Bioreactor Design for Sustainable Energy: Case Study of Cow Manure Waste

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Abstract: The potential of cow manure in Indonesia presents an opportunity to be utilized in technological development, particularly using livestock waste as raw material. This technological development aims to produce alternative fuel to replace LPG for cooking purposes. The processing of cow manure into biogas offers significant economic benefits. Furthermore, the use of cow manure as a raw material for biogas can reduce dependence on fossil energy sources and provide a sustainable and efficient energy solution for national energy needs. The development of bioreactor technology also has the potential to increase energy efficiency in communities, support the productivity of mushroom cultivation, and contribute to better waste management through the prudent use of cow manure. Biogas, as one of the processed products, is a combustible natural gas, with the main components being methane (CH_4), hydrogen (H_2), and carbon dioxide (CO_2). This composition makes biogas an attractive alternative energy source for further development. However, most biodigester installations for biogas production remain relatively simple, necessitating the development of better system designs to support effective biogas production monitoring. In this study, the biodigester installation is designed with dimensions of 14.326 meters in length, 4.991 meters in width, and 1.992 meters in depth. The objective of this research is to design a biodigester apparatus capable of processing cow manure waste into renewable energy, such as biogas, which can be utilized by local communities for cooking and mushroom cultivation. In addition to biogas, another by-product is liquid waste from the biogas processing, which can be used as liquid fertilizer, while solid waste can be utilized as planting media for the surrounding community.

Keywords: Biogas, Digester, Renewable Energy.

Introduction

The global availability of petroleum is decreasing, while prices continue to increase. Along with technological developments, the demand for energy, especially petroleum, has increased significantly. This situation encourages the need to develop alternative energy sources such as bioenergy. The depletion of petroleum reserves and the problem of gas emissions from fossil fuels make it necessary for countries to switch to renewable energy. One solution that can be applied is the utilization of cow dung for biogas production. Biogas, as an alternative energy, has a number of advantages over fossil fuels, including being more environmentally friendly and renewable (Zumaro & Arbi, 2017). Cattle farms have been a widely utilized location in biogas research because cow dung is the main ingredient in biogas production. Biogas itself is a combustible gas, produced through aerobic and anaerobic fermentation processes of organic materials such as animal and human waste, agricultural waste biomass, or a mixture of both in a digester (Eddy Djatmiko et al., 2023). The main ingredients in biogas that have been studied include methane, carbon dioxide, and hydrogen (Alfanz et al., 2016). In addition to methane, hydrogen (H_2) also has potential as an alternative fuel, although 95% of hydrogen used today is produced from natural gas processing, including through fermentation in biodigesters.

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Biodigester is a closed device or container that supports the decomposition process of organic materials such as human and animal feces and other organic waste through anaerobic reactions that produce biogas (Kemal, 2022). In Indonesia, biodigester technology has been widely applied, such as the fixed-dome reactor adopted from technology in countries such as Bangladesh, Cambodia, Laos, Pakistan, Nepal, and Vietnam.

In general, bioreactors are classified into two types, namely aerobic and anaerobic bioreactors, with anaerobic bioreactors being more commonly used for biogas production. The anaerobic process takes a long time and involves three stages, namely hydrolysis, acedogenesis (acidification), and methanogenesis, with the final stage being the formation of methane gas (Rajagukguk, 2020, cited by Musafa et al., 2023). The process starts with hydrolysis (decomposition), followed by asedogenesis (fermentation or acidification), and ends with methanogenesis for methane gas production.

The process produces three types of product phases, namely gas, liquid and solid, each of which has a different function. This research provides a biodigester design to process cow dung waste in optimizing the potential of biogas as renewable energy, as well as providing a perspective to the community that cow dung waste has great benefits, both for household and agricultural needs.

