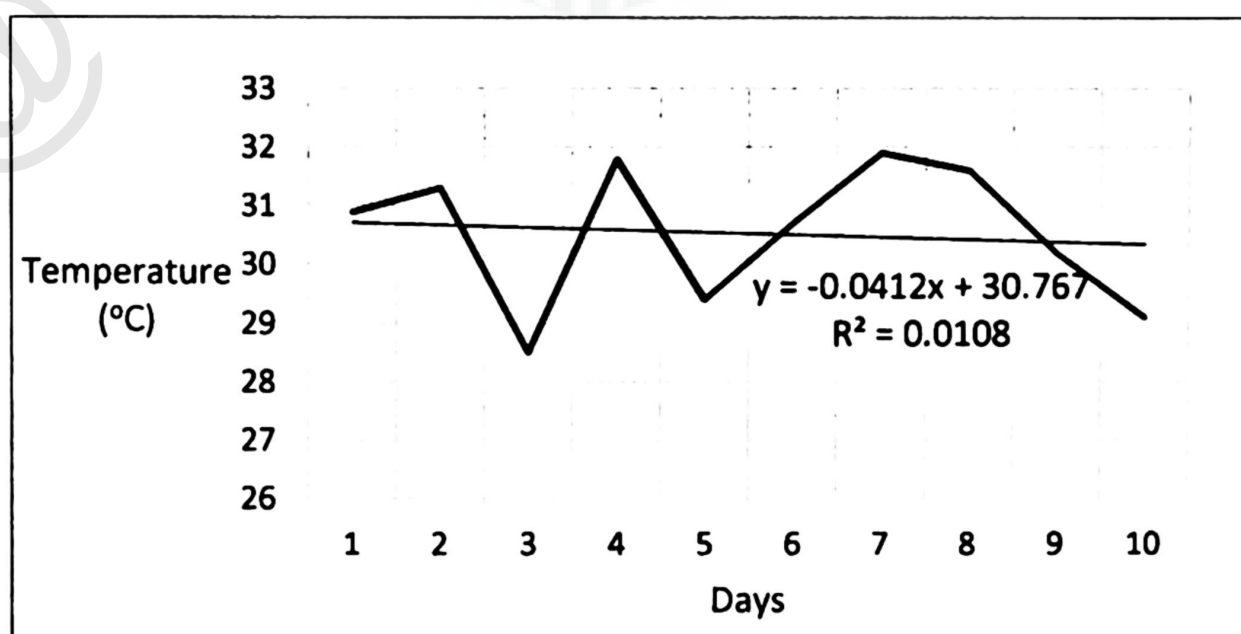


Figure 4.8: Reading of temperature inside the portable biodigester for ten days of mixing.

4.4.1.3 Effect of non-mixing on biogas production

After 10 days of mixing process, the experiment is continued by non-mixing where the floating lid was not rotated and the system was kept feeding every day with the same value of COD for another 10 days. The Graph 4.9 shown that biogas production was decreasing over days based on the trend line shown in graph. On the first two days, the biogas production still at high volume with reading of 4.7 and 3.8 litre due to the mixing process from the previous test (subsection 4.1.1.1). Then, the biogas become more stable from day five until the end of experiment. The average biogas production at the end of each variable is 4.8 litre during mixing while 3.3 litre without mixing. This proved our hypothesis on mixing process that can increase biogas production (Arapatka, 1994).

