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Cost-Effective Methane Monitoring in Biogas Production: An Investigation Using MQ-4 Sensor Technology

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Abstract—Methane measurement is very important to determine the calorific value of biogas fuel. Gas chromatograph is a typical equipment used for measuring methane content. However, this tool is costly and requires a large amount of gas sample. The proper and low-cost device for measuring methane content is the MQ-4 sensor. This sensor can be linked to a microcontroller such as Arduino and
5
has a measuring range from 200 to 10,000 ppm. This study aims to investigate the methane concentration from biogas that is derived from cow manure (CM) and a blend of municipal solid waste (MSW). The MQ-4 sensor was placed inside the headspace of degister tank along with electric circuits. The monitoring showed that the mean and standard deviation was found to be 1.557 ± 0.321% (for 7-day), 4.453 ± 0.233% (for 14-day) and 3.294 ± 0.091% (for 21-day). In addition, the highest methane content was found in the CM sample, reaching 3,603 ppm during 21 days retention time. Comparatively, the methane concentration generated from the blend of MSW sample showed, 1,959 ppm within the same time period. Overall, this device provides reliable, affordable and low-cost solution for methane measurement. Additionally, the durability of the sensor is good for many applications.

Keywords— methane, MQ-4, cost-effective, microcontroller, renewable energy

NOMENCLATURE

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CH_4	Methane
ppm	Parts per million
AD	Anaerobic digestion
MSW	Municipal solid waste
CM	Cow manure

I. INTRODUCTION

In the last few years, greenhouse gas pollution has been increasing rapidly. One of the main causes is methane gas. Methane is a potent greenhouse gas. Methane gas emits infrared radiation, leading to the greenhouse effect [1]–[3]. Methane is a gas that is produced as a result of microbially activity under anaerobic conditions [4]. Generally, this gas
12
generated during the digestion process by organic waste
12
including kitchen waste, municipal solid waste as well as cow manure, which is also known as enteric methane [5], [6]. Anaerobic digestion (AD) is a biological process that breaks down organic materials, including cow manure. The methane consentration determines the calorific value of fuels from biogas [7], [8]. The higher the methane concentration, the higher the calorific value of the fuel. In order to measure the concentration of methane gas, a gas chromatograph equipped with a thermal conductivity detector is a device that is typically used in a laboratory. Another device for detecting methane composition in biogas or sewer lines is an infrared sensor GEM2000/5000. Both instruments have drawbacks such as being costly and requiring a large quantity of gas sample [9].

The inexpensive instrument for methane measurements is the MQ-4 sensor. This sensor operates based on the change in metal oxide semiconductor material conductivity. The approximately price of this sensor is Rp90,000.00. The MQ-4 sensor generally has a response time range of several seconds and can measure from 200 to 10,000 ppm of methane gas [10]. This sensor can be operated with an environmental temperature between−10°C and 50°C. Additionally, the sensor can be connected to microcontroller such as arduino for data acquisition. Several sensors inluding the MQ-2, also have the capability to detect methane gas. However, the sensitivity of the MQ-2 is lower compared to the MQ-4 sensor [11]. The MQ-2 sensor is a general-purpose sensor that detects a variety of gases and is not as sensitive for methane detection specifically as the MQ-4. Subsequently, the MQ-4 sensor is more effective and selective towards methane gas. This indicates that the MQ-4 can distinguish methane from different gases [12].

The study by sucipto et al. [13] designed a device for methane detection based on a microcontroller. The study utilized the MQ-4 sensor for methane detection and the Arduino Uno as the microcontroller. The results of the measurement were not provided in detailed. However, the study mostly focuses on the coding program. Kristian and David [14] also introduced a dangerous gas monitoring system using the Internet of Things. The MQ-4 sensor was used for measuring methane and the ESP8266 was used for IoT devices. The study discussed integrating the sensor into

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IoT platform. Both studies show similar drawbacks, as the response of the MQ-4 sensor was not well investigated. This issue can affect the accuracy of the MQ-4 sensor, resulting in a lack of precision and reliability.

