Enhancement of biogas production from bio-sludge and batch experiment for biogas potential set-up

การเพิ่มผลผลิตก๊าซชีวภาพจากกากตะกอนชีวภาพและการเตรียมชุดทดลองศึกษาศักยภาพการผลิตก๊าซชีวภาพ

Nutchanat Chamchoi*

Abstract

Anaerobic digestion is an efficient waste treatment and generates biogas. The producing biogas can be used for electricity and heat a generator. Biogas obtained from bio-sludge is an attempt to achieve the waste gain and minimization. The enhancement of biogas production from bio-sludge can be achieved by conducting of a treatment stage before or after anaerobic digestion. Thermal-alkaline condition at 170 °C with pH 10 used as a pre-treatment provided an improvement of 54% of biogas production while, athermal microwave showed an increase in 16% of biogas production.

The important aspects to create a batch experiment on biogas potential from the waste include the homogeneity and analysis of the waste composition, which consists of total solids, volatile solids, total kjeldahl nitrogen, ammonium, lipids, COD, and pH. Volatile fatty acids evolution is recommended to monitor during the batch experiment for investigating the relation or inhibition effect on biogas production especially during the start-up period of the experiment. Nevertheless, considering of statistical and experimental control is also recommended for accuracy and reliability of the obtained results.

Keywords : Anaerobic digestion, Biogas production, Bio-sludge, Volatile fatty acids

บทคัดย่อ

การย่อยแบบไร้อากาศเป็นระบบกำจัดของเสียที่มีประสิทธิภาพ และก่อให้เกิดผลผลิตก๊าซชีวภาพ ก๊าซชีวภาพที่ผลิตขึ้นสามารถใช้สำหรับเครื่องผลิตกระแสไฟฟ้าและความร้อน ก๊าซชีวภาพ

* Lecturer, Faculty of Public Health and Environment, Huachiew Chalermprakiet University

ที่ได้มาจากกากตะกอนชีวภาพเป็นหนึ่งในความพยายามลดและใช้ประโยชน์จากของเสีย การเพิ่มผลผลิตก๊าซชีวภาพที่ได้มาจากกากตะกอนชีวภาพ ทำได้โดยเพิ่มขั้นตอนบำบัดก่อนหรือหลังการย่อยแบบไร้อากาศ การใช้ความร้อนร่วมกับสภาพด่างที่ 170 องศาเซลเซียส พีเอช 10 เป็นขั้นตอนบำบัดก่อนการย่อยแบบไร้อากาศ ทำให้สามารถเพิ่มผลผลิตก๊าซชีวภาพได้ร้อยละ 54 ในขณะที่การใช้ความร้อนจากไมโครเวฟ ทำให้ผลผลิตก๊าซชีวภาพเพิ่มขึ้นร้อยละ 16

สิ่งสำคัญในการศึกษาทดลองเพื่อประเมินศักยภาพการผลิตก๊าซชีวภาพจากของเสีย ประกอบด้วย ความเป็นเนื้อเดียวกันของของเสีย และการวิเคราะห์องค์ประกอบของของเสีย ได้แก่ ของแข็งทั้งหมด ของแข็งระเหยง่าย ทีเคเอ็น แอมโมเนียม ไขมัน ซีโอดี และพีเอช การติดตามตรวจสอบการเปลี่ยนแปลงของปริมาณกรดไขมันระเหยง่ายเป็นสิ่งที่แนะนำเช่นกัน เพื่อสังเกตความสัมพันธ์หรือผลยับยั้งที่มีต่อผลผลิตก๊าซชีวภาพ โดยเฉพาะในช่วงเริ่มต้นของการทดลอง นอกจากนั้น ควรพิจารณาด้านสถิติและชุดทดลองควบคุม เพื่อความถูกต้องและน่าเชื่อถือของผลการทดลองที่ได้

คำสำคัญ : การย่อยแบบไร้อากาศ ผลผลิตก๊าซชีวภาพ กากตะกอนชีวภาพ กรดไขมันระเหยง่าย

1. Introduction

By-product from wastewater treatment, bio-sludge, requires a proper disposal procedure. Generally, sludge disposal methods consisted of landfill, composting, and incineration (Pollution Control Department. 2008). Alternatively, in present, it can be used in anaerobic digestion for producing biogas.

Biogas can be used in factory boilers and engine generator sets to produce electricity and heat. The use of biogas is increasing rapidly today according to the continuity rising of fuel costs and the taxation burden increases, as well. The compressed biogas can be used in vehicle transportation, which becoming widely used in European countries. In Thailand, biogas is obtained from two major sources such as sanitary landfill and animal farm (Energy for Environment Foundation. 2005). The problem for obtaining available landfill gas is from the non-steady quantity and quality production. Target animal farm producing biogas in Thailand is a pig farm in different scales as small, medium, and big farm (Energy for Environment Foundation. 2005).

