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Fabrication of biogas production prototypes from cattle manure on smallholder farm into renewable energy in a balanced and sustainable manner

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Abstract The result showed the amount of biogas which produced by the biogas production prototype, obtained from cattle manure fermentation averaged 0.058±0.02 m^3 or 58 L and the monthly average was 1.74 m^3. The biogas obtained from this prototype consisted of 2.88% nitrogen (N_2), 57.78% methane (CH_4), and 39.29% carbon dioxide (CO_2). The flame produced resulting by producing biogas revealed a reddish-blue color. The amount of CH_4 and biogas were varied to cattle feeds which related to manure property, and climate. The COD was significantly reduced by biogas production. There was a positive correlation between CH_4 and chemical compositions in terms of neutral detergent fiber (NDF), cellulose, hemicellulose, total carbohydrate (TCB), non-fiber carbohydrate (NFC), and nitrogen free extract (NFE) of cattle manure. The smallholder farmers in the community of of Ban Noi Chom Sri Mai Village, Sakon Nakhon Province were trained how to use the prototype to produce biogas. It was found that the participants were able to understand the biogas production process. The participants were satisfied with the design and safety system of the biogas production prototype which had a gas storage tank, safety valve, pressure gauge, etc. The community was interested in applying it to other agricultural waste.

Keywords: Methane gas, Animal waste, Sludge, Energy, Households

Introduction

In raising cattle, the waste (cow manure) produced is approximately 10% of the cattle's body weight per day. It consists of feces and urine mixed in a 3 to 1 ratio. On average, dairy cows produce 62 kg of waste each day, compared to 37 kg for beef cattle (Gupta *et al*., 2016). The methane gas (CH_4), which constitutes up to 55-65% of all CH_4 produced by livestock farming waste, has the potential to cause global warming at 21 times more than carbon dioxide (CO_2). The total

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population of beef and dairy cattle in Thailand is more than 10 million head (Department of Livestock Development, 2023). Using animal manure as a raw material for biogas production is an effective way to reduce the impact of animal waste and bring benefits to the community. Biogas or digester gas is a gas produced by anaerobic bacteria decomposing organic matter (OM) or various biomass under anaerobic digestion conditions. Biogas consists mainly of CH_4 and CO_2, nitrogen gas (N_2), hydrogen gas (H_2), and hydrogen sulfide gas (H_2S) (Borek *et al*., 2021). The proportion of each gas type depends on various environmental factors, including the raw material composition, pH value, temperature, and retention time (Gadirli *et al*., 2024). The components of cattle manure are lignin, cellulose, hemicellulose, various minerals, and microorganisms produce CH_4 gas in fermentation. However, the feed of cows varies in the different seasons and also in different areas, such as forage, hay, silage, and concentrate feed which affects the components of manure and biogas production (Chainetr *et al*., 2022). 35-40 L of biogas can be produced from 1 kg of cattle manure when combined with water and left to ferment (Gupta *et al*., 2016). The pH of the raw materials used to make biogas should be between 6.5 and 7.5 in order to be appropriate for the methanogenic bacteria that produce biogas. However, if it is acidic, such as food scraps consisting of vegetables and fruits, mixing cattle manure with food scraps will improve biogas production. The co-digestion between cow manure and food waste reduces the COD value from 30,000 to 5,000-7,000 mL/L (Pakvilai, 2021).

The small-scale biogas production system from animal manure for small households in Thailand is in the form of a channel digester made from PVC plastic (lagoon) or a fixed dome from concrete which has a size of approximately 8-16 cm^3 (Department of Alternative Energy Development and Efficiency, 2011). 96.2% of beef cattle farmers are small-scale farmers who raise 1 - 20 cattle (Department of Livestock Development, 2023). Biogas from animal manure is therefore a cheap energy source obtained from cattle waste for cooking and the reduction of energy costs. Moreover, the waste left over from the fermentation (sludge and effluent) can be used as fertilizer for plants (Prathumyot *et al*., 2019; Borek *et al*., 2021). Development of small-scale biogas systems suitable for households in rural areas provides a way to access renewable energy for communities more easily than systems that require large amounts of raw materials (Roubik and Mazancova, 2020). In addition, compressing biogas into gas tanks makes the use of biogas more flexible, long-lasting, adaptable, and safe to use even outside gas production well zones. Panyaping *et al*. (2021) found that gas can be compressed into a liquefied petroleum gas (LPG) tank at a pressure of 4 bars by using a diaphragm pump to compress it into a 15.8 kg tank 160 L. Singh *et al*. (2010) described using a mixture of microorganisms to increase methane content in biogas production from cow dung slurry. A batch system was run in a 10 L fermenter at 35ºC for a total of 41 days. It was found that the microorganisms collected from municipal waste produced the highest amounts of biogas and methane as compared to microorganisms from different sources, which were 0.547 L/gVS (volatile solid) and 0.323 L/gVS, respectively, and had the highest proportion of 68%. Khunpakdee *et al*. (2017) studied the development of a biogas production system from co-digestion of microorganisms, chicken manure, and Napier grass in a closed vortex bioreactor system. Biogas production from co-digestion of microorganisms, chicken manure, and Napier grass in a closed vortex bioreactor in a single-step. After the water was stored for a period of 38 days, the pH value during the time of CH_4 gas production was in the range of 7.9 and 7.82, respectively. Moreover, each season affected such factors as sunlight, temperature, humidity, and rain (Bavutti *et al*., 2014; Gupta *et al*., 2022). The training programme was a way of promoting the utilization of biogas production in the community (Tansom *et al*., 2020). Interviews of the participants demonstrated the interest of the participants and how the training could impact on social life and the environment. Many projects studied the impact of using biogas plants from cow dung on social life and the environment by the use of interviews (Roubik and Mazancova, 2020; Tansom *et al*., 2020; Shaibur *et al*., 2021). The households who used the biogas plant were satisfied due to the reduction in the use of natural fuels for cooking, such as firewood, agricultural residues, and LPG gas. Moreover, biogas production processing could decrease the expense of chemical fertilizer by using sludge as an organic fertilizer (Roubik and Mazancova, 2020; Tansom *et al*., 2020; Shaibur *et al*., 2021).