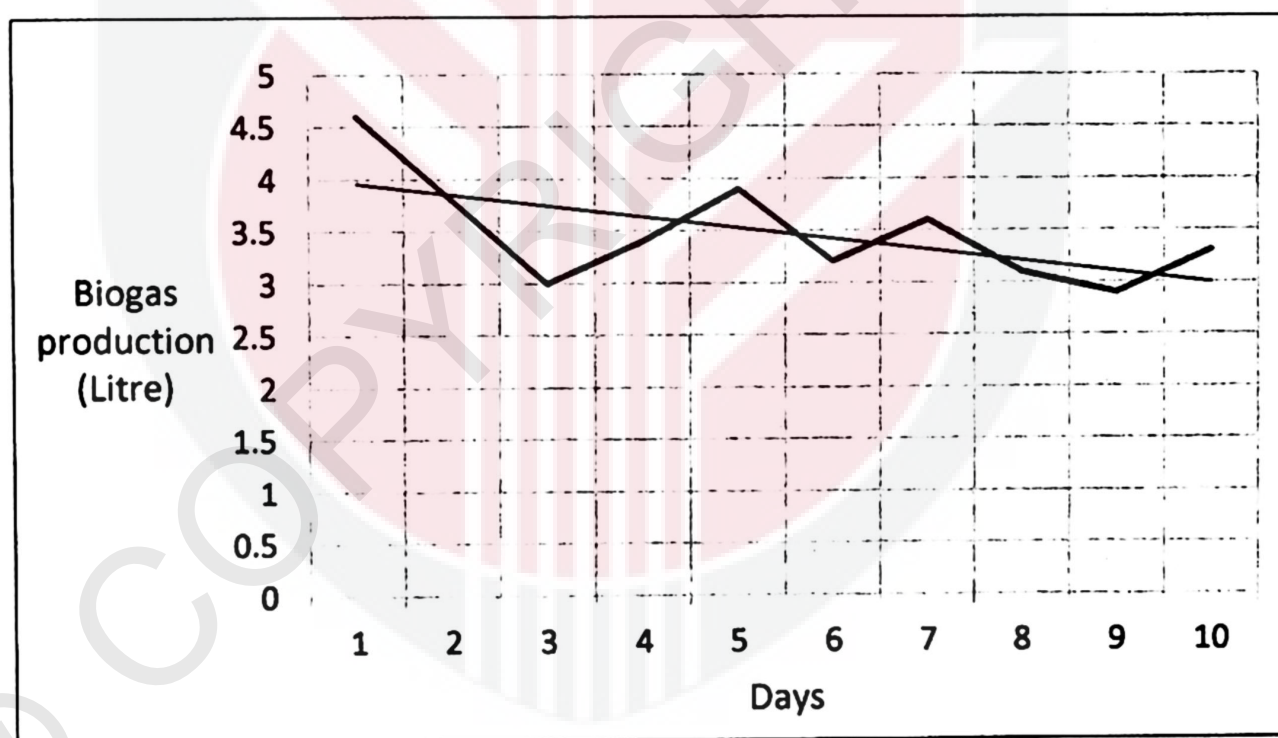


Figure 4.9: Biogas production (litre) from food waste for ten days of non-mixing.

From the graph 4.9, the biogas daily production was always fluctuating which it was also affected to the daily surrounding temperature. Figure 4.10 shown the temperature inside the biodigester which directly affecting the biogas production. As shown from trend of graph daily temperature during set up and mixing, the trend of

graph daily temperature during non-mixing also giving same trend as biogas production.

