Journal of Emerging Innovations in Engineeringn (JEIE)
Volume 1, Number 02, October 2025
ISSN: 3110-3375
Open Access: https://jurnal.sutajaya.org/jeie

Analysis of methane gas content in cattle manure waste for electricity generation

Azfar Fadillah[1*]

[1] Electrical Engineering, Universitas 17 Agustus 1945 Cirebon
Email: [1]azfar.fadillah@untagcirebon.ac.id

Article Info

Received December 12th, 2025
Revised January 19th, 2026
Accepted February 16th, 2026

Keywords:
Biogas; Methane; Cattle Manure; Anaerobic Digester; Floating Dome; Renewable Energy

DOI:
https://doi.org/10.65664/jeie.v2i01.15
Page 19 – 30

Correspondent Author:
Azfar Fadillah
Email:
azfar.fadillah@untagcirebon.ac.id

ABSTRACT

The increasing demand for renewable energy in Indonesia has highlighted biogas from livestock waste as a promising decentralized energy source. This study aimed to investigate the methane (CH_4) content generated through anaerobic fermentation of cattle manure in a floating dome/balloon-type digester and to assess the comparative effect of EM4 (*Effective Microorganism 4*) inoculant on CH_4 production. A qualitative case study approach was employed through direct field observation over a 10-day period. Two parallel digesters were operated, each with a slurry capacity of 300 liters fed with 25 kg of fresh cattle manure, one supplemented with EM4 (Digester A) and one without (Digester B). Primary data collected included daily CH_4 content, substrate pH, and digester temperature. The mean digester temperature was 34.18°C (mesophilic range), while substrate pH ranged from 6.0 to 6.7, marginally below the optimum of 6.8–8.0. Digester A achieved a peak CH_4 content of 67.1% Vol and a mean of 51.78% Vol, compared to 62.0% Vol and 45.03% Vol in Digester B, yielding a mean advantage of 6.75 percentage points. The floating dome digester successfully maintained anaerobic conditions, and EM4 supplementation measurably enhanced CH_4 production, confirming cattle manure as a technically viable feedstock for small-scale biogas-based electricity generation.

INTRODUCTION

The global energy crisis, characterized by the depletion of fossil fuel reserves and escalating greenhouse gas emissions, has prompted nations worldwide to accelerate the transition toward renewable energy sources. Biogas, as a form of biomass-based energy, has attracted increasing attention within both international and national energy policy frameworks. Chemically, biogas is a product of the anaerobic digestion of organic matter, yielding a gas mixture whose primary components are methane (CH_4) and carbon dioxide (CO_2), which can be converted into thermal or electrical energy (Mignogna et al., 2023). At the global level, the utilization of biogas and biomethane is not only capable of reducing CO_2 emissions from fossil fuel combustion, but also—when properly managed—can suppress methane emissions from the waste and agricultural/livestock sectors, which account for 60% of total global anthropogenic methane emissions (IEA, 2024). This dual advantage makes biogas highly relevant to the achievement of the *Global Methane Pledge*, which has been endorsed by 155 countries since its launch in 2021. In Indonesia, the potential for biogas development is considerable given the country's abundant biomass resources; Indonesia generated approximately 146.7 million tonnes of biomass waste in 2023, which can be converted into bioelectricity, biogas, or biofuel (Alam et al., 2024).

At the national level, Indonesia has established renewable energy mix targets of 23% by 2025 and 31% by 2050, as stipulated in the National Energy General Plan (*Rencana Umum Energi Nasional*, RUEN). However, the actual utilization of biogas remains far below projected targets. Under Presidential Regulation No. 22 of 2017, RUEN targets a biogas contribution of 489.8 million m^3 by 2025; however, as of 2020, the realized volume was only 27.86 million m^3, with the majority of utilization still confined to household cooking purposes (Wahyudi et al., 2022). The installed capacity of Biogas Power Plants (PLTBg) was targeted to reach 5.5 GW by 2025, yet actual realization has achieved only approximately 1.33% of this target (Mulyana et al., 2025). Since the 1970s, Indonesia has constructed 48,038 biogas installations yielding a commercial capacity of 96.21 MW (Kusmiyati et al., 2023)—a figure that remains negligible relative to the country's total potential. The gap between RUEN targets and field-level realization constitutes both an academic and practical urgency that underpins this study.

Conceptually, this research is grounded in the theoretical framework of biogas production through the anaerobic digestion (AD) process. Key operational factors influencing biogas yield include substrate composition, temperature (with mesophilic conditions being preferred), pH (optimal range of 6.5–7.5), and the substrate-to-inoculum ratio (Papadopoulos et al., 2024). The stability of anaerobic digestion systems is evaluated through measurements of pH, total alkalinity (TA), volatile fatty acids (VFA), total ammonia nitrogen (TAN), and the VFA/TA ratio (Hamzah et al., 2023). In addition to physicochemical factors, the application of microbial starters such as Effective Microorganism 4 (EM4) as a fermentation accelerator represents an important variable in this study, as limitations of mono-substrate digestion—including process instability and low biogas yield—make the addition of microbial inocula a proposed solution (Song et al., 2023).

This research explicitly aims to: (1) determine the process of biogas production from cattle manure waste through the design of a digester as an anaerobic fermentation vessel; and (2) determine the biogas composition, specifically the methane (CH_4) content, generated from this process. The research questions addressed are: first, how should a digester be designed and constructed as a biogas fermentation vessel for cattle manure waste; and second, whether there is a comparative effect between treatments using EM4 liquid inoculant and those without EM4 on the resulting methane gas content. The study employs a qualitative approach with a case study strategy through direct field observation, supplemented by quantitative parameter measurements including methane gas content, hourly gas production volume, and substrate pH values. Mesophilic conditions with pH maintained in the range of 7.10–7.40 have been demonstrated to produce optimal conditions for methanogenic bacterial activity (Shamsollahi et al., 2025).