This research aimed to improve the efficiency of the traditional biogas production process by creating a prototype biogas production and designing a new biogas production prototype.

Materials and methods

This research protocol was no involvement in animal body use /animal contact which was approved by the Institutional Animal Care and Use Committee of Sakon Nakhon Rajabhat University (IACUCSNRU).

Design and assembly of a biogas production prototype system.

This experiment designed a biogas production prototype for studying and monitoring a system that conveniently collects samples from cattle manure, gas, and sludge, which showed the amount of gas produced, and increased the efficiency of biogas pressure while considering the safety of users as well. The equipment is displayed in Table 1. The prototype was installed in the community of Ban Noi Chom Sri Mai Village, Hang Hong Subdistrict, Mueang Sakon Nakhon District, Sakon Nakhon Province, Thailand. The experimental data were collected during 180 days.

Table 1. The equipment used for assembling biogas production prototype system

No.	Material	Quantity
1.	Filling tank size: diameter 0.30 meters, height 0.40 meters	1
2.	Fermentation cone tank size: diameter 1.20 meters, height 1.70 meters	1
3.	Gas storage tank size: diameter 0.45 meters, height 1.55 meters	1
4.	Steel pipe 1/2 inches, length 2 meters/piece	1
5.	Steel pipe 3/8 inches, length 2 meters/piece	1
6.	Steel pipe 3 inches, length 2 meters/piece	1
7.	Steel pipe 4 inches, length 2 meters/piece	1
8.	Control valve 3/8 inches	3
9.	Gas pressure regulator	1
10.	Pressure gauge	2
11.	Safety valve	1
12.	Pressure hose size 1/2 inches (10 meters)	1
13.	PVC pipe, size 1/2 inches, length 0.5 meters/piece	4
14.	Gas compressor pump 1/2 horsepower	1
15.	Elbow 1/2 inches	7
16.	Three-way joint, 1/2 inches, internal thread	2
17.	Diaphragm gas meter	1
18.	Connection chamber	1

Fresh cattle manure material

Samples of fresh cattle manure were collected in the morning from the ground under the shed which is mixed from all the cattle animals there, by the farm owner using buckets to fill the filling tank (No. 1 as shown in Figure 1). Additionally, five Brahman x Thai native cattle, aged between 3-5 years, weighing approximately 150-600 kg, were housed in wooden cages (15 m × 8 m, L × W). All cattle were similarly fed rice straw and fresh grass (*Hemarthria compressa* and/or natural grass) as roughage *ad libitum* and had free access to water and a mineral block. Cattle were offered feed twice daily at 07.30 h and 17.00 h, and they were allowed grazing pasture during the day which is comparable to the farmers usual method of producing cattle feed.

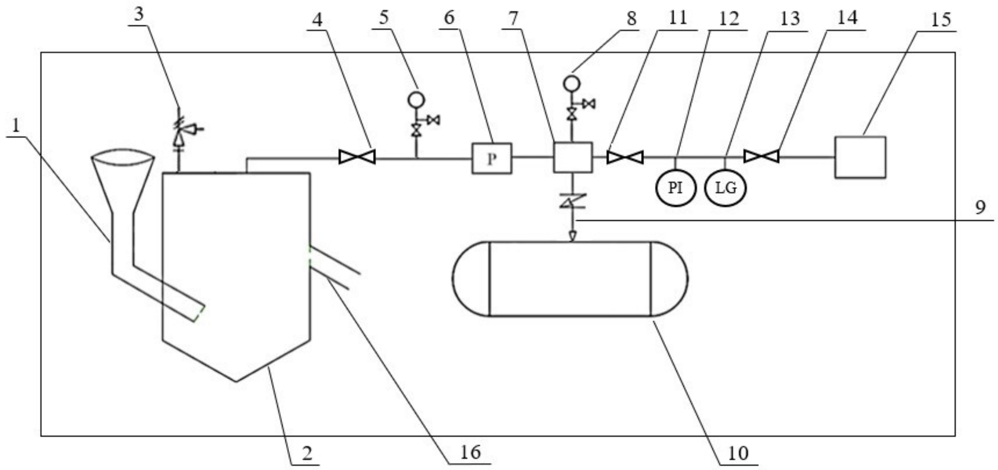

Figure 1. Diagram design of the biogas production prototype set
1/ Filling tank set 2/ Fermentation tank set 3/ Safety valve 4/ Control valve 5/ Pressure gauge 6/ Gas compressor pump 7/ Connection chamber 8/ Pressure gauge 9/ Directional control valve 10/ Biogas storage tank set 11/ Control valve 12/ Gas pressure regulator 13/ Diaphragm gas meter 14/ Control valve 15/ Cooking stove set 16/ Pipe overflows from tank

Components of the biogas production prototype

The filling tank (No. 1 as shown in Figure 1) was made of steel, of a conical shape, and with a diameter of 0.30 m, a height of 0.40 m (Figure 2 (A)), and a working volume of 10 L of feed from raw materials, such as manure. A 4-inch steel pipe was installed at the side of the filling tank. The filling tank was designed as a cone-shaped tank which would be convenient for filling with cattle manure which is next to the fermentation tank. A fermentation tank (No. 2 in Figure 1) was made of steel, of a cylindrical conical shape at the end, a diameter of 1.20 m, a height of 1.70 m (Figure 2 (B)), and a working volume of 1,390 L. A 3-inch steel pipe was installed at the side of the fermentation tank through which the sludge was released. A safety valve was installed on the top of the fermentation tank to prevent the gas pressure exceeding the specified limit. A pipe with a control valve and a pressure gauge were connected to the gas compressor pump and a chamber. There was a pressure gauge in the chamber to measure the gas pressure. The biogas was compressed and flowed into the biogas storage tank via a control valve (Figure 3). The biogas storage tank (No. 10 in Figure 1) was made of steel, in a capsule shape, with a diameter of 0.45 m, a height of 1.55 m (Figure 2 (C)), and a usable capacity of 250 L. To activate the biogas from the gas storage tank, there is a control valve which opens and closes. To connect the gas pressure regulator to a diaphragm gas meter there is a control valve which opens and closes to reduce the gas pressure in the pipe before it is connected to a 1/2-inch hose to the cooking stove (Figure 3). When turning on the gas, you can read the amount of biogas used for cooking from a diaphragm gas meter (Landis Gyr (AMPY) Gas Meter model 750).