2. Anaerobic digestion process

Anaerobic digestion process is an efficient waste treatment technology that harnesses natural anaerobic decomposition to reduce waste volume and generate biogas at the same time (Chen, et al. 2008). Biogas typically contains 55-75% of methane and 30-45% of carbon dioxide (Igoni, et al. 2008).

The process begins with the hydrolysis, acidogenesis, acetogenesis, and finally methanogenesis (Ciborowski. 2004) (Figure 1). Hydrolysis is a chemical reaction during which one or more water molecules are split into hydrogen and hydroxide ions which may go on to participate in further reactions. Acidogenesis is a biological reaction where simple monomers are converted into volatile fatty acids. Acetogenesis is a biological reaction where volatile fatty acids are converted into acetic acid, carbon dioxide, and hydrogen. Finally, methanogenesis is a biological reaction where acetates are converted into methane and carbon dioxide, while hydrogen is consumed. A simplified generic chemical equation for the overall processes outlined above is as follows :

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad \text{........(1)}$$

An important aspect of the anaerobic digestion process consists of temperature, hydrogen-ion concentration, carbon-nitrogen ratio, loading rate, as well as moisture and heat contents which should be considered to achieve optimal conditions for biogas production. Optimal conditions for anaerobic digestion include pH value of 6.8-8.0. This pH value is for optimal bacterial activity. Carbon to nitrogen ratio of about 30 : 1 is an ideal for the raw material fed into a biogas plant. An optimal temperature ranges are the mesophilic and thermophilic of 30-38 °C and 44-57 °C, respectively (Igoni, et al. 2008). Biogas produced outside this range may have a higher percentage of carbon dioxide and other gases than within this range. In order to achieve high amount of biogas production, the applied improvement methods like pre-treatment and post-treatment for the digestion process are interesting aspect.

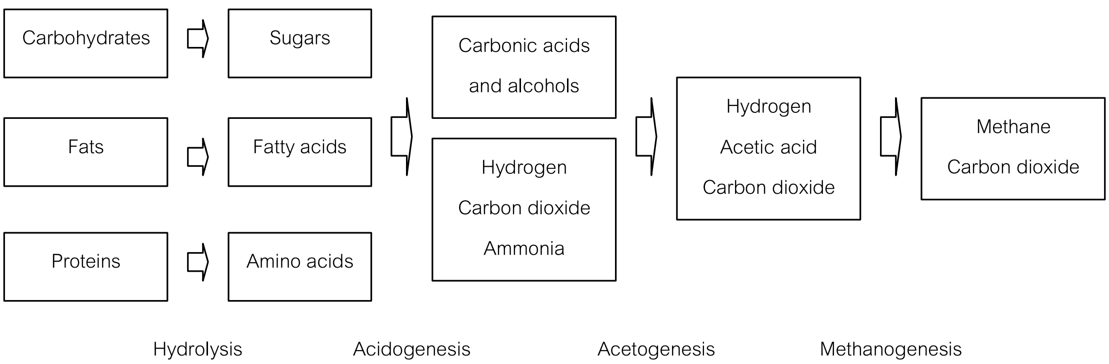


Figure 1 Key process stages of anaerobic digestion

3. Bio-Sludge

Biological wastewater treatment produces different sorts of sludge within the individual process steps such as primary sludge, activated sludge, and tertiary sludge (Lenntech Water Treatment & Air Purification Holding B.V. 2008) (Figure 2). The term "Bio-sludge" is used and such sludge produced from the treatment of wastewater both in on-site (e.g. septic tank) and off-site (e.g. activated sludge) systems.

