Research article

Performance Assessment of Simple Covered Lagoon Digester in Large-scale Pig Farm in Cambodia

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Abstract Simple covered lagoons are used to treat wastewater from commercial pig farms in Cambodia into biogas. The electricity is generated from biogas using a generator. However, high level of H_2S corrodes or breaks down the generator. This study aims to desulfurize biogas with commercial ferrous oxide pellets (Fe_2O_3). The effects of desulfurization system on biogas production, electricity generation, and CO_2 reduction are discussed. The results show that H_2S was reduced from 2,000 ppm before treatment to around 50 ppm after treatment. CH_4 (57.7 ± 8.76%) and CO_2 (24.7 ± 2.67%) contents were not affected by desulfurization. O_2 content was changed from 0.3 to 4.8%. High O_2 level was a sign of pipe leakage, lowering CH_4 and eventually electricity production. The increase of O_2 level decreased CH_4, thus lowering generator performance. Actual electrical output power produced from biogas was 368.5 ± 29.3 kW, with loading rates of 57.6 ± 4.6% and generator efficiency of 26.8 ± 1.7%. Estimated amounts of 22,818 tCO_2equ were reduced by the biogas system. The desulfurization system was highly effective in H_2S removal without affecting biogas quality. For the long-term biogas systems in Cambodia, local-made desulfurization systems should be tested and compared with imported products.

Keywords biogas, CO_2 reduction, simple covered lagoon, CH_4, desulfurization, electricity generation

INTRODUCTION

Globally, the energy sector that covers electricity, heat, and transport contributes to 73.2% of GHG emissions, whereas livestock accounts for 14.5% (Quinton, 2019). To produce one kWh of electricity, 0.657 kg CO_2 is produced. Meanwhile, a fattening pig ready for slaughter produces 448.3 kg CO_2 (Philippe and Nicks, 2015).

To tackle these issues, zero-emissions in all sectors are discussed in the 26th United Nations Climate Change Conference of the Parties (COP26) held in Glasgow, Scotland, with its intended achievements to keep global warming below 1.5^{o}C this century, specifically targeting CH_4 reduction (UNEP, 2021). According to IPCC (2014), CH_4 is 28 more potent than CO_2 regarding the 100-year global warming potential, so letting it into the atmosphere is much more harmful to the environment. Climate change mitigation in livestock production can be done by anaerobic digestion (AD) technology (Achinas et al., 2017).

In Cambodia, commercial pig farms have increased due to their ability to control the environment necessary for fast pig growth and effective disease prevention (MAFF, 2019). In those farms, evaporative cooling systems are used to maintain temperatures of 25 to 27^{o}C inside the barns (Thanapongtharm et al., 2018). In consequence, electricity consumption is an average of 30 kWh per head (Putmai et al., 2020). Daily wastewater generated from sows, fatteners, and piglets is 64, 24, and 20 m^3 $head^{-1}$, respectively (Kulpredarat, 2016). It has been reported that the pig farm with fattening pigs above 3000 heads have a potential to produce biogas through AD technology.

A common AD type used to treat wastewater from commercial pig farms in Cambodia is a simple covered lagoon digester, with 44 units reported in 2019 (NBP, 2019). They are preferred due to its low-cost construction, easy operation (Rahman and Borhan, 2012) and its suitability for wastewater that contains 0.5 - 2% of dry matter (DM). Hin et al. (2021) found that wastewater from pig farms in Cambodia contains 0.9% DM.

Biogas is a gas mixture that contains CH_4 (60 - 70%), CO_2 (30 - 40%), and other trace elements (Okoro and Sun, 2019; Safferman et al., 2007). CH_4 is the only source of energy to produce heat and electricity for farm use. Nevertheless, biogas contains high hydrogen sulfide (H_2S) concentration up to 3,500 ppm (Hin et al., 2021; Dumont, 2015). H_2S is corrosive to the engine and toxic to humans. H_2S level must be limited to 200-500 ppm for generator operation (Rodrighez et al., 2014). Generally, H_2S removal can be done physically by regulated air injection (Hines et al., 2019), chemically by application of sodium hydroxide (NaOH), potassium hydroxide (KOH), or Ferrous oxide (Fe_2O_3) (Zulkeflia et al., 2016), or biologically by the use of biofilters (Barbusiński and Kalemba, 2016). However, proper desulfurization techniques are little known in Cambodia, especially for large-scale biogas systems. The study aims (1) to compare biogas quality before and after being treated with ferrous oxide (Fe_2O_3) fed in a Chinese commercial desulfurization system, (2) to determine the working capacity of the biogas generator, and (3) to evaluate biogas production, electricity production, the generator efficiency, and CO_2 reduction equivalence.