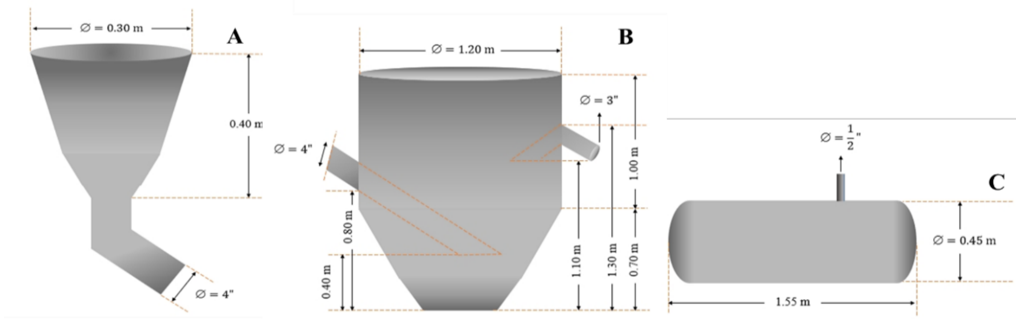

Figure 2. Dimensions of illustration of the biogas production prototype set (A): Filling tank set (Filling tank size: diameter 0.30 m, height 0.40 m, (B): Fermentation tank set (Fermentation cone tank set size: diameter 1.20 m, height 1.70 m, and (C) Biogas storage tank set (Gas storage tank size: diameter 0.45 m, height 1.55 m)

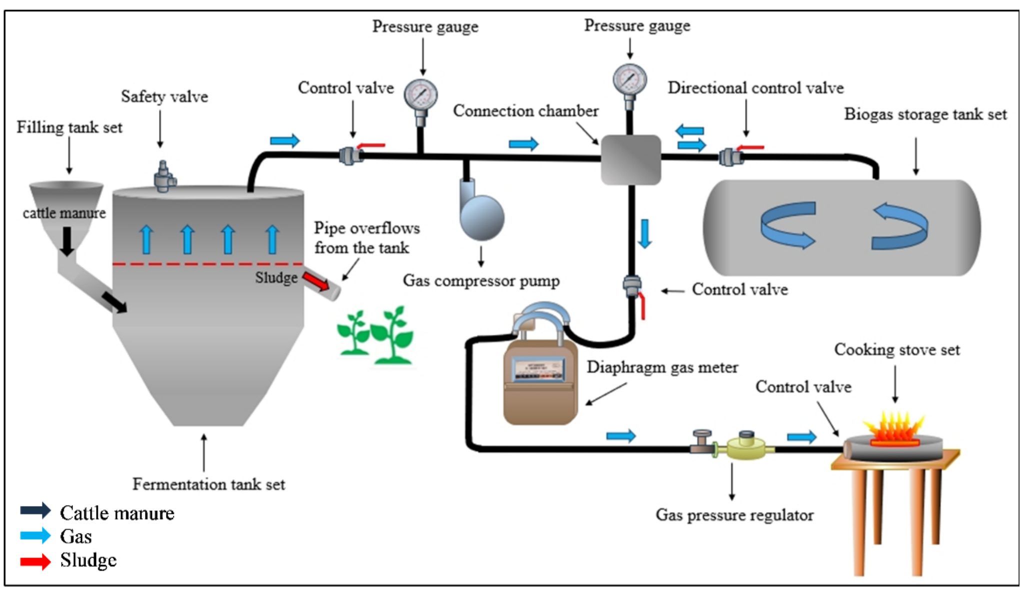

Figure 3. Schematic showing of gas flow direction inside the biogas production prototype set

Cattle manure, sludge, and biogas analysis

Fresh cattle manure was mixed with water in a 1:1 ratio (40 L of fresh cattle manure: 40 L of water). This mixture was then subjected to a 1) chemical composition analysis and then use to 2) fill the biogas production prototype (Figure 4) every day for 90 days consecutively. It took approximately 7-15 days of fermentation before the biogas was produced. The cattle manure and sludge were measured for pH, electrical conductivity (EC; mS/cm), and temperature (ºC) by using a portable multiparameter. Then the cattle manure and sludge were dried at 105ºC for 24 h after the digester process and analyzed for moisture content. A sample of cattle manure and sludge were weighed before and after being dried at 105ºC for 4 h and then analyzed for total solid (TS; %). Afterwards, the residue sample was burnt at 550ºC for 1 h and analyzed for fixed solids (FS; %) and volatile solids (VS; %) (APHA, 1998). The cattle manure and sludge were dried at 105ºC for 1 h and analyzed for total carbon (%), total nitrogen (%), and total hydrogen (%) by the LECO method with a CHN628 instrument. Afterwards, the ratio of carbon to nitrogen (C/N ratio) was calculated from this data. The chemical oxygen demand (COD) (mg/l) of the cattle manure and sludge was analyzed by using the closed-reflux method: Spectroquant® COD Cell Test with Spectroquant® Pharo 300; MECK. Biogas was collected twice, once in the early rainy season and once in the late rainy season as the feed differs according to the season. The composition of the biogas was analyzed in terms of H_2, N_2, CH_4, and CO_2 by gas chromatography (GC) Shimasu (GC-8A).

