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Design and Optimization of a Modified CoLar System for Biogas Agroindustry Development: Case Study at PT Juang Jaya Abdi Alam, South Lampung Regency

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Abstract. One of the efforts made by the government to achieve national beef self-sufficiency is increasing cattle farming. However, while providing benefits, this increase also has negative impacts, particularly in the form of improperly managed cow manure waste that can cause environmental pollution. This study aims to design and optimize a biogas reactor system based on the Modified Covered Lagoon Anaerobic Reactor (CoLAR) for the development of a biogas agro-industry, as a solution for processing cow dung waste through anaerobic biological processes on an industrial scale. The case study was conducted at PT Juang Jaya Abdi Alam, South Lampung Regency, which produces approximately 198,000 kg/day of organic waste from 8,500 to 9,500 cows, most of which has not been optimally utilized. The methods used in this research include observation, expert interviews, surveys, and literature review. The most appropriate reactor type was selected using the Exponential Comparison Method (MPE). This multi-criteria decision-making approach applies weighted scores to technical, environmental, and financial criteria. Three reactor types were evaluated, namely Complete Mix, Plug Flow, and Modified CoLAR. Based on expert scoring, Modified CoLAR was identified as the most suitable option. The designed system consists of a dilution unit, mixing unit, solid-liquid separator, and an anaerobic reactor with an internal stirring system and an HDPE geomembrane cover. The results showed that the Modified CoLAR was the most suitable option, with a total reactor volume of 11,935 m³, biogas production of 1,663.2 m³/day, methane gas volume of 1,092.72 m³/day, and an electricity generation potential of 5,135.784 kWh/day.

Keywords: *organic waste, biogas*, *modified CoLAR, agro-industry*, *exponential comparison method*

1. Introduction

The cattle industry significantly contributes to the government's efforts to realize national meat self-sufficiency. However, the population and scale of livestock farming also

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impact the increasing volume of cow manure waste that has not been managed optimally. One large-scale cattle fattening company, PT Juang Jaya Abdi Alam, located in South Lampung Regency, produces ±198,000 kg of cow manure waste from 8,500-9,500 cows per day [1]. A significant portion of the cow dung waste remains unutilized, often leading to accumulation that causes a potential risk of environmental pollution [2].

One of the efforts to prevent such pollution is utilizing cow dung waste into biogas through anaerobic fermentation. Biogas is a form of renewable energy that can be used as fuel and a source of electricity [3]. In addition to being environmentally friendly, biogas systems also produce by-products in the form of organic fertilizers that farmers can reuse. However, the application of biogas technology in the livestock sector is still limited, especially on an industrial scale. Not all reactor systems are compatible with the company's specific waste characteristics and operational conditions [4].

Various biogas reactors, such as *complete mix*, *plug-flow,* and *covered lagoon* reactors, are commonly used. Among them, the Covered Lagoon Anaerobic Reactor (CoLAR) is considered a more economical and efficient option for treating large-scale waste with high solids content because it requires lower construction and maintenance costs, operates under passive mixing conditions, and is capable of handling high organic loads without the need for complex mechanical components. Its design is also relatively simple and adaptable to tropical environments [4]. This is supported by previous studies confirming CoLAR's suitability for high-strength wastewater and agricultural waste with low operational complexity and favorable energy output [4]. However, using standard CoLAR still has limitations, especially regarding the effectiveness of the stirring system and the separation efficiency of the solid and liquid fractions [5]. To overcome this, modification of the CoLAR design is needed to improve the performance of the organic waste-to-energy conversion process.

Based on the literature review, few studies have specifically examined the design of a modified CoLAR system adapted to the tropical conditions and characteristics of Indonesian livestock waste. Some previous studies have focused on biogas potential and financial feasibility, but have not technically designed installation systems that are adaptive to field conditions. Therefore, this research has scientific novelty in developing and optimizing a modified CoLAR reactor system according to the real needs and challenges at the study site.

The hypothesis in this study is that the design of the Modified CoLAR system, which integrates dilution, internal stirring, and solid-liquid separation, will improve the efficiency of

the biogas production process and generate viable and sustainable electrical energy potential. This integration is expected to enhance anaerobic digestion performance through several mechanisms. Dilution helps optimize substrate concentration, creating an environment that supports the activity of methanogenic bacteria. Internal stirring improves the contact between microorganisms and organic matter, accelerating decomposition. Meanwhile, solid-liquid separation reduces the retention of non-degradable solids in the reactor, increasing gas production efficiency and reducing the hydraulic retention time. The system is also expected to be applicable in large-scale cattle farming agro-industries.

