Quantitative Analysis of Methane in a Biogas Reactor Using an MQ-4 Sensor for Low-Cost Monitoring

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Abstract. This research aims to analyze the quantitative concentration of methane in a biogas reactor using an MQ-4 sensor. The novelty revealed by this research lies in the development of a low-cost, real-time monitoring system for methane content in biogas reactors. The device integrates the methane reactor, methane measurement apparatus, and pressure measurement instrumentation into a single unit, creating an affordable and reliable device suitable for small-scale biogas applications. The MQ-4 sensor was selected due to its affordable cost and reliability in detecting methane within the range of 200 to 10,000 ppm. An Arduino Mega 2560 was used to integrate the MQ-4 and BME280 sensors and for data logging. The device is portable and affordable for measuring methane levels in biogas production, making it suitable for both laboratory and field applications. The biogas was produced from animal dung, specifically cow manure, and collected in a 150 L biogas reactor. The analysis revealed that the methane concentrations during the 7-day retention periods fluctuated within a narrow range of 485 to 495 ppm. The mean value and standard deviation (expressed as a percentage of the mean) from the triplicate measurements were 1.557 ± 0.317%, indicating a high level of measurement precision. Overall, the MQ-4 semiconductor gas sensor demonstrated exceptional analytical performance characteristics for quantitative methane detection throughout the experimental period.

Keywords: Anaerobic Digestion, Arduino-Based Monitoring, Gas Detection, Low-cost Sensor

1 Introduction

Contemporary climate change threats resulting from greenhouse gas emissions produced by non-renewable energy resources have accelerated the pursuit of renewable energy alternatives (Chen et al., 2022; Negara et al., 2025; Raihan et al., 2023). The implementation of renewable energy technologies represents a strategic approach to addressing these critical environmental challenges. Methane gas occurs naturally through microbially mediated processes under anaerobic conditions (Wang et al., 2023). As a potent greenhouse gas, methane contributes significantly to global

A. A. N. G. Sapteka et al. (eds.), *Proceedings of the International Conference on Sustainable Green Tourism Applied Science - Engineering Applied Science 2025 (ICOSTAS-EAS 2025)*, Advances in Engineering Research 280,
https://doi.org/10.2991/978-94-6463-878-3_21

temperature increases, possessing a warming potential approximately 21 times greater than that of carbon dioxide (Negara et al., 2021). Anaerobic digestion (AD) is a technology for renewable energy production that converts organic feedstock into biogas, a mixture of methane and carbon dioxide (Feiz et al., 2022). Anaerobic digestion is commonly used to address both energy issues and waste management. The decomposition of biodegradable organic substrates in anaerobic digestion is carried out in an airtight environment. Anaerobic digestion consists of several stages, include hydrolysis, acidogenesis, acetogenesis, and methanogenesis. These stages are connected, which results in crucial information for the effectiveness of the digestion operation (Negara et al., 2024).

The methane production rate, defined as the product of biogas flow rate and methane composition, serves as a critical parameter for online control and optimization of anaerobic digester operations. In laboratory settings, methane composition is typically quantified using gas chromatography equipped with thermal conductivity detectors. However, these analytical instruments present significant limitations, including high capital costs, substantial gas sample volume requirements, or both characteristics simultaneously. The MQ-4 methane sensor represents a cost-effective alternative, with an approximate cost of US$6. This sensor is capable of measuring methane concentrations within the range of 200 to 10,000 ppm (Iswanto et al., 2021) and operates effectively under environmental conditions, including temperatures between 10°C and 50°C and relative humidity levels below 95%.

Several previous studies have investigated methane concentration measurements using the MQ-4 gas sensor. The research conducted by Sucipto et al. (Sucipto et al., 2023) developed a microcontroller-based device for methane detection. This study employed the MQ-4 sensor for methane detection in conjunction with an Arduino Uno microcontroller. Although detailed measurement results were not provided, the research primarily focused on the implementation of programming. Additional research conducted by Susilo & David (Susilo & David, 2023) introduced a hazardous gas monitoring system utilizing Internet of Things (IoT) technology. The MQ-4 sensor was employed for methane measurement, while the ESP8266 module served as the IoT communication device. This study examined the integration of the sensor into an IoT platform. Both investigations exhibit similar limitations, as the response characteristics of the MQ-4 sensor were not comprehensively examined. This deficiency may compromise the accuracy of the MQ-4 sensor, potentially resulting in reduced precision and reliability of measurements.

