J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

Design of Market Waste Biodigester as an Effort to Produce Renewable Energy for Climate Change Mitigation Strategy

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Article info
Received:
Dec 11, 2023
Revised:
Feb 23, 2024
Accepted:
Mar 20, 2024
Published:
Mar 31, 2024

Keywords:
Solid Waste Transportation, ghg emission, anaerobic digester, renewable energy

Abstract

The mismanagement of solid waste transportation to landfills contributes to various environmental issues, including increased greenhouse gas (GHG) emissions, propagation of disease vectors, aesthetic degradation, and interference with market activities. Addressing these challenges necessitates efficient waste processing at the source to mitigate waste accumulation at temporary dump sites and reduce GHG emissions. This study proposes the design of an integrated anaerobic digester at Pasar Kemiri Muka, specifically selected for its ability to convert organic waste into renewable energy. The anaerobic process is advantageous as it produces methane with a high calorific value, suitable for generating electricity. The generated electricity is then utilized to improve street lighting in the market area, which currently suffers from insufficient and poor-quality lighting. The proposed system is designed to power 14 LED street lights, requiring only 10m² for installation and incurring an operational cost of IDR 525,000. This approach not only provides a sustainable energy source but also enhances local infrastructure, contributing to a cleaner and more efficient market environment.

1. Introduction

Nowadays, the solid waste problem is still a difficult thing to deal with in Indonesia. Even population growth continues to increase every year, which is directly proportional to the amount of solid waste generated. The increasing amount of solid waste can result in environmental degradation and health problems if not managed properly [1]. Indonesia as a developing country can produce twice as much organic waste (biodegradable waste) as developed countries, which is around 50-80% of total municipal solid waste [2],[3],[4],[5],[6]. Meanwhile, a large contributor of biodegradable waste, namely traditional markets, contributes 7% of the city's total organic waste generation transported to landfills [7]. The high rate of food waste generation in Indonesia can be caused by several things, which are the warm climate, lack of technology and expertise, and infrastructure for preserving food from agricultural locations to markets. This causes 40% of food to become waste [8].

The waste is piled up in landfills without receiving significant processing. Currently, there are only 5 landfill locations in Indonesia that are operated using the sanitary landfill method, and 35% of the total landfill sites in Indonesia are operated using the open dumping method [9], [10]. The remainder means that waste processing has been carried out in landfills, but it has not been carried out thoroughly [10]. Organic waste buried in landfills will naturally go through a degradation process by microorganisms either aerobically or anaerobically, a volatilization process, and a chemical reaction. This process will produce greenhouse gases which can cause global warming [11][12]. During these processes in the landfill, gases are emitted from the landfill which are referred to as landfill gases (LFG). According to Williams (2001), LFG are primarily composed of methane (45-60%), Carbon dioxide (40-60%), Nitrogen (2-5%), Oxygen (0.1-1%), hydrogen (0-0.2%), carbon monoxide (0-0.2%), ammonia (0.1-1%), and Non-Methane Organic Compounds (NMOCs) [13]. Mismanagement of a landfill can result in uncontrolled emissions of LFG, which contribute significantly to climate change; strong odors, litter, and dust in the surrounding area; and seepage of waste leachate into groundwater and surface water [14]. Greenhouse gases (GHGs) such as CH_4 and CO_2 pose a major threat to various aspects of the environment, including unprecedented types of flooding, sea level rise, rainfall pattern distortion, unpredictable and intense hurricanes, massive heatwaves, and glacier loss, to name a few [13].

The cities of Jakarta, Bogor, Depok, Tangerang, Bekasi are very important economic centers in Indonesia, especially commercial activities [16]. In Depok City, there is Pasar Kemiri Muka which is the biggest market in the city. All the people's daily needs can be purchased at the market. With a land area of 2.6 Ha and a building area of 1.2 Ha, it contains 524 shop units, 480 small shop units, east parking area, west parking area, places of worship and other supporting facilities. Pasar Kemiri Muka Depok produces an average waste generation of 34 tonnes/day. Even though it is equipped with a temporary dump site, the waste can reach the height of the shop roof every day (5 meters). This is because waste transportation is only carried out once every 3 weeks with a volume of transport trucks that does not match the actual waste generation in the field. The intensity of transportation is not commensurate with the waste entering the temporary dump site. Apart from the market, waste at temporary dump site of Pasar Kemiri Muka also comes from residential areas around the market. The condition of the waste at the temporary dump site is rotting, blackened, producing leachate, maggots and a very unpleasant odor. The smell comes from gas produced by the decomposition of organic waste, most of which are greenhouse gases [12]. Apart from causing global warming, gas trapped in piles of rubbish has the potential to produce explosions if not released. This condition has resulted in many protests from the community around the market to the City's environmental Services (Dinas Lingkungan Hidup), there have even been demonstrations and the accumulation of rubbish in front of the DLH office by the demonstrators [15].

