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Development of Environmental Friendly Mini Biogas to Generate Electricity by means of Food Waste

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Abstract
Biogas can provide a clean, easily controlled source of renewable energy from organic waste materials for a small labour input, replacing firewood or fossil fuels which are becoming more expensive as supply falls behind demand. During the conversion process pathogen levels are reduced and plant nutrients made more readily available, so better crops can be grown while existing resources are conserved. Since small scale units can be relatively simple to build and operate biogas should be used directly if possible for cooking, heating, lighting and absorption refrigeration, since both electricity generation and compression of gas for storage or use in vehicles use large amounts of energy for a small output of useful energy. This concept is suited to distributed systems where waste is treated near the source, and sludge is also reused locally, to minimise transport and initial capital cost compared to a centralised system. As the distributed system will need a support network biogas contributes to the triple bottom line, benefiting the environment, reducing costs and contributing to the social structure. This paper will present the feasibility study on mini biogas power plant (MBPP) which is first developed and operated in Malaysia and launched at Universiti Sains Malaysia (USM). USM with the collaboration Enerbon Sdn Bhd setup up this mini biogas power plant as an education and research and development to professionals and researchers and at the same time give opportunity to the people who are interest with this system to see and experience their self by looking how this mini biogas power plant works. The objectives of this paper are two-fold; firstly to determine whether food wastes (canteen and cafeterias wastes) can produce methane gas (biogas) that can generate heat and electricity and secondly to establish how much methane gas (biogas) can be produced with the certain amount of the feedstock. It should be pointed out that this MBPP can generate 600kW electricity per day as this system can generate electricity about 25kW/h. The methane produced per day is approximately 180 cubic metres. The higher the wastes, the higher the amount of methane gas produced. The cow dung is used to increase the bacteria in the tank; the methane gas production will be higher if the bacteria breed.

Keywords: biogas plant, food waste, energy, electricity, , feedstock, methane gas, cow dung

Introduction
A biogas production system must be specially designed and requires regular attention by someone familiar with the needs and operation of the digester. Associated manure handling equipment and gas utilization components are also required. The digester does not remove significant nutrients and requires environmentally responsible manure storage and handling system. A well designed and operated digester will require modest daily attention and maintenance. The care and feeding of a digester is not unlike feeding a cow or a pig, it responds best to consistent feeding and the appropriate environmental for temperature and anaerobic- oxygen free conditions. The earlier a problem in operation is identified the easier it is to fix and still maintain productivity [1].
Biogas generation is a chemical process whereby organic matter is decomposed. Slurry of cow dung and other similar feedstock is retained in the biogas plant for a period of time called the hydraulic retention time (HRT) of the plant [2]. When organic matter like animal dung, human excreta, leafy plant materials, etc. are digested an aerobically (in the absence of oxygen), a highly combustible mixture of gases comprising 60% methane (CH4) and 37% carbon dioxide (CO2) with traces of sulphur dioxide and 3% Hydrogen (H2) is produced. A batch of 25 kg of cow dung digested an aerobically for 40 days produces 1 cubic meter of biogas with a calorific value of calorific value of 5125 kcal/m^3. The remaining slurry coming out of the plant is rich in manure value and useful for farming purposes [2].
Biogas production using anaerobic digestion which is oxygen free is a biological treatment process to reduce odour, produce energy and improve the storage and handling characteristics of manure. Anaerobic digestion is a series of processes in which micro-organisms break down biodegradable material in the absence of oxygen to produce a methane rich biogas. Anaerobic Digestion can be used to treat organic farm, industrial and domestic waste. The anaerobic digestion process produces biogas, usually around 60% methane, 40% Carbon dioxide. This biogas can be

used to generate heat and electricity via a CHP engine, used directly in a biogas boiler, or cleaned and compressed for injection into the local gas grid or use as a vehicle fuel. Anaerobic digestion is widely in the waste water industry, and is common in Europe treating farm, municipal and commercial waste. It is used as a renewable energy source because biogas can offset fossil fuel use. The nutrient-rich digestive which is also produced is a valuable fertiliser and can replace the use of chemical fertilisers.

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a fuel in any country for any heating purpose, such as cooking. It can also be used in anaerobic digesters where it is typically used in a gas engine to convert the energy in the gas into electricity and heat [2]. Biogas can be compressed, much like natural gas, and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel so it qualifies for renewable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane. Figure 1 shows the green house gas reduction by biogas plant installation [3,4].

