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Empowering Rural Sustainability: Advancing Household-Scale Biogas Reactor Technology with Fiber Reinforced Plastic (FRP) in Suntenjaya Village, Lembang

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ABSTRACT

Rural communities require appropriate technology to process livestock waste that has been polluting the environment, particularly water bodies such as rivers. Biogas technology offers a solution by converting waste into renewable energy, namely biogas, which can be utilized for daily needs and high-quality organic fertilizer production. Unfortunately, the biogas reactors currently in use were developed over 50 years ago without significant innovations. Hence, there is a pressing need for a more efficient (affordable and user-friendly) and effective (in terms of performance) biogas reactor technology suitable for rural communities—specifically, the Fiber Reinforced Plastic (FRP) biogas reactor technology. The objective of this endeavor is to create a household-scale prototype FRP biogas reactor, designed according to specific requirements and standardized for widespread use. This prototype will be implemented and tested in the field, allowing for dissemination to a broader audience. For modeling purposes, the FRP reactor design will be applied in a demonstration plot in Sunten Jaya Village, Lembang Subdistrict, West Bandung Regency. The results from the demonstration plot reveal that the produced biogas amounts to 40 L/kg of cow dung.

Keywords*: Biogas, FRP, Fiber Reinforced Plastic, Lembang.*

1. INTRODUCTION

Currently, society is facing a situation that demands appropriate technology to address the challenges of livestock waste management, which has led to pollution, especially in areas like the Citarum River Basin. This pollution is not confined to the village level but extends to a broader scale. There is an urgent need for a solution capable of addressing these challenges.

However, in this situation, we also see significant opportunities to transform livestock waste into valuable resources. One potential approach is through the production of energy and organic fertilizer using biogas technology. Presently, biogas technology commonly used in communities often involves the use of brick-concrete materials, which can be costly and require extensive land for construction. Therefore, this situation presents an opportunity for the development of more effective and efficient biogas reactor technology. This technology has the potential to be a solution to overcome the challenges faced by communities in reducing pollution and sustainably utilizing livestock waste **(Backes et al., 2022)**. Consequently, the development of this technology has the potential to bring significant benefits to both the community and the surrounding environment.

The scope of this activity encompasses small-scale household livestock farming in the villages of Suntenjaya - Lembang, Bandung Regency, and West Bandung Regency, which are part of the Citarum River Watershed region **(Zulhadi et al., 2023)**. It is crucial to note that livestock farming activities in the Bandung Basin area have significantly contributed to a substantial decline in environmental quality, particularly in the Citarum River Watershed. This is due to the direct disposal of a large portion of livestock waste, contaminating the rivers in the area **(Kusumah et al., 2023)**. Therefore, the development of biogas technology for household livestock is a highly essential need. The biogas reactor installed in this empowerment activity also serves as a demonstration plot for disseminating appropriate technology, making it known to a broader market. Thus, the developed technology can contribute to the progress and welfare of the community. Consequently, the dissemination of biogas technology can enhance environmental quality, reduce greenhouse gas emissions, and improve rural household access to sustainable and renewable energy sources. Additionally, it provides high-quality organic fertilizer that is environmentally friendly **(Marselina et al., 2022)**.

Until now, the widely used biogas reactor has been the fixed dome model with concrete construction. One of the shortcomings in the implementation of the fixed dome biogas model is the lack of effective quality control management during the construction of the biogas reactor and the absence of durable biogas equipment development. This has resulted in suboptimal functionality of the constructed biogas reactors, hindering their proper operation and ultimately impeding the widespread adoption of biogas in the community **(Aminah et al., 2023; Harun & Ilham, 2023)**. Therefore, to avoid inconsistent construction quality and the lack of durable biogas equipment, it is necessary to develop a household-scale biogas reactor model using composite materials, specifically Fiber Reinforced Plastic (FRP), with a prefabrication pattern before dissemination to the community. This ensures the quality of the reactor, and the prefabrication method employed allows for a rapid installation of the biogas reactor **(Backes et al., 2023; Rasheed et al., 2023; You et al., 2023)**.