Therefore, it is necessary to process the waste at the source which can reduce the amount of waste in temporary dump site which is related to waste generation in landfill so that it can reduce gas production, especially greenhouse gases. One way is to design an integrated anaerobic digester in the market area. The anaerobic process was chosen because it has the advantage of producing renewable energy (methane) with a fairly high calorific value which can be used to produce electricity. The electricity produced from biogas conversion will be used as street lighting at the Pasar Kemiri Muka due to the lack and poor quality of street lighting.

2. Methodology

The form of this research is descriptive quantitative which combines primary data from the existing conditions of Pasar Kemiri Muka, and secondary data from related agency data and other supporting literatures. Primary data includes a map of the Kemiri Muka Market location, and photos of the existing conditions of the research location, while secondary data includes waste generation data, biogas and electricity conversion data, as well as other supporting data for biogas reactor design. Before carrying out a detailed design, a comparison of design alternatives is carried out first regarding the biogas digester workflow. There are three (3) alternative designs which are then compared and the best alternative is selected using the Analytical Hierarchy Process (AHP) method. Comparative indicators in evaluating design alternatives include lamp energy consumption, land area, and operational costs. The selected design alternatives obtained were then designed in detail for biodigester design, mass balance for organic waste utilization, as well as a draft budget.

Analytical Hierarchy Process abbreviated as AHP is a decision-support model developed by Thomas L. Saaty (2008). This decision support model describes complex multifactor or multicriteria problems as a hierarchy. Hierarchy itself is defined as a representation of a complex problem in a multilevel structure, where the first level is the goal, followed by the levels of factors, criteria, subcriteria, etc. until the last level of alternatives is discussed [24]. The working principle of the AHP is to simplify a complex, unstructured, strategic, and dynamic problem into its parts, and arrange them in a hierarchy.

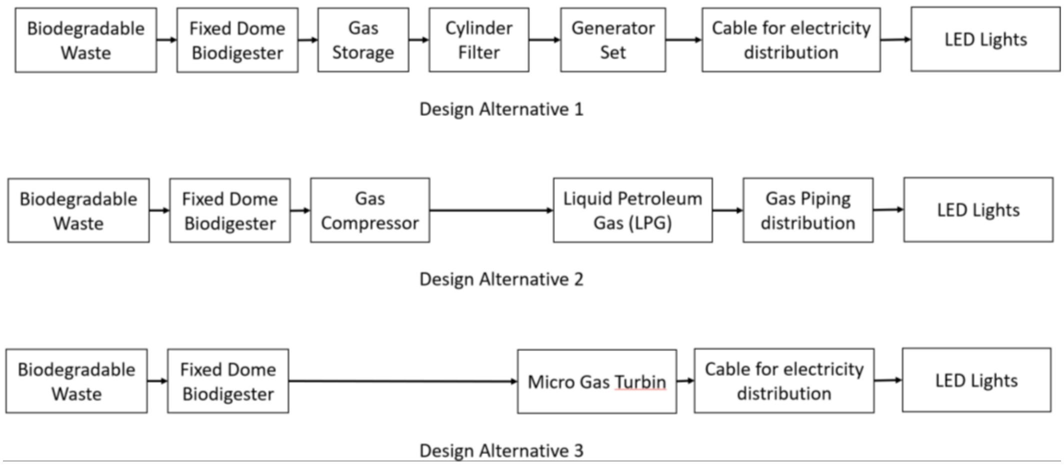


Figure 1. Comparison of three design alternatives

3. Results and discussions

3.1. Potential Electrical Energy

The organic waste produced by the Kemiri Muka Market, Depok City per day is 34 tons with a percentage of vegetable and fruit waste of 39%, plastic waste of 32%, food waste of 18% and others in the form of cardboard, newspapers, cans and bottles as much as 11% [18]. Thus, the amount of organic waste produced at Kemiri Muka Market is as follows:

Biodegradable Waste Generation = Percentage of Organic Waste × Total Waste Generation
Biodegradable Waste Generation = (39% + 18%) × 34 ton/day = 19,38 ton/day

The amount of biodegradable waste consisting of vegetable, fruit, and food waste at the Kemiri Muka Market is 19.38 tonnes/day. This waste can be reprocessed into biogas using a fixed dome-type biodigester and used to provide street lighting at the Kemiri Muka Market. 1 kg of waste will produce 0.0452 $m3/kg$ biogas [19] so, the biogas that will be produced from 19.38 tonnes of biodegradable waste at Kemiri Muka Market per day is [20]:

Biodegradable Waste Generation = 19,38 ton/day = 19380 kg/day
Volume of Biogas Production (VBP) = 0,0452 m^3/kg × Biodegradable Waste Generation
Volume of Biogas Production (VBP) = 0,0452 m^3/kg × 19380 kg/day = 875,89 m^3/day
Volume of Methane Gas (VMG) = 54% × VBP
Volume of Methane Gas (VMG) = 54% × 875,98 m^3/day = 474,03 m3/day
1 m^3 biogas = 11.72 kWh (Conversion Factor)
Electrical Energy Potential (E) = VMF × Conversion Factor
Potensi energi listrik (E) = 473,03 m^3/day × 11,72 $kWh/hari$ = 5543,91 kWh/day

3.2. Design Alternatives

The differences in biogas reactor workflow for design alternatives are on the type of energy used, energy distribution methods, and the type of lamp used. Details of these differences can be seen in **Figure 1**.

3.2.1. Design Alternative 1 (Generator Set)

Biodegradable waste is the main raw material for making biogas, where the waste will go through an anaerobic process in a fixed dome-type biodigester. Next to the biodigester, a gas storage will be installed. It is necessary to design a piping system that will start from the biodigester outlet pipe to the gas storage, then to the filter, and will enter the generator. A filter tube containing KOH and activated carbon is needed to absorb CO_2 and H_2S. Then the biogas will become fuel for the generator set (Genset) which will produce electricity for light bulbs provided on the market. In distributing electricity, electricity cables will be used which will be connected through electricity poles as support. Then to make it easier to turn the generator off and on automatically or automatically, the AMF (Automatic Main Failure) generator panel is used [17].

Table 1. Specification of Biogas Generator Set

Features	**Single Cylinder** **4-stroke** **OHV** **Force air-cooled** **Single-phase AC synchronization with brush alternator**
Ac Voltage	230 V
AC Output/Max	Running Power: 1200 Watt
Frequency	50/60 Hz
Starting System	Recoil Start/Electric Start
Fuel	Biogas
Fuel Capacity	0.55 Liter
Weight	65 Kg
Other	Min. Fuel Consumption: 1.46 m^3/hour
Biogas Temperature	0-60ºC
Gas Pressure	15-100KPa
Amount of Methane	55%

Source: [21]

- The biogas needed to power the generator for 24 hours based on the Minimum Fuel Consumption in the generator specifications is 24 hours x 1.46 m3/hour = 35.04 m^3/hour
- Biogas produced by piles of organic waste is 414,94 m^3/day.

The generator will be installed far from the public and also placed in an open room so that it has good air circulation and the generator does not heat up quickly. In terms of operational condition, it is also not difficult, because there is a piping system made from storage gas, a biogas pipeline to the generator. In terms of user convenience, you can use the buttons on the generator panel so it doesn't require a lot of power. Placement of transmission lines in street lighting will use electric cables and use electric poles as supports so that they do not take up space in the market. The specifications for the biogas generator set can be seen in **Table 1**.

3.2.2. Design Alternative 2 (Liquid Petroleum Gas)

Organic raw materials in the form of food waste will be put into the digester. The process in a fixed dome biodigester will occur in a closed manner without the presence of oxygen (anaerobic conditions). Organic material will be broken down by bacteria and will produce a gas called biogas. Biogas collected in the digester will be put into Liquid Petroleum Gas (LPG) using a gas compressor. The LPG gas will later be distributed to power Petromax lamps used for street lighting in the market.