Mini biogas power plant (MBPP) is first launched in Malaysia at Universiti Sains Malaysia (USM) that is capable of generating 600 kW of electricity a day from food waste in the campus. This pioneering project is aimed at building a prototype to be used by interior communities with problems pertaining obtaining regular electricity supply. Food waste provided by all cafeterias and canteens in the campus will be converted into methane which will be turned to generate electricity [5]. The plant has two tanks that can accommodate 1000kg of food and organic waste such as grass, vegetables waste, leftover rice and leftover fish.

The electricity generated could be channelled to the university's power supply grid. Communities with a lot of organic waste but no connection to the grid would benefit most from MBPP, in which MBPP per se produces approximately 180 cubic metres of methane a day from readily available local waste material. This methane produced is actually equal to 180 litres of diesel per day of generated electric power, making the plant an ideal alternative for remote and island communities that depend on diesel to run generator sets for their power needs [6]. At an estimated cost of RM800,000 (US$260,000) per MBPP, and with fuel and transportation costs to a remote or island location adding up to some RM4.00 per litre, it is possible to recover the initial investment in three to six years [7,8].

This paper will present comprehensively the feasibility study on using mini biogas power plant (MBPP) which is first developed and operated in Malaysia and launched at Universiti Sains Malaysia (USM). The main objectives of this paper are two-fold; firstly to determine whether food wastes (canteen and cafeterias wastes) can produce methane gas (biogas) that can generate heat and electricity and secondly to establish how much methane gas (biogas) can be produced with the certain amount of the feedstock.

2. Materials and Compositions

The main material in this study is mini biogas power plant (MBPP) that consists of two tanks. The objective for this research is to know whether this MBPP can produce methane gas and generate electricity as much as the achievement that its works on the other country before by using food wastes (cafeterias and canteens) as the feedstock. Figure 1 shows the modular concept of the MBPP, is in prefabricated design and can be installed easily while Figure 2 visualizes two digester tank where all the canteen waste was put in with the cow dung and pure water (solid with liquid). After a day, all the waste will be pumped into the digester at the left site that contains water (in the form of liquid).

Figure 1. The modular concept of the MBPP, is in prefabricated design and can be installed easily.

Figure 2. Two digester tank where all the canteen waste was put in with the cow dung and pure water

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This mini biogas power plant will show the amount of methane gas produced with the certain amount of feedstock used everyday. This machine works 24 hours per days with the amount of feedstock from 200kg to 1000kg. These mini biogas power plants use anaerobic digestion (no present of oxygen) and the feedstock is mixed with the cow dung and water. The feedstock was comes from canteens and cafeterias waste for example leftover rice, vegetables waste, fish waste, fruits and any other food lefts.

3. Experimental Setup

By using food waste and organic waste from cafeterias and canteens around the campus, this mini biogas power plant will digest all the waste to turn it into methane in order to produce electricity. With the total amount of 1000kg of mixed food waste per day, there is about 180 cubic metre of methane can be produced and about 600kW electricity can be generated. The flow of work done to turn waste to electric energy:

i. About 1000 kg of waste was placed into tank 1 and tank 2 every other day.
ii. The tank was filled with water and cow dung. All the materials were digested together (solid + liquid).
iii. On the next day, the digested waste was pumped into the digester that only consists of water (liquid).
iv. After that, the wastes decompose and methane gas was generated.
v. Methane rises to the top and is collected into digested bag.
vi. Methane was then used to produce heat or generate electricity.
vii. Step i) to vi) were repeated daily.

The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55–75% methane, which for reactors with free liquids can be increased to 80-90% methane using in-situ gas purification techniques. As-produced, biogas also contains water vapour. The fractional volume of water vapour is a function of biogas temperature; correction of measured gas volume for both water vapour content and thermal expansion is easily done via a simple mathematic algorithm which yields the standardized volume of dry biogas.