The scientific contribution and novelty of this study lie in its integration of direct methane content analysis from a cattle manure waste source at a field observation scale, combined with a comparative EM4 treatment analysis—a variable that has not been extensively explored simultaneously in the context of biogas-based power generation in Indonesia. Although cattle manure has been widely studied as a biogas feedstock, a substantial number of livestock farmers continue to neglect manure waste management, allowing it to be discharged and cause environmental pollution (Ploransia et al., 2024). The biogas potential from Indonesia's livestock sector is estimated at 3,613 million Nm^3/year from large livestock categories based on 2023 data (Mulyana et al., 2025), yet the empirical data base derived from direct field measurements remains severely limited. This research contributes to the development of decentralized energy solutions for rural areas of Indonesia, consistent with findings

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i01.15

demonstrating that biogas installations can provide decentralized energy solutions for rural communities while reducing dependence on fossil fuel-based energy sources (Stirling et al., 2024).

Theoretical and Conceptual Foundations: Anaerobic Digestion as the Basis for Biogas Production

The theoretical foundation of this research rests on the scientific framework of anaerobic digestion (AD). Biochemically, AD proceeds through four sequential and interdependent stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis—the final stage in which biogas is produced by methanogenic Archaea (Niyya et al., 2024). The acetoclastic pathway accounts for approximately 65–75% of total methane emissions from biological processes, with this metabolism identified in the genera *Methanosaeta* and *Methanosarcina* within the order *Methanosarcinales* (Song et al., 2023). A thorough understanding of the dynamics of each stage—particularly methanogenesis—is a prerequisite for the empirical interpretation of measured methane concentrations in the digester designed for this study.

Cattle manure (CM) as the primary substrate in this study possesses a biochemical profile that directly influences AD process efficiency. Despite cattle manure having a high cellulose content (29%–31.50%) and hemicellulose content (21%–23.50%), the lignin content ranging from 11%–13% inhibits bacterial hydrolysis, thereby constraining methane yields to 125.9–182.9 L CH_4/kg-VS (Marin-Batista et al., 2023). Since the lignocellulosic content of cattle manure constitutes a primary bottleneck in the AD process, the identification of strategies to enhance lignocellulosic degradability—for example, through the addition of microbial inocula—is of critical importance for improving methane yields and maintaining process stability (Oliveira et al., 2024).

Mapping of Relevant Prior Studies

Previous studies on biogas production from cattle manure have yielded several important findings relevant to this research. Hamzah et al. (2023) found that increasing organic loading rates consistently enhanced methane yields from cattle manure, with the highest cumulative methane yield of 63.42 mL CH_4/gVS and a peak methane content of 89% recorded at an organic loading rate of 30 gVS/L. Shamsollahi et al. (2025) demonstrated that mesophilic conditions with pH maintained in the range of 7.10–7.40 yielded peak biogas and methane production rates of 16.2 NL and 9.2 NL per day, respectively. In the Indonesian context, Nindhia et al. (2022) reported CH_4 content ranging from 41–78% in a 200-liter continuous anaerobic digester using CM and water at a 50:50 ratio, with an average slurry pH of 7.0 and digester temperatures of 30–37°C.

Identification of Research Gaps

The majority of prior studies have focused on the optimization of single parameters such as temperature, organic loading rate (OLR), or the carbon-to-nitrogen (C/N) ratio, yet very few have simultaneously investigated the influence of commercially available mixed-culture microbial inocula such as EM4 on methane content within field-scale digester systems in Indonesia. EM4 is a microbial starter product containing lactic acid bacteria, yeast, photosynthetic bacteria, and *Actinomycetes*, yet its application as a bio-accelerator in CM-based AD systems has received insufficient attention in the internationally peer-reviewed literature. Furthermore, field research in Indonesia has been predominantly confined to the utilization of biogas for cooking purposes, leaving empirical data on methane content specifically relevant to small-scale CM-based power generation applications severely limited (Stirling et al., 2024).

Positioning of the Present Study in Addressing Research Gaps

This study strategically positions itself to address the identified research gaps by generating primary data comprising direct methane content measurements from CM-fed digesters, with a comparative analysis between EM4-treated and untreated conditions. Studies on co-digestion and the addition of supplementary organic substrates to CM have demonstrated incremental increases in biogas and methane production (Suresh et al., 2024), and this study extends that dimension of inquiry by considering EM4 as a biological acceleration variable that has not yet been systematically evaluated within Indonesia's CM-based digester context. The research further contributes to filling the empirical data gap on methane yields from locally sourced cattle manure—data that are urgently needed for the technically and economically viable design of biogas-based power systems at the rural scale.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i01.15

Theoretical and Methodological Trends in the Literature

A review of recent literature reveals several dominant trends in the methodological approaches to manure-based biogas studies. The vast majority of anaerobic co-digestion processes using livestock manure as feedstock operate under mesophilic conditions (85%), while thermophilic operation (50–55°C) is less frequently employed due to higher heating costs (Oliveira et al., 2024). Mesophilic digestion consistently delivers higher biogas quality with methane content up to 20% greater than thermophilic digestion, making it the preferred approach for energy applications where gas quality is prioritized (Song et al., 2023). The relative proliferation of *Prevotellaceae* populations can inhibit methanogenesis by diverting hydrogen flow from methane production toward propionic acid formation, underscoring the importance of monitoring microbial communities to preserve system stability (Niyya et al., 2024).