Materials and Methods

Study Area

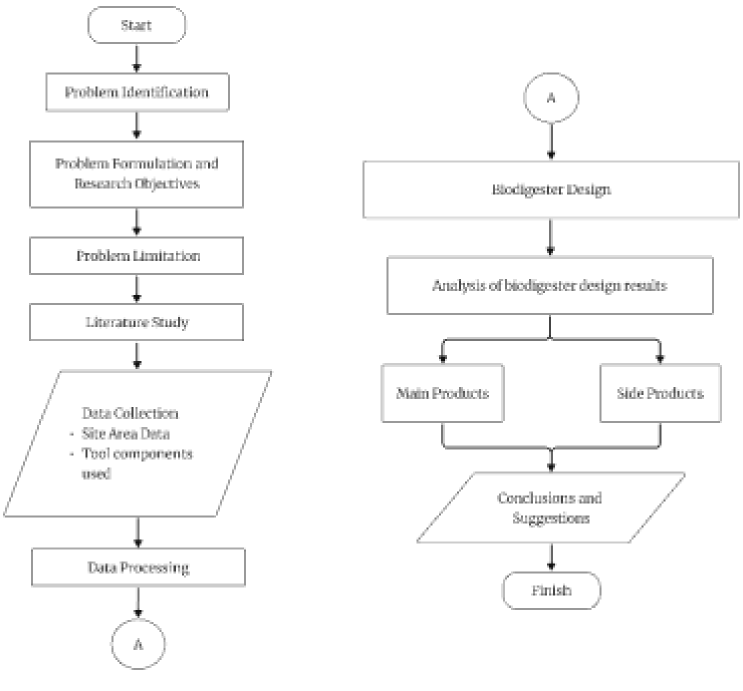

Figure 1. research design.

Figure 1 shows the stages of the research that has been conducted. The biodigester design was designed for long-term use, with the materials selected consisting of concrete cement, fiberglass, sand, and iron. The use of a combination of concrete cement to strengthen the biodigester structure combined with highly airtight fiberglass results in an efficient and high-quality structure. This design includes several main components, namely the inlet, biogas digester, balance outlet, slurry outlet, filter, and pump. Each component has its own function; for example, the biogas digester is equipped with a stirrer to ensure even processing. In addition to the stirrer, there is also a filter to filter animal waste sediment, as well as a pump and pipelines that drain the biogas product to its use location. This biodigester not only functions as a waste processor into renewable energy that can replace LPG, but also produces by-products in the form of solids and liquids.

Procedures

The bioreactor design is adjusted to the land conditions that will be used for its construction. The land calculation is based on the size of the main components of the bioreactor, such as the inlet, biogas digester, balance outlet, slurry outlet, filter, and pump. After determining the required land area, the data was used to create a two-dimensional drawing, which was then followed by the creation of a three-dimensional model using the SketchUp application. This design allows the identification of the position of the supporting components of the digester, which although have different functions, are still interconnected. After the three-dimensional model is completed, the construction phase is carried out by placing the components according to the model.

The construction begins with making a hole according to the land area, then placing the inlet, biogas digester, balance outlet, slurry outlet, and filter in sequence. The inlet, biogas digester, balance outlet, and slurry outlet components are made of fiberglass, while the filter basin is made of concrete and equipped with a rust-resistant galvanized iron filter. The pipe connected to the filter is designed to channel the liquid byproduct to the paddy field area. After all the components were installed, the remaining space was backfilled with excavated soil, then poured with concrete to make the installation durable for the long term. Before casting, it was ensured that the pipelines were perfectly connected without any gaps.

In addition to the design, the daily operation of the bioreactor is also important. Every morning, the cow shed is cleaned without the use of detergents or soaps, then the cow dung is collected and stirred to make it homogeneous, facilitating the decomposition process in the biodigester. Once homogeneous, the manure is fed through the inlet, and inside the digester, the manure undergoes an anaerobic process. The gas produced will collect at the top of the digester dome, while the slurry is released to the outlet balance tub. From this basin, slurry with high density settles at the slurry outlet, while lighter ones and liquids are directed to the filter. In the filter, there is a separation between liquid and sediment. The liquid by-product can be pumped into the fields to fertilize the soil or stored in jerry cans as liquid organic fertilizer that benefits the community's crops. The gas product is directed to support livestock and agricultural activities.

Result and Discussion

Result

Table 1. Land area required.

Specification	Unit
Length	14,326 m
Width	4,991 m
Height	1,992 m

Table 2. Components of bio digester.

No	Tool Components
1	Inlet
2	Digester Biogas
3	Outlet Balance
4	Outlet Slury
5	Filter
6	Pump