This study investigated the measurement of methane in biogas using the MQ-4 sensor. The investigation was conducted by assesing the response of the MQ-4 sensor over various retention time periods to provide a commprehensive methane measurement. The feedstock for biogas is derived from cow manure and a blend of municipal solid waste. The MQ-4 sensor was connected to an arduino as a data logger and controller. Methane concentration is measured in ppm (parts per million) by the sensor. Methane results are accumulated during the investigation. This study also shows the temperature inside the digester tank.

II. Method

A. Materials

This study used two different types of substrates which were cow manure (CM) and a blend of municipal solid waste (MSW). Both feedstocks were selected due to their massive availability especially in Indonesia. Globally, CM contains approximately 18−20% volatile solids including lignin, hemicellulose, cellulose, fats, proteins and carbohydrates for a dry weight basis [15][16]. Therefore, CM typically produces high amounts of methane gas. The characteristics of CM can be seen in Table I. The specific MSW employed in this study was carrot peels, tomato peels and banana peels. This is due to their high nutrient and carbohydrate content [17]. Additionally, tomato peels are rich in nutrients and sugars like nitrogen, which also make them readily degradable. Carrot peels have a lower content of lignin compared to other vegetable wastes, as a result they are easily degraded by anaerobic bacteria [18].

TABLE I. COW MANURE CHARACTERISTICS[16]

Element	Unit	Cow Manure
Volatile solids	gVS/kg wet weight	120.7
Total phosphorous	gP/kg VS	0.670
Total ammonia nitrogen	gN/kg VS	0.233
Total solids	gTS/kg wet weight	143.8
Total organic carbon	%DM	50.2
Chloride ion	Mg/kg DM	6990
C/N	%	20.74
Electrical conductivity	µS/cm	1226.5
pH	-	7.16
Carbon	%DM	54.31
Hydrogen	%DM	5.85
Oxygen	%DM	37.04
Nitrogen	%DM	2.8

B. Experimental setup of anaerobic digestion

The experimental schematic diagram can be seen in Fig. 1. The MQ-4 sensor was applied in this research to detect methane content in biogas. The detailed specification of MQ-4 sensor is shown in Table II. In order to measure the temperature inside the degister, a single k-type thermocouple was employed in this research. This sensor has a measurement range from 0°C to 1,024°C. Both sensors were placed in the digester headspace and connected to the necessary electrical circuit. A 10-liters volume of plastic drum was used as the digester tank in this study. The upper side of the digester was fitted tightly with a nylon adapter and connected to Tygon tubing. The tubing was equipped with a rubber septum for gas flow. The temperature was maintained in mesophilic temperature range during the fermentation process. An ATmega 2560 microcontroller was used in this study for data acquisition. This microcontroller has 54 input pins and 16 output pins.

The technical details of the microcontroller are shown in Table III. An I2C LCD 20×4 was used in this research as the display system for monitoring methane concentration. In order to save the investigation data, an SD card module equipped with 16 GB memory was used. The investigation conducted a 21-day monitoring period. This duration was selected based on the typical timeline required for the anaerobic digestion process to complete its various phases and generate biogas in large quantities. The monitoring period ensuring that the anaerobic digestion process had reached a stable state and was generating biogas in significant quantities. This duration is commonly observed in the literature and industry practices for optimizing biogas production from various organic feedstocks. The actual experimental investigation can be seen in Fig. 2.

TABLE II. TECHNICAL DETAILS OF THE MQ-4 SENSOR[9]

Parameter	Specifications
Model	MQ-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
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 CH4)

TABLE III. TECHNICAL DETAILS OF THE MICROCONTROLLER

Type	Description
Microcontroller	ATmega 2560
Operating voltage	5V
Input voltage	6-20V
Digital I/O pins	54 (of which provide PWM output)
Analog input pins	16
DC current per I/O pins	20 mA
Flash memory	256 kB of which 8 kB used by bootloader
SRAM	8 kB
EEPROM	4 kB
Clock speed	16 MHz