MATERIALS AND METHOD

Materials

The tools used in this study included A biogas 5000 analyser, supplied by Geotech, UK and Hioki PW3365-20-01/5000 power logger (Hin et al., 2021).

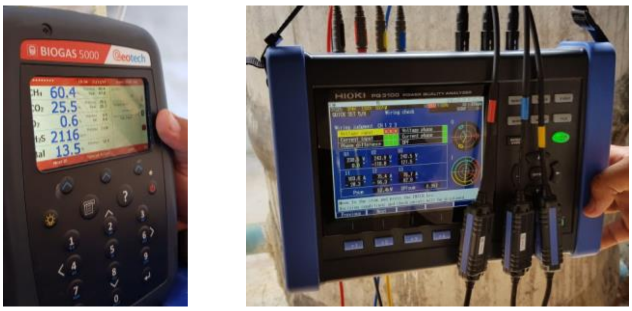

Fig. 1 Geotech biogas 5000 (left) and Hioki PW3365-20-01/5000 power logger (right)

Methods

The research was conducted from January to August 2021 in a large-scale pig farm that raised 38,000 fattening pigs and 3,100 sows under cooling evaporative systems in Sihanoukville Province, Cambodia. The farm used a full biogas system: a simple covered lagoon digester (76,000 m^3 volume), a biogas desulfurization system fed with 2,400 kg of Fe_2O_3, a flow meter with maximum flow rate of 500 Nm^3 biogas, two 640-kW second-hand biogas generators, and a flare used to burn excess biogas. The desulfurization rate was 0.5 kg Fe_2O_3 per 1 Nm^3 biogas.

The biogas 5000 analyser was used to measure biogas quality before and after being treated through the desulfurization system filled with Fe_2O_3 at blowing pressure of 5.6 kPa. Due to travel restriction inside the farm, the data were recorded once a month for 7 consecutive months. Each time, measurements were made three times to obtain average values. The power logger was attached to the generator wiring for 3 hours at a time of data collection to measure actual output power produced from biogas. However, actual output power could be measured only with the post-treated biogas because there was only one outlet pipe connecting the biogas desulfurization system to the generator.

Data Sampling

The collected data were CH_4 (%), CO_2 (%), H_2S (ppm), and O_2 (%). Hourly biogas flow (Nm^3 h^{-1}) and biogas temperature (ºC) were also recorded by using the flow meter that exists in the system. Additionally, four formulas were used in this study as follows. In formula one, CO_2 reduction equivalent (tCO_2 equ.) by avoidance of CH_4 emission equals CH_4-to-CO_2 equivalent x CH_4 density x Annual CH_4 production, while CO_2 reduction by avoidance of grid electricity equals electricity-to-CO_2 equivalent x annual electricity demand met by methane production. CH_4-to-CO_2 equivalent is 28, and electricity-to-CO_2 equivalent is 0.657 kg CO_2 per kWh (Hin et al., 2021). In formula three, Electrical loading rate (%) equals output power divided by the rated power. Formula four is the generator efficiency (%) which was calculated by dividing the output power by the power chemically produced through the internal combustion of biogas. Net caloric value (NCV) of biogas with 60% CH_4 is equal to 20 MJ Nm^{-3}. Thus, the chemical power (kW) produced by biogas combustion is equal to hourly biogas consumption by the generator multiplied by NCV and divided by 360.

Data Analysis and Interpretation

Data were analyzed using the R studio version 4.1.1. Paired sample t-test was employed to compare the biogas quality before and after desulfurization. A simple linear regression was used to identify relationship between CH_4 and O_2. A contour plot was used to determine the effects of biogas flow and CH_4 concentration on active output power produced from the generator. Descriptive statistics were utilized to depict generator performance, biogas generation, and CO_2 reduction.