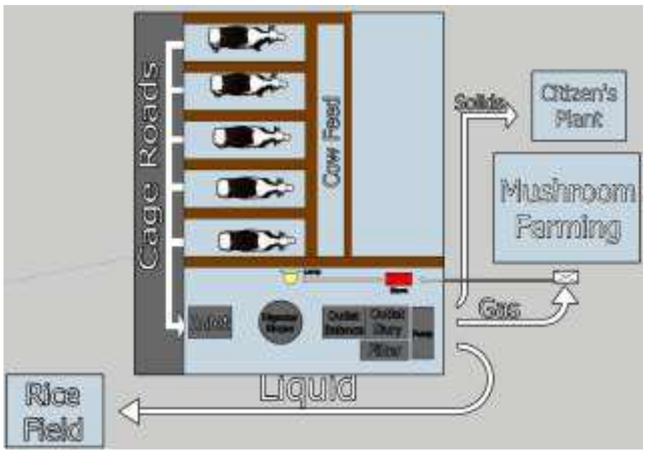

Figure-2 Plan 2 of the biodigester design

Figure-3 3-dimensional design of biodigester inside view

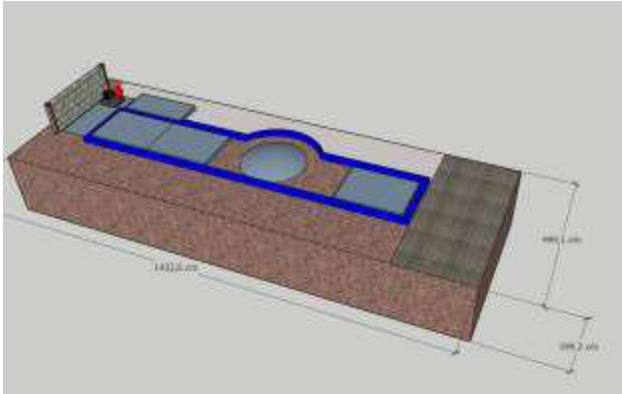

Figure-4 3-dimensional design of biodigester rear view

Discussion

Biodigesters are important devices in the treatment of unused organic waste, especially animal manure. In a biodigester, a three-stage process of natural gas generation from manure waste occurs, namely hydrolysis, acidification, and methanogenesis. This study presents the design of a simple yet effective biodigester for the long-term treatment of cow dung waste, aiming to utilize renewable energy and provide gas for cooking as well as additional nutrients for crops.

The first step in designing the biodigester was to determine the land required, with Table 1 showing the optimized land dimensions. The biodigester design has dimensions of 14.326 meters long, 4.991 meters wide, and 1.992 meters deep. The biodigester is planned to be built in a vacant area near the farm to facilitate the transfer of cow dung and distribution of the resulting product to nearby residents. The design is designed to hold a capacity of up to 5 m^3. The main components shown in Table 2 include an Inlet to introduce the material, a biogas digester to process the waste into gas, liquid, and solids, a balance Outlet to keep the gas under control in the digester, a slurry Outlet to remove the solid sediment, a Filter to filter the manure, and a Pump to deliver the gas and liquid to the paddy field.

Once the dimensions of the land were determined, a two-dimensional design was drawn using SketchUp, followed by the creation of a three-dimensional model, as shown in Figure 2 and Figure 3. The biodigester is placed underground to maintain temperature stability and reduce cow dung odor during the treatment process. The 5 m^3 biodigester is designed with concrete-coated fiberglass material, making it sturdy and durable, while supporting the government's energy transition from fossil fuels to waste-based renewable energy. The drawback of this design is that it is difficult to detect leaks in pipelines embedded in the ground. Additional facilities, such as stirrers in the biodigester, help mix the slurry, while pumps and pipelines support the distribution of gas and liquid products for agricultural needs.

The treatment process begins when cow manure waste is fed through the inlet to the biodigester, where it goes through three stages: hydrolysis, acidification, and methanogenesis. The gas formed will collect at the top of the digester, while the slurry is removed through the balance outlet and into the slurry outlet, where the liquid phase is passed to the filter for separation. The treatment results in the main product of gas which is used by the community for mushroom cultivation, as well as by-products in the form of liquids and solids. The gas supports the use of humidifiers to maintain the humidity required in mushroom cultivation. The liquid by-product can be pumped into the rice fields as liquid fertilizer, and the solids are used as manure to improve the fertility of the soil and crops.

Conclusions

Biodigesters play an important role in the treatment of organic waste, especially animal manure, to produce environmentally friendly renewable energy. The biodigester's simple yet effective design, with a sturdy structure of concrete-coated fiberglass, allows for long-term utilization that supports efforts to transition energy from fossil fuels to renewable energy. In this process, waste undergoes a series of stages, namely hydrolysis, acidification, and methanogenesis, which produce gas as the main product and liquids and solids as by-products. The gas product can support community activities, such as mushroom cultivation with humidifiers, while the liquid and solid by-products serve as organic fertilizers that are beneficial for plants. With the integrated placement of the biodigester on the land around the farm, the flow of inward waste and outward processed products can be efficiently managed. The overall design and operation of this biodigester not only reduces dependence on LPG, but also provides an environmentally friendly solution to meet the community's energy needs as well as optimizing waste into value-added products for the farm and surrounding environment.

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