The objectives of this study were: (1) to design a modified CoLAR-based solid cattle waste treatment system suitable for the conditions of PT Juang Jaya Abdi Alam; (2) to optimize the technical design of the reactor installation to increase bioconversion efficiency; and (3) to calculate the electrical energy production potential of the designed system. This research is expected to serve as a viable, efficient, and sustainable model for biogas system design, contributing to the advancement of biomass-based renewable energy within Indonesia's livestock sector.

2. Materials and Methods

2.1 Materials and Tools

The materials used in this research include primary data in the form of field observations, interviews with experts, and questionnaires. Secondary data were obtained from scientific journals, technical reports, statistical data of related agencies, and company documents. The tools used are computers for data analysis and office stationery.

2.3 Research Methods

This research uses a descriptive and evaluative approach through observation, survey, interview, and literature study methods. The main objective is to design a biogas reactor system that fits the actual conditions in the field and optimize the design of the CoLAR (*Covered Lagoon Anaerobic Reactor*) system with adaptive technical modifications.

2.4 Research Stages

This research consists of two main stages:

a. Determination of the optimal biogas reactor installation type through comparative analysis of three reactor types (*complete-mix*, *plug-flow,* and modified CoLAR) using MPE.

b. Design and optimization of the modified CoLAR system, including the design of the dilution unit, stirring system, solid-liquid separation, reactor volume, and estimation of the capacity of electrical energy produced.

The detailed research stages are illustrated in Figure 1.

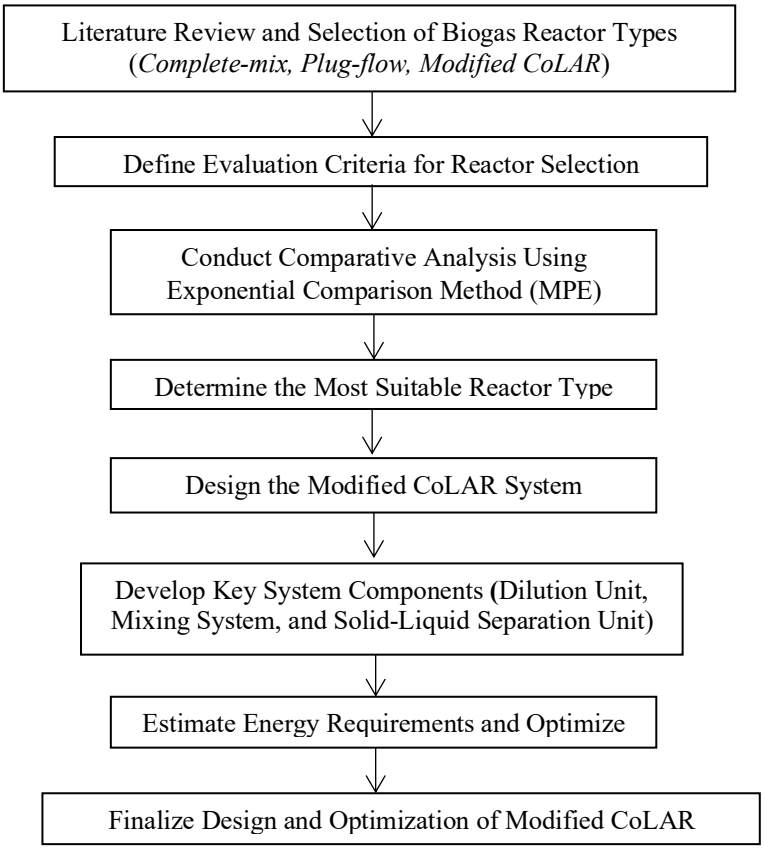

Figure 1. Research flow diagram

3. Results and Discussion

3.1 Determination of the Right Type of Biogas Reactor

The selection of the biogas reactor type was based on the specific characteristics of the waste at the study site. The waste consists primarily of cow dung mixed with organic bedding materials such as sawdust and coconut coir, resulting in a substrate with relatively high total solids (TS) and fiber content. The manure is not flushed with water, producing a thick, semi-solid consistency with low moisture content. This high-solids, high-organic-load profile makes the waste more suitable for reactor types that can handle dense substrates, such as the Modified CoLAR system.