The equation based on Shaibur *et al.* (2021) was used to calculate the efficiency rate of the biogas prototype.

$$\text{Efficiency Rate (ER)} = \frac{\text{Gas Production}}{\text{Production Capacity}} \text{x } 100$$

Figure 4. Composition of the biogas production prototype installed in the community field

Chemical composition analysis

Fresh cattle manure, sludge, and roughage samples were dried in a hot air oven (Memmert UF 750, Memmert GmbH, Germany) at 60°C for 48 h. The samples were grounded and sieved through a 2 mm sieve to analyze the chemical composition by proximate analysis, including dry matter (DM), crude protein (CP), ash, ether extract (EE), and crude fiber (CF) content were conducted following the standard methods of AOAC (1990). Gross energy (GE) was analyzed by an automatic dynamic bomb calorimeter (IKA®Werke, C5000, Germany). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were analyzed following the method of Van Soest *et al.* (1991).

Technology transfer and knowledge impact on biogas production among community members or interested individuals

Training in biogas production was conducted in the community of Ban Noi Chom Si Mai village, Hang Hong sub-district, Mueang Sakon Nakhon district, Sakon Nakhon province. The primary survey data used interviews using a Likert scale with 5 levels as approved by Sakon Nakhon Rajabhat University EC Form COA No. 068/2566, IEC NO. HE 66-054. Data were collected from 30 participants (n = 30). The survey aimed to evaluate the participants' basic knowledge and understanding of biogas production as well as their interest in the process and their willingness to participate in future research activities.

Statistical analysis

The three replications of data of the materials and biogas, including properties and chemical composition, were analyzed by using R statistics (R Core Team, 2023). The mean differences among the samples were compared by using Fisher's least significant difference (LSD) test. The data from an interview with the participants was analyzed using IBM SPSS Statistics (Version 21) (IBM Corp, 2012).

Results

Result showed the various properties of cattle manure and sludge(Table 2). Cattle manure revealed a total solids (TS), fixed solids (FS), and volatile solids (VS) at 15.61, 15.90, and 84.10%, respectively After the biogas production process, it was found that the sludge had TS, FS, and VS values of 18.72, 29.71, and 70.29%, respectively. The carbon (C), hydrogen (H), and nitrogen (N) contents of cattle manure were 40.92, 5.87, and 1.42%, respectively. After the fermentation process, the C and H contents of manure in the overflow decreased (P<0.01), resulting to decrease in the C/N ratio (P<0.01). This study found that the biogas volume obtained from fermentation from the prototype averaged 0.058±0.02 m^3/d and approximately 1.735±0.64 m^3/month. Cattle manure and sludge had an average moisture content of 84.18 and 81.99% (P<0.001) (Table 2), respectively, and 15.82 and 18.01% DM (% of fresh) respectively.

Table 2. Properties and chemical composition of cattle manure and sludge (Mean ± SD)

Properties	Cattle manure	Sludge	P-value
pH	7.39±0.14	7.08±0.10	**
Electrical conductivity (mS/cm)	4.91±1.73	8.92±3.16	*
Temperature (ºC)	31.88±0.48	30.02±0.13	***
Moisture (%)	84.18±0.36	81.99±0.72	***
Total Solids (%)	15.61±0.37	18.72±0.46	***
Fixed Solid (%)	15.90±0.74	29.71±0.41	***
Volatile Solid (%)	84.10±0.74	70.29±0.41	***
Total Carbon (%)	40.92±0.05	35.80±0.07	***
Total Hydrogen (%)	5.87±0.05	5.28±0.03	**
Total Nitrogen (%)	1.42±0.00	1.49±0.01	**
Carbon/Nitrogen Ratio	28.74±0.10	24.04±0.20	**
Chemical oxygen demand (mg/L)	16,830.00±0.00^a	9,643.33±2.89^b	***
Dry matter (%)	98.95±0.24	99.54±0.39	ns
Crude protein (%)	2.97±0.87	2.44±0.40	ns
Ash (%)	24.02±0.42^b	28.67±1.05^a	*
Ether extract (%)	1.45±0.07	1.24±0.06	ns
Crude fiber (%)	12.52±0.89	10.02±0.24	ns
Gross energy (Cal/g)	3897.13±4.89^a	3477.12±5.40^b	***
Neutral detergent fiber (%)	53.78±1.58^a	50.40±0.64^b	*
Acid detergent fiber (%)	34.00±0.02^b	36.71±0.25^a	**
Acid detergent lignin (%)	9.76±0.08^b	11.58±0.30^a	*
Cellulose[1/] (%)	19.78±2.25	14.06±0.31	ns
Hemicellulose[2/] (%)	24.24±0.06^b	25.13±0.06^a	**
Total carbohydrate[3/] (%)	70.50±0.98	67.19±1.10	ns
Non-fiber carbohydrate[4/] (%)	17.77±3.45	16.89±0.65	ns
Nitrogen free extract[5/] (%)	57.98±1.87	57.17±0.86	ns

[1/]Cellulose: %acid detergent fiber- %acid detergent lignin, [2/]Hemicellulose: % neutral detergent fiber-acid detergent fiber, [3/]Total carbohydrate: 100-(%crude protein+%ether extract+%ash+%moisture), [4/]Non-fiber carbohydrate (NFC): 100-(%crude protein+%ether extract+%neutral detergent fiber+%ash), [5/]Nitrogen free extract (NFE): 100-(%moisture+%ash+%crude protein+%ether extract+%crude fiber), P-value: ns: non-significance ($p > 0.05$), * significance at $p < 0.05$, ** significance at $p < 0.01$, *** significance at $p < 0.001$, Different letter in the same row represent significant differences

The test findings for the production of CH_4 gas prototype from cattle manure from mid-June to August 2023 (61 days) demonstrated that the volume of CH_4 production was substantial, measuring 4.732 m^3. Cattle manure used as an initial raw material for methane gas production in this research had a fiber content of 12.52% (Table 2), produced from cattle-fed roughage, such as rice straw and fresh grass, which had a crude fiber content of 30.16. and 29.26%, respectively without supplementation of concentrate feed. Meanwhile, the values of neutral detergent fiber, acid detergent fiber, hemicellulose, and cellulose of rice straw and fresh grass were higher than those of the concentrate feed of ruminants. The chemical composition of rice straw and fresh grass are shown in Table 3.