This model has been a reference for the development of household-scale biogas reactors in several countries over the past decade, including China, Vietnam, Cambodia, Bangladesh, and others, each with various adaptations. In addition to its advantages in material standardization, this reactor model demonstrates long-term durability, requires only one day for installation, is cost-effective, easy to install, leak-resistant, earthquake-resistant, and highly suitable for application in swampy areas and disaster-prone regions **(Mohammed et al., 2022; Sawale & Kulkarni, 2022)**. As an illustration, China, in the last decade, has constructed more than 40 million household-scale biogas reactors, with over 70% of them utilizing prefabrication technology with FRP, abandoning the traditional fixed dome reactor with concrete construction. This shift is deemed more practical, cost-effective, and expeditious in disseminating clean renewable energy sources for rural communities **(Islam et al., 2023; Thakur et al., 2022)**. The idea of prefabricating household-scale biogas reactors with FRP technology gained prominence after a study tour and training opportunity provided by the Chinese government in October 2011 at Yunnan Normal University. This initiative emerged as a response to the challenges faced in the deployment of biogas reactors in Indonesia. Until today, the number of reactors built through the national Biogas Rumah program in the last seven years is only 15,000, a considerably small figure compared to the existing development potential and significantly lagging behind other countries' achievements **(Baiti, 2023)**.

The Energy Window project aims to contribute to reducing greenhouse gas emissions by providing clean and environmentally friendly energy sources while supporting low-carbon emission farming practices. The proposed solution involves developing a rural household-scale biogas reactor design using Fiber Reinforced Plastic (FRP) technology. The innovation offered in this work focuses on adapting the biogas reactor design to the Indonesian tropical context and standardizing the model, materials, and production processes to enable mass production of biogas reactors with consistent quality applicable throughout Indonesia.

2. METHOD

In the process of installing an FRP biogas reactor in Suntenjaya Village, there are several stages that are followed, starting from the reactor design as shown in Figure 1. In general, the method used consists of two major parts, namely the reactor design stage and the reactor installation stage.