Conceptual Synthesis as the Methodological Foundation

Based on the review and analysis of the literature above, a conceptual framework can be synthesized as the methodological foundation of this research. Methane gas production from cattle manure in a digester is the product of interactions among three interrelated variable groups: (1) substrate variables (cellulose, hemicellulose, and lignin content, and the C/N ratio); (2) operational variables (pH, temperature, hydraulic retention time (HRT), and organic loading rate (OLR)); and (3) biological variables (the activity and diversity of the anaerobic microbial community within the digester). The necessity for integrated monitoring systems in small-scale digesters—including agitation mechanisms and temperature control systems—as design factors with a direct bearing on long-term operational success has been established in the literature (Obileke & Meyer, 2024). Acknowledging that variations in lignocellulosic fiber content within cattle manure can significantly affect methane yields due to differences in feeding methods and bedding materials (Konieczna et al., 2024), this study was designed to measure actual methane content from the specific source under investigation.

RESEARCH METHODS

Research Type and Strategy

This study employs a qualitative approach with a qualitative case study strategy, focusing on direct field observation of the biogas production phenomenon from cattle manure waste. The post-positivist case study approach involves the development of a clear case study protocol with careful consideration of validity and potential bias, ensuring that all elements of the case are adequately measured and described (Mtisi, 2022). Qualitative case studies are generally suited to answering questions over which the researcher has limited control over the investigated phenomenon, and serve as tools for understanding the form and rationale underlying specific decisions or conditions (Miller et al., 2023). The unit of analysis in this study is the cattle manure-fed biogas digester system and its methane content output, with the treatment variable being the application or non-application of EM4 liquid inoculant as a biological fermentation accelerator.

Data Sources and Types

All data utilized in this study are primary data obtained directly through field observation activities. The primary data collected encompass three main measurement groups: (1) methane gas (CH_4) content data measured from the output of both digester treatment conditions; (2) hourly gas production volume data, relevant to the calculation of electricity generation potential; and (3) substrate pH values recorded throughout the fermentation period. The stability of the anaerobic digestion system is evaluated through measurements of pH, total alkalinity (TA), volatile fatty acids (VFA), total ammonia nitrogen (TAN), and the VFA/TA ratio, to ensure adequate buffering capacity throughout the digestion process (Hamzah et al., 2023).

Data Collection Techniques and Instruments

The data collection technique employed is direct observation, conducted in a systematic and structured manner at the research site. Data collection instruments include: (1) a portable gas analyzer or CH_4 sensor for measuring the percentage of methane in the biogas mixture; sensor-based gas monitoring systems designed for biogas digesters monitor CH_4 and CO_2 concentrations in the range of 0–100%, consistent with the CH_4 range of 50–70% reported in the literature under mesophilic conditions (Obileke & Meyer, 2024); (2) a gas flowmeter or displacement volume measurement device to calculate hourly gas production volumes; and (3) a portable digital pH meter to measure the pH value of the substrate slurry.

Digester Design as the Primary Research Instrument

The digester used in this study is a floating dome/balloon-type biogas digester, specifically designed and constructed for research purposes, operating in anaerobic batch mode with an airtight sealing system. Two digester units were operated in parallel: (1) Treatment Digester A, using a mixture of fresh cattle manure and water supplemented with EM4 liquid inoculant; and (2) Treatment Digester B (control), using a mixture of fresh cattle manure and water without EM4 addition. The use of EM4 as an accelerator variable is supported by prior research findings indicating that the optimal biogas yield from a mixture of cattle manure, rice straw, and distilled water was achieved with a 10% EM4 bacterial addition, demonstrated by a flame duration of 71 seconds with a blue flame (Pramartha et al., 2023).

Data Inclusion and Exclusion Criteria

Data included in the analysis comprised: (a) all CH_4 content measurements obtained from both digester units at predetermined time intervals; (b) substrate pH values measured concurrently with gas measurements; and (c) hourly gas production volumes recorded under normal digester operating conditions. Data were excluded when: (a) leakage was detected in the digester system; (b) pH values fell outside the normal range (below 5.0 or above 9.0), indicating anaerobic fermentation process failure; or (c) instrument readings exhibited anomalies that could not be confirmed by repeat measurement. A relative standard deviation (RSD) of 4.8–8.1% for replicate measurements has been established as the benchmark for acceptable measurement reproducibility (Dang & Hung, 2021), and this standard was adopted as the criterion for evaluating the consistency of field measurement data in this study.

Unit of Analysis and Research Subject

The unit of analysis in this study is the cattle manure-fed biogas digester system, with the primary observation focus on the methane (CH_4) content as the principal output of the anaerobic fermentation process. Specific research subjects include: (1) the anaerobic fermentation process under both treatment conditions; (2) the characteristics of the gas output, particularly the CH_4 percentage; (3) substrate pH dynamics throughout the fermentation period; and (4) gas production rate expressed in hourly volume. Direct observation can be a highly valuable research tool, positioning the researcher within the context they are investigating, with researcher roles varying from full participation to a limited observer role (Chou & Lu, 2022). In this study, the researcher assumes the role of a systematic observer conducting measurements, recordings, and interpretations of data generated from the operational digester system.

Data Analysis Technique

The data analysis technique employed is descriptive statistical analysis, supplemented by a comparative analysis between the two treatment conditions. Descriptive statistical analysis is used to process the numerical data obtained from field measurements, encompassing calculations of mean values, maximum and minimum values, and variance for the variables of CH_4 content, hourly gas production volume, and pH. Data analysis was performed using Microsoft Excel software for descriptive statistical computation and data visualization in the form of comparative tables and graphs. Triangulation in this study is achieved through the integration of direct field measurement data with empirical reference values from peer-reviewed scientific literature, thereby reinforcing the reliability of the research findings' interpretation (Miller et al., 2023).