Table 3. Chemical composition of cattle feed (Mean ± SD)

Items	Rice straw	Fresh Grass	P-value
Dry matter (%)	93.40±0.54	90.82±5.32	ns
Crude protein (%)	$3.55±0.01^b$	$12.24±0.10^a$	***
Nitrogen (%)	$0.57±0.00^b$	$1.96±0.02^a$	***
Ash (%)	$8.12±0.00^b$	$10.07±0.08^a$	***
Ether extract (%)	$0.68±0.03^b$	$1.27±0.04^a$	**
Crude fiber (%)	30.16±0.93	29.26±1.02	ns
Gross energy (Cal/g)	$3838.02±14.86^b$	$4075.07±3.55^a$	**
Neutral detergent fiber (%)	$68.72±1.26^a$	$64.19±0.10^b$	**
Acid detergent fiber (%)	45.02±0.12	45.15±0.26	ns
Acid detergent lignin (%)	$5.51±0.32^b$	$9.14±0.08^a$	**
Cellulose (%)	23.66±1.65	19.10±0.31	ns
Hemicellulose (%)	$39.51±0.44^a$	$36.01±0.18^b$	**
Total carbohydrate[1] (%)	81.04±0.56	67.24±5.38	ns
Non-fiber carbohydrate[2] (%)	$18.97±1.79^a$	$12.18±0.11^b$	*
Nitrogen free extract[3] (%)	50.88±1.50	37.98±6.40	ns

Cellulose: %acid detergent fiber- %acid detergent lignin, Hemicellulose: % neutral detergent fiber-acid detergent fiber, [1]Total carbohydrate: 100-(%crude protein+%ether extract+%ash+%moisture), [2]Non-fiber carbohydrate: 100-(% crude protein +% ether extract +% neutral detergent fiber +%ash), [3]Nitrogen free extract = 100–(%moisture+%ash+%crude protein+%ether extract+%crude fiber), P-value: ns: non-significance ($p>0.05$), * significance at $p < 0.05$, ** significance at $p < 0.01$, *** significance at $p < 0.001$, Different letter in the same row represent significant differences

The biogas obtained from this prototype consisted of 2.88% N_2, 57.78% CH_4, and 39.29% CO_2 in the dry season when cattle were fed only rice straw. On the other hand, the biogas obtained from this prototype in the rainy season when cattle were fed rice straw and fresh grass, consisted of 14.44% N_2, and 46.92% CH_4, compared to 38.62% CO_2 in the dry season (Figure 5). The prototype in this research has a digester size with a volume of 1.39 m^3 and the daily average volume of biogas obtained from fermentation was 0.058 m^3. The monthly average was 1.735±0.64 m^3 (Figure 6). The color of the flame resulting from biogas combustion is reddish blue (Figure 6 (B)).

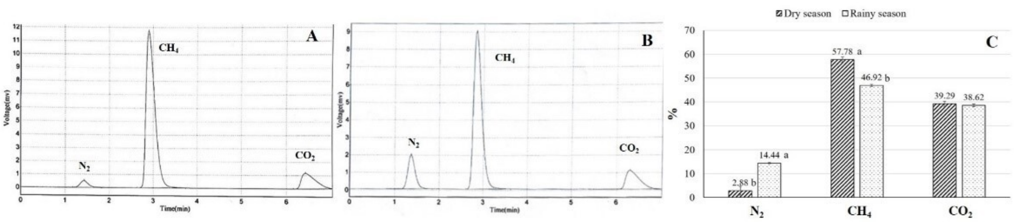

Figure 5. Composition of biogas from the biogas production prototype A-chromatogram of biogas in dry season B-chromatogram of biogas in rainy season and C-percentage of biogas composition in dry and rainy season

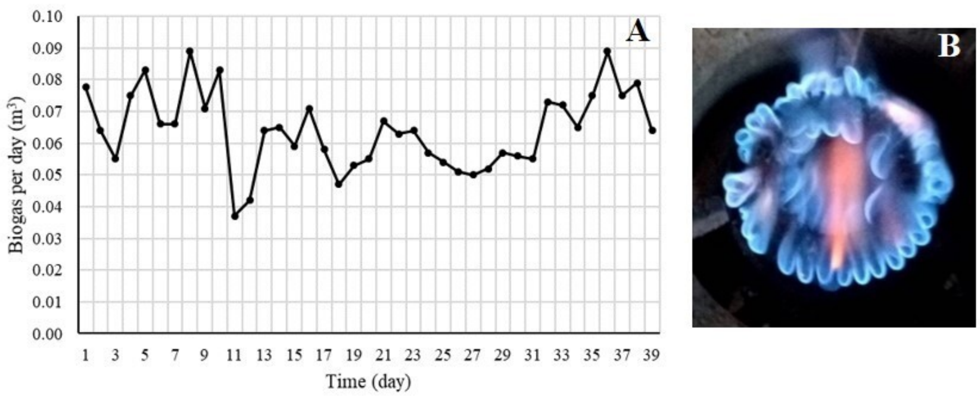

Figure 6. Volume of biogas per day (A), and color of flame on combustion of biogas (B)

This study's initial findings revealed that there was no biogas production at the beginning of the experiment when the fermentation tank was set above the ground. The climate in the first twelve days (approximately in early April 2023) was at a high temperature with low humidity (Figure 7). Therefore, half of the fermentation tank was moved below the soil level to solve this problem. Figure 8 shows the relationship between biogas content and climate. There was a negative relationship between biogas content and maximum humidity. While the maximum temperature showed a negative correlation with humidity but a positive correlation with evaporation and photoperiods (data not shown). CH_4 showed a positive correlation with NDF, cellulose, hemicellulose, NFC, and NFE but a negative correlation with ash, CP, ADL, and EE (Figure 9). This corresponded to the CH_4 content in the rainy season when cattle were fed rice straw (66.72% NDF) and fresh grass (64.19% NDF) which average of NDF was lower than in the dry season when cattle were fed only rice straw.