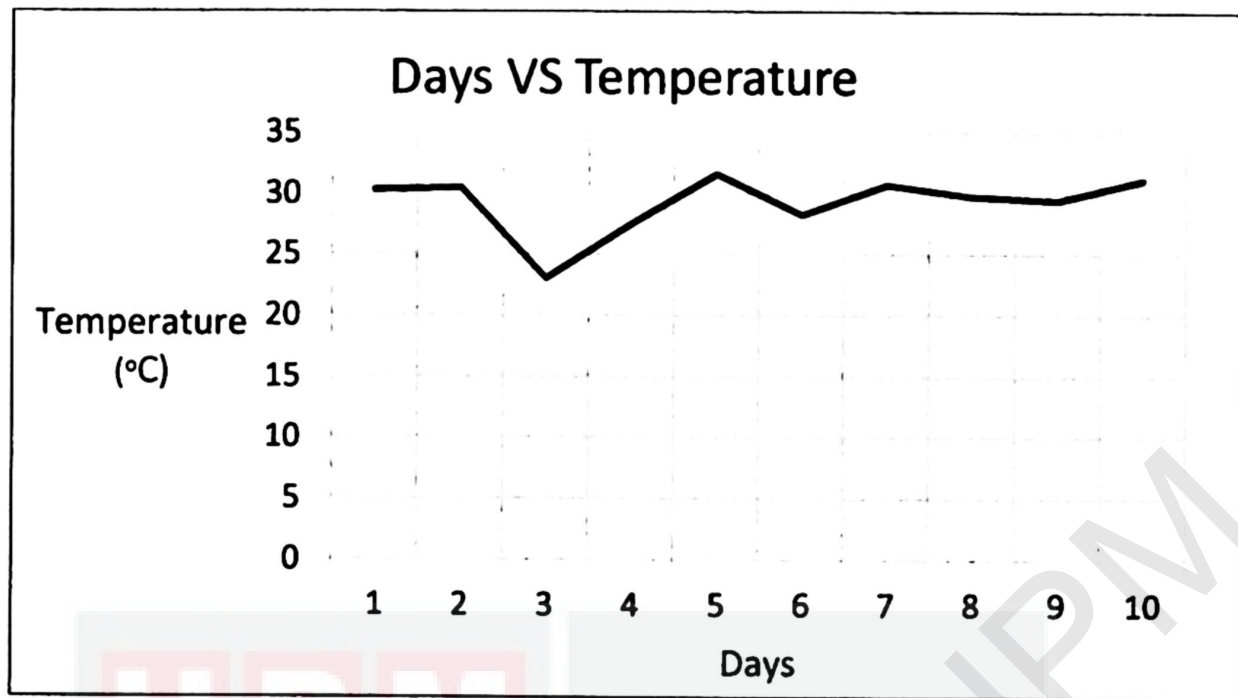


Figure 4.10: Reading of temperature inside the portable biodigester for ten days of non-mixing.

4.4.1.4 pH evaluation

The value of pH plays important roles in biogas production and in particular, can be considered a key variable due to its influence on many other soil proprieties and processes affecting plant growth (Gentili, Ambrosini, Montagnani, Caronni, & Citterio, 2018). From Figure 4.11, during first 2 weeks, the pH of influent has average pH value of 7 due to the pH of cow dung was approximately 7 or neutral (Belyeu, 2017). During this period, no food waste sample is introducing to the system. Then, on day 13, the trend of the graph was changed, the pH value drops due to the food waste sample. The influent pH value was constant at 3 from day 23 until the end of the experiment. For the effluent pH value as shown in Figure 4.11, the pH value at day 24 was 6.8. This was because of the cow dung sample was discharge through effluent port from the second part which influence the pH value to be neutral near to 7. Then, the reading was drops and constant at pH 4.5 until the end of the experiments. This value is important to make sure the effluent liquid use as fertilizer is not too acidic which

can affect the quality of the fertilizer itself (Gentili, Ambrosini, Montagnani, Caronni, & Citterio, 2018).