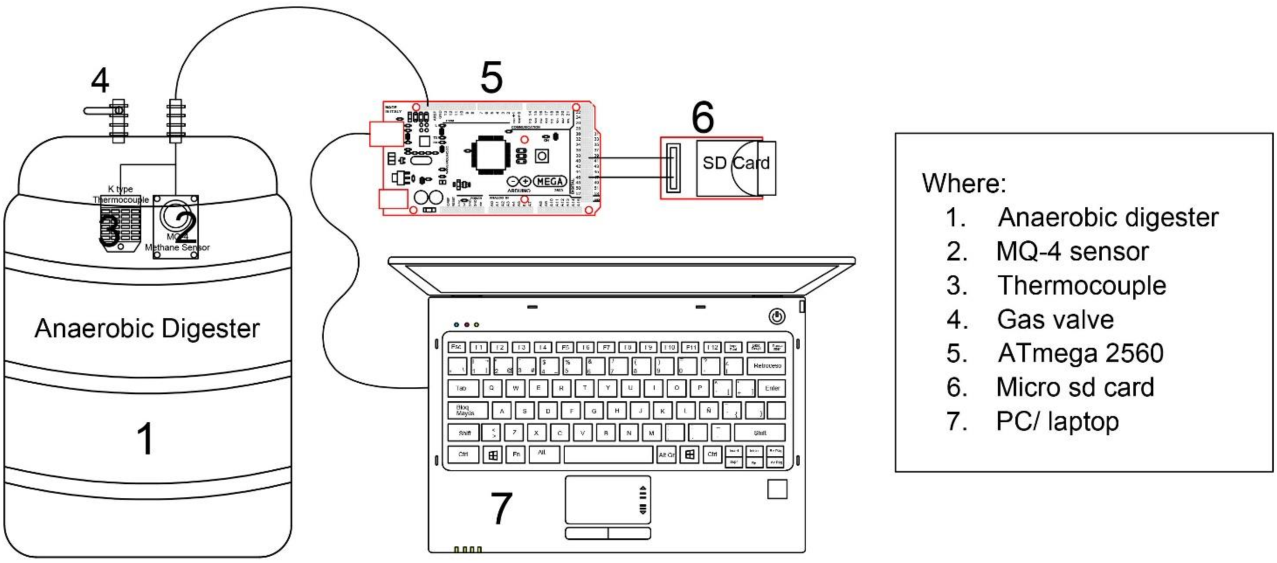


Fig 1. Schematic diagram of the investigation

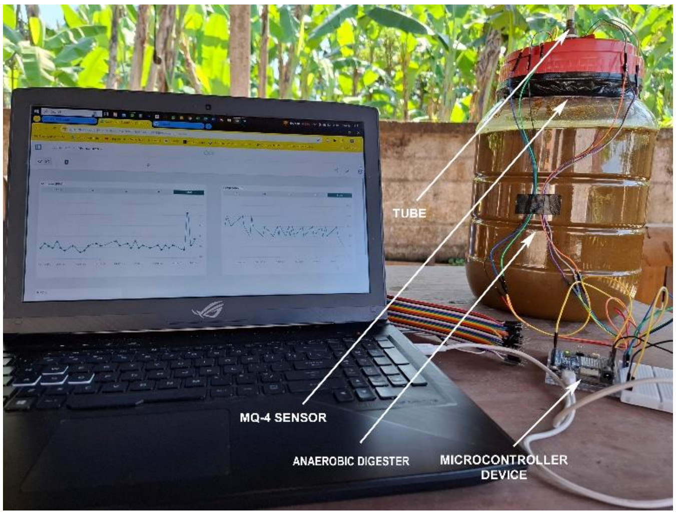


Fig 2. Actual experimental investigation of anaerobic digestion

9 ## III. Result and Discussion

A. Response of MQ-4 across different retention time periods

Fig. 3-5 shows charactersistics of the MQ-4 sensor across different retention time periods (7 days, 14 days and 21 days) of biogas. The measurements were taken directly inside the anaerobic digester tank for approximately 300 s
10 in order to determine the response of the MQ-4 sensor at various retention times. For the 7-day retention time, the value fluctuated between 480 ppm and 490 ppm. For the
22 14-day retention time, the value was found to be between 1,900 ppm and 1,940 ppm. On the other hand, for the 21-day retention time, the value fluctuated between 3,600 ppm
5 and 3,615 ppm. The mean and standard deviation (expressed as % of mean) are based on different retention time periods (7 days, 14 days and 21 days). From the Fig. 3, it can be