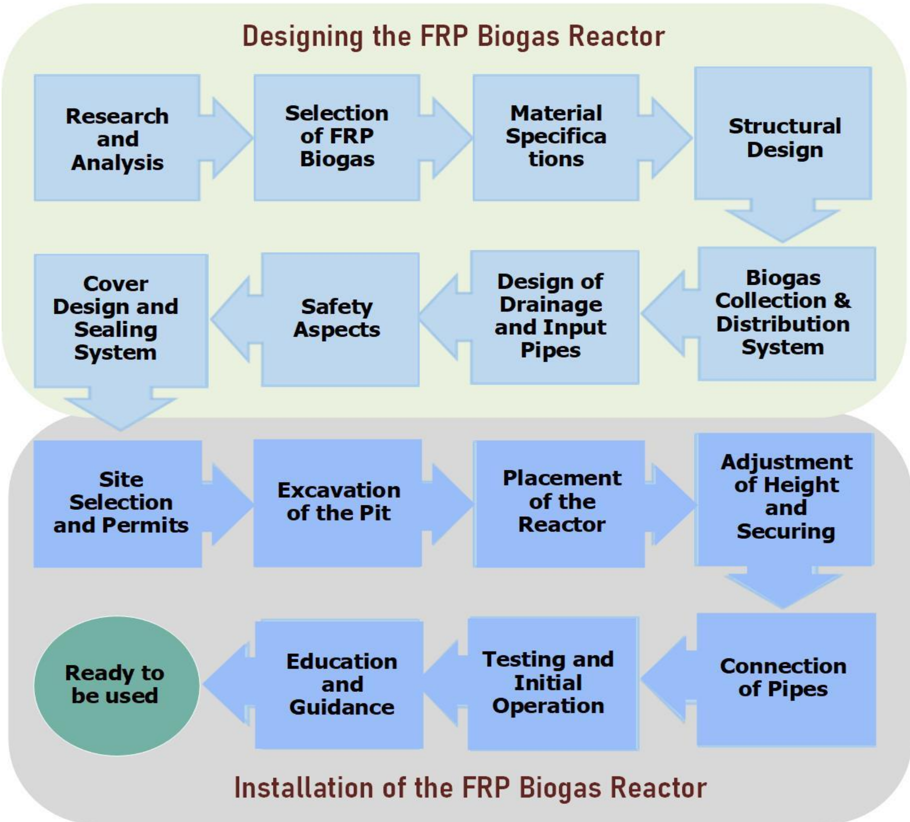

Figure 1. Stages of installing the FRP biogas reactor

In stage of Research and Analysis we conduct comprehensive research on community needs, environmental conditions, and local resources and analyze the type of livestock waste to be processed and estimate the desired biogas production volume. Afterward we select the FRP biogas reactor type, where we choose the type of FRP biogas reactor that best suits the needs and local conditions, and consider factors such as size, shape, and capacity. After that we determine the specifications of the FRP materials to be used, ensuring adequate strength, corrosion resistance, and flexibility. Then we create the structural design of the FRP biogas reactor, including precise dimensions, wall thickness, and other features, and structural stability and ease of installation. For the stage of Biogas Collection and Distribution System, we design a system for collecting biogas from the reactor and distributing it to the point of use or storage. After that, we develop the design for waste drainage pipes and input pipes into the reactor and ensure these pipes are well-positioned and connected. For the Safety Aspects, we consider safety features, such as safety valves or protectors, to prevent excessive pressure or gas leaks. Finally, we design the reactor cover and sealing system to ensure safety and prevent gas leaks. Future plans for the design of this FRP reactor will continue to be optimized and analyzed economically as we have done in other cases **(Parapat, Amin, et al., 2023; Parapat, Rosa, et al., 2023)**. After getting the optimal design, we will also plan to make a biogas reactor on a factory scale **(Parapat et al., 2020)**.

In the part of Installation of the FRP Biogas Reactor, the first stage is the Site Selection and Permits where we choose the installation site according to the design requirements and obtain the necessary permits from local authorities. After that the Excavation of the Pit, digging the pit as per the structural design of the reactor, and then position the reactor inside the pit, following the specifications outlined in the design. Afterward, we connect the waste and gas pipes to the reactor according to the pre-designed pipe system. The final step is to to conduct initial tests to ensure there are no leaks and all systems function properly and provide initial operational instructions to the household. For continuous use, we educate the household on how to use the biogas reactor and provide maintenance guidelines.

The manufacturing of reinforced fiber plastic composite is carried out by considering the calculated needs, including aspects of strength, flexibility, and air tightness of the material. This process also takes into account production, transportation, and on-site installation aspects. So far, the construction of biogas reactors has used materials such as bricks and cement, facing several challenges. Some of these include a lengthy installation time (10-14 days per reactor), dependence on specialized and certified builders, and work quality highly reliant on the skills of the builders and the local building materials, resulting in non-standardization. Additionally, these reactors are not earthquake-resistant, making them expensive and inefficient when applied in swampy/peat areas. They require extensive land for installation, are challenging to scale up, and tend to be costly.

Biogas reactors utilizing FRP composite materials can address the aforementioned issues. Composites are engineered materials created by combining two or more substances that mutually enhance each other's positive effects. The purpose of creating composite materials is to obtain strong material strength, and all supporting materials used must reinforce each other. It's crucial to ensure that no single material weakens the overall structure. In our FRP biogas reactor, the main components of composite materials are a) matrix and b) reinforcement (Figure 2).

a. Matrix

The matrix serves as the primary or base material of the composite that will enhance its mechanical properties. By adding reinforcement materials, it is expected that the matrix will become stronger. One essential property of the matrix material is its ability to bond well with the reinforcement material. This ensures that when the composite material is subjected to a load—especially tensile stress—the reinforcing material does not separate or experience fiber pull-out.

b. Reinforcement

As the name suggests, reinforcement is the material that provides strength to the composite material. Since its function is to reinforce, this material must have better mechanical properties than the matrix. A good composite material is achieved when the reinforcement material does not fail prematurely before the matrix undergoes damage.