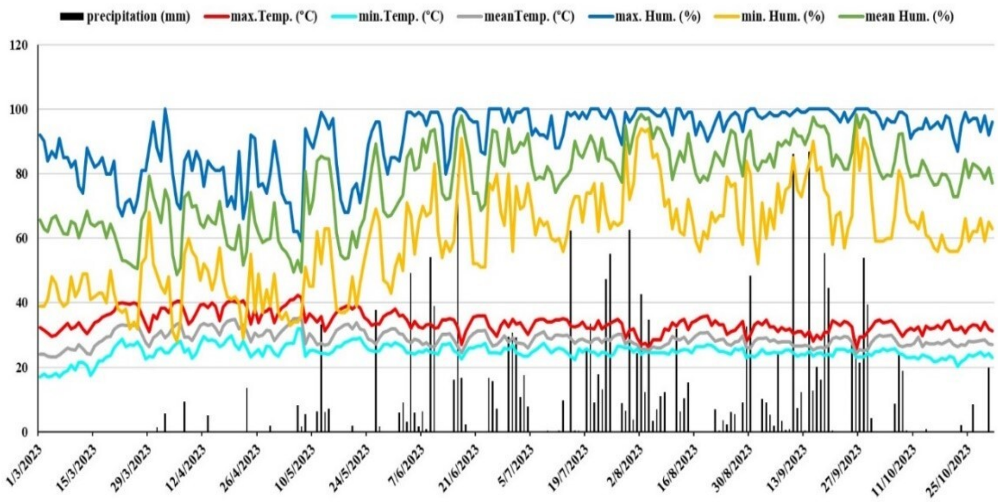

Figure 7. Climate data of Sakon Nakhon Province, Thailand in 2023: precipitation (mm), maximum temperature (ºC), minimum temperature (ºC), mean temperature (ºC), maximum humidity (%), minimum humidity (%), and mean humidity (%) (Thai Meteorological Department, 2024)

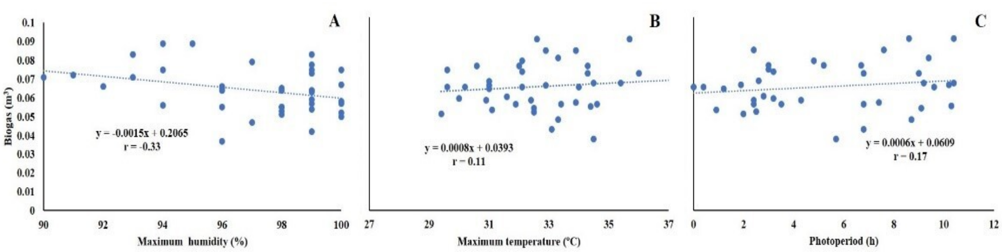

Figure 8. Scatter plot between biogas and maximum humidity (A), maximum temperature (B), and photoperiod (C) percentage of biogas composition in dry and rainy season

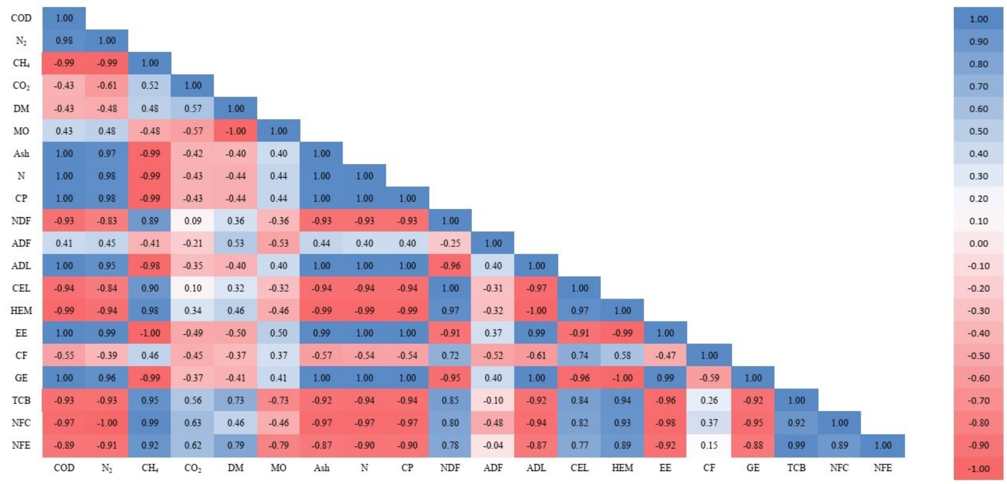

Figure 9. Correlation matrix among properties of cattle feed and gas composition
Note: COD: chemical oxygen demand, N_2: nitrogen gas, CH_4: methane gas, CO_2: carbon dioxide gas, DM: dry matter, MO: moisture, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, ADL: acid detergent lignin, CEL: cellulose, HEM: hemicellulose, EE: ether extract, CF: crude fiber, GE: gross energy, TCB: total carbohydrate, NFC: non-fiber carbohydrate, NFE: nitrogen free extract

The farmers' perceptions of the biogas production prototype and their evaluation of a score of 5 was the highest level of satisfaction and a score of 1 was the lowest (Table 4). Most of the participants were 46-55 years' old (46.7%) followed by 36-45 years' old (20%). The survey assessed the following aspects: basic knowledge and understanding, level of interest, and level of participation in research activities. The "raw material in community for biogas production" item had an average score of satisfaction (4.23). This represents the various materials which were used for filling the biogas prototype. The advantages of using waste materials for the biogas prototype from household and agriculture were: it is a safe system, it saves costs in using cooking gas, it is an alternative energy, and it reduces environmental pollution. Moreover, the farmers showed an interest in the use of a biogas prototype for the household or the community.