The following is the composition of biogas which can be seen in **Table 2**.

Table 2. Biogas Composition

Composition	**Percentage (%)**
Methane (CH4)	55-75
Carbon Dioxide (CO2)	25-45
Nitrogen (N2)	0-0,3
Hydrogen (H2)	1-5
Hydrogen Sulfide (H2S)	0-3
Oxygen (O2)	0,1-0,5

Calculation:

- Gas cylinder requirements
  - Amount of the biogas produced: 414 m^3
  - LPG cylinder capacity of 50 kg
  - So the amount of biogas produced/LPG capacity = 414 m^3/50 kg = 8.28 = 8 cylinders

Table 3. Detail Engineering Design of Micro Gas Turbine [23]

Primary Data	**Value**
Ideal Compressor Work (Wkideal)	8,544 kJ/kg
Ideal Heat Needed (Qin ideal)	987,07 kj/kg
Ideal Turbine Work (WT ideal)	633,95 kJ/kg
Heat out of Turbine (Qout)	361,66 kJ/kg
Power of Turbine (kW)	2,13 kW
Turbine Efficiency (ŋT)	97,9%
Compressor Efficiency (ŋk)	98%
Fuel Flow Rate (mfuel)	0,0313 kg/s
Air Flow Rate (mudara)	0,1478 kg/s
Turbine Rotation	3000 rpm
Fuel	biogas
Biogas Capacity	2,5 m3/^{hour}
Methane Composition in Biogas	53-70%

Calculation:

- Volume of gas micro turbine = 4 m^3
- Biogas capacity based on micro gas turbine is 2,5 m^3/hour

So, the biogas needed to power the micro gas turbine for a day: 24 hours x 2,5 m^3/hour = 60 m^3/hour

Biogas is used as a substitute for conventional fuels such as gasoline and diesel. Apart from that, biogas can be converted into electricity using a purification and storage system in gas cylinders or tanks. Before using biogas, it must be purified because biogas contains around 55-75% usable methane, but also contains impurities such as carbon dioxide, water vapor, and 25% hydrogen sulfide. Following are the steps for distributing biogas into gas cylinders.

a. Biogas production: biogas has been produced through anaerobic fermentation from biodegradable waste at the Muka Kemiri market Depok.
b. Biogas Collection: the biogas produced is collected in gas cylinders or gas storage tanks
c. Biogas Purification: the collected biogas is then purified by removing water content, particles and other gases such as carbon dioxide (CO_2) and sulfur (H_2S).
d. Biogas storage: purified biogas is stored in a storage tank for distribution into gas cylinders.
e. Biogas Distribution: biogas will be distributed into gas cylinders via gas pipes and gas compressors.
f. Compaction of biogas: biogas that flows into gas cylinders must first be compressed with a high enough pressure so that it can be stored in gas cylinders.
g. Gas cylinder filling: the compressed biogas is then filled into gas cylinders using appropriate gas cylinder filling equipment.

3.2.3. Design Alternative 3 (Micro Gas Turbin)

This process occurs in a fixed dome biodigester. The biogas that has been produced in the digester will be distributed to the micro gas turbine. In a micro gas turbine, it will start from the compressor which functions as an air absorber to increase pressure. Then it will enter the combustion chamber to be heated first before use. After being heated, the gas resulting from the combustion process will flow to the turbine so that it will rotate the turbine and at the same time rotate the electric generator [22]. This gas will later produce electricity to power neon lights which will be used as street lighting in markets. Distribution of electricity to the lights will use electric cables from the microturbine to the neon lights with the help of electric poles. The following is the micro gas turbine design data which can be seen in **Table 3**.

3.3. Evaluation of Design Alternatives

The comparison of the characteristics of each design alternative is carried out, as in **Table 4**. The characteristics that will be compared are the light energy consumption of each alternative, the area of land required for the equipment, and the operational costs of each alternative.