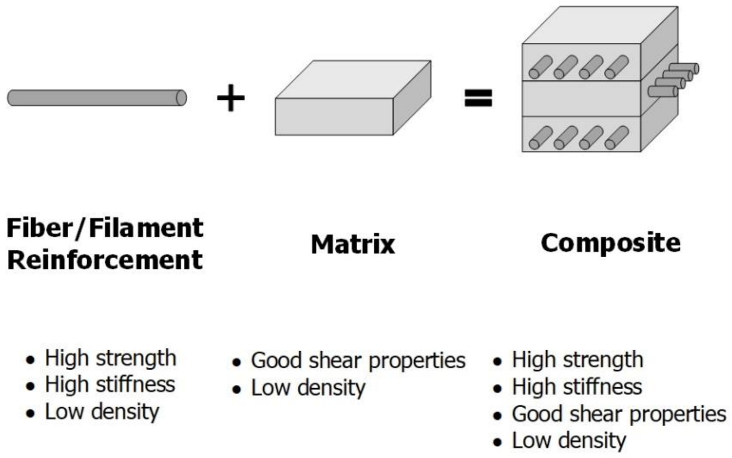

Figure 2. Composite fabrication for FRP biogas reactor

Figure 3. Manufacture of FRP biogas reactor

Composite material technology is one of the intelligent engineering technologies to obtain a new material that is far superior to the raw materials used. Composite materials are often known for being lightweight yet remarkably strong. However, the limitation of the materials used and the manufacturing process can sometimes be a challenge. Consequently, the use of composite materials is restricted to components requiring high precision. Manufacture of FRP biogas reactor showed in figure 3.

3. RESULTS AND DISCUSSION

Production of biogas from raw materials such as cow dung consists of pretreatment, anaerobic hydrolysis, and methane production. Pretreatment can be performed to increase the total methane yield and facilitate the conversion of biopolymers found in cellulose. The pretreatment methods can involve both chemical and biological processes.

Biogas primarily contains around 60% methane (CH_4) and can be utilized for biogas stoves, lighting with biogas lamps, and electricity. One cubic meter of biogas is equivalent to 0.46 kg of LPG, or 4 hours of cooking, or 12 hours of biogas lamp usage. One cubic meter of biogas can be produced from 20-25 kg of livestock manure. Bio-slurry or biogas residue is a product of biogas processing from livestock manure and water through an oxygen-free process (anaerobic) in a closed space. Other contents in bio-slurry include amino acids, fatty acids, organic acids, humic acid, vitamin B-12, auxin hormones, cytokinins, antibiotics, and micro-nutrients (Fe, Cu, Zn, Mn, Mo). The benefits of bio-slurry include its use as organic fertilizer, soil conditioner, and microbe bioactivator in the soil. It can also serve as a medium for mushroom cultivation and vermiculture, an organic pesticide, a source of phytohormones for plants, and a medium for planting and seedling. The biogas yield from this FRP reactor is 0.4 or 40 L of biogas per kg of cow dung. This yield is comparable with the result that has been reported **(Afrian, 2017)**.

This community service program is one of the ways to process and utilize livestock waste that has been polluting the environment. Improperly treated livestock waste, when disposed of without proper processing, can pollute the environment, especially river bodies. One technology capable of processing and utilizing livestock waste is biogas. Biogas technology can transform livestock waste into renewable energy for daily use and high-quality organic fertilizer. The biogas technology to be developed in this community service program is a household-scale biogas reactor made of Fiber Reinforced Plastic. It is expected to have a long lifespan and make it easier for the community to manage livestock waste. Additionally, this biogas reactor can generate gas for daily household needs. Users simply need to input livestock waste into the biogas reactor and wait for it to produce gas. The installation process for the biogas reactor involves three stages: area analysis, reactor installation, and biogas stove installation.

3.1 Area analysis

The area analysis activity was conducted at one of the houses in Sunten Jaya village where a biogas reactor will be installed. This activity aims to facilitate the infrastructure and facilities for the installation and use of the biogas reactor (Figure 4). The presence of numerous rocks beneath the surface of the soil can complicate the excavation of holes for the reactor installation. Additionally, placing the biogas reactor too far from the user's house may pose difficulties for users in inputting livestock waste as feed into the biogas reactor.

