Short Communication

Potential development of compressed bio-methane gas production from pig farms and elephant grass silage for transportation in Thailand

Natthawud Dussadee *, Kamoldara Reansuwan, Rameshprabu Ramaraj

School of Renewable Energy, Maejo University, Sansai, Chiang Mai 50290, Thailand

HIGHLIGHTS

- We developed an anaerobic co-digestion process of pig manure with grass silage.
- We set up an industrial scale experience to utilize biogas.
- Compressed bio-methane gas (CBG) to be used as automotive fuel.
- Potential developments of CBG gas production deliver to transport.

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ABSTRACT

This research project evaluated biogas production using anaerobic co-digestion of pig manure and elephant grass silage in large scale to delivered transportation directly for cars. Anaerobic co-digestion was estimated in three full-scale continuously stirred tank reactors (CSTRs) at 40 °C. In the form of compressed bio-methane gas (CBG) production was 14,400 m³/day (CH₄ 60–70%) amount of CBG was 9600 m³/day. The procedure was enhanced by using molecular sieve, activated carbon for removal of moisture and CO₂, membrane H₂S and CO₂ respectively. The results were demonstrated the amount of CO₂, H₂S gas was reduced along with CH₄ was improved up to 90% by volume and compressed to 250 bar tank pressure gauge to the fuel for cars. The CBG production, methane gas improvement and performance were evaluated before entering the delivered systems according to the energy standards. The production of CBG is advantageous to strengthen the Thailand biogas market.

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1. Introduction

Renewable resources of energy are a part of the Asian region fight against climate changes, at the same time they contribute to economic growth, increasing the number of employed people and provide energetic safety. Biogas production and use are generally regarded as a sustainable practice that can guarantee high greenhouse gas savings (Weiland, 2010). The biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits and is an additional source of income for farmers. Consequently, biogas technology is becoming increasingly popular throughout the world, particularly in countries where governments promote domestic biogas systems.

Thailand is one of the fastest growing, energy intensive economies in Southeast Asia. Energy demand required to meet the economic growth of Thailand is high and growing every year. Currently, energy is one of most sensitive issues in Thailand, where almost 50% of the total commercial energy supply was imported (Aggarangsi et al., 2013). Thailand is an agricultural country with around 34% of the households throughout the country working in agriculture and 93% of them located in rural areas. The two major activities in the agriculture area are the cultivation of crops (54%) and integrated crop–livestock farming (35%). The major forms of livestock in Thailand are pigs, chicken and cattle (Charoensook et al., 2013). Accordingly, Thailand, as the country has the potential biogas as a country with a lot of agriculture; including raw materials from crops and livestock, it can be used to develop renewable energy in the form of biogas is methane gas caused by the decomposition of organic matter in the system. And the biogas resources are from industrial wastewater and live stock manure, which have potential of 7800 and 13,000 TJ/year, respectively (Tippayawong and Thanompongchart, 2010). In Thailand, biogas is mostly derived from domestic pig manure used as fuel. Recently, most of the agricultural biogas plants digest manure with the addition co-substrates to increase the content of organic material for achieving a higher gas yield (Álvarez et al., 2010). For these reasons co-digestion is commonly practiced and most recommended co-substrate was manure.

Co-digestion has been defined as the anaerobic treatment of a mixture of at least two different substrates with the aim of...
improving the efficiency of the anaerobic digestion process. At present, there are an increasing number of full-scale co-digestion plants treating manure and industrial organic wastes. Co-digestion of mixed substrates offers many advantages, including ecological, technological, and economic benefits, compared to digesting a single substrate. However, combining two or more different types of feedstocks requires careful selection to improve the efficiency of anaerobic digestion (Álvarez et al., 2010). The main resource is represented by animal manure and slurries from cattle and pig production units as well as from poultry, fish, etc. And agricultural substrate suitable for anaerobic digestion is represented by energy crops, of which most common are grain crops, grass crops and maize. Grass crops are among the most promising energy crops for biogas production (Seppälä et al., 2013).