This study presents a quantitative analysis of methane measurement in biogas utilizing the MQ-4 sensor. The investigation was conducted by evaluating the sensor response across various retention time periods to provide comprehensive data on methane measurements. The MQ-4 sensor was interfaced with an Arduino microcontroller system, which functioned as both a data acquisition unit and process controller.

2 Methodology

2.1 Methane Measurement Device

Fig. 1 shows the experimental setup of the methane measurement device. The process of anaerobic digestion was carried out in a 150-liter HDPE plastic drum. HDPE is highly resistant to the corrosive byproducts of anaerobic digestion (Obileke et al., 2020), such as organic acids and hydrogen sulfide, making it ideal for constructing biogas storage tanks or digesters. An airtight mason jar was utilized in this study to facilitate the operation of the sensors. To ensure a proper seal, a screw lid equipped with an O-ring was installed on the top of the jar. The MQ-4 (200-10,000 ppm) methane gas sensor was placed inside the mason jar for methane detection. Table 1 shows the detailed specifications of the MQ-4 sensor (Yang et al., 2019). The sensor contains a metal oxide semiconductor as the sensing material. When methane gas comes into contact with the sensor's surface, it reacts with the oxygen adsorbed on the surface of SnO_2. The mason jar lid features two holes designed for inserting a nylon adapter, allowing for the secure passage of electrical cables. These cables transmit signals from the sensors and supply power to the breadboard, which is a 400-point solderless breadboard. Additionally, fifty grams of silica gel were distributed at the base of the jar to absorb the humidity from the gases inside. This study utilizes the BME280 sensor, which can detect humidity levels ranging from 0 to 100% relative humidity, pressure between 300 and 1100 hPa, and temperatures from -40 to +85°C.

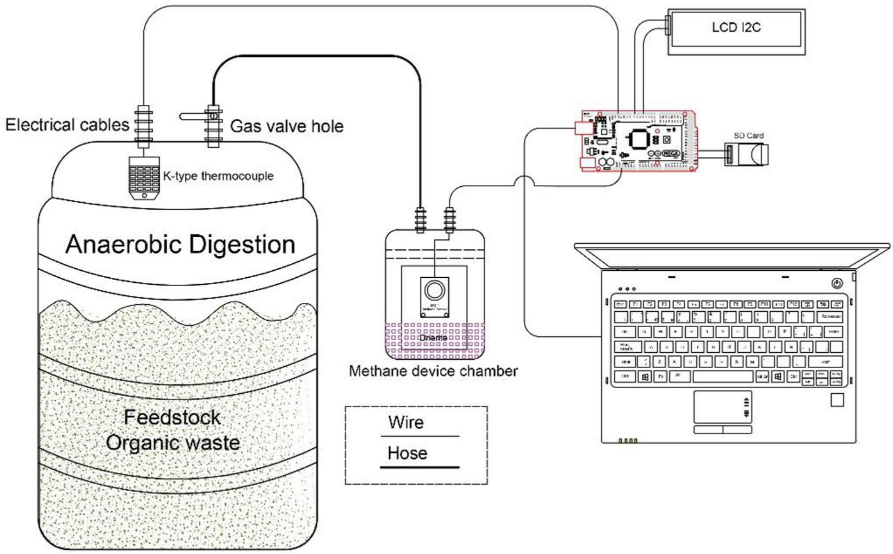

Figure 1. Overview of the Experimental Configuration

Table 1. In-Depth Specifications for the MQ-4 Sensor (Yang et al., 2019)

Specification	Details
Model	ATmega 2560
Load resistance	Adjustable
Heater resistance	26Ω±3Ω
Heater consumption	≤950mW
Sensitivity	Rs (in air) /Rs (in 5000ppmCH4) ≥5
Output voltage	2.5V～4.0V (in 5000ppm CH_4)
Sensor type	Semiconductor
Standard encapsulation	Bakelite, Metal cap
Target gas	Methane
Loop voltage	≤24V DC
Heater voltage	5.0V±0.1V AC or DC