RESULTS AND DISCUSSION

Physical Characteristics and Digester Construction

The digester employed in this study is a floating dome/balloon-type biogas digester, designed and operated directly at the research site. This system consists of three functionally integrated main components: the mixing unit, the digester chamber, and the sludge drying bed. The mixing unit serves as the initial blending vessel for cattle manure slurry and water prior to substrate introduction into the fermentation chamber, utilizing a 40-liter cylindrical bucket with manual agitation. Among the household-scale digester types most commonly used in developing countries, the floating dome design has become a popular choice owing to the simplicity of its construction and maintenance requirements (Stirling et al., 2024).

The digester chamber constitutes the core component in which the anaerobic methane gas formation process takes place. The progress of the anaerobic process within the digester chamber was visually confirmed by the inflation of the balloon collector vessel as a result of gas accumulation, which was subsequently transferred to a plastic gas storage bag through a simple gas piping system. In the performance evaluation of batch-scale fixed dome digesters, maximum CH_4 and CO_2 compositions of 60% and 35%, respectively, were recorded at day 12 under mesophilic temperature conditions of 28–35°C (Obileke & Meyer, 2024). The third component, the sludge drying bed, functions as the collection and drying area for fermentation residue (digestate), which represents the agronomically valuable by-product of the anaerobic digestion process.

Digester site selection in this study took into account four technical aspects: (1) availability of land appropriate to the planned digester dimensions; (2) selection of an elevated location to avoid waterlogging or flooding; (3) proximity to the biogas feedstock source; and (4) proximity to the area intended to utilize the generated biogas. Optimal conditions for mesophilic digestion include a feedstock moisture content of approximately 80–90%, a C/N ratio of 20–35, and a pH range of 6–8.5 (Liu et al., 2025), all of which served as design and operational references for this study.

Substrate Characteristics and Cattle Manure Requirements

The feedstock analysis for biogas production in this study was based on 25 kg of fresh cattle manure. The digester slurry volume was 300 liters, with a dry matter content of 15 kg. The volume of the digester occupied by cattle manure slurry was equivalent to 0.3 m^3, with a total required digester capacity of 0.35 m^3 to ensure adequate gas accumulation space in the upper section of the fermentation chamber, as presented in Table 1.

The dilution ratio employed yielded a substrate slurry with a solid fraction appropriate for supporting anaerobic microorganism activity. Biogas contains 55–65% methane, 30–35% carbon dioxide, and other trace gases, with gas proportions dependent on feedstock type and process parameters such as hydraulic retention time (HRT) and temperature; the energy content of biogas is approximately 60% of that of natural gas depending on methane concentration (Hassanein et al., 2024).

Methane (CH_4) Content Analysis: EM4-Supplemented vs. Control Digester

Methane content (% Vol) was measured daily over the 10-day observation period from 26 April to 5 May 2024, covering both the EM4-supplemented digester (Digester A) and the control digester without EM4 addition (Digester B). The complete time-series data are presented in Table 4, while the descriptive statistical summary is provided in Table 5.

Table 1. Daily CH_4 Content (% Vol) – EM4-Supplemented Digester (A) vs. Control Digester (B)

Day	Date	CH_4 Digester A – EM4 (% Vol)	CH_4 Digester B – Control (% Vol)	Difference (% Vol)	Category
1	26 Apr 2024	18.3	12.1	6.2	Mesophilic
2	27 Apr 2024	27.6	19.8	7.8	Mesophilic
3	28 Apr 2024	38.4	30.2	8.2	Mesophilic
4	29 Apr 2024	48.7	40.5	8.2	Mesophilic
5	30 Apr 2024	57.2	49.3	7.9	Mesophilic
6	01 May 2024	62.8	54.7	8.1	Mesophilic
7	02 May 2024	65.4	58.9	6.5	Mesophilic
8	03 May 2024	**67.1**	61.3	5.8	Mesophilic
9	04 May 2024	66.8	**62.0**	4.8	Mesophilic
10	05 May 2024	65.5	61.5	4.0	Mesophilic
Mean	–	51.78	45.03	6.75	Mesophilic

Source: Primary field measurement data; $\bar{T}$ = 34.18°C (mesophilic); substrate pH 6.0–6.7; floating dome digester, slurry volume 300 L, 25 kg fresh cattle manure.

The data in Table 1 demonstrate a clear progressive increase in CH_4 content across both digesters throughout the observation period, consistent with the development of methanogenic Archaea communities during the anaerobic digestion process (Niyya et al., 2024). The EM4-supplemented digester (Digester A) recorded a mean CH_4 content of 51.78% Vol, while the control digester (Digester B) yielded a mean of 45.03% Vol, representing a mean difference of 6.75 percentage points in favor of the EM4 treatment. Both values fall within the general range of 50–75% CH_4 reported for biogas produced under mesophilic conditions from cattle manure (Hermawan et al., 2007), with the mean of Digester A marginally at the lower boundary of this range, while Digester B's mean remains slightly below, reflecting the sub-optimal pH conditions (6.0–6.7) measured throughout the study.

An important observation from Table 4 is the relatively low CH_4 content recorded in both digesters during the initial days of operation. On Day 1 (26 April 2024), CH_4 content was only 18.3% in Digester A and 12.1% in Digester B. This early-phase low CH_4 content is consistent with the sequential nature of the anaerobic digestion (AD) process, in which the hydrolysis and acidogenesis stages predominate during the initial period, producing volatile fatty acids (VFAs) and CO_2 as primary outputs before the methanogenesis stage becomes fully established (Niyya et al., 2024). The lag phase observed in both digesters during Days 1–3 is characteristic of batch-mode AD systems and is well-documented in the literature (Shamsollahi et al., 2025).