seen the mean and standard deviation was 1.557 ± 0.321% (for 7-day). This relatively low percentage suggests high measurement consistency at this early stage. Furthermore, the mean and standard deviation was found 4.453 ± 0.233% (for 14-day) as shown in Fig. 4. This increase in both absolute retention time and relative variability could indicate a buildup of methane in the monitored environment or changes in the sensor's response characteristics over time. Subsequently, Fig. 5 show the mean and standard deviation was 3.294 ± 0.091% (for 21-day). This result was the lowest of all three time points. This high consistency might indicate stabilization of environmental conditions or sensor behavior. The decreasing trend in relative standard deviation (0.321%, 0.233%, and 0.091% for 7, 14, and 21 days, respectively) suggests an improvement in measurement precision or increased environmental stability over time.

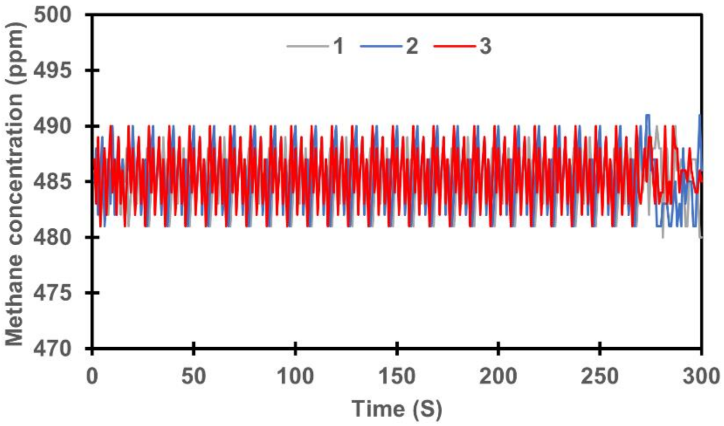
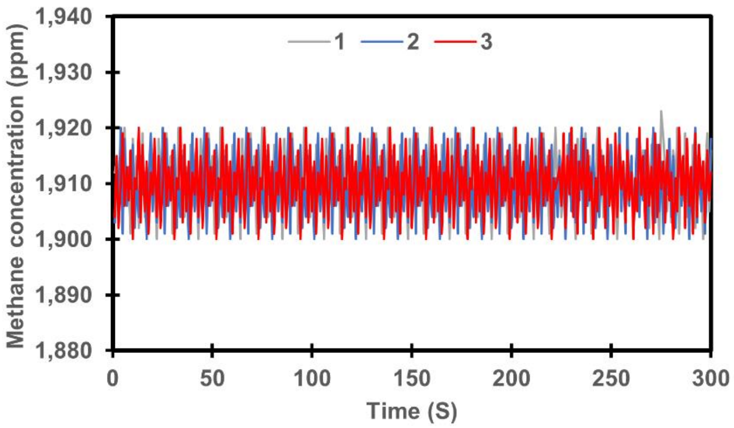
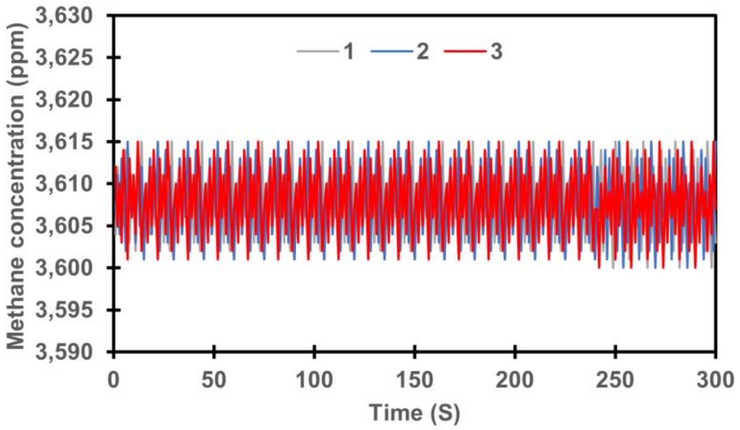