In some cases, biogas contains siloxanes. These siloxanes are formed from the anaerobic decomposition of materials commonly found in soaps and detergents. During combustion of biogas containing siloxanes, silicon is released and can combine with free oxygen or various other elements in the combustion gas. Deposits are formed containing mostly silica or silicates and can also contain calcium, sulfur, zinc, phosphorus. Such white mineral deposits accumulate to a surface thickness of several millimetres and must be removed by chemical or mechanical means. The biogas production is not a constant process, it is depending on the biological activities of the microorganism and the biomass. The two temperature conventional operational temperature levels for anaerobic digesters are determined by the species of methanogens in the digesters.

i) Mesophilic digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C, where mesophiles are the primary microorganism present.
ii) Thermophilic digestion takes place optimally around 49 to 57 °C, or at elevated temperatures up to 70 °C, where thermophiles are the primary microorganisms present.

The digesters that are used for the purpose of production of biogas can be used in mesophilic conditions, which mean a temperature range of 20 to 25 degrees Celsius to 40 to 45 degrees Celsius. The digesters can also be run in thermophilic conditions, where the temperature range is from 50 to 55 degrees Celsius to 60 to 65 degrees Celsius. Both these conditions call for separate species of bacteria. It is thought that the mesophilic operations are more safe and stable than the thermophilic operations that are capable of inactivating the parasites of animals and the various pathogens. Through the lab test that has been conducted in the environmental lab, the temperature of the water in the tank 1 and in the digester are 35.7°C and 37.5°C respectively. Figure 3 shows samples that were taken from tank and digester.

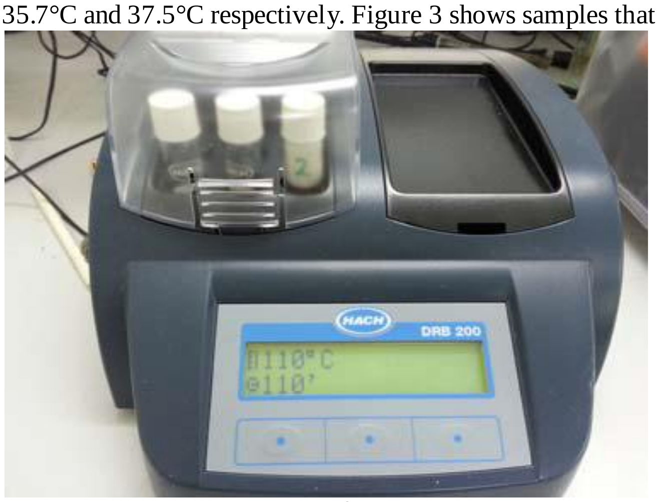

Figure 3. Samples taken from tank and digester

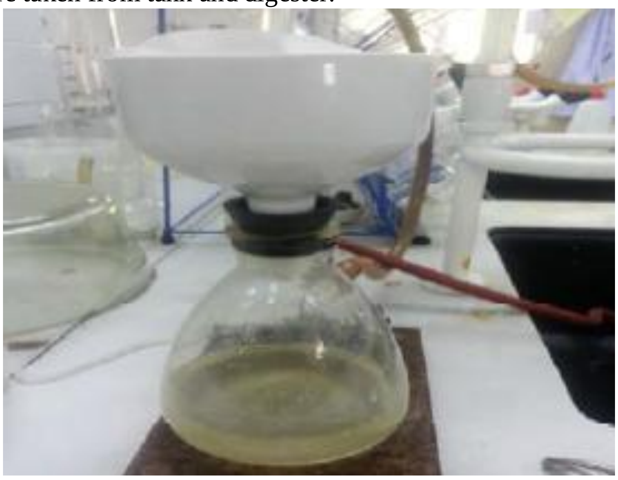

Figure 4: The filtration process of the suspended solid

At the hydrolysis process it is important to make sure that the pH value are 4 to 5 and for the methanogenesis are 7 to 8. Preparation of feeding substrate for pH value is very important with the condition no oxygen and darkness is about less than 1%.The heating of digesters is also pretty important in this regard. The pH of the slurry has to be close to 7. This is pretty much possible provided that cow dung is employed in the form of a substrate. If favourable conditions may be provided then as much as sixty litres of biogas may be produced for one kilogram of cow dung. Through the lab test that has been conducted in the environmental lab, the pH values obtained from tank 1 and in the digester are 4.78 and 7.11 correspondingly. Figure 4 visualizes the filtration process of the suspended solid.