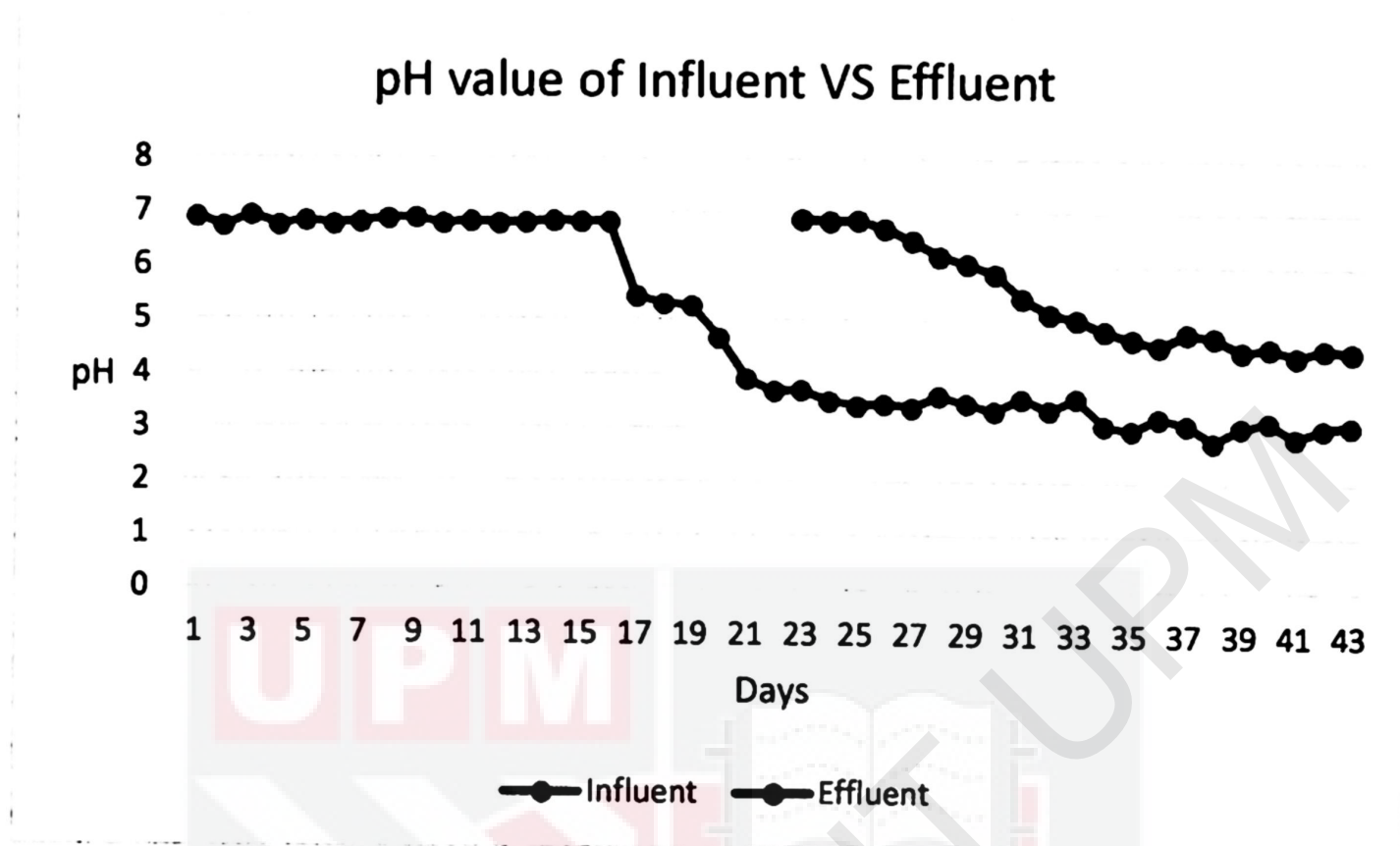


Figure 4.11: pH value at the influent and effluent port throughout experiment.

4.4.2 Effluent content

4.4.2.1 Total solid content (TSC)

The total solids (TS) content (a measure of the water content) is a key parameter in anaerobic digestion of poultry litter which affects hydrolysis and methanogenesis rates (Indren, Birzer, Kidd, & Medwell, 2020). Figure 4.5 shows the total solid content of the food waste and effluent sample during mixing and non-mixing. The average total solid content of food waste during the experiment is about 31% while the value drops to 1 to 2 percent during the discharge at the effluent sample showing that the effluent sample is high in moisture content. This is because most of the solid was hold inside the main part and settle at the bottom as the sludge while the liquid was overflow to second part. The value of TSC in the effluent liquid during mixing was higher compare to the non-mixing which is 2% compare to 1% due to the

cow dung sample that still remain in the second part. The cow dung was added into both part at the startup operation which then remove slowly through the effluent port. This give the value of TSC of the effluent during mixing higher as the TSC of cow dung was commonly from 12% to 14% (Sadaka & Engler, 2003).