Fig 3. Response of MQ-4 sensor for methane measurement over 7 days



13 Fig 4. Response of MQ-4 sensor for methane measurement over 14 days



13 Fig 5. Response of MQ-4 sensor for methane measurement over 21 days

B. Response of MQ-4 across different retention time periods

Fig. 6 shows the cumulative concentration resulting from a small anaerobic digester. At 3 days, it can be seen there was a slight difference in methane production, which was 124 ppm for CM and 121 ppm for blend of MSW. The early digestion phase of methane production can be seen at 7 days. The methane concentration showed about 488 ppm and 239 ppm from CM and the blend of MSW respectively. Subsequently, biogas from CM was increased to 987 ppm at 9 days. This phenomenon correlates to the exponential methane generation phase as methanogenic bacteria yield biogas from volatile fatty acids during early hydrolysis and acetogenesis steps [16]. At around 15 days, the methane rate of CM was found to have sharply increased to 2,449 ppm and the methane concentration from the blend of MSW was found to be lower about 945 ppm. This is reffered to the heightened presence of organic substrates inside the digester. The process of degradation has a longer duration in microbial system due to the heightened abundance of organic matters. Both CM and the blend of MSW exhibited a similar trend in increase during experiment period [19].

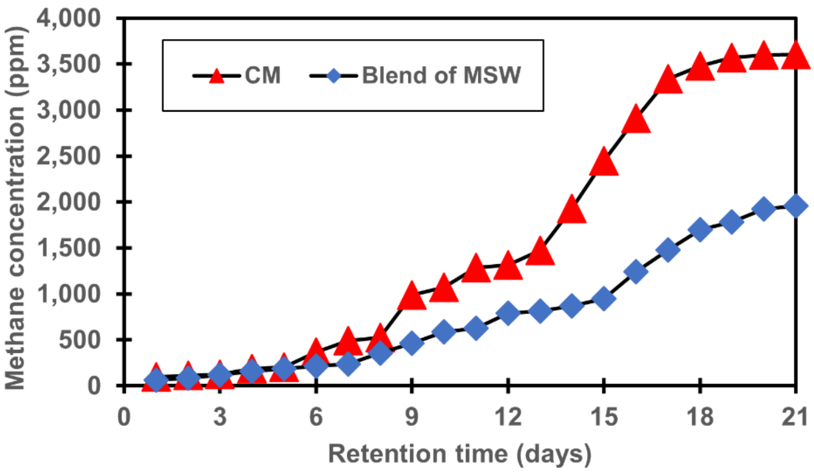


Fig 6. Cumulative methane production

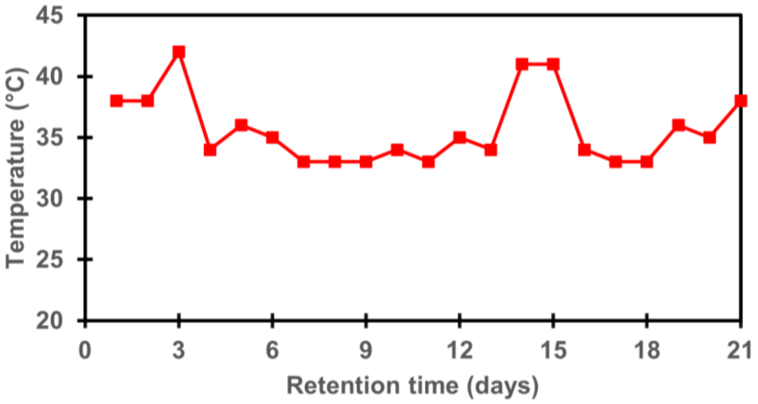


Fig 7. Temperature monitoring inside anaerobic digester

From the monitoring, the highest methane production was found in the CM which was 3,603 ppm at 21 days experiment. On the other hand, the methane production in the blend of MSW found to be 1,959 ppm at the same time period. The significantly higher methane concentration of CM can be attributed to its fiber-rich composition resulting in ideal substrates for methanogenesis [20]. The temperature monitoring inside the anaerobic digester can be seen in Fig 7. From the monitoring, the temperature during investigation was found to be over 30°C. This phenomenon indicated mesophilic digestion, which has temperature range 25°C to 40°C.