To determine the most appropriate reactor for PT Juang Jaya Abdi Alam, a comparative evaluation of three alternatives, Complete Mix, Plug Flow, and Modified

Covered Lagoon Anaerobic Reactor (CoLAR), was conducted using the Exponential Comparison Method (MPE). Observation, expert interviews, and stakeholder consultations informed this multi-criteria decision-making method. Eight evaluation criteria were defined: investment cost, operational cost, land requirement, need for skilled labor, production capacity, efficiency, environmental impact, and applicability to local conditions. Each criterion was assigned a weight based on its importance, as shown in Table 1.

Table 1. Criteria and Weights in Reactor Selection

Criterion	Description	Weight
Investment Cost	Initial capital required for construction	5
Operational Cost	Recurring cost to run the system	5
Land Requirement	Area needed for the installation	2
Skilled Labor Need	Required level of operator expertise	3
Production Capacity	Volume of biogas output	4
Efficiency	Gas yield effectiveness	4
Environmental Impact	Emissions and pollution control	4
Application Suitability	Adaptability to local conditions	5

These three reactor types were selected based on literature review, field conditions, and expert judgment. The MPE analysis involved score assignments from three academic experts, and the results are presented in Table 2.

Table 2. MPE Scores for Reactor Alternatives

Expert	Complete Mix	Plug Flow	Modified CoLAR
1	1.987	7.728	5.656
2	0.937	1.405	8.670
3	0.859	0.859	2.777
Average	1.261	3.331	5.701

The Modified CoLAR system was the most suitable option based on these scores. Experts highlighted its advantages regarding low capital and operational costs, adaptation to tropical climates, and compatibility with existing waste management practices. Its capacity to process high-solids manure mixed with bedding materials common at the company further reinforced its selection. This is in line with the results of previous studies [4], which showed that the CoLAR system is effective for treating large-scale effluents with high solids content.

3.2 Estimation of Biogas Production Capacity

The estimation of biogas production in this study was based on the average livestock population at PT Juang Jaya Abdi Alam, which consists of approximately 9,000 heads of cattle. Each cow produces around 22 kg of manure daily, resulting in 198,000 kg/day of raw

manure. This manure is mixed with organic bedding materials such as sawdust and coconut coir, leading to a high-solids substrate with significant fiber content.

Based on laboratory analysis and comparison with published data, the total solids (TS) content was assumed to be 21%, and the volatile solids (VS) content was estimated at 19% of the fresh weight. Thus:

$$TS = 198{,}000 \text{ kg/day} \times 21\% = 41{,}580 \text{ kg/day}$$

$$VS = 198{,}000 \text{ kg/day} \times 19\% = 37{,}620 \text{ kg/day}$$

To estimate the volume of biogas produced, the following empirical equation was applied:

$$\text{Biogas volume (m}^3\text{/day)} = VS \times \text{biogas yield (m}^3\text{/kg VS)}$$

The yield factor used was 0.0442 m³/kg VS, based on previous studies [2], suitable for cow dung with bedding content. This yields:

$$\text{Biogas} = 37{,}620 \times 0.0442 = 1{,}663.2 \text{ m}^3\text{/day}$$

The methane content of the biogas was assumed to be 65.7%, based on compositional data for cow dung mixed with agricultural residues [6]:

$$\text{Methane volume} = 1{,}663.2 \times 65.7\% = 1{,}092.72 \text{ m}^3\text{/day}$$

The electrical energy potential of methane gas was calculated using the conversion factor: 1 m³ CH_4 = 4.7 kWh [7].

$$\text{Electricity potential} = 1{,}092.72 \times 4.7 = 5{,}135.78 \text{ kWh/day}$$

$$\text{Available power} = 5{,}135.78 \div 24 = 214 \text{ kW}$$

This power level is sufficient to supply electricity to around 203 households, assuming each uses 1,300 VA electricity. The results of the biogas and energy potential estimation are summarized in Table 3.