2.2 MQ-4 Sensor Validation

Multiple tests were performed to confirm the device's operation. After assembling the device, it was first checked for any gas leaks. The chamber received six 10ml injections of air every 12 minutes, with pressure readings taken throughout. These injections were done without resetting the chamber to atmospheric pressure. Following the sixth injection, the pressure was monitored for 12 hours overnight. To validate the MQ-4 sensor, several measurements were conducted over different periods, specifically at 7 days and 14 days. This extended timeframe enabled a comprehensive assessment of the sensor's performance and reliability under various conditions. The results of these measurements were analyzed using standard deviation, a statistical method that helps quantify the amount of variation or dispersion in a set of data values. This analysis not only enhances the accuracy of the measurements but also provides a robust validation of the sensor's functionality. A low standard deviation indicates that the sensor produces stable and repeatable readings, while a high standard deviation may suggest potential issues with the sensor's reliability. Additionally, this thorough validation process is essential for establishing confidence in the sensor's capabilities and its suitability for detecting gas concentrations.

3 Result and Discussion

3.1 MQ-4 Sensor Response Analysis for 7-Day Retention Periods

Biogas concentration measurements were conducted across multiple retention periods of 7 and 14 days to evaluate the temporal progression of anaerobic decomposition systematically. These systematic sampling intervals, conducted at 7-day increments, enabled comprehensive monitoring of methane concentration dynamics throughout the experimental period. Data acquisition was performed at 5-minute intervals using an MQ-4 gas sensor. Fig. 2 shows the MQ-4 sensor response curves for triplicate measurements at the 7-day retention period. The observed methane concentrations exhibited oscillations within a narrow range of 485-495 ppm, indicating initial phases of microbial-mediated biodegradation processes (Náthia-Neves et al., 2018). The mean and standard deviation (expressed as a percentage of the mean) from triplicate measurements were 1.557 ± 0.317%, demonstrating high measurement precision. The relatively low standard deviation suggests robust reproducibility of the experimental conditions and reliable sensor performance throughout the measurement period.

