Design of conventional mixer for biogas digester

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Abstract. The aim of this research is to design the mixer for a digester to produce biogas. The mixer is designed to mix various sludge types in all anaerobic digestion applications, in order to achieve a homogeneous mixture in tanks. It has four main parts consisting of lever players, two sets of the support frame, and two sets of blades. The mixer is enclosed in a dome-type digester made from fiberglass with 2.2-meter height, 1.8-meter diameter, and 5.6 cubic meter digester volume. The mixed volume in the stirred digester is 5 cubic meters. With small size, it is suitable for small and medium enterprises in sewage treatment to produce biogas.

1. Introduction

Developed countries in the world have left fossil energy, which is considered 'unclean', and compete to develop renewable energy that is environmentally friendly in accordance to the goal of green technology to provide human needs without causing environmental damage. One concept aims to pay attention to the availability of natural resources in an effort to meet the needs of human life.

Alternative energy that is environmentally friendly and renewable is biogas. Biogas from organic waste and livestock manure can be used as a substitute fuel for kerosene or fuelwood and as a fuel to drive gas generators for electricity. In 2015, the European Union topped biogas electricity production compared to the world's biogas capacity [1]. Since the abolition of kerosene subsidies in Indonesia, small-scale tofu producers use gas-fired boilers as the right solution to increase calorie efficiency and reduce pollution from fuelwood [2]. The use of biogas in Indonesia for electricity generation depends on current energy policies and relies on biogas as a substitute for fossil fuels to generate power [3]. In principle, the production of biogas can be done quite simply by putting the substrate (e.g. cow dung) into an anaerobic digester unit. Silkworm breeding caterpillars and caterpillar excreta also can produce biogas which is comparable to other substrates derived from agriculture such as livestock manure, pigs and chickens [4]. The use of digester for biogas can help recycle animal waste in the surrounding environment. Factors of pH, temperature, substrate, loading rate, hydraulic retention time (HRT), C/N ratio and mixing affect the biogas production [5].

2. Literature review

Mixing provides uniform temperature and pH conditions in the biodigester and facilitates the release of gas produced by bacteria. Based on the interest to improve the quality of the biogas produced, digester mixers have been mechanically designed. Patents on the digester, for example, can be found in the United States Patent with US patent number 7320753 B2 patented on January 22, 2008, entitled "Anaerobic Digester System for Animal Waste Stabilization and Biogas Recovery" [6], patent number 8298424 B2 patented on October 30, 2012, entitled "Apartment-shaped Anaerobic Digester for Producing Biogas"[7], and patent number US 8771980 B2 patented on July 8, 2014, entitled "Combine
Liquid to Solid-phase Anaerobic Digestion for Biogas Production from Municipal and Agricultural Waste” [8]. These patents describe the system and type of digester, but not explain and use a mixer in the digester.

2.1. Type of digester

Three main types of digester used in developing countries for livestock waste: Chinese fixed-dome digester, Indian floating drum digester, and tube digester [9]. Currently, there is the fourth type of digester, the type of fiberglass digester.

2.1.1. Fixed-dome type. This type of digester was developed in China, so it is also called the Chinese type. The digester consists of a filling hole, the main part of the digester where the waste undergoes an anaerobic fermentation process and a gas reservoir at the top. The main part of the digester is equipped with a manhole covered with reinforced concrete slabs, which also functions as a safety when there is too much pressure. The gas that emerges is released through a gas pipe equipped with a valve/faucet. The advantages of this design are no moving parts, durable (long life), made underground so that it is protected from various weather or other disturbances and does not need space (above ground). The strength of the digester construction is strongly influenced by the quality of the material (cement, red brick, sand and water-resistant coatings). The weaknesses of this design are prone to cracks in the gas reservoir and the gas pressure is not stable because there is no gas valve.