Table 3. Estimated Biogas Output and Energy Potential

Description	Value
Total Manure Produced	198,000 kg/day
Total Solid (TS)	41,580 kg/day
Volatile Solid (VS)	37,620 kg/day
Estimated Biogas Volume	1,663.2 m³/day
Methane Volume	1,092.72 m³/day
Electricity Potential	5,135.78 kWh/day
Available Power	214 kW

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3.3 Modified CoLAR System Design

The Modified CoLAR system designed in this study includes several technical improvements adapted to the specific characteristics of the waste and operational practices at PT Juang Jaya Abdi Alam. These modifications enhance process efficiency, improve biogas production, and ensure ease of operation in large-scale cattle farming.

a. Dilution and Mixing Unit

The cow manure at the site is relatively dry and mixed with bedding materials such as sawdust and coconut fiber, which increases its total solids and fiber content. Since water is not used in the cleaning process, a dilution process was necessary to create an optimal substrate. The feedstock needs to have 90% water and 7–10% solids for optimal microbial activity [8]. Therefore, a 1:2 manure-to-water ratio was applied. This dilution facilitates microbial degradation and accelerates biogas production by improving the substrate's consistency.

b. Internal Stirring System

An internal stirring system was implemented using three perforated PVC pipes, one for fresh slurry input and two for recirculating digestate from the reactor. This system mimics a pumped (jet) mixing mechanism without injecting gas. It prevents sedimentation, promotes homogeneity, and enhances contact between microbes and the substrate. This system was chosen because it aligns with best practices for anaerobic digestion and field conditions, where solids tend to settle due to high fiber content.

c. Solid-Liquid Separator

Before entering the reactor, the waste mixture undergoes separation using a mechanical separator (2 units at 50 m^3/hour). This step aims to reduce retention time, enhance biogas production efficiency, and allow solid components to be processed into compost or reused as bedding. Meanwhile, the more volatile and biodegradable liquid fraction is directed into the reactor. This separation accelerates digestion and improves methane yield.

d. Modified CoLAR Reactor Design

The reactor was designed as four separate lagoons, each with a 2,984 m^3 volume totaling 11,935 m^3. This sizing was calculated based on hydraulic retention time (20 days) and 80% adequate volume capacity. Dividing the reactor into multiple units was intended to simplify maintenance and provide redundancy in case of system failure. Each lagoon is

lined with 1 mm HDPE geomembrane, a gas barrier that prevents emissions and groundwater contamination.

These design decisions were supported by field measurements, operational needs, and references such as [4, 8], which demonstrate the effectiveness of CoLAR systems in managing high-volume organic waste in tropical environments.

The overall configuration of the Modified CoLAR system, including dilution, stirring, solid-liquid separation, and reactor layout, is illustrated in Figure 2**.**