Grassland biomass is suitable in numerous ways for producing energy. Using grassland biomass for producing energy especially biogas production currently is the most common. There are so many types of grasses that are popularly grown in Thailand. Grass is converted to silage to be used as feedstock for anaerobic digestion (Seppälä et al., 2013). Furthermore, grass silage, due to its high digestible organic matter content, is also an excellent feedstock for anaerobic digestion. Elephant grass (Pennisetum purpureum) is one of the most promising grasses available for ruminant production in tropical and subtropical areas because of its high potential dry matter yield (Yang et al., 2013). Consequently, the main objective of this research was to produce large amount of biogas yield from pig farms and co-digesting with grass and to deliver the transport directly.

2. Methods

2.1. Grass silage preparation and reactor design

Pig manure and pig form waste water was obtained from a pig farm “the sacred pig farm and Sons Farms Ltd” in Chiang Mai, Mae Taeng district, Thailand. The farm has 35,000 pigs; those pigs were produce fresh active substrate of about 10–12 tons per day mixed with the effluent a day and the farm size is about 300 m². Elephant grass was collected from the agriculture form which was cultivated around Mae Taeng district, Thailand. The Elephant grass silage (grass silage) was used about 20–23 tons per day which was grown at 45 days period. The grass silage particle size was 1.0 mm.

In this study performed with continuously stirred tank reactors (CSTRs) and triplicate production units (i.e. CSTR1, CSTR2, and CSTR3) were used; each unit having a working capacity of 1700 m³ per tank and a volume control for consistent feed. The CSTRs were placed on a three-position stirrer hotplate system.

2.2. Substrates preparation and experiment procedure

The continuous experiment fed with sewage sludge and shredded grass was stably operated for 31 days (data was not shown). As the main objective of this work was the anaerobic treatment of pig manure and wastes (due to the relatively high volume generated in the region), with elephant grass silage as co-digestion experiments using CSTRs. The experiments were carried out at mesophilic (40 °C) temperature. The prepared pig farms substrates (10–12 tons per day) and grass silage (20–23 tons per day) was pumped through a grinder and then to the equalization tank. The tank capacity was 150 m³. The equalization tank was preheated with preheating unit up to fixed fermentation temperature. The thermal capacity was 600 kW.h. This setup was connected with two anaerobic bacteria cultivation tanks (capacity is 20 m³) and anaerobic bacteria storage / dosing tank (2 × 0.2 m³). The bio substrate feed was provided 32,500 kg/24 h, as liquid 325 m³/24 h to the fermenters. Fermenters were run 24 h continuously; cascade continuous temperatures of the fermentation tank were fixed and constant throttling feed regularly. In addition, the installations of tank agitator, agitator control system of PLC (Programmable Logic Controller) were connected with fermentation tank. Subsequently, the gas production process was monitored and followed the gas quality improvements. The process of gas quality improvement was performed by using molecular sieve, activated carbon for removal of moisture and membrane for hydrogen sulfide (H₂S) and carbon dioxide (CO₂) removal, respectively. Gas quality improvement was tested and evaluated the system performance and quality improvement after that compressed gas cylinders. It so called compressed biomethane gas (CBG) product. The CBG was delivered to the right and a gas pump supplier for cars in Thailand.

2.3. Analytical methods

The pH determination procedure was adopted from Weiland (2010). Biogas composition in laboratory test (CH4, CO2, H2, H2S, and O2) was measured using an automated gas analyzer according to Brett Schneider et al. (2004). Biogas composition was analyzed according to ASTM-D1945-03 (2010). Standard test method for analysis of natural gas by gas chromatography (GC) and to Standard UNE-EN ISO-6976-2005, Natural Gas-Calculation of calorific values, density, relative density and Wobbe index from composition (UNE-EN ISO-6976, 1995).

3. Results and discussion

3.1. Biogas production

Anaerobic co-digestion of pig substracts and grass silage on the digestion process was studied in three CSTRs units with the same substrate. The efficiency of gas production in biogas digesters depends on temperature, pH, and suitable co-digesting bio substrates and reactor design (Vindis et al., 2009). Biogas fermenters were maintained at constant rates of temperature and pH; were continuously monitored and stable operation of the process was continued. Temperature markedly affects the biogas yield during anaerobic digestion of manure by affecting the thermodynamics of acetogenic reactions and methanogenic reactions. Most of methanogenic microorganisms are mesophiles and very sensitive to thermal temperature. Constant temperature is important for preventing negative effects on biogas production (Weiland, 2010). Consequently, the available literatures suggestions, chosen optima temperature was 40 °C in this study.