C. MQ-4 sensor roles for methane measurement

The device was employed to measure the methane concentration of biogas produced from a small-scale anaerobic digester. The small digester has been operated for over ten months. The benefit of methane measurements using MQ-4 sensor is that it provides reliable, affordable and low-cost data. This sensor is easily associated with any type of microcontroller and requires fewer electronic components to operate. The MQ-4 sensor is a cost-effective solution for methane (CH_4) measurement. The characteristics of the MQ-4 sensor, particularly its low cost and ease of integration, make it a suitable choice for research endeavors focused on methane measurement, such as those related to biogas production, landfill gas monitoring, or agricultural emissions quantification. In addition, the affordability and accessibility of the MQ-4 sensor enable researchers to deploy multiple units, create sensor networks, or incorporate the sensor into custom-designed measurement systems, thereby enhancing the scope and depth of their investigations.

IV. Conclusion

The MQ-4 sensor has been investigated for methane measurement in this paper. The investigated methane variations were derived from biogas that was produced by CM and the blend of MSW. It was found that the CM had relatively higher methane concentration compared to the blend of MSW. The CM was considered to be a good feedstock for biogas because it generated high methane production. The mean and standard deviation of the MQ-4 sensor was found to be 1.557 ± 0.321% (for 7 days), 4.453 ± 0.233% (for 14 days) and 3.294 ± 0.091% (for 21 days). This means the sensor has good performance for methane measurement. The high consistency might indicate stabilization of environmental conditions or sensor behavior. Additionally, the higher methane production was found to be 3,603 ppm for CM and 1,959 ppm for the blend of MSW. The rate of methane production increased during the retention time.

REFERENCES

[1] A. Calbry-Muzyka, H. Madi, F. Rüsch-Pfund, M. Gandiglio, and S. Biollaz, "Biogas composition from agricultural sources and organic fraction of municipal solid waste," *Renew. Energy*, vol. 181, pp. 1000–1007, 2022, doi: 10.1016/j.renene.2021.09.100.

[2] I. G. A. Negara, A. A. N. B. Mulawarman, I. G. Santosa, and L. P. I. Midiani, "STUDI EKSPERIMENTAL GENERATOR ELEKTRIK BERBAHAN BAKAR BIOGAS GUNA MENDUKUNG NET ZERO EMISSION," vol. 14, no. 2, pp. 689–700, 2023, doi: 10.21776/jrm.v14i2.1431.

[3] I. G. A. Negara, T. G. T. Nindhia, I. W. Surata, T. S. Nindhia, and S. K. Shukla, "Method on utilization of low quality biogas as a fuel for 4 stroke spark ignition engine of electric generator," *Key Eng. Mater.*, vol. 877 KEM, pp. 147–152, 2021, doi: 10.4028/www.scientific.net/KEM.877.147.

[4] S. Achinas, J. Krooneman, and G. J. W. Euverink, "Enhanced Biogas Production from the Anaerobic Batch Treatment of Banana Peels," *Engineering*, vol. 5, no. 5, pp. 970–978, 2019, doi: 10.1016/j.eng.2018.11.036.

[5] T. B. Pirzadah, B. Malik, R. A. Bhat, and K. R. Hakeem, "Early-stage response in anaerobic bioreactors due to high sulfate loads: Hydrogen sulfide yield and other organic volatile sulfur compounds as a sign of microbial community modifications," *Bioresour. Technol.*, no. xxxx, 2022, doi: 10.1002/9781119789444.

[6] L. M. Shitophyta, M. H. Darmawan, and Y. Rusfidiantoni, "Produksi Biogas dari Kotoran Sapi dengan Biodigester Kontinyu dan Batch: Review," *J. Chem. Process Eng.*, vol. 7, no. 2, pp. 85–90, 2022, doi: 10.33536/jcpe.v7i2.903.

[7] Iswanto, A. Ma'arif, B. Kebenaran, and P. Megantoro, "Design of gas concentration measurement and monitoring system for biogas power plant," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 22, no. 2, pp. 726–732, 2021, doi: 10.11591/ijeecs.v22.i2.pp726-732.

[8] B. Bharathiraja, T. Sudharsana, J. Jayamuthunagai, R. Praveenkumar, S. Chozhavendhan, and J. Iyyappan, "Biogas production – A review on composition, fuel properties, feed stock and principles of anaerobic digestion," *Renew. Sustain. Energy Rev.*, vol. 90, no. April, pp. 570–582, 2018, doi: 10.1016/j.rser.2018.03.093.