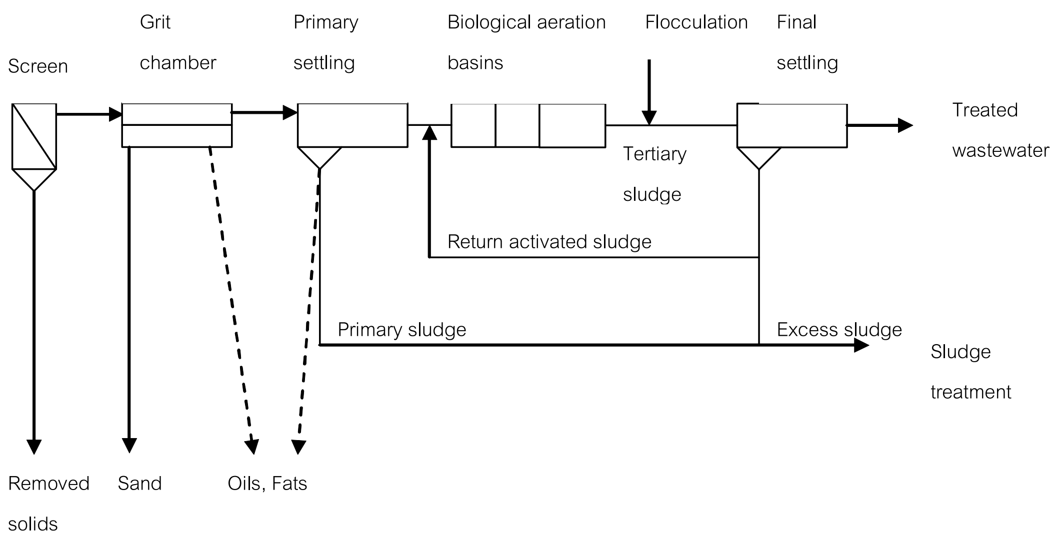


Figure 2 Sludge sorts

Many kinds of organic solid waste or sludge were used in anaerobic digestion for producing biogas such as organic fraction of municipal solid waste, industrial sludge, and cattle manure (Capela, et al. 2008). Zupan CiC, et al. (2008) reported that when organic waste was added to the digester influent, the biogas quantity increased by 80%. The general composition of bio-sludge is shown in Table 1 (Valo, et al. 2004).

Table 1 Composition of bio-sludge; waste activated sludge

Parameters	Total	Soluble
Total solids (g dm^{-3})	17.1	3.3
Volatile solids (g dm^{-3})	12.0	0.8
COD (mg O_2 dm^{-3})	17,400	470
pH	6.8	-

4. Treatment conditions for enhancement of biogas production

The attempts to enhance biogas production have been conducted especially in European countries due to a lot of existing biogas plant along farming area in their countries. The research carried on the enhancement of biogas production is separated into 3 aspects in different treatment conditions.

4.1 Thermal treatment

Thermal condition is mostly used as pre-treatment and post-treatment stage for anaerobic digestion. The studies have been conducted under temperature range of 50-90 °C (Gavala, et al. 2003 ; Vlyssides and Karlis. 2004) and 120-175 °C (Stuckey and McCarty. 1984 ; Takashima, et al. 1996 ; Barjenbruch and Kopplow. 2003 ; Valo, et al. 2004).

4.2 Thermal-alkaline treatment

Alkaline heat is used in a pre-treatment with the total efficiency for methane production of 0.28 L of CH_4 per g of VSS loading (Vlyssides and Karlis. 2004) and in a post-treatment, it showed selectively destroyed unbiodegradable components of the activated sludge (Takashima, et al. 1996).

Alkaline condition can be provided with using potassium hydroxide (KOH) or sodium hydroxide (NaOH). The alkaline solution is added to the sample in order to reach high pH (i.e., pH of above 10) and then heat at selected temperature and time (i.e., 170 °C for 15 min) (Valo, et al. 2004).

Both high temperature and alkaline condition used as the pre-treatment stage showed an improvement of biogas production. Temperature of 170 °C with pH 10 was reported as an optimal condition for anaerobic digestion, which showed an improvement of 54% in biogas production (Valo, et al. 2004).

4.3 Athermal microwave treatment

Athermal microwave treatment has been tested in a microwave at 1.2 °C/min with temperature range of 50-96 °C (Eskicioglu, et al. 2007). The results which showed an improvement of biogas production indicated that athermal effect had a positive impact on the mesophilic anaerobic biodegradability of waste activated sludge. The biochemical methane potential (BMP) tests also showed that microwave acclimated inoculum digesting pretreated (to 96 °C) waste activated sludge, produced 16±4% higher biogas compared to the control after 15 d of mesophilic batch digestion.

5. Batch Experiment for biogas potential set-up

5.1 Preparation of the sample waste

Waste sample should be roughly blended if it shows originally heterogeneous in physical appearance for ensuring homogenous sampling. However, the properly blending system should maintain the original composition of the waste as well. Anaerobic digestion is normally conducted in batch experiments using glass bottles in various sizes (Figure 3). The recommended size is 1 L with the proportion of inoculum and waste slurry of 400 mL : 100 mL (Hansen, et al. 2004). The waste added in the batch vials in an amount of 100 mL slurry in water. Then, the waste mixed with water into slurry of selected ratios depends on each experimental objective. The 2gVS of the waste per 400 mL inoculum was previously reported as an optimum substrate/inoculum composition for methane potential assays (Hansen, et al. 2004). Inoculum should be continuously stirred and kept under anaerobic conditions during transferring stage. After the waste slurry and inoculum is added into the bottles, the bottles should be flushed with N2 for 2-3 mins. to provide anaerobic conditions. The bottles are then placed in the incubator at thermophilic temperature (i.e. 55 °C). Batch test should be carried out in at least triplicate for accuracy results. One bottle for each experimental design should be used for volatile fatty acids sampling, while the others are used for detection of the accumulated methane production in the head space of the vials. Three blanks with only water and inoculum are recommended to include for measuring the methane production from the inoculum only. Moreover, the controls are also recommended to perform using a reference substrate like avicel (cellulose) for reliable results.