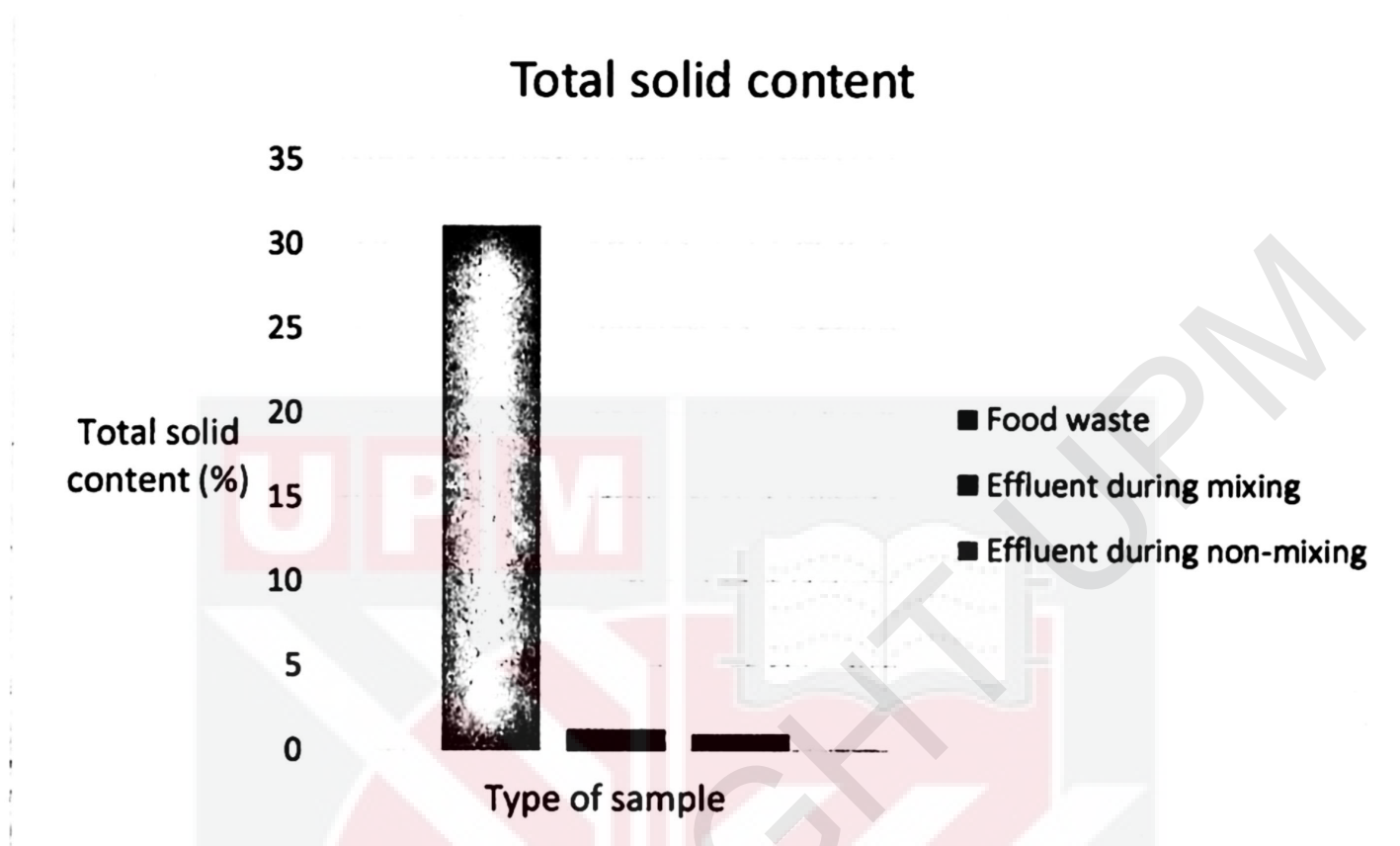


Figure 4.12: Total solid of food waste and effluent sample.

4.4.2.2 Chemical Oxygen Demand

Chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution (Li & Liu, 2019). It is commonly expressed in mass of oxygen consumed over volume of solution (mg/L). A COD test can be used to easily quantify the amount of organics in water. The higher the value of COD the higher organic content which can be act as substrate to the bacteria culture (Li & Liu, 2019). This also means the higher the COD value, the higher potential of the system to produce more biogas. During the experiment, we were using 2 sample of food waste which both of them were collected from the same restaurant. From Figure 4.13, COD value of two food waste sample was 275 000 for FW 1 and 310 000 mg per litre for FW 2. The COD in the effluent was become much lower range about 14 000 to 25 000 mg per liter during the experiment where the value was

constantly drop against time as shown in Graph 4.14. This indicate that the COD removal was high by the system which can be translate to the higher potential of biogas production during anaerobic process. The COD removal during mixing was 91% compare to without mixing which is 95%.