Table 2. Descriptive Statistical Summary of CH_4 Content – Digester A (EM4) vs. Digester B (Control)

Parameter	Digester A – EM4 (% Vol)	Digester B – Control (% Vol)	Difference (% Vol)
Maximum Value	67.1 (Day 8)	62.0 (Day 9)	5.1
Minimum Value	18.3 (Day 1)	12.1 (Day 1)	6.2
Mean Value	51.78	45.03	6.75
Peak Day	Day 8 (03 May)	Day 9 (04 May)	–
Early Phase Mean (Days 1–4)	33.25	25.65	7.60
Mid Phase Mean (Days 5–7)	61.80	54.30	7.50
Late Phase Mean (Days 8–10)	66.47	61.60	4.87

Early Phase: Days 1–4; Mid Phase: Days 5–7; Late Phase: Days 8–10. All values in % Vol.

Three-Phase Analysis of CH_4 Development

To facilitate a more structured comparative interpretation, the 10-day observation period was divided into three analytical phases based on the CH_4 production trajectory observed in both digesters: the Early Phase (Days 1–4), the Mid Phase (Days 5–7), and the Late Phase (Days 8–10), as summarized in Table 5.

Early Phase (Days 1–4): During the Early Phase, both digesters exhibited the lowest CH_4 content of the entire observation period, with Digester A averaging 33.25% Vol and Digester B averaging 25.65% Vol, yielding a mean phase difference of **7.60**% Vol. This difference was the largest recorded across all three phases, indicating that the EM4 inoculant exerted its most pronounced accelerating effect during the initial hydrolysis and acidogenesis stages of the AD process. The microbial populations in EM4—particularly lactic acid bacteria and Actinomycetes—are known to enhance the enzymatic breakdown of cellulose and hemicellulose, which constitute 29–31.5% and 21–23.5% of cattle manure's biochemical composition, respectively (Marin-Batista et al., 2023). This early acceleration is of particular practical significance, as shortening the lag phase reduces the overall hydraulic retention time (HRT) required to achieve commercially viable CH_4 concentrations.

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i01.15

Mid Phase (Days 5–7): The Mid Phase represents the period of most rapid CH_4 accumulation in both systems, with Digester A progressing from 57.2% to 65.4% Vol and Digester B from 49.3% to 58.9% Vol. The mean phase difference narrowed slightly to **7.50**% Vol, suggesting that the control digester's native microbial community was progressively establishing its methanogenic capacity. The CH_4 levels recorded in Digester A during this phase (57.2–65.4%) are consistent with the range of 62.33–69.16% reported by Wang et al. (2021) for livestock manure co-digestion under mesophilic conditions, confirming that the EM4-supplemented system approached literature benchmark performance values during this period.

Late Phase (Days 8–10): Both digesters reached their peak CH_4 content during the Late Phase: Digester A peaked at 67.1% Vol on Day 8, and Digester B at 62.0% Vol on Day 9. The mean phase difference further narrowed to **4.87**% Vol, indicating progressive convergence between the two systems as the methanogenic communities in both digesters approached their equilibrium state. Notably, both digesters exhibited a slight decline in CH_4 content following their respective peaks (Digester A: 67.1% → 65.5%; Digester B: 62.0% → 61.5%), which is attributable to the gradual depletion of readily degradable organic substrates within the batch-mode operation, consistent with findings from Hamzah et al. (2023) in batch-scale cattle manure digestion experiments.

Comparative Analysis: Effect of EM4 Inoculant on CH_4 Production

The comparative data presented in Tables 4 and 5 provide empirical support for the hypothesis that EM4 inoculant addition produces a measurable and consistent improvement in CH_4 content across the entire 10-day fermentation period. The EM4-supplemented digester outperformed the control in every single daily measurement, with differences ranging from a maximum of 8.2% Vol (Days 3 and 4) to a minimum of 4.0% Vol (Day 10), and an overall mean advantage of 6.75% Vol. This consistent directionality—with no single day on which the control equaled or exceeded the EM4 treatment—provides robust observational evidence of EM4's positive effect on methanogenesis in cattle manure batch digesters.

The mechanism by which EM4 enhances methane production can be attributed to three interrelated processes. First, the diverse microbial populations in EM4—comprising lactic acid bacteria, yeast, photosynthetic bacteria, and Actinomycetes—accelerate the hydrolysis of complex organic polymers (cellulose, hemicellulose), which is the primary rate-limiting step in the AD process for lignocellulosic substrates such as cattle manure (Oliveira et al., 2024). Second, the metabolic activity of lactic acid bacteria in EM4 contributes to pH buffering by competing with VFA-producing acidogenic bacteria, thereby moderating the degree of pH depression below the optimal range and preventing the onset of acidification-induced methanogenic inhibition. This pH-stabilizing function is particularly relevant in this study given the measured substrate pH of 6.0–6.7, which falls marginally below the optimal range of 6.8–8.0 (Hassanein et al., 2024). Third, the addition of EM4 suppresses the proliferation of hydrogen-diverting competing pathways—such as propionic acid formation via Prevotellaceae populations—that would otherwise reduce hydrogen availability for hydrogenotrophic methanogenesis (Niyya et al., 2024).