4. Results and discussions

The results obtained from the hypothetical case study, the result is shown in Table 1. The mini biogas system costs about RM1.0 – RM 1.2 millions including the operational cost which is diesel that costs RM4 per litre. This mini biogas power plant needs only a battery backup of about 6 hours to add fuels on the generator or when doing maintenance to the generator. The cost for solar energy system is higher than biogas system which sums up around RM 4.5 Million due to the cost for battery backup. Solar energy system needs battery backup when it is raining or cloudy, that makes the solar panel unable to receive sunlight. In this situation, solar panel cannot generate any electricity. The cost for battery backup makes the solar system's cost higher than biogas.

Therefore, it is better to use biogas mini power plant at remote areas because it does not cost a lot and generates electricity easier without causing any problem. Furthermore, this system can be installed easily due to it being modular which means it is portable and can be transferred and installed anywhere. The biogas mini power plant only needs food and organic waste to generate electricity energy and the generator is guaranteed to work 24 hours a day regardless of the weather. The supply of wastes is continuous as long as there are people that lives in the vicinity; ensuring that this system will work well. If solar system is used, it may cause a problem during rainy day because the system will not be able to receive any sunlight and needs battery for backup. The battery will cost a lot and the place needed to store the battery is also high in cost. The price needed is too high to be used in remote areas.

Table 1: The comparison between biogas' and solar system's costs

Types of energy	**Biogas with generator**	**Solar energy with batteries**
Source	Needs 1000kg/day organic feedstock and operator	Needs 150 kWp panel capacity with 4-5h max sun shine plus additional light
Efficiency	600kW and 182m^3 Methane Gas per day	4hours sunshine (150kWp x 4) = 600kW per day
Operational cost	Need diesel to run the generator (1 litres diesel = RM4)	No need
Battery backup	Battery backup for 6 hour only	Battery backup for 2 days (for raining and cloudy day)
Production	Gas and electricity	Electricity
Cost	RM 1.0 – 1.2 Million	RM4.5 Million (needed a lot of battery backup for raining days)

By having an amount of 1000 kg waste per day, the electricity generated will be about 600kW per day due to the fact that this mini biogas power plant can produce up to 25kWh. About 180 cubic metre methane gas is produced and will be burned to generate electricity. If there are more wastes, the electricity energy generated will also increase. The maximum electricity that can be generated by this mini biogas power plant is 720Kw with the amount of waste of 1200kg per day. The result of the methane and electricity produced is as shown in Table 2 below.

Table 2. The production of methane gas and electricity per day

Feedstock – Organic active (canteens and cafeterias waste)				
Feedstock substrate	CH4/VS and /Feedstock (m^3CH4/kg VS)		Power/tFs (per day)	
			kWh/d	kWh/h
Food Waste	0.196	196.0	646.80	26.95

The production of biogas result indicated that about 26.95 kWh/h electricity can be generated with the total amount of 1000kg/d of food waste supplied. There is about 646.80kWh/d electricity can be produced a day. Methane gas that can be produced per day is 196.0 cubic metres. It is proved that all the foods waste from canteens and cafeterias can generate more methane gas and electricity. The dry matter content in this mixed waste is about 40% while the volatile solid makes up about 98%. The result shown was higher from other country's results because this mini biogas power plant has a change in their design that increases their workability and efficiency.

Table 3 shows the amount of the feedstock used by week. The amount of feedstock is same in week 1 to week 3 because the bacteria in the tank (cow dung) need at least 3 weeks to multiply the bacteria. The higher the bacteria, the higher the methane gas production. At the week 4 until week 12 the amount of feedstock place in the tank increase to multiply the bacteria but until 1000kg the feedstock will remains constant.

Table 3. Table of feedstock used per week

Weeks	Amount of feedstock (kg)	Amount of methane gas production (m3)
1	200	35.48
2	200	37.23
3	200	39.20
4	400	70.76
5	400	78.40
6	500	98.00
7	600	117.60
8	700	137.20
9	800	156.80
10	900	176.40
11	1000	196.00
12	1000	196.00