RESULTS AND DISCUSSION

Biogas Quality

Biogas quality before and after desulfurization system was compared (Fig. 2). Differences in H_2S were detected ($P < 0.001$; Fig. 2a) and it was reduced from 2,061 ± 138.9 ppm before treatment to 50.1 ± 10.2 ppm after treatment. However, one month after the utilization of Fe_2O_3, H_2S rose to more than 200 ppm. The pre-treated H_2S level is similar from previous studies (Dumont, 2015) and (Hin et al., 2021). On the other hands, CH_4 and CO_2 was 57.7 ± 8.76% and 24.7 ± 2.67%, respectively and was not affected by desulfurization (Fig. 2b). These values were lower, when compared to the literature by Safferman et al. (2007) for pig manure in Europe and by Hin et al. (2021) for pig manure in Cambodia and by Wongsapai et al. (2008) in Thailand. Low CH_4 and CO_2

values tends to be affected by the atmospheric air that penetrated into the system through pipelines or the edges of the lagoon plastic cover sheet.

Relationship of CH_4 with O_2 and Average Load with Biogas Flow and CH_4

We studied the relationship between CH_4 and O_2 to determine why CH_4 content was relatively low, as seen in Fig. 2b. Fig. 3a shows that CH_4 decreased with the increase of O_2 ($P < 0.001$; $R^2 = 0.92$). When O_2 increases by 1%, CH_4 decreases by 4.64%. Normally, O_2 level in raw biogas is low. A recommended level of O_2 entering the lagoon should be in the range of 0.3-3% (Hines et al., 2015). So, its high content in this study may signify air penetration into the system, which can be through the pipelines, water traps, or the edges of the lagoon plastic cover sheet. In case leakage is found at the lagoon, high O_2 inhibits methanogenic activities because CH_4 is strictly produced under anaerobic conditions (Botheju and Bakke, 2011). The result of this study is similar to that conducted by Hin et al. (2021). Thus, proper detection is required to inspect pipelines, water traps, and the covered lagoon.

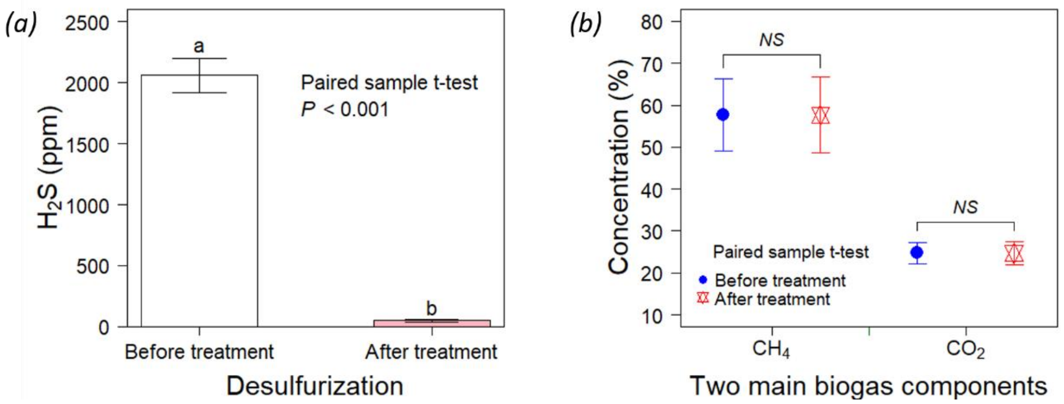

Fig. 2 Comparison of H_2S (*a*) and CH_4 and CO_2 (*b*) before and after desulfurization (Mean ± SD; N = 21)

Paired sample t-test was used for the analysis. Different alphabetic letters denote significant differences at the error level of 0.05, and NS means non-significance.

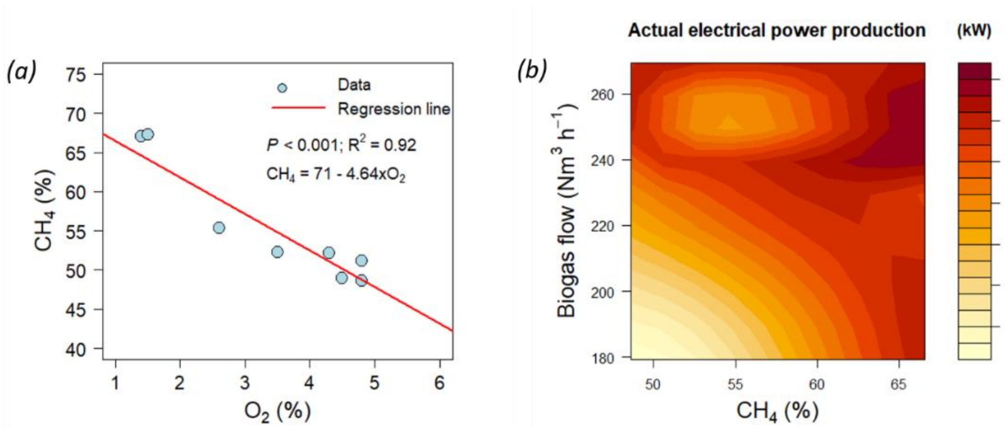

Fig. 3 Relationship between CH_4 and O_2 (*a*), and determination of average load as a function of biogas flow and CH_4 (*b*)