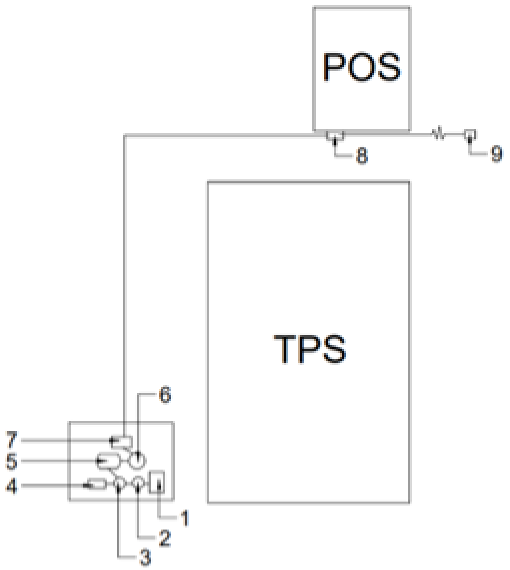
Table 4. Comparison of the characteristics of alternative biogas designs for street lighting for the Kemiri Muka Market

Alternatives	Consumption of Light Energy	Area of land (m2)	Operational Cost
Generator Set	1. Use LED light 60 watt as road lighting 2. 1 LED lamp needs electricity 0,384 kWh 3. Based on the calculation of potential produced electricity, the biogas can power 12 LED lights	area needed to install the design is 10 m^2	526.000 IDR
Liquid Petroleum Gas (LPG)	1. gas light is used 2. 1 gas light needs 0,075 kg gas/hour 3. Based on the calculation of potential produced gas, the biogas can power 10 gas lights	area needed to install the design is 3 m^2	221.200 IDR
Micro Gas Turbine	1. neon light is used 2. 1 neon light needs electricity 0,591 kWh 3. Based on the calculation of potential produced electricity, the biogas can power 8 neon lights	Area needed is 4m^2	165.500 IDR

3.4. Selection of Design Alternatives by AHP Method

The first step in the AHP method is to assign an important criteria scale to each criterion to determine the level of the most important criteria to the least important. The highest level of importance is the energy consumption of the lamp. This is because the main aim of designing a tool for utilizing organic waste at the Kemiri Muka Market into biogas which is used for street lighting. The biogas produced can affect the number of lamps that will be used, so calculations are carried out to determine the amount of energy required by the lamp.

After determining the priority scale of importance for each criterion, a comparison of the criteria will be carried out between the criteria in the fixed dome type biodigester unit based on the level of importance. Based on this comparison, it will produce a weight that will be used in determining the selected alternative based on the largest weight. Based on the results of calculating the consistency ratio (CR) on the comparison of criteria between criteria, a value <0.1 is produced. This weighting resulted in alternative design 1 being selected as the best design to be implemented at the Kemiri Muka Market, Depok.



Information:
1. Waste Chopping Machine
2. Inlet Tank
3. Biodigester Fixed Dome
4. Outlet Tank
5. Biogas Storage
6. Filter Cylinder
7. Generator Set
8. Panel of Generator Set
9. Street LED Light