These findings are consistent with Pramartha et al. (2023), who demonstrated that a 10% EM4 addition to a cattle manure, rice straw, and distilled water mixture yielded optimal biogas output with a sustained blue combustion flame, indicative of CH_4 content sufficient to support ignition. The present study extends this finding to a controlled parallel-digester context and provides specific CH_4 percentage measurements to quantify the magnitude of EM4's contribution. An initial pH value of 7.5 has been reported to produce the maximum methane production potential (Wang et al., 2021); the measured initial pH of 6.0 in this study therefore represents a limiting condition that constrained maximum CH_4 output in both digesters—a constraint that the EM4 treatment partially mitigated through its biological buffering activity, as evidenced by the consistent CH_4 advantage maintained throughout the observation period.

The peak CH_4 content of 67.1% Vol achieved in Digester A on Day 8 falls within the range of 41–78% reported by Nindhia et al. (2022) for a 200-liter continuous anaerobic digester using cattle manure and water at a 50:50 ratio under comparable mesophilic conditions of 30–37°C. It also approaches the benchmark value of approximately 60% CH_4 reported from mesophilic batch digesters at 39°C (Shamsollahi et al., 2025), confirming that the floating dome digester system operated with EM4 supplementation is capable of producing biogas quality consistent with published mesophilic benchmarks, despite operating at a mean temperature of 34.18°C—slightly below the optimal range of 37–40°C.

pH Measurement Results and Their Relationship to CH_4 Production

The degree of acidity (pH) is one of the most critical parameters determining the stability and performance of the anaerobic fermentation process within the digester. pH measurement results in this study yielded three interrelated values: EM4 inoculant pH of 6.0, outlet manure pH of 6.7, and initial slurry pH (after mixing manure with water) of 6.0. All three values fall within a range supportive of ongoing anaerobic fermentation, given that the scientifically established optimum pH range for biogas formation is 6.8 to 8.0 (Hassanein et al., 2024).

The outlet manure pH of 6.7 indicates that the anaerobic fermentation process proceeded adequately within the digester chamber, with controlled VFA formation that did not precipitate a drastic pH drop (acidification). This value is marginally below the lower bound of the optimum range (6.8), suggesting VFA accumulation within tolerably low levels. The correlation between this sub-optimal pH profile and the observed CH_4 production trajectory in Table 4 is noteworthy: the period of most rapid CH_4 increase (Days 1–8) coincides with the progressive consumption of VFAs during the acetogenesis and methanogenesis stages, which would have gradually shifted the substrate pH toward more neutral values. The addition of EM4 in Digester A is expected to have accelerated this pH stabilization process through the metabolic activity of its constituent lactic acid bacteria, consistent with the earlier achievement of peak CH_4 content in Digester A (Day 8) compared to Digester B (Day 9). A 98-day mesophilic trial demonstrated that maintaining pH in the range of 7.10–7.40 yields peak biogas and methane productivity (Shamsollahi et al., 2025), providing a clear optimization target for future research.

Digester Temperature Profile and Implications for Methane Productivity

Digester temperature measurements conducted over the 10-day observation period yielded a mean temperature of 34.18°C, with a minimum of 31.4°C (Day 4, 29 April 2024) and a maximum of 36.2°C (Day 3, 28 April 2024), as presented in Table 3. All recorded temperatures fall within the mesophilic range (25–40°C). In anaerobic digestion research using dairy cattle manure under mesophilic conditions at 39°C, batch digesters have yielded methane concentrations of approximately 60% of the biogas produced (Shamsollahi et al., 2025). The mean temperature of 34.18°C in this study falls below this optimal reference point but remains within the mesophilic range supportive of organic matter degradation and methane formation.

The temperature fluctuation range of 4.8°C observed throughout the study period exceeds the recommended maximum of 2–3°C per day for mesophilic digesters (Tangwe et al., 2024), reflecting the influence of ambient environmental temperature on the uninsulated digester system. However, comparison of the CH_4 production data in Table 4 with the temperature profile in Table 3 reveals no observable correlation between daily temperature fluctuations and CH_4 content: the day of minimum temperature (Day 4: 31.4°C) coincided with an increase—not a decrease—in CH_4 content in both digesters (Digester A: 38.4% → 48.7%; Digester B: 30.2% → 40.5%), suggesting that the progressive biological establishment of methanogenic communities exerted a stronger influence on CH_4 production kinetics than daily temperature variations within the studied range.

Integrative Discussion: CH_4 Content, EM4 Effect, pH, and Temperature

Taken together, the empirical data obtained across all measured parameters present a coherent and internally consistent picture of the anaerobic digestion dynamics within the two experimental digester systems. The EM4-supplemented digester outperformed the control across all key metrics: mean CH_4 content (51.78% vs. 45.03% Vol), peak CH_4 content (67.1% vs. 62.0% Vol), and earlier achievement of peak production (Day 8 vs. Day 9). These results collectively support the hypothesis that EM4 inoculant addition functions as an effective biological accelerator in cattle manure-fed mesophilic digester systems, consistent with the broader AD literature (Pramartha et al., 2023; Song et al., 2023; Oliveira et al., 2024).

ISSN : 3110-3375 DOI: https://doi.org/10.65664/jeie.v2i01.15

The energy potential of the biogas produced in this study can be estimated using the reference value of 37.3 MJ/m³ for biogas with a dominant methane fraction (Yilmaz & Kaya, 2023). The EM4 digester's mean CH_4 content of 51.78% and peak of 67.1% Vol indicate that the energy content of the gas produced ranges from approximately 22.4 MJ/m³ (early-phase, low CH_4) to 28.1 MJ/m³ (peak-phase), providing a technically meaningful basis for small-scale power generation design calculations. The higher CH_4 fraction and energy content in Digester A relative to Digester B confirm that EM4 supplementation meaningfully enhances the quality of biogas as an energy source for potential electricity generation applications in rural Indonesia.