Table 4. Farmers' perceptions of knowledge and merit of biogas production prototype and farmers' demand (n=30)

Items	Mean	SD
Raw material in community for biogas production	4.23	0.82
Principle of biogas production	3.80	0.92
Factors affecting biogas production	3.83	0.91
Using waste materials from household and agriculture	4.20	0.92
Design and Safety system of biogas production prototype such gas storage tank, safty valve, pressure gauge etc	4.46	0.63
Safety system of biogas production prototype	3.90	1.03
Cooking gas cost saving	4.16	0.87
Alternative energy	4.00	0.88
Reducing environmental pollution	4.20	0.89
Setting biogas production at home/in community	4.13	0.89
Participation in biogas production prototype design	4.23	0.73
Disseminate biogas production information to other communities	4.23	0.82

Discussion

Considering the properties of cattle manure and sludge showed that in the biogas production process, more organic substances (VS) are used than inorganic substances (FS), causing the proportion of VS to decrease after the fermentation process. The raw materials affected the concentration of CH_4. After the experiment that used cow manure as a raw material, there was 58.5% CH_4, while previous studies using cow manure as a raw material produced 91.97% CH_4. Using chicken manure as a raw material produced 91.24% CH_4 (Diagi *et al*., 2019), while using chicken manure mixed with Napier grass as raw material produced 74.6% CH_4 (Khunpakdee *et al*., 2017). However, when chicken manure was used as a raw material, it produced 52.04% CH_4, and when chicken manure was mixed with pig manure it produced 57.83% CH_4 (Chaiphet *et al*., 2018). Despite using identical animal excrement as a raw material, there were variations in the amount of CH_4 produced, which could be attributed to the different diets given to each animal group. These affected the properties of the raw materials used, such as the pH, TS, FS, VS, C/N ratio, etc. The pH values of cow manure and sludge were similar at 7.39 and 7.08, respectively. Pakvilai (2021) reported that the optimum pH value for biogas production is between 6.5-7.5 because the bacteria that produce biogas (methanogenic bacteria) are sensitive to low pH values. A suitable pH values for the fermentation of microorganisms in the biogas production process is in the range of 6.5-8.2 (Khunpakdee *et al*., 2017). These pH values are ideal for the anaerobic breakdown of OM by a variety of microbes by means of diverse physiological mechanisms (Sterling *et al*., 2001). Khunpakdee *et al*. (2017) studied the biogas production from co-digestion of the microorganisms of chicken manure and Napier grass in a closed vortex bioreactor system (single-step fermentation tank), the pH value of CH_4 gas production was in the range of 7.9 and 7.82, respectively. The pH value of the fermentation tank was suitable for CH_4 gas to produce microorganisms. Wannakomol (2017) discovered that the pH value increased from 7.23 to 8.83 when microorganisms and shrimp farming waste were co-fermented in the ratio 15W:15SW. These conditions prevented microorganisms from growing and from producing CH_4. One of the suitable factors that affect the CH_4 production process apart from pH and temperature is DM content. An appropriate temperature for biogas production is DM lower than 40% in the hydrolysis/acidogenesis process, and lower than 30% DM in the methanogenesis process (Chandra *et al*., 2012).

Cattle regularly receive feed, which is fermented in the rumen by microorganisms which results in the production of gases, such as CH_4 and CO_2. The gas generated is released through eructation. The bacteria that synthesize methane gas (methanogenic bacteria) generally live in the rumen of ruminants, often attaching to protozoa symbiotically. The methanogens group of microorganisms synthesizes CH_4 from CO_2 and O_2 (Hobson and Stewart, 1997). In the environment of the rumen (reticulo-rumen), the pH value should be in the range of 6.5-7.0 with an appropriate temperature of about 38-40ºC, in addition to being controlled by the type and ingested feed quantity. While the temperature of cow manure (31.88ºC) was slightly higher than that of the sludge (30.02ºC). It was still in the range where mesophilic microorganisms could work in the system at 30-35ºC (Chandra *et al*., 2012). Mesophilic bacteria are a group used in the fermentation of various types of food or wastewater treatment and prefer moderate temperatures between 30-45ºC (Pornchaloem and Rattanapanone, 2023).

Concentrates were normally low in fiber (less than 18%), including feeds such as seeds, cereals such as maize, rice bran, wheat bran, sorghum, bean meal, coconut meal, or by-products from plants and animals. This is consistent with factors related to the ratio of roughage to concentrate in ruminants affecting CH_4 production. High starch diets have been linked to decreased protozoa populations, which have been linked to decreased CH_4 (Morgavi *et al*., 2010). The CH_4-synthesizing bacteria adheres to the cell wall of the protozoa, while the methane production process is performed by the microorganism Archaea, a group of methanogens in the phylum *Euryarchaeota* (Patra, 2012). This is consistent with the decrease in CH_4 emissions proportional to energy consumption when ruminant animals are fed more concentrate diets (Martin *et al*., 2010). Acetic acid (C_2), butyric acid (C_4), and CH_4 increased when a diet high in fiber was fed to the ruminant animals. The pH of the rumen is almost neutral when ruminants consume roughage, but it is significantly lowered in ruminants that consume diets which contain more grain. This results in a highly acidic rumen, which increases the amount of lactate which is an excessive acid rather than end products such as VFAs in terms of C_2 and C_4. The aforementioned findings aligned with the findings of Martin-Orue *et al.* (2000), while propionic acid (C_3) levels in cattle fed on high-grain diets were higher than those on low-grain diets. Thiangchanta *et al.* (2022) reported that the feed type, the proportion of roughage (grass or pineapple peel) and concentrate affected the CH_4 production of cattle. The CH_4 gas concentration was related to the level of roughage, which was consistent with Dinn *et al*. (1998) who found that a total mixed ration (TMR) had different concentrations of protein and by-pass amino acids which affected the amount of N in feces, and urine. The manure of dairy cows fed pangola grass was also shown to produce more methane gas than the manure of dairy cow given pineapple peel, according to a report by Chainetr *et al.* (2022).