The low CH_4 reduces the biogas generator performance. Figure 3b indicates an average load as a function of hourly biogas consumption and CH_4 content. With the same biogas flow rate, low CH_4 content reduces the amounts of electrical power produced. To maintain the same electrical power produced with low CH_4, unusual high biogas flow rates were recorded, which leads to the overuse of daily produced biogas. In contrast, CH_4 content of 60 - 65% gives better generator performance and reduce the hourly biogas consumption at the same output power.

Specific Biogas Characteristics for Generator Operation

Fed into the generator, the biogas was pushed by an electrical blower at 5.6 ± 0.5 kPa. Its temperature averaged 37.0 ± 5.1ºC, rated best for biogas production (Babaei and Shayegan, 2020). Biogas system produced 4,478 Nm^3 day^{-1}, but the actual daily biogas consumption was 4,862 ± 64.6 Nm^3 day^{-1} (Table 2). Therefore, the amount of biogas consumption was 8.6% greater than the biogas production.

Table 1 Biogas production, electricity consumption, and CO_2 reduction equivalent

Description	Unit	Mean ± SD
Biogas temperature	ºC	37.0 ± 5.1
Estimated daily biogas production	Nm^3 day^{-1}	4,478
Recorded daily biogas consumption	Nm^3 day^{-1}	4,862 ± 64.6
Biogas flow rate	Nm^3 h^{-1}	237.6 ± 29.6
Actual generator power	kW	640
Specific biogas consumption	Nm^3 kWh^{-1}	0.64 ± 0.08
Actual output power	kW	368.5 ± 29.3
Chemical power produced by biogas combustion	kW	1365.9 ± 174.9
Loading rate	%	57.6 ± 4.6
Genset efficiency	%	26.8 ± 1.7
CO_2 reduction equivalent	tCO_2equ yr^{-1}	22,818
CO_2 reduction equivalent per head	tCO_2equ yr^{-1} $head^{-1}$	0.56

In Table 1, the generator was a 640-kW biogas generator, and actual electrical output power produced from biogas was 368.5 ± 29.3 kW, so the loading rate of the generator was estimated at 57.6 ± 4.6% of its full capacity. With the hourly biogas flow rate of 237.6 ± 29.6 Nm^3 h^{-1}, the theoretical electrical power generated from biogas was estimated at 1365.9 ± 174.9 kW. Therefore, the generator efficiency was 26.8 ± 1.7%, and it was higher than the study by De Souza et al. (2016) and Jeong et al. (2009). The specific biogas consumption in this study was 0.64 ± 0.08 Nm^3 kWh^{-1}, which was lower than that studied by De Souza et al. (2016), whose finding was 0.76 m^3 kWh^{-1}.

CO_2 Reduction Equivalent

Using the biogas system reduces the enormous amounts of CO_2 and CH_4 emissions. In this study, the CO_2 reduction equivalent was estimated at 22,818 tCO2equ yr^{-1}, or 0.56 tCO2equ yr^{-1} $head^{-1}$. CO_2 reduction was lower than that studied by Hin et al. (2021). However, it was higher than Peerapong and Limmeechokchai (2017), whose founding was 0.47 tCO_2eq yr^{-1} $head^{-1}$ and for Thai pig farms. The difference in CO_2 emission reduction tends to link with estimated daily manure production.

CONCLUSION

The use of desulfurization system greatly reduced H_2S, but did not affect CH_4 and CO_2 contents. Biogas quality was undermined by higher O_2 levels in it. With low biogas quality, actual electrical power produced from biogas was also low. However, considerable amounts of CO_2 can be cut with this biogas system. The limitations of this study are that the biogas generator performance could be evaluated only with already treated biogas because it is the actual farm operation and altering the system or reconnecting raw biogas pipes to the generator are very costly. Further research will improve biogas quality with locally made desulfurization systems and prolong the age of iron oxide pellet use to reduce labor and increase system operation efficiency.

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