Co-digestion of pig manure with energy crop residues can increase the biogas yield by maintaining an optimal pH for methanogens. Hence, pH is necessary to be in desired range because it directly affects the growth of microbes. Biomethanation formation takes place within a reasonably narrow pH range, from 6.8 to 7.5. At such level, methane content in the biogas could theoretically be up to 72–82% at pH 7.2–7.4 (Rittmann and McCarty, 2001); therefore in this selected optimum pH was 7.3 for this research. Anaerobic digestion of animal slurry, agricultural feedstock for biogas production is commonly practiced in continuously stirred tank reactor (CSTR). Also known as a completely stirred tank reactor, the complete mixed system is most commonly a circular tank with a mechanical agitator. The mixing prevents settling and maintains contact between bacteria and the manure/prepared...
substrate. It also helps maintain a uniform temperature. In addition, CSTR is the most widespread technology is characterized by mesophilic conditions (Fantozzi and Buratti, 2009). The estimation of biogas production and operation processes is listed in Table 1. The present results show that anaerobic digestion of pig manure and grass silage in CSTRs is feasible. The triplicate CSTR fermentation biogas production was 14,400 m$^3$/day; CBG production (i.e. 9600 m$^3$/ or 6.8 tons per day) was containing methane (CH$_4$) 60–70% of total compressed biomethane gas. Biogas consists of multiple gas species such as CH$_4$ 50–70% and CO$_2$ 30–50%; the rest is other gases such as ammonia (NH$_3$) and water vapor, etc. The study results were expressed the composition of biogas, CH$_4$, CO$_2$, O$_2$ and H$_2$S contents were found as 68.8%, 29.7%, 0% and 768 ppm, respectively.

3.2. Compressed biomethane

Biogas is comprised of CH$_4$, CO$_2$, and other compounds including H$_2$S, water, and other trace gas compounds afore mentioned. To utilize biogas as a transport fuel, CO$_2$ and H$_2$S must be removed from the concentration to leave biomethane. Moreover, before biogas can be used as vehicle gas, a process of upgrading is necessary (Deublein and Steinhauser, 2008). Murphy and Power (2009) emphasized that a successful method of removing the key component CO$_2$ is by water scrubbing as CO$_2$ dissolves far more readily in water than CH$_4$. In addition, the amount of CH$_4$ should be increased by the equivalent of natural gas for vehicles (NGV) or compressed natural gas (CNG) and compressed into a tank force. By removing carbon dioxide, moisture, hydrogen sulfide and other impurities biogas can be upgraded to biomethane, a product equivalent to natural gas. Biomethane can be used as compressed natural gas (CNG) in natural gas vehicles. Compressed natural gas (CNG) is a form of natural gas storage that is stored at a high pressure around 200 bar. In the form of which could be biogas upgraded to biomethane and subsequently used as a transport fuel in a CNG vehicle. CBG is equivalent to CNG. Compressed biomethane is almost identical to compressed natural gas, which is currently used as a transport fuel in many countries worldwide such as Sweden and Austria. Furthermore these countries are also using compressed biomethane as a standard transport fuel. In this study, CBG production processes are shown in Fig. 1.

3.3. Biogas quality improvement and technologies

Improvement of biogas is crucial in order to meet requirements which are demanded not only by the application of the burners, but also by the gas grid which transports the gas. To obtain biomethane of a quality comparable to the natural gas with high methane content, it is necessary further enrichment of biogas. This is the most demanding process in terms of the technology. In this work, a method for biogas scrubbing and CH$_4$ enrichment process was presented in Fig. 2. Nowadays, PSA (Pressure Swing Adsorption) and water scrubbing is the most employed technique for upgrading biogas (Bekkering et al., 2010).