In the experiment, the proportion of organic matter (VS) decreased after the fermentation process which may be due to microorganisms decomposing the OM into biogas (Khunpakdee *et al*., 2017). This is similar to the TS that decreased as the time of fermentation increased (Pakvilai, 2021). The proportion between C/N ratio was 28.74, which is consistent with the C/N proportion that is suitable for biogas production (between 20-30) (Gupta *et al*., 2022). Related research has shown the C/N ratio of various raw materials is as follows: chicken manure 11.14, Napier grass 43.48 (Khunpakdee *et al*., 2017), and pig manure 12.62 (Chaiphet *et al*., 2018). The biogas produced from the prototype machine using cattle manure as a raw material in the dry season contained 2.88% N_2, 57.78% CH_4, and 39.29% CO_2. Diagi *et al*. (2019) found that the biogas produced from cattle manure contained 1.35% N_2, 91.97% CH_4, and 6.68% CO_2. The low proportion of CH_4 may be due to the TS value of cattle manure (15.61%) in our study being lower than the TS of cattle manure (47.5%) in the research of Diagi *et al*. (2019).

COD was used for indicating pollutants in wastewater. The decrease of COD in organic matter can improve wastewater quality (Suryawan *et al*., 2021). In the biogas system, organic matter was used to produce biogas which resulted in a decrease in COD concentration (Phorndon *et al.,* 2021). Phorndon *et al.* (2021) studied the COD value of vinasse wastewater compared to the amount of biogas and they found that the amount of COD decreased by more than 70% from 25,000 - 35,000 mg/L to 7,500 - 10,500 mg/L and, similarly, the research of Khunpakdee *et al*. (2017) that used microorganisms to ferment with chicken manure and Napier grass in a closed pond system bioreactor. A whirlpool was found to be effective in removing COD values of up to 65%. When compared with the prototype of our research, it was found that the COD value decreased by 42%, indicating that our prototype was effective in eliminating COD from the environment. The decrease in CH_4 in the rainy season might be due to the feed of the cattle in the rainy season had higher average of cellulose than in the dry season. This is similar to Mibulo *et al*. (2023) who showed that pineapple peels and banana peels had 7.86 and 20.99% cellulose, respectively. In the biogas produced by the prototype system, CH_4 from pineapple peels and banana peels were 70.6 and 64.1%, respectively. The efficiency rate (ER) was calculated as 4.17% of the size of the digester tank. It showed low ER compared to previous prototypes such as a PVC bag biogas production pond (ER 25%, with digester volume of 8 m^3) (Department of Alternative Energy Development and Efficiency, 2011) or a covered lagoon where the fermentation circulated (ER 32.8%, with a digester volume of 0.250 m^3) (Khunpakdee *et al*., 2017). It can be seen that the prototype of our experiment has a fermentation tanks with a volume not suitable for household use. The low ER might have been the result of the increased sunlight which would have caused a high temperature in the steel fermentation tank when the steel was heated by sunlight to a greater degree than would occur in a plastic tank. The high temperature would have affected the microorganisms in the digestion process (Gupta *et al*., 2022). In relation to anaerobic digesters, Bavutti *et al*. (2014) also explained that the temperature and the biogas content were related. The temperature of the digestion bath was lowered by the digester dome's color, which had a high value of solar reflection.

The Department of Alternative Energy Development and Efficiency (2011) showed that 1.0 m^3 of biogas can replace energy in various forms such as thermal energy 39.4 MJ, cooking gas (Liquefied Petroleum Gas; LPG) 0.46 kg, gasoline 0.67 L, and electrical energy 1.40 kWh. In a period of 1 month, the prototype machine produces 1.735 m^3 of biogas, equivalent to 0.80 kg of cooking gas, saving 22.56 Thai baht (THB) per month on cooking gas or approximately 0.64 US DOLLARS (USD). The following reference rate was used: 1 USD (35.0850 THB) (Bank of Thailand, 2024) (calculated from the price of a gas container of 15 kg, is equivalent to 423 THB on August 30th, 2023 (Energy Policy and Planning Office Ministry of Energy, 2023), or approximately 12.06 USD). The chemical compositions of cattle manure and the types of cattle feed had relationships with CH_4. Mibulo *et al.* (2023) found that co-digestion of animal manure and fruit peels could produce a high content of CH_4 because cellulose and hemicellulose from plants were converted to biogas. The prototype should be placed in an area away from heat sources like solar. As manure property related to biogas content, the recommendation in the dry season is to add other agricultural waste to increase the proportions of NDF, cellulose, hemicellulose, NFC, and NFE. The storage tank should be applied to portable for distribution of the biogas in the community in the future.

Biogas was seen to be useful as a renewable energy source to reduce cooking fuel expenses and also it produced organic fertilizer as a by-product. The process of promoting biogas production from community materials in small households provides a guideline for environmental conservation and the utilization of renewable energy (Roubik and Mazancova, 2020; Tansom *et al*., 2020; Shaibur *et al*., 2021). Therefore, the biogas prototype using cow manure was found to be suitable for this community of small farms.

It concluded that this biogas prototype was developed for small farms in a local community, and possibly help farmers reduce cattle manure waste on the farm and CH_4 emissions from cattle manure fermentation. The average biogas volume obtained was 0.058±0.02 m^3/day and approximately 1.735±0.64 m^3/month under the condition of filling 40 L of cattle manure daily for 90 days consecutively. Moreover, different types of cattle feeds affected manure and biogas properties. For the advantage, the compressed biogas in the storage tank allows the biogas production prototype to cook for longer than 30 min a day and the safety materials. This prototype was acceptable to the smallholder farmers who participated in the training. The other agricultural waste in the community, applied in the prototype, should have high TCB, NFC, and hemicellulose together with animal manure.

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Conflicts of interest

The authors declare no conflict of interest.

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