Figure 4. Area analysis in Suntenjaya village

3.2 Reactor installation

Before the reactor installation, excavation is carried out at the designated location based on the area analysis. Traditional digging tools are used to open holes according to the reactor's diameter (Figure 4). During the excavation process, there are rocks and emerging springs that hinder the digging process. Therefore, safety and precision need to be observed to avoid hindering the reactor installation.

Figure 4. Excavation of holes for reactor installation

After the holes are perfectly excavated, the next step is reactor installation. The reactor is positioned according to the planned location, ensuring no parts interfere with the placement. Pipes are carefully placed in the ground and connected according to the pre-prepared design. Ensure that each installation part is precisely fitted for optimal performance (Figure 5). Throughout the installation process, safety and compliance with environmental regulations must be prioritized. After installation is complete, the excavated holes can be covered with original soil or suitable material to ensure safety, aesthetics, and environmental sustainability.

Figure 5. Reactor installation

3.3 Biogas stove installation

The installation of a biogas stove involves a series of organized steps to ensure the system operates efficiently. Firstly, a strategic location for stove installation must be chosen, considering the availability of biogas and kitchen needs. Subsequently, the biogas pipeline is carefully connected from the biogas production source (biogas reactor) to the biogas stove. It is essential to inspect for leaks and ensure the entire system is well-connected. Following this, pressure regulators and biogas meters can be installed to control the flow and measure consumption. Lastly, operational testing is crucial to ensure both the reactor and stove function properly (Figure 6).

Operational testing is conducted by introducing a feed consisting of livestock waste and groundwater in a 1:1 ratio to fill the reactor on the first day. After biogas is produced, users consistently input a feed of 2 buckets (50 L) of livestock waste and groundwater in a 1:1 ratio each day. By carefully installing the biogas reactor and stove, we can support the use of renewable energy and contribute to environmental sustainability.

Figure 6. Installation and utilization of biogas stove

3.4 Feedback from FRP biogas reactor users

Iman and his family, recipients of the FRP biogas reactor grant in Cikapundung district, RT. 01, RW. 13, Suntenjaya Village - Lembang, provided positive feedback regarding its usage (Figure 7). He expressed satisfaction with the convenience of using biogas in daily activities, especially in cooking. Previously, Iman used LPG cylinders and wood stoves. Iman expressed interest in using biogas as an energy source at home after witnessing relatives benefit from it over the years. According to him, biogas is not only environmentally friendly but also economical as it reduces dependence on conventional energy sources. Iman also explained that the biogas system installed in his home can transform animal waste, usually collected for fertilizer, into gas. During usage, the only issue encountered was gas leakage from the valve, which was easily fixed and did not pose a significant problem. Additionally, Iman suggested incorporating a stirring tank for easier and more measured mixing of animal waste with water before feeding it into the reactor. They hope that the FRP biogas reactor will endure in the long run.

Figure 7. Interview with the recipient of the FRP reactor

4. CONCLUSIONS

A biogas reactor prototype with FRP material has been installed in Suntenjaya Lembang village to process cow dung. Production of biogas from cow dung involves several stages, including pretreatment, anaerobic hydrolysis, and methane production. The produced biogas, predominantly containing about 60% methane, can be utilized for various purposes such as biogas stoves, lighting, and electricity. The biogas yield from this FRP reactor is 40 L of biogas per kg of cow dung. This community service program aims to address environmental pollution caused by livestock waste by employing biogas technology, specifically by creating a household-scale biogas reactor using Fiber Reinforced Plastic. The installation of the reactor involves area analysis, excavation, reactor installation, and biogas stove installation. The results of operational testing show that both the reactor and stove function effectively, receiving positive feedback from users regarding the ease of biogas utilization in daily activities. The FRP biogas reactor is expected to contribute to waste management in livestock farming, generate renewable energy, and support environmental sustainability. The outcomes of the program indicate that a well-functioning biogas system using the FRP reactor can and should be further developed. The reactor size appears to have no significant impact on system efficiency. This system is more space and cost-efficient and can address land availability issues.

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