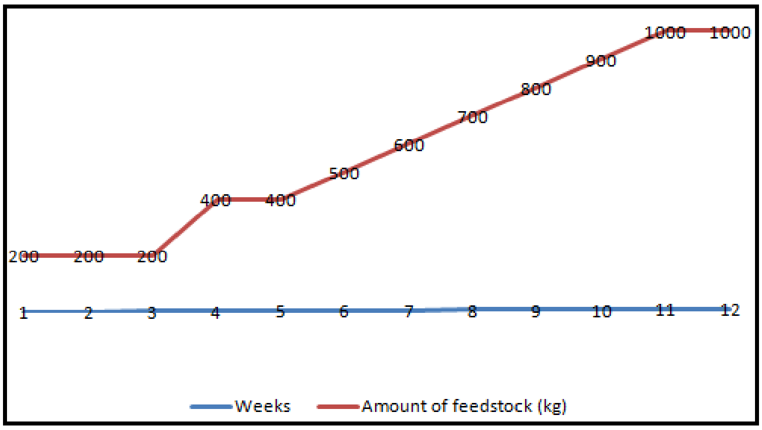

Figure 5. The amount of feedstock used by week

Based on Figure 5, it is shows the increasing of the number of the feedstock by the weeks. This MBPP already function about 3 months, and at the week 11 to week 12 the number of feedstocks are remain constant. On the other hand, according to Figure 6, the production of methane gas production increase when the feedstock increase. At the beginning, the number of feedstock is 200kg and the number of methane gas production s are around 35.48, 37.32 and 39.20 respectively. Figure 6 shows the amount of methane gas produced per week

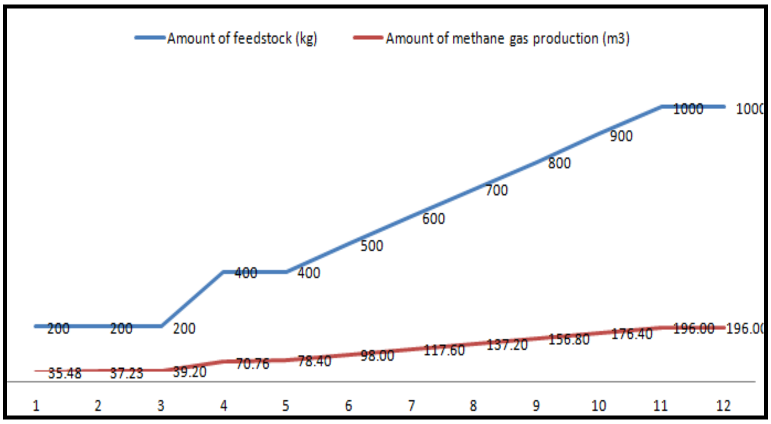

Figure 6. The amount of methane gas produced per week

Figure 7 shows the number of electric generated increase by weeks is remains constant at the week 11 and 12 with the amount of 646.80kW. It clearly visualised that the amount of electric power increase by weeks.

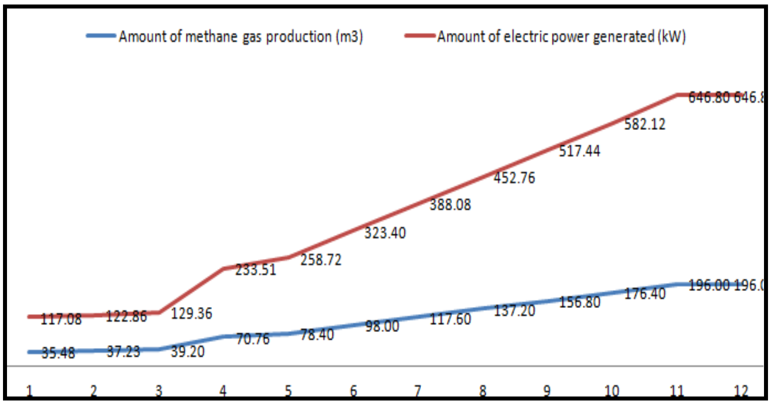

Figure 7. The number of electric power generated per week

Conclusions

The most suitable power plant system to be installed at remote area is mini biogas power plant compared to solar energy system because of several reasons. First of all, this mini biogas power plant is easy to set-up because it is made in a modular system that could be installed or uninstalled and transferred easily everywhere and anywhere. When there is a human, there will be waste. It is not hard to collect the wastes to be used in generating the energy rather than waiting for the sunlight that is dependable on the weather. If it is raining season, they villagers will not suffer to stay in dark at night and feeling hot during the day. The generator will work 24 hours to generate electricity as long as there are wastes and the generator have enough fuels to work.

If there is 1000kg waste per day, the mini biogas power plant can generate about 180 cubic metre methane gas and 600kW electricity per day. The waste produced should be enough to support this system. It is acceptable if the waste is lower than 1000kg per day, as long as it could support all the needs that the people demand at their place. The higher the amount of wastes could produce the higher the amount of electricity.

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