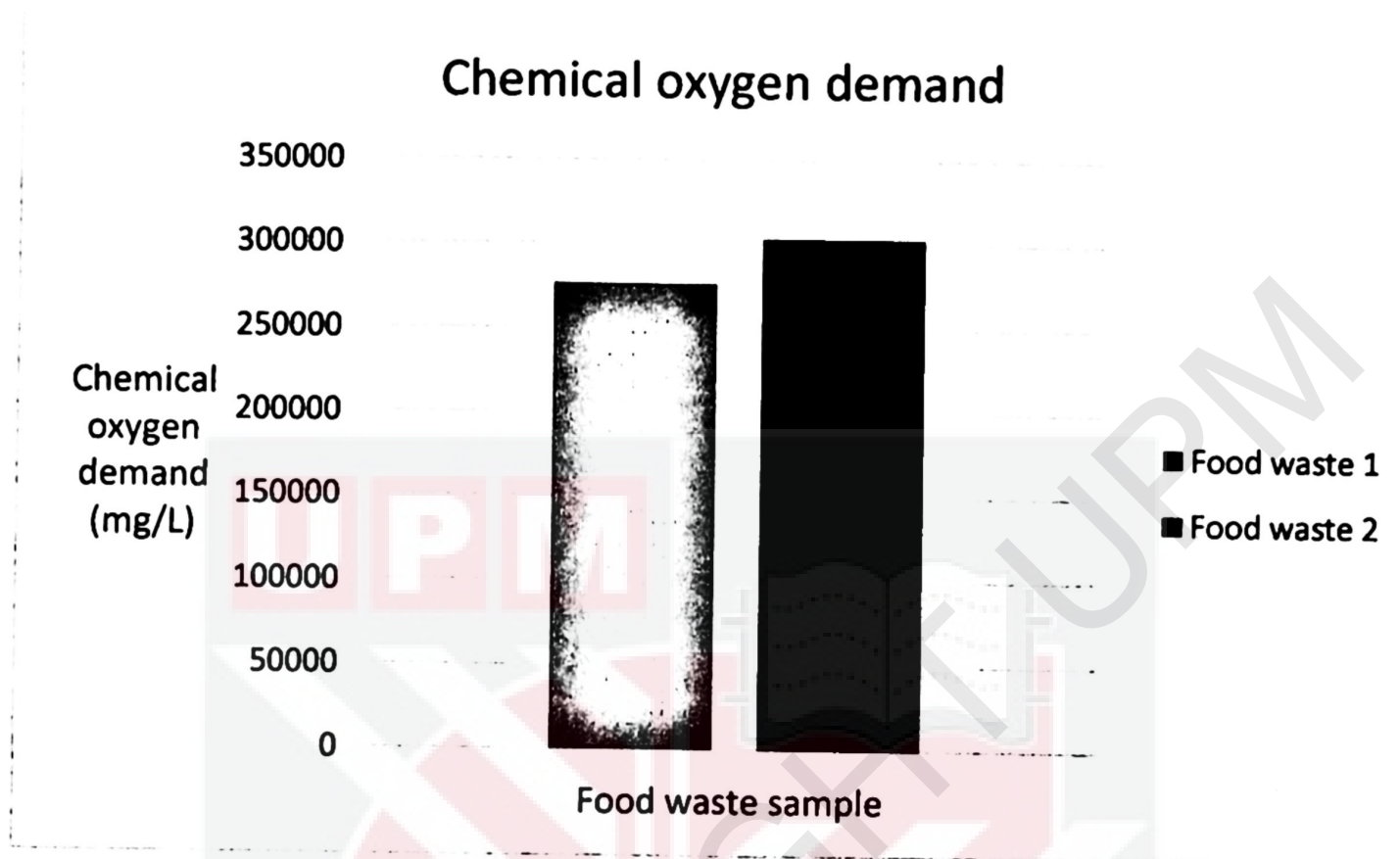


Figure 4.13: Chemical oxygen demand value for food waste sample.