[9] S. Yang, Y. Liu, N. Wu, Y. Zhang, S. Svoronos, and P. Pullammanappallil, "Low-cost, Arduino-based, portable device for measurement of methane composition in biogas," *Renew. Energy*, vol. 138, pp. 224–229, 2019, doi: 10.1016/j.renene.2019.01.083.

[10] N. M. Sakayo, J. N. Mutuku, and J. M. Ngaruiya, "Design and Calibration of a Microcontroller Based MQ-4 Gas Sensor for Domestic Cooking Gas System," *Int. J. Appl. Phys.*, vol. 6, no. 2, pp. 31–40, 2019, doi: 10.14445/23500301/ijap-v6i2p106.

[11] M. M. Hossain and N. Khandaker, "Developing low-cost methane gas concentration measuring device," *Sukatha procedia*, no. July, pp. 54–59, 2021, doi: 10.32438/sa.120.3010.

[12] I. G. A. Negara, D. S. Anakottapary, I. B. G. Widiantara, L. P. I. Midiani, T. G. T. Nindhia, and I. G. N. N. Santhiarsa, "Integrated microcontroller mq sensors for monitoring biogas: Advancements in methane and hydrogen sulfide detection," *J. Teknosains*, vol. 13, no. 2, p. 140, 2024, doi: 10.22146/teknosains.91936.

[13] A. Sucipto, A. Brilliantina, E. K. N. Sari, R. Wijaya, D. Triardianto, and A. Adhamatika, "Rancang Bangun Alat Deteksi Dan Pengukur Gas Emisi Karbondioksida (CO2) Dan Gas Emisi Metana (CH4) Berbasis Mikrokontoler," *JUSTER J. Sains dan Terap.*, vol. 2, no. 1, pp. 122–126, 2023, doi: 10.57218/juster.v2i1.541.

[14] T. Susilo and F. David, "Sistem Pemantauan Gas Berbahaya Pada Peternakan Ayam Berbasis Internet of Things," *IT-Explore J. Penerapan Teknol. Inf. dan Komun.*, vol. 2, no. 3, pp. 247–257, 2023, doi: 10.24246/itexplore.v2i3.2023.pp247-257.

[15] C. Font-Palma, "Methods for the Treatment of Cattle Manure—A Review," *C*, vol. 5, no. 2, p. 27, 2019, doi: 10.3390/c5020027.

[16] T. Alkhrissat, "The impact of organic loading on the anaerobic digestion of cow manure: Methane production and kinetic analysis," *Case Stud. Chem. Environ. Eng.*, vol. 9, no. December 2023, p. 100589, 2024, doi: 10.1016/j.cscee.2023.100589.

[17] T. Llano, C. Arce, and D. C. Finger, "Optimization of biogas production through anaerobic digestion of municipal solid waste: a case study in the capital area of Reykjavik, Iceland," *J. Chem. Technol. Biotechnol.*, vol. 96, no. 5, pp. 1333–1344, 2021, doi: 10.1002/jctb.6654.

[18] C. Morales-Polo, M. del Mar Cledera-Castro, and B. Yolanda Moratilla Soria, "Reviewing the anaerobic digestion of food waste: From waste generation and anaerobic process to its perspectives," *Appl. Sci.*, vol. 8, no. 10, 2018, doi: 10.3390/app8101804.

[19] G. Náthia-Neves, M. Berni, G. Dragone, S. I. Mussatto, and T. Forster-Carneiro, "Anaerobic digestion process: technological aspects and recent developments," *Int. J. Environ. Sci. Technol.*, vol. 15, no. 9, pp. 2033–2046, 2018, doi: 10.1007/s13762-018-1682-2.

[20] K. Obileke, S. Mamphweli, E. L. Meyer, G. Makaka, and N. Nwokolo, "Design and Fabrication of a Plastic Biogas Digester for the Production of Biogas from Cow Dung," *J. Eng.*, vol. 2020, pp. 1–11, 2020, doi: 10.1155/2020/1848714.