Figure 2. Layout of the design on Kemiri Muka Market

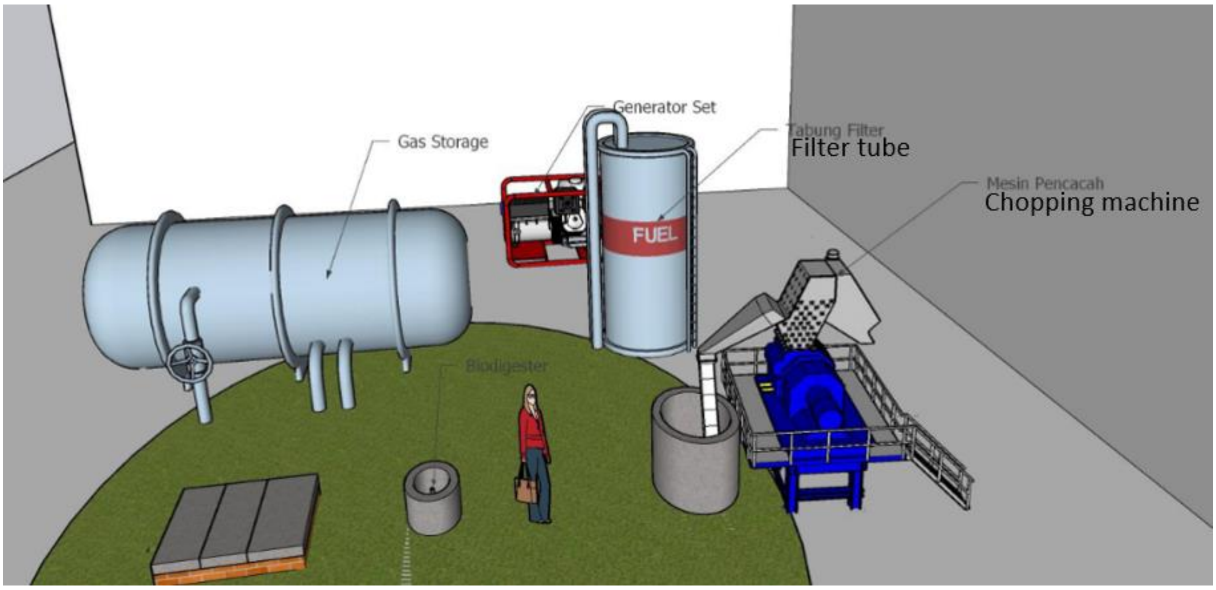


Figure 3. Waste Utilization Machine in Kemiri Muka Market

3.5 Detail Design of Selected Alternative

Layout of the position of the biogas reactor relative to the position of the temporary dump site and Kemiri Muka Market as well as the 3D design of a series of tools can be seen in **Figures 2** and **3**.

3.6. Mass Balance

The mass balance diagram of the use of organic waste for street lighting at the Kemiri Muka Market can be seen in **Figure 4**.

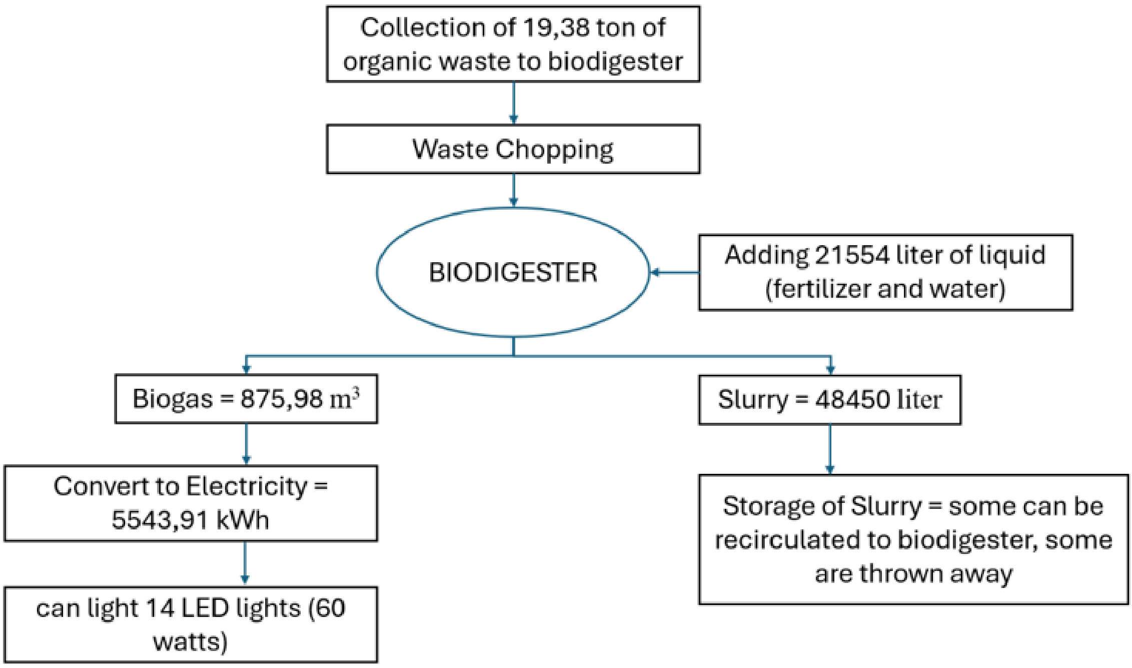


Fig. 4. The mass balance of organic waste utilization

Calculation [25]:

$Total$ Amount of Wet Biodegradable Waste = 19,38 ton = 19.380 $liter$

Water Content of Biodegradable Waste = 88,78%

Water Content of Wet Biodegradable Waste = $Total$ Amount of Wet Biodegradable Waste × 88,78%

= 19.380 $liter$ × 88,78%

= 17.206 $liter$

The liquid that must be added to 19,380 liters of waste is 38,760 liters of liquid, but the waste has a water content of 17,206 liters so the amount of liquid that must be added to the digester is 21,554 liters of liquid. 19,380 liters of waste and 21,554 liters of liquid will produce 875.98 m^3 of biogas and 48,450 liters of slurry.

$Volume$ of Biogas Production (VBP) = 0,0452 $m3/kg/$× $Total$ Amount of Wet Biodegradable Waste
= 0,0452 $m3kg/$× 19380 kg
= 875,98 $m^{3/day}$
$Volume$ of slurry $produc$tion = 2,5 × 19380 $liter$ = 48450 $liter$

3.6. Cost Plan

Description of the work required to realize this design consists of preparatory work (cleaning the work site and measuring the land, as well as installing the bauplan), inlet tank installation work, biodigester installation work, outlet tank installation work, gas storage installation work, filter tube installation work, work final storage tank installation, as well as equipment forming and supporting the installation. The total investment costs required are around IDR 561,657,899.69. Meanwhile, operational costs only require around 526,000/month IDR.

4. Conclusion

The biogas produced by the waste from Kemiri Muka Market can reach 875.89 m^3/day. This rate results from microorganism degradation of waste at the source. If transportation is carried out to the landfill, this rate will be greater due to the addition of emissions from transport vehicles, with a distance of 9km to the Cipayung landfill. The biogas produced can light 14 LED lights with a power of 40 watts. Apart from reducing the release of GHG into the atmosphere, processing waste at source with a biodigester can also save market operational costs by utilizing biogas to become electricity for market lighting.

References:

[1] Dhiani, H. P., H. Arsid, T. A., Ma'fiyah, Surti Wardani.: Manajemen sistem pengelolaan sampah yang mampu memanfaatkan potensi sampah secara optimal. Jurnal Pengabdian Kepada Masyarakat. 2(3), 1-7 (2021)

[2] Dalankopoulos, E., Badr, O.P., Robert, SD.: Municipal solid waste: a prediction methodology for the generation rate and composition in the European Union countries and the United States of America. Resour. Conserv. Recy. 24, 155 – 166 (1998)

[3] Sudibyo, H.R., Majid, A.I., Pradana, Y.S., Budhijanto, W., Deendarlianto, Budiman, A.: Technological evaluation of municipal solid waste management system in Indonesia. Energy Proced. 105, 263-269 (2017)

[4] Badan Pusat Statistik Jakarta: Provinsi DKI Jakarta dalam Angka 2019. BPS Jakarta. Retrived from https://jakarta.bps.go.id/ on October 2023.

[5] Akhmad A., Ulhasanah N., Sari MM.: Desain komposter sampah pasar sebagai solusi persampahan di negara berkembang (Studi kasus: Jakarta, Indonesia). Jurnal Ilmu Lingkungan. 20 (2) pp 356-365 (2022). doi:10.14710/jil.20.2.356-364

[6] Ulhasanah, N., Sari MM., Akhmad A.: The mascot (market waste composter) for market waste of developing country – case study: Jakarta, Indonesia. The Journal od Solid Waste Technology and Management, Vol 48, Number 3. Pp 443-449 (2022)

[7] Pemerintah Provinsi DKI Jakarta: Rata-rata jumlah sampah yang masuk ke tempat pembuangan sampah terakhir (TPST) Bantar Gebang. Retrieved from statistik.jakarta.go.id/rata-rata-jumlahsampah-yang-masuk-ke-tempat-pembuangansampah-terakhir-tpst-bantar-gebang-2019/ on October 2023

[8] The University of Sheffield: Reducing food waste in developing countries. Retrieved from https://www.sheffield.ac.uk/efm/sustainability/waste on October 2023

[9] Puspa, A.: KLHK: 35% TPA di Indonesia masih terapkan sistem open dumping. Retrieved from https://mediaindonesia.com/humaniora/539547/klhk-35-tpa-di-indonesia-masih-terapkan-sistem-open-dumping on October 2023z