2.1.2. Floating type. This type was developed in India. It consists of a cylindrical digester room and on top of it, a floating iron drum is placed upside down which serves to accommodate the gas produced by the digester. The digester is built using brick, sand, cement materials. This drum can move up and down which serves to store the gas fermented in the digester. The drum floats on the liquid and the movement depends on the amount of gas produced. The gas reservoir will move up when the gas increases and falls again when the gas decreases, along with the use and production of the gas. The advantages of this design are simple construction tools and easy to operate. The gas pressure is constant because the gas reservoir that moves follows the amount of gas. The amount of gas can be easily seen by looking at the ups and downs of the drum. The weakness of this design is the digester prone to corrosion, so the usage time is short.

2.1.3. Tube type or balloon digester. This type of digester is widely used on a household scale, made of plastic material with waste/dirt and outlet pipe slurry discharge at the end of the pipe, and a gas exit pipe at the top. This digester consists of one part that functions as a digester and gas storage, each mixed in one chamber without insulation. Organic material is located at the bottom because it has a greater weight than the gas that will fill in the upper cavity. The advantages of this design are simple construction, lightweight, cheap manufacturing costs, easy to clean, easy to install and easy to move. The weaknesses of this design are relatively short (4 years) usage time and damage easily.

2.1.4. Fiberglass digester. This type of digester, which is widely used on a household scale, uses fiberglass so it is more efficient in handling and changing the biogas site. This digester consists of one part that functions as a digester and gas storage, each mixed in one chamber without insulation. Digester from fiberglass material is very efficient because it is very impermeable, lightweight and strong. If there is a leak, it is easily repaired or reshaped as before, and the more efficient is that the digester can be moved at any time if the farmer does not use it anymore. The main advantage of fiberglass digester is its ease of implementation and handling, low investment costs and more environmentally friendly [10].

Mixing in a biogas digester needs to be done so that no scum is formed, to reduce precipitation and increase productivity. The mixing treatment serves to obtain a homogeneous substrate mixture so there is no deposition of the filling material in the digester, providing optimal conditions for the growth of microorganisms because there is direct contact with the substrate in utilizing the substrate as a nutrient.
to produce biogas so that biogas production can increase. Mixing during the fermentation process also serves to prevent the occurrence of floating objects on the surface of the liquid which can cause obstruction of gas that will come out of the digester, as well as useful for mixing methanogenic bacteria with substrates.

2.2. Digester support components
In addition to the four main components above, a supporting component must be added to a digester to produce a large and safe amount of biogas. Some supporting components are:

2.2.1. Pressure relief valve (control valve). The safety valve is used as a regulator of gas pressure in the digester. The safety valve uses the principle of the T pipe. If the gas pressure in the gas line is higher than the water column, the gas will come out through the T pipe, so that the pressure in the digester will decrease.

2.2.2. Mixer system. The purpose of mixing is to keep the solid material from settling at the bottom of the digester. Mixing is very beneficial for the material inside the digester and keeping the temperature evenly distributed throughout all parts. By keeping the potential of the material to settle at the bottom of the digester small, the concentration is evenly distributed and gives the possibility of the entire material experiencing anaerobic fermentation process evenly. In addition, mixing can facilitate the release of gas produced by bacteria to the biogas reservoir. Mixing can be done by:
- Mechanical mixing, which uses a shaft under which there is a kind of propeller.
- Circulating the ingredients in the digester using a pump and re-flowing through the top of the digester.

Mixing also provides uniform temperature and pH conditions in the biodigester and facilitates the release of gas produced by bacteria. Based on the interest to improve the quality of the biogas produced, a digester mixer is mechanically designed.

The disadvantages of previous studies on mixer such as fin and support materials that are not corrosion resistant, not light, not durable, not waterproof and less efficient in substrate mixing can be overcome by the study of the digester mixer which has three fin support pairs and the manufacturing process by means of printed and using acrylic material.

3. Design methodology
As there is no information in the literature about the design and dimensioning of conventional mixer for biogas digester, the most sourced information on the subject is from the internet. Biogas digesters are generally made of plastic (low-density polyethylene (LDPE), high-density polyethylene (HDPE) or polyvinyl chloride (PVC)), and therefore they are flexible and take the form of containers in which they are installed, most often installed in the ground.