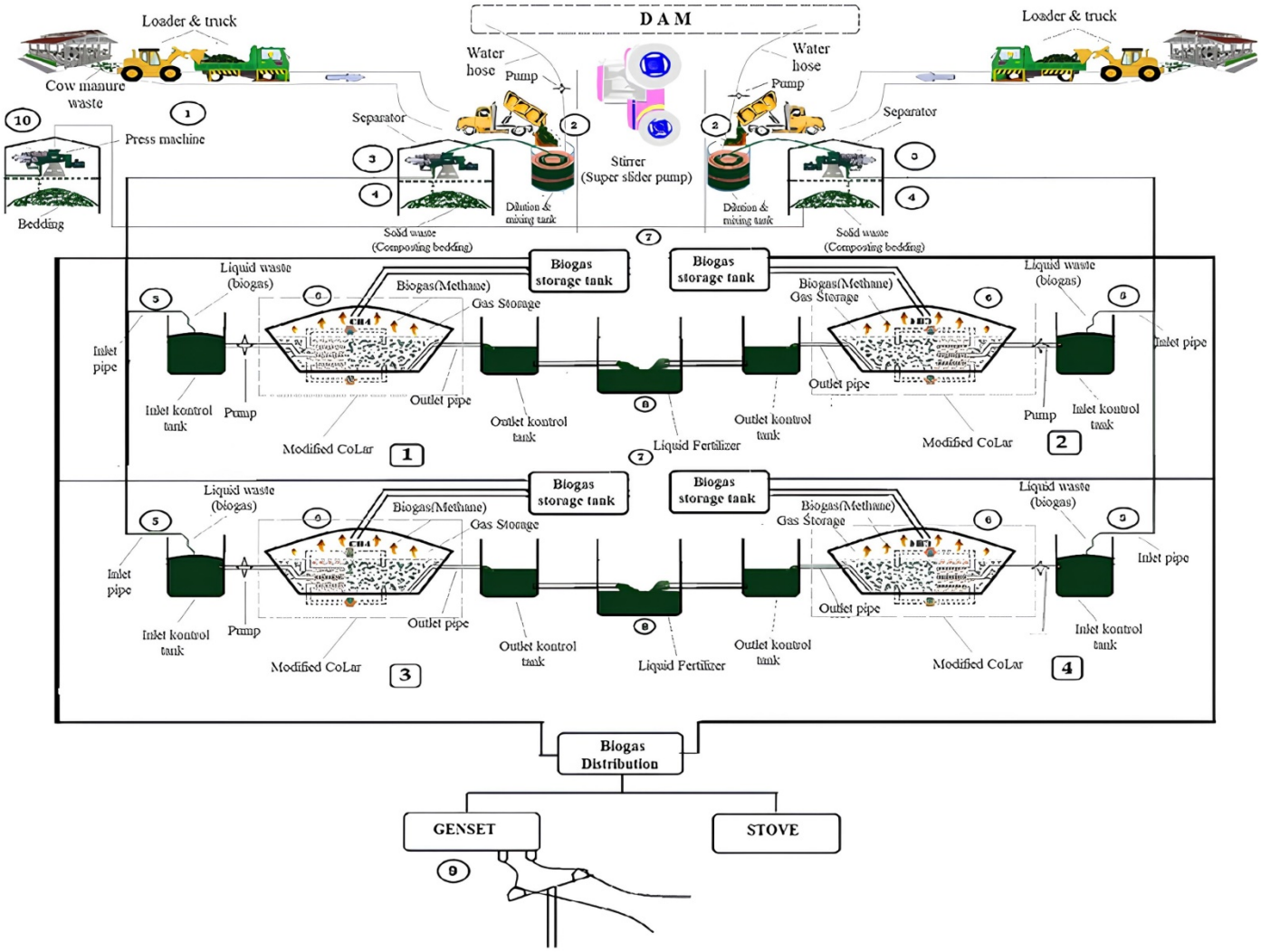

Figure 2. Design of the Modified *Covered Lagoon Anaerobic Reactor* (CoLAR) System for Cow Manure Waste Treatment at PT Juang Jaya Abdi Alam.

3.4 System Efficiency and Environmental Impact

The Modified CoLAR system's efficiency is reflected in its energy conversion rate and environmental benefits. With an estimated methane yield of 1,092.72 m^3/day, the reactor demonstrates an efficient conversion from organic waste to renewable energy.

Open anaerobic digestion minimizes environmental impacts, which reduces COD levels, suppresses methane and CO_2 emissions, and captures odors. The system achieves high gas capture efficiency by employing a geomembrane cover while preventing groundwater contamination.

Although in-situ COD/BOD measurements from PT Juang Jaya Abdi Alam were not available at the time of study, reference data from similar CoLAR applications [4] report COD removal rates exceeding 70%. Assuming similar removal efficiency, the Modified CoLAR design at this site is projected to be practical and environmentally responsible.

Furthermore, the energy produced can supply internal operations and nearby communities, contributing to local energy resilience and representing a sustainable agro-industrial biogas implementation model.

3.5 Sustainable Agroindustry and Energy Implications

The implementation of this system enables the company to not only address its waste management challenges but also to produce alternative energy for operational needs, with the potential for distribution to surrounding communities. This system represents a sustainable agro-industry model relevant to be applied in other tropical farming areas in Indonesia, with great potential as a renewable and efficient source of biobased energy.

4. Conclusion

This research resulted in designing a modified CoLAR system suitable for the agro-industry waste characteristics and operational needs at PT Juang Jaya Abdi Alam. Based on the analysis, the system is estimated to produce 1,663.2 m^3 of biogas per day with an electricity potential of 5,135.784 kWh. This design presents an alternative approach to organic waste management, potentially contributing to advancing renewable energy and the long-term sustainability of livestock-based agro-industries in tropical regions.

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