Biogas contains water vapor, and the removal of water vapor is essential as it combines with the other contaminants such as hydrogen sulfide or halogenated compounds to produce corrosive acids. Gas purification can also be carried out using some form of silica, alumina, activated carbon or silicates, which are also known as molecular sieves (Pettersson and Wellington, 2009). In this study, two molecular sieve tanks are used and capacity was 3.2 m$^3$ per tank to absorb water from the biogas. By a proper choice of adsorbent, the process can remove CO$_2$, H$_2$S, moisture and other impurities either selectively or simultaneously from biogas. H$_2$S is formed from digestion of proteins and other material that contain sulfur. Since H$_2$S is highly corrosive it is highly recommended to separate it early in the biogas upgrading process (Deublein and Steinhauser, 2008). In addition, the activated carbon tank (2 m) was used to eliminate H$_2$S to less than 1 ppm before entering the gas tank. The gas tank size was 200 m$^3$ and a gas pressure was 0.6 bar using gas compressor package with a 20 bar. It was suitable for CO$_2$ removal process (Nord et al., 2009).

Removal of CO$_2$ from natural gas using membrane separation has become a promising approach as compared to conventional

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**Table 1** Biogas production system and measurement.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of reactor (fermentation tanks)</td>
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<td>Tank</td>
</tr>
<tr>
<td>Type of reactor</td>
<td>CSTR</td>
<td></td>
</tr>
<tr>
<td>Volume of reactor</td>
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<td>m$^3$</td>
</tr>
<tr>
<td>Used volume of reactor</td>
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<td>m$^3$</td>
</tr>
<tr>
<td>Volume of biogas</td>
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<td>m$^3$</td>
</tr>
<tr>
<td>Biogas production rate$^a$</td>
<td>600</td>
<td>m$^3$/h</td>
</tr>
<tr>
<td>CBG production rate$^b$</td>
<td>14,400</td>
<td>m$^3$/d</td>
</tr>
<tr>
<td></td>
<td>9600</td>
<td>m$^3$/d</td>
</tr>
<tr>
<td></td>
<td>6883</td>
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</tr>
<tr>
<td></td>
<td>6.8</td>
<td>tons/d</td>
</tr>
</tbody>
</table>

$^a$ Biogas production rate = volume of biogas $\times$ quantity of reactor.

$^b$ CBG production rate = biogas production rate $\times$ methane 60% (biogas).

$^c$ CBG production rate = specific gravity of methane gas 0.717 kg/m$^3$.

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**Fig. 1.** The compressed biomethane gas production (CBG).
processes. Membrane technology is becoming more important for CO₂ separation from natural gas. This is due to advantages such as operational simplicity, high reliability, low capital and operating cost, environmentally friendly, good weight and space efficiency along with reduced energy consumption (Dortmundt and Doshi, 1999). CO₂ membrane technology of UOP–LLC was adopted in this study (Dortmundt and Doshi, 1999). The membrane set up was connected with compressor booster. Compressed gas was passed through the compressor booster; it containing ground storage pressure of 250 bar and a flow rate of 330 m³/h. The control system and addition of CBG (CBG decant panel) was monitored continuously by PLC (Programmable Logic Controller). The system performance quality and compressed gas cylinders were evaluated. Gas samples were collected and analyzed. Gas improvement before and after purification yields are listed in Table 2.

Before entering the improve system biogas containing CH₄, CO₂, O₂ are 68.8%, 29.7% and 0% with H₂S 768 ppm. After the enhancement process CBG meet the standard of the Department of Energy; the CBG having CH₄, CO₂, O₂ are 89.35%, 10.05% 0% and 0.02% with <0.01 ppm H₂S. Consequently, H₂S was removed to below the detection limit and methane content was reached about 90%. Production of CBG was used as automotive fuel for NGV substitution. This study was examined the use of CBG for cars in Mae Taeng District. The upgraded biogas will be used for vehicles in rural areas. CBG production units are installed on pig farms in Mae Taeng District, Chiang Mai Province, Thailand.

4. Conclusion

Biogas production is best tool to solve the problems of global warming, energy security and waste management. Anaerobic co-digestion of the concentrated pig manure with grass silage was operated at mesophilic temperature. The results obtained in this study suggest that co-digestion of pig manure and grass silage is a promising approach for improving biogas production. The upgraded gas was containing CH₄ (89.35%), CO₂ (10.05%), O₂ (0.02%) and H₂S (<0.01 ppm), which were meet up the standard of the Department of Energy. Efficiency criteria explained good performance throughout the study.

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