The volume of liquid should fill the volume of the ditch where the digester is located. To get the total volume, the cylinder cross-section is multiplied by the length of the digester, assuming this volume will remain unchanged after the digester is placed in the ditch. The trench dimension is given in each case as 'recommended', but no methodology or justification is provided. However, this dimension is very important because, in practice, they determine the real volume of fluid. Martí-Herrero [11] reports that the recommended dimensions, in many cases studied, are not consistent with the circumference of plastic. Also, in cases where the data is coherent, the loss of HRT due to the final liquid volume is lower (once the digester is placed in the trench) ranges from 6% to 51% compared to the expected HRT by design. In the same report, Martí-Herrero highlighted that biogas pressure affects final HRT and can produce a reduction of between 15% and 17% compared to the theoretical value expected by the design [11].
3.1. Design of digester

Figure 1 shows the design of the digester design carried out in this research. To determine the design volume of the biogas digester, we first looked for the metric volume capacity of methane gas production (specific yield), as determined from the following equation:

$$V_s = \frac{B_0 \times S_o}{HRT} \times \left[1 - \frac{K}{HRT + \mu m - 1 + K}\right]$$  

Where:
- $V_s$ = methane gas metric volume capacity (specific yield) (m³/day)
- $K$ = kinetic coefficient
- $B_o$ = the highest methane gas production capacity (m³/kg)
- $S_o$ = the concentration of volatile solid in the input material (kg/m³)
- $HRT$ = Hydraulic Retention Time (day)
- $\mu m$ = maximum specific growth rate of organisms per day

4. Results of design

This design relates to a manual biogas digester stirrer, especially for stirring biogas-producing organic waste in a dome-type digester made of fiberglass, 2.5-meter high, 1.8-meter diameter, 5600-liter digester volume. The stirrer consists of the turning lever connected to the horizontal shaft supported by bearing, the rotation of the horizontal shaft is channelled to the vertical shaft supported by bearing using a straight cone gear. The vertical axis is connected to three pairs of drivers; each driver have three vertical fins and one horizontal fin.

The type of digester designed in this study is a fixed-dome type. This type of digester has two parts, namely a digester as a digester for biogas material and as a home for bacteria both acid-forming and methane-forming bacteria. The second part is the fixed-dome. Named permanent dome because the shape resembles a dome and this part is a gas collector that is not moving (fixed).

The digester is made of fiberglass, which has advantages of a cheaper construction cost than floating digester, more efficient in handling and changing the biogas place, more impermeable, lighter and stronger. Gas production will increase the pressure in the digester. If a leak occurs, it is easily repaired or reshaped as before, placed in the ground so that it is protected from various weather or other disturbances and does not need a room. The digester can be moved at any time if the farmer does not use it anymore.
The manual mechanic mixer of biogas digester according to this paper is a device used to mix biogas-producing organic waste in a fixed-dome type digester. There is no motivation for the digester mixer to be operated to continue operating anaerobic stirring in the tank [12]. To get a better geometric configuration and mixing system in a biogas digester, one of them is done by analyzing computational fluid dynamics (CFD) [13]. The design in the biogas digester can be simulated with the two-phase liquid-gas flow using CFD software [14]. Varying the substrate inlet mass flow rate and organic loading rate could have a positive impact of the digester [15]. This study will be explained in detail below accompanied by examples of its realization. For convenience, this study will be explained with reference to Figures 2 to 5.

![Figure 2. Mixer in the digester planted in the ground.](image)

Figure 2 shows the mixer position (1) is at the top of the top of a digester (2) and the inside is inside the digester planted to the ground (3). Digester contains organic waste which can produce biogas, such as cow dung.