Figure 3 Batch experiment of biogas potential using glass bottles (Source; Department of Environmental Engineering, DTU, Denmark)

5.2 Monitoring and evaluation of data

Methane content in the headspace of the test bottles should be measured throughout the experiment. The effect of pre-treatment conditions can be evaluated by comparison of methane yields from untreated and treated samples. During the first week of experiment, the measurement is recommended to conduct daily. Later, it can be flexible observed once or twice a week. Volatile fatty acids (VFA) evolution in each substrate concentration should be monitored during the experiment to investigate the relation or inhibition effect on methane potential. During non steady state operational periods (start-up or organic shock loads), VFA will accumulate as a result of an imbalance between production and consumption in the process (Angelidaki, et al. 2006).

The headspace of each bottle is calculated by subtracting the added amount of inoculum and substrate (assuming the density of substrate and inoculum is 1 g mL^{-1}) from the volume of the bottle. Gas sampling of 0.2 ml of headspace is measured directly on the GC and the produced amount of methane is determined followed the accepted method. The method of Hansen and others. (2004) is the one from the Technical University of Denmark (DTU). The actual methane production from the waste is calculated by subtract the methane production from the blanks containing only inoculum.

5.3 Parameter requirement for monitoring of biogas production

Determination of the waste composition such as total solids (TS), volatile solids (VS), pH, COD, total Kjeldahl nitrogen (TKN), ammonium (NH_4-N), and lipids are important parameters used for batch biogas potential. TS and VS are normally measured by drying the sample at 105 °C for 24 hours and then igniting it at 550 °C for 2 hours respectively. The pH and COD can be analysed by pH meter and closed reflux method, respectively. TKN and ammonium are generally measured by the titrimetric method. Lipids can be analyzed by the soxhlet method. All parameters should be analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA. 1998). Protein content in the waste can be estimated by multiplying the organic N content with 6.25 which corresponds to the molecular weight/N-weight ratio of a typical amino acid. Biogas composition emphasis on methane is quantified with a gas chromatograph equips with either a thermal FID or TCD detector working in the range of methane content ~ 5-100%. Volatile fatty acid (VFA) is an intermediate compound in anaerobic reaction. It can also be analyzed by gas chromatography. All required parameters and analyzed methods are summarized in Table 2.

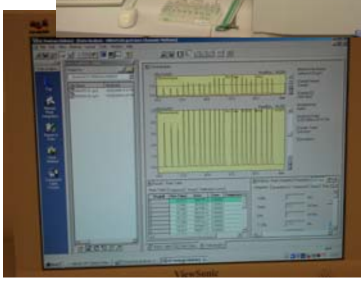
Table 2 Parameters requirement and analyzed methods for batch biogas potential study

Parameters	Analyzed methods/Equipment used
Total solids	Drying at 105 °C
Volatile solids	Igniting at 550 °C
pH	pH meter
COD	Closed reflux method
Total Kjeldahl nitrogen	Titrimetric method
Ammonium	Titrimetric method
Lipids	Soxhlet method
Biogas; Methane	Gas chromatography
Volatile fatty acids	Gas chromatography

Furnace and Incubator VS and TS

Soxhlet apparatus for lipids

Distillation apparatus for ammonium



Gas chromatography forbiogas and VFA

Figure 4 Apparatus for batch biogas analysis

(Source; Department of Environmental Engineering, DTU, Denmark)

6. Conclusions

The enhancement of biogas production from bio-sludge can be conducted by using pre-treatment and post-treatment of anaerobic digestion. Thermal and thermal-alkaline conditions are used in both pre-treatment and post-treatment, whereas athermal microwave has been used as pre-treatment stage. The treatment conditions resulted in an improvement of biogas production of 54% and 16% for thermal-alkaline and athermal microwave, respectively. Important issues for batch experiment of biogas potential study include the homogeneity of waste and the analysis of waste composition, which can be used for estimating of theoretical biogas production. Accuracy and reliability of experiment and monitoring data is achieved by conducting of the experimental control and considering of statistical aspect.

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