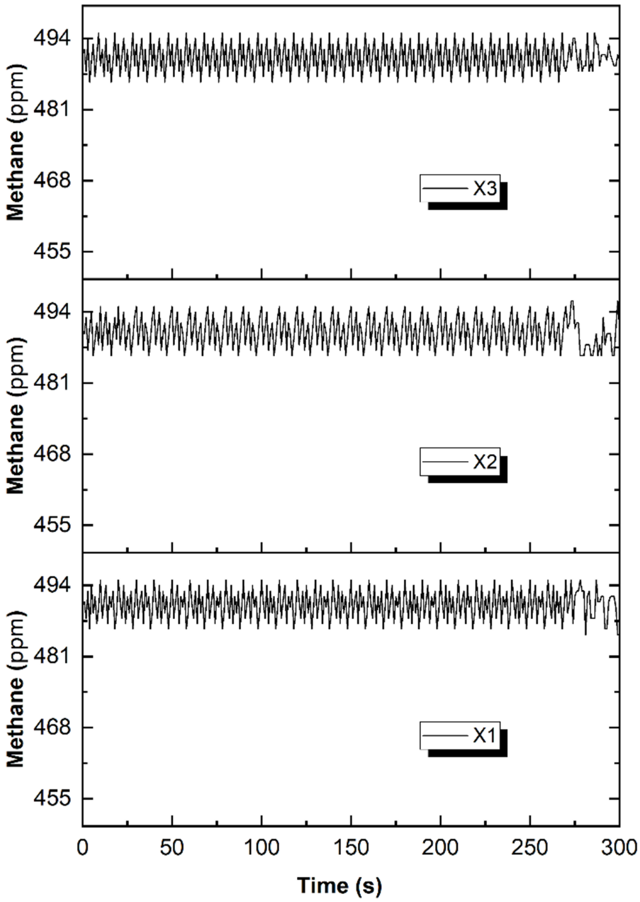

Figure 2. MQ-4 Sensor Response at the 7-Day Retention Period

3.2 MQ-4 Sensor Response Analysis for 14-Day Retention Periods

Fig. 3 shows the temporal response profile of the MQ-4 sensor at the 14-day retention period, demonstrating methane concentrations ranging from 1,900 to 1,920 ppm. This marked elevation in methane concentration, representing an approximately 4-fold increase compared to the 7-day measurements, can be attributed to the establishment of a robust methanogenic community within the anaerobic system (Negara et al., 2023). The observed concentration increase aligns with typical growth kinetics of methanogenic archaea, which exhibit lag phases of 7-10 days under mesophilic conditions before reaching optimal metabolic activity. The mean and standard deviation of the 14-day retention period yielded 4.453 ± 0.232%, indicating highly stable methanogenic activity. The reduced coefficient of variation compared to the 7-day measurements suggests the establishment of a more stable microbial community structure. This enhanced stability is characteristic of the transition from hydrolytic/acidogenic phases to active methanogenesis, where specialized archaeal populations such as Methanobacterium and Methanosarcina species typically become predominant in the microbial community.

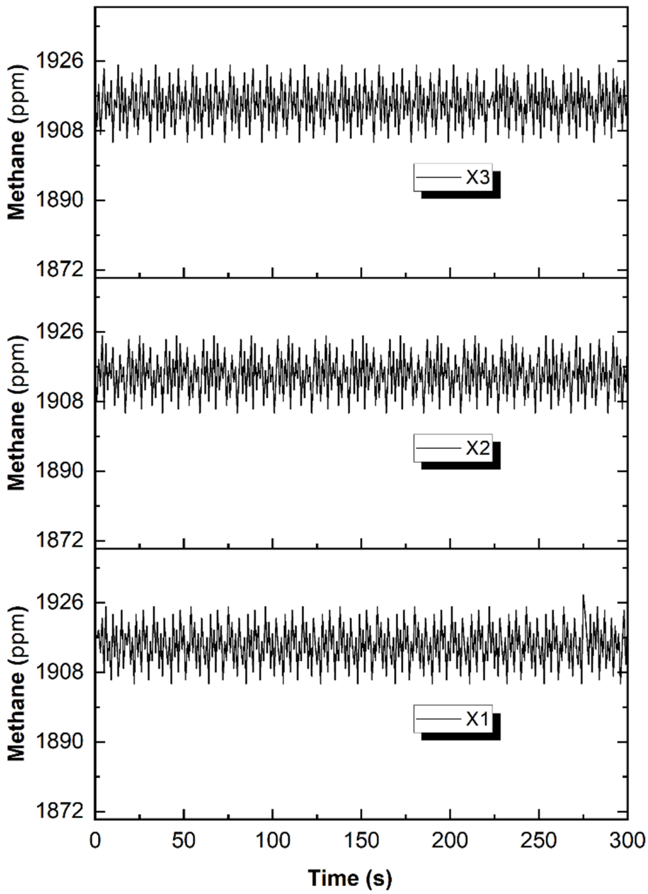

Figure 3. MQ-4 Sensor Response at the 14-Day Retention Period

The MQ-4 semiconductor gas sensor demonstrated exceptional analytical performance characteristics for quantitative methane detection throughout the experimental period. The sensor, which operates on the principle of varying electrical conductivity in response to exposure to the target gas, exhibited high measurement fidelity with consistent response patterns across all retention periods. Additionally, this sensor can be used for further monitoring of small-scale smart biogas production. Its reliable performance makes it an ideal tool for optimizing biogas systems and ensuring efficient gas management. For further research, the data already obtained will be compared to other measurement methods, such as gas chromatography, to strengthen the analysis and enhance the reliability of the current MQ-4 sensor.

4 Conclusion

This research successfully demonstrated the effectiveness of the MQ-4 sensor as a cost-effective solution for quantitative methane analysis in biogas reactors. The integration of the MQ-4 sensor with the Arduino Mega 2560 microcontroller, combined with the BME280 environmental sensor, created a portable and affordable monitoring system suitable for both laboratory and field applications. This low-cost approach, with the MQ-4 sensor costing approximately US$6, offers a practical alternative to expensive gas chromatography equipment while maintaining measurement reliability. The system's capability for real-time monitoring makes it valuable for optimizing biogas production processes and advancing sustainable energy technologies in addressing contemporary climate challenges.

Acknowledgment

The authors acknowledge the financial support received from P3M, Politeknik Negeri Bali.

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