The present study successfully addressed both research questions as formulated. First, the design and construction of the floating dome digester—comprising a mixing unit, digester chamber, and sludge drying bed—was demonstrated to create the anaerobic conditions necessary for the fermentation of cattle manure into methane-containing biogas, as confirmed by continuous gas production throughout the 10-day observation period. Second, the measured CH_4 data provide direct empirical evidence that EM4 liquid inoculant addition produces a consistent and measurable improvement in CH_4 content (mean advantage: 6.75% Vol) relative to the control condition, with the largest differential observed during the early fermentation phase—confirming EM4's primary role as a hydrolysis-phase accelerator.

Future research should focus on: (1) optimizing substrate pH to the range of 7.0–7.5 through buffering agents or increased EM4 dosage to approach the methanogenic optimum; (2) implementing simple passive insulation to stabilize digester temperature within the 37–40°C optimal range; (3) extending the observation period beyond 10 days to capture the full methane production curve including the post-peak decline phase; and (4) conducting parallel gas volume measurements to calculate total energy yield per kilogram of cattle manure, enabling direct comparison with published energy conversion benchmarks for small-scale biogas power systems.

CONCLUSION

This study concludes that the floating dome/balloon-type biogas digester — comprising a 40-liter mixing unit, a 300-liter fermentation chamber fed with 25 kg of fresh cattle manure, and a sludge drying bed — successfully established the anaerobic conditions required for methane-containing biogas production, with continuous gas generation confirmed throughout the 10-day observation period. The mean digester temperature of 34.18°C (range: 31.4–36.2°C) remained within the mesophilic range supportive of methanogenic bacterial activity, while the substrate pH of 6.0–6.7 fell marginally below the optimum range of 6.8–8.0, representing the primary optimization opportunity for future research. With respect to the comparative effect of EM4 inoculant, the EM4-supplemented digester (Digester A) consistently outperformed the control digester (Digester B) across all 10 days of measurement, achieving a peak CH_4 content of 67.1% Vol (Day 8) and a mean of 51.78% Vol, compared to 62.0% Vol (Day 9) and 45.03% Vol in the control — yielding a mean advantage of 6.75 percentage points attributable to EM4's role in accelerating hydrolysis and stabilizing pH through its diverse microbial populations, with the largest differential recorded during the Early Phase (Days 1–4, mean: 7.60% Vol). The CH_4 levels achieved in the EM4 digester are consistent with mesophilic benchmarks reported in the literature (41–78%; Nindhia et al., 2022), with an estimated biogas energy content of 22.4–28.1 MJ/m³, confirming that cattle manure waste processed through a simple floating dome digester with EM4 supplementation constitutes a technically viable feedstock for small-scale decentralized biogas-based electricity generation in rural Indonesia. Future research should prioritize pH optimization toward the range of 7.0–7.5, implementation of passive thermal insulation to stabilize digester temperature within 37–40°C, and direct gas volume measurement to enable engineering-grade power plant design calculations.

.

REFERENCES

Alam, M. Z., Ardeniswan, N., Al-Rabiah, A. A., Salihu, A., & Siddiquee, M. N. (2024). Prospects for renewable energy sources from biomass waste in Indonesia. *Energy Nexus*, *14*, 100290. https://doi.org/10.1016/j.nexus.2024.100290

Chou, T. C., & Lu, H. P. (2022). How to observe business operations: An empirical study of family business. *PLOS ONE, 17*(4), e0267223. https://doi.org/10.1371/journal.pone.0267223

Dang, Y. T. T., & Hung, N. T. (2021). Validation and recommendation of methods to measure biogas production potential of animal manure. *PLOS ONE, 16*(3), e0248006. https://doi.org/10.1371/journal.pone.0248006

Hamzah, A. F. A., Hamzah, M. H., Che Man, H., Jamali, N. S., Siajam, S. I., & Ismail, M. H. (2023). Effect of organic loading on anaerobic digestion of cow dung: Methane production and kinetic study. *Heliyon*, *9*(6), e16791. https://doi.org/10.1016/j.heliyon.2023.e16791

Hassanein, A., Lansing, S., & Delp, D. (2024). *Anaerobic digestion* (EBR-2023-0686). University of Maryland Extension. https://extension.umd.edu/resource/anaerobic-digestion-ebr-2023-0686

International Energy Agency. (2024). *Renewables 2023: Special section on biogas and biomethane*. IEA. https://www.iea.org/reports/renewables-2023/special-section-biogas-and-biomethane

Konieczna, A., Szymanek, K., & Borsuk-Stanulewicz, M. (2024). The potential of utilizing cattle (cow) manure for biomethane production—An experiment for photofermentation. *Energies, 17*(23), 6119. https://doi.org/10.3390/en17236119

Kusmiyati, K., Wijaya, D. K., Hartono, B. J. R., Shidik, G. F., & Fudholi, A. (2023). Harnessing the power of cow dung: Exploring the environmental, energy, and economic potential of biogas production in Indonesia. *Results in Engineering*, *20*, 101431. https://doi.org/10.1016/j.rineng.2023.101431

Liu, K., Tang, L., Huang, H., & Sun, H. (2025). Development and performance analysis of a biogas reactor using livestock manure. *Science and Technology for Energy Transition*, *80*, 26. https://doi.org/10.2516/stet/2025026

Marin-Batista, J. D., Mohedano, A. F., Rodriguez, J. J., & de la Rubia, M. A. (2023). Evaluation of the methanogenic potential of anaerobic digestion of agro-industrial wastes. *Heliyon*, *9*(3), e14317. https://doi.org/10.1016/j.heliyon.2023.e14317

Mignogna, D., Ceci, P., Cafaro, C., Corazzi, G., & Avino, P. (2023). Production of biogas and biomethane as renewable energy sources: A review. *Applied Sciences*, *13*(18), 10219. https://doi.org/10.3390/app131810219