[10] Eniversal Eco: Pengertian dan konsep sanitary landfill. Retrieved from https://www.universaleco.id/blog/detail/pengertian-dan-konsep-sanitary-

landfill/310#:~:text=Di%20Indonesia%20sendiri%2C%20terdapat%20beberapa%20TPA%20yang%20sudah,Truik%2C%20Lombok%20Tengah%205%20TPA%20Deliserdang%2C%20Sumatera%20Utara on October 2023
[11] Sánchez, A., Artola, A., Font, X., Gea, T., Barrena, R., Gabriel, D., Sánchez-Monedero, M.A., Roig, A., Cayuela, M.L., Mondini, C.: Greenhouse gas from organic waste composting: emissions and measurement. 13(3): 223-238 (2015). DOI: 10.1007/s10311-015-0507-5
[12] Njoku P.O., Edokpayi J.N.: Estimation of landfill gas production and potential utilization in a south africa landfill. Journal of the air and waste management associaton. 73(1) (2022). DOI: 10.1080/10962247.2022.2072976
[13] Williams, R. R. C.: Landfill gas primer an overview for environmental health professionals. USA: The Agency for Toxic Substances and Disease Registry (ATSDR) USA. Retrieved from https://www.atsdr.cdc.gov/HAC/landfill/html/intro.html on October 2023
[14] Capaccioni, B., Caramiello, C., Tatàno, F., & Viscione, A.: Effects of a temporary HDPE cover on landfill gas emissions: Multiyear evaluation with the static chamber approach at an Italian landfill. Waste Management, 31(5), 956-965 (2011)
[15] Halim M.C., Movanita ANK.: Geramnya pedagang pasar kemiri muka, gunungan sampah hampir setinggi atap kios. Retrieved from https://megapolitan.kompas.com/read/2023/05/30/08011611/geramnya-pedagang-pasar-kemiri-muka-gunungan-sampah-hampir-setinggi-atap?page=all on October 2023.
[16] House of Manna: Pasar-pasar tradisional di Depok. Retrieved from https://www.depoknetizen.com/2018/04/pasar-pasar-tradisional-di-depok.html on October 2023
[17] Gunardi, A., Wibowo Muhammad Satria: Analisis kinerja genset berbahan bakar biogas dan biometan pada unit CLPDTR. Jurnal Politeknik Negeri Sriwijaya Tekim. 1(1). 6-10 (2020)
[18] Abidin, Jenal et al.: Sistem pengelolaan sampah di pasar tradisional kota Depok. Jurnal Sanitiasi Lingkungan, 1(2), 56 – 63 (2021)
[19] Soeprijanto, dkk.: Pembuatan biogas dari kotoran sapi menggunakan biodigester di desa Jumput Kabupaten Bojonegoro. Jurnal Pengabdian Kepada Masyarakat, 1(1), 17–25 (2017). https://doi.org/10.12962/j26139960.v1i1.294.
[20] Singgih, B., Yusmiati: Teknologi produksi biogas dari limbah ternak untuk memenuhi kebutuhan energi rumah tangga. Jurnal Inovasi Pembangunan, 6(1), 40-48 (2018)
[21] KencanaOnline: Biodigester, biogas reaktor. (2020)
[22] Kusnadi, Arifin, M., Darussalam, R., & Rajani, A.: (2016). Rancangan mikro gas turbin berbahan bakar biogas untuk pembangkit tenaga listrik biomass berkapasitas 2,5 Kw, studi kasus: Ciparay Bandung. Jurnal Prosiding Seminar Nasional Fisika, 5(1), 67-72 (2016)
[23] Hermawan, Prasetyo, Rhakasywi, Artanto, Pane: Perancangan wheel turbine pada pembangkit listrik mikro gas turbin. POROS. 16(2):173 (2017)
[24] Saaty, T.L.: Decision making with the analytic hierarchy process. Int. J. Services Sciences, 83 – 89- (2008)
[25] Rhohman, F dkk.: Analisa matematis hasil biogas dari sampah sayuran berdasarkan perbedaan jumlah bahan. Jurnal Mesin Nusantara. 4(2), 84 – 89 (2021)