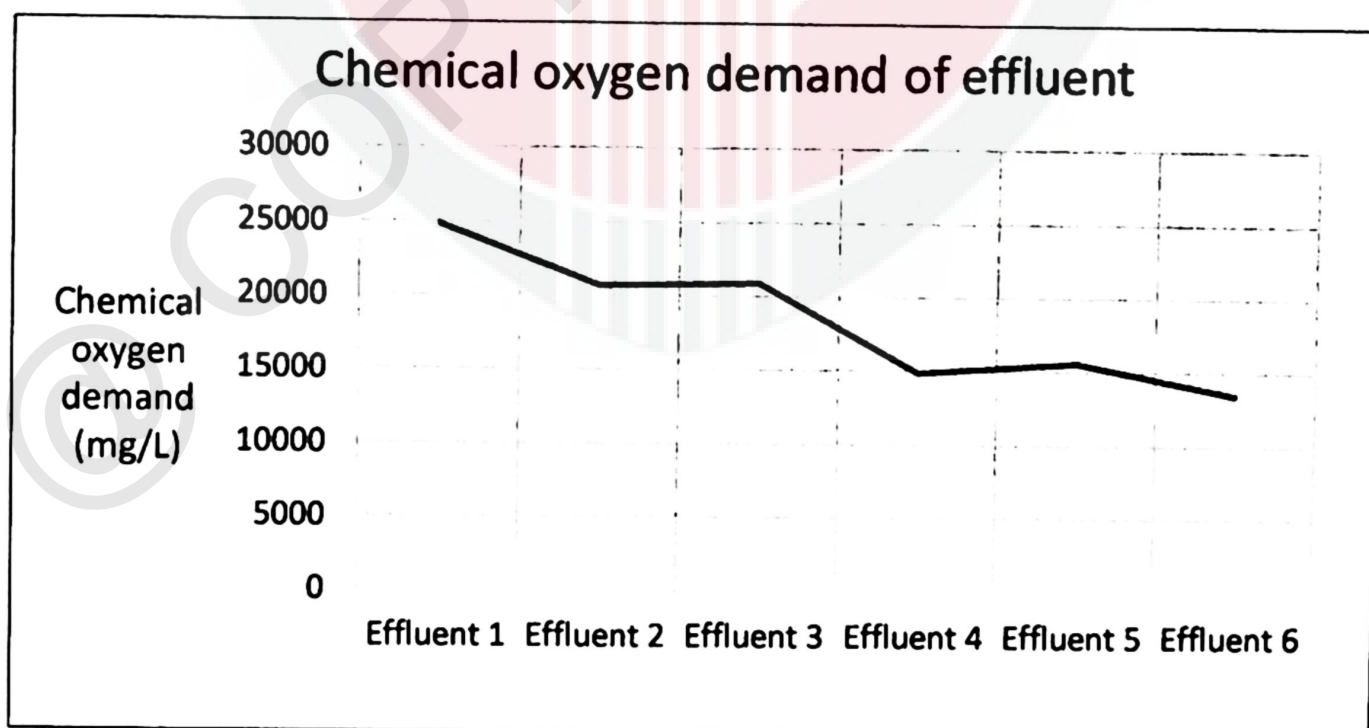


Figure 4.14: Chemical oxygen demand value for effluent sample.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

At the end of the project, a portable biodigester for household use is successfully designed and fabricated. This portable biodigester is fully manual which can reduce the maintenance cost while producing biogas with more efficient with the help of mixing process. Therefore, it is highly recommended to replace the existing portable biodigester which is does not have mixing process. The amount of biogas produce per day during mixing is in average 4.7 litre compare to without mixing which is about 3.3 litre proving that this portable digester is better than existing portable biodigester.

More research and development need to be conducted for further improvement since the machine is a new invention.

5.1 Recommendation

Some recommendations are suggested to be made in the future to solve the problem existed in the portable biodigester for household use. Table 5.1 below shows the summary of recommendation and improvement that can be done.

Table 5.1: Recommendation of improvement that can be done

Mechanism	Recommendation
Mixing	Another pair of impeller is needed to improve mixing efficiency.
Effluent removal	The diameter of effluent port need to be bigger and more straight forward to reduce the clogging problem during effluent discharge

The problem arises in the mixing mechanism where a pair of impeller is not too efficient to spread the food waste properly. When the floating lid is at minimum level, the existing impeller is only mix the lower part. Therefore, another pair of impeller is suggested to be designed for a better mixing efficiency. Meanwhile in effluent removal mechanism, the clogging problem is commonly occurring because of the diameter of the effluent port is too small. This can be overcome by using the bigger diameter pipe of make the flow is more straight forward for a better flow.

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