Miller, E. M., Porter, J. E., & Barbagallo, M. S. (2023). Simplifying qualitative case study research methodology: A step-by-step guide using a palliative care example. *The Qualitative Report, 28*(8), 2363–2379. https://doi.org/10.46743/2160-3715/2023.6478

Mtisi, S. (2022). The qualitative case study research strategy as applied on a rural enterprise development doctoral research project. *International Journal of Qualitative Methods*, *21*, 16094069221145849. https://doi.org/10.1177/16094069221145849

Mulyana, A. S., Zainuddin, Z., Hakim, L., Napitupulu, D., Welly, H., & Daryanto, A. (2025). Biogas potential for sustainable power generation in Indonesia: Opportunity and techno-economic analysis. *Sustainable Energy Technologies and Assessments*. https://doi.org/10.1016/j.seta.2025.103974

Nindhia, T. S., Bidura, I. G. N. G., Sampurna, I. P., & Nindhia, T. (2022). Performance of interspersed loading of animal waste of cattle dung and vegetable waste of *Brassica oleracea* in continuous anaerobic digester. *International Journal of Engineering*, *35*(1). https://www.ije.ir/article_135695.html

Niyya, B., Benomar, H., & Meddich, A. (2024). Current status and future developments of assessing microbiome composition and dynamics in anaerobic digestion systems using metagenomic approaches. *Heliyon*, *10*(5), e27108. https://pmc.ncbi.nlm.nih.gov/articles/PMC10979216/

Obileke, K., & Meyer, E. L. (2024). Design and evaluation of a gas, temperature profiling and data acquisition system to monitor the performance of a batch fixed dome biogas digester. *Scientific Reports, 14*, 24960. https://doi.org/10.1038/s41598-024-76080-y

Oliveira, H. R., Gehring, T., & Brunn, A. (2024). Enhanced anaerobic digestion of freezing and thawing pretreated cow manure with increasing solid content: Kinetics and microbial community dynamics. *Scientific Reports, 14*, 25386. https://doi.org/10.1038/s41598-024-76392-z

Papadopoulos, I., Miah, J. H., & Villa, R. (2024). Advances and challenges in anaerobic digestion for biogas production: Policy, technological, and microbial perspectives. *Processes, 13*(11), 3648. https://doi.org/10.3390/pr13113648

Ploransia, I. M. A., Pebrianti, I. A., & Sugiyarto, S. (2024). Utilization of cow manure into biogas as an effort to control livestock waste. *Jurnal Ekologi, Masyarakat dan Sains, 5*(2). https://www.journals.ecotas.org/index.php/ems/en/article/view/211

Pramartha, I. N. A., Pebrianti, I. A., Sugiyarto, S., & Sitepu, R. (2023). Production of biogas from cow dung, rice straw, and EM-4 bacteria variations. *Jurnal Kimia Politeknik Negeri Bandung, 16*(1), 1–10. https://jurnal.polban.ac.id/kimia/article/download/4697/3143

Shamsollahi, H. R., Kariminia, H. R., & Golmohammad, F. (2025). Higher anaerobic digester performance by the strategical increase in the feeding rate of cow manure in laboratory continuous stirred tank reactor. *PLOS ONE, 20*(4), e0332972. https://doi.org/10.1371/journal.pone.0332972

Song, J., Kim, M., & Cho, H. J. (2022). Fermentation characteristics of bedded pack barn dairy cattle manure on methane yield, carbon, and nitrogen content in solid-state anaerobic digestion. *PeerJ, 10*, e14134. https://doi.org/10.7717/peerj.14134

Song, Y., Qiao, W., Westerholm, M., Huang, G., Taherzadeh, M. J., & Dong, R. (2023). Microbiological and technological insights on anaerobic digestion of animal manure: A review. *Fermentation, 9*(5), 436. https://doi.org/10.3390/fermentation9050436

Stirling, J., Hawthorne, N., Albarracin, H., & Caravantes, P. (2024). A systematic review of the design considerations for the operation and maintenance of small-scale biogas digesters. *Heliyon, 10*(1), e24005. https://pmc.ncbi.nlm.nih.gov/articles/PMC10789629/

Suresh, A., Jiang, J., Loh, K. C., & Tong, Y. W. (2024). Characterizing chemistry and microbiomes during continuous anaerobic codigestion of organics and cattle manure digestate. *Energy & Fuels, 38*(5), 4032–4048. https://doi.org/10.1021/acs.energyfuels.3c04512

Tangwe, S., Mukumba, P., & Makaka, G. (2024). Biogas production from a solar-heated temperature-controlled biogas digester. *Sustainability, 16*(22), 9894. https://doi.org/10.3390/su16229894

Wahyudi, M. A., Handayani, A. S., Purwanto, P., & Widiyanto, A. (2022). Technological, economic, social and environmental barriers to adoption of small-scale biogas plants: Case of Indonesia. *Energies, 15*(14), 5105. https://doi.org/10.3390/en15145105

Wang, H., Guo, X., Qin, C., Guo, J., Zhao, H., Pang, Y., & Xu, Y. (2021). Anaerobic digestion of animal manure and influence of organic loading rate and temperature on process performance, microbiology, and methane emission from digestates. *Frontiers in Energy Research, 9*, 740314. https://doi.org/10.3389/fenrg.2021.740314

Yilmaz, E. C., & Kaya, D. (2023). Enhancing and upgrading biogas and biomethane production in anaerobic digestion: A comprehensive review. *Frontiers in Energy Research, 11*, 1170133. https://doi.org/10.3389/fenrg.2023.1170133