Figure 3 shows a detail view of the front of the mixer in the horizontal portion of Figure 2. The embodiment consists of a rotating lever (4) of a diameter of 250-350 mm, preferably 300 mm, with a thickness of 18-22 mm, preferably 20 mm, for driving the mechanical mixer manually, horizontal shaft (5) measuring 1080 mm in length with a diameter of 30-40 mm, preferably 35 mm which serves as the successor shaft of the rotary lever rotation (4), bearing (6) type P207 and F207 totaling four pieces that function as anchoring and horizontal shaft housing (5) and vertical shaft (8). A pair of straight conical gears (7) with a number of teeth of 5-30 pieces are preferably 26 pieces with 30-40 mm diameter holes preferably 35 mm which are used to change the direction of rotation of the lever shaft from horizontal to vertical. The vertical shaft (8) is a diameter of 30-40 mm preferably 35 mm with a length of 2500 mm which aims to continue the rotating vertical shaft with the vertical fin (10) and the horizontal fin (11) mixer. The rotating lever accepts the human force using the hand which is connected to the horizontal axis. This shaft is supported by the bearing so that the shaft can still rotate, which is connected to the straight cone gear, the gear here functions as a rotation of the horizontal to vertical force, on the vertical shaft connected to the mixer. When the rotating lever is rotated, then on the vertical shaft also rotates, and will also drive fin cantilever, vertical fins, and horizontal fins.
Figure 3. The front view of the mixer roller in the horizontal section.

Figure 4. Three-dimensional view of the mixer in the vertical section.

Figure 4 shows a detailed picture of the three-dimensional mixer in the vertical section. The embodiment consists of vertical shaft (8), fin cantilever (9) totalling three pairs measuring 30-40 mm in diameter preferably 35 mm, vertical fin (10) totaling 6-12 pieces preferably 9 pieces with a length of 2000 mm, horizontal fins (11) amount to 2-5 pieces, preferably 3 pieces with a length of 750 mm.

Figure 5. Top view of fin profile.

Figure 5 shows the view of the fin profile. The embodiment is an acrylic plate with a thickness of 6-12 mm, preferably 10 mm.

The workings of this stirrer are by rotating the rotating lever in an anticlockwise direction using human power so that the horizontal shaft will rotate in the same direction. The rotation of the horizontal shaft will be converted to a clockwise rotation on the vertical shaft by using straight conical gears, fin cantilever, vertical fin, and horizontal fin that will mix the waste material contained in the digester.
Figure 6. Schematic figure of the digester.

The main part of the digester is a place where dirt undergoes an anaerobic fermentation process so that it can produce biogas. The top of the digester is a dome with a height of 2.2 meters, a diameter of 1.8 meters, a cone height of 0.4 meters so that a volume of 5600 liters is obtained. This digester is designed to accommodate dirt from 4 dairy cows, each cow produces 15-25 kg of dirt per day that can be converted to as much as 0.36 m$^3$ of biogas per day. Four cows, therefore, produce 60-100 kg of dirt per day that can be processed into 1.44 m$^3$ of biogas. This is sufficient fuel for cooking for one family of 5 people, where biogas needed for cooking is 0.25 m$^3$ per person or 1.25 m$^3$ per family per day.

Figure 7 shows the real captured view of the digester that has been made. The digester has an improved shape and size in terms of adjusting to the place where the digester is or will be installed, namely in small and medium enterprises (SMEs) for quail farmers in Subang, West Java. The waste used to produce biogas using cow manure as a starter by adding waste from quails with the following properties: pH 7.1 (neutral), organic-C 17.61% (very high), N 1.32%, P$_2$O$_5$ 3.10%, K$_2$O 1.24% and C/N 13.

Figure 7. Digester for SMEs.
5. Conclusions
This study shows the design of conventional mixer for biogas digesters of a fixed-dome type. The mixer is enclosed in a dome-type digester, the material made from fiberglass, with 2.2-meter height, 1.8-meter diameter and 5600-liter digester volume. The mixed volume in the stirred digester is 5 cubic meters. It is designed to accommodate dirt from 4 dairy cows, each cow produces 15-25 kg of dirt per day that can produce as much as 0.36 m$^3$ of biogas per day. With small size, it is suitable for SMEs in sewage treatment to produce biogas.

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