Energy recovery of sewage sludge treatment by anaerobic co-digestion

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Abstract. Sewage sludge produced from wastewater treatment is one of the challenges facing many countries in their development process; therefore, the sewage sludge needs treating suitably. Besides, recovering energy from waste to save operating costs in treatment plants is also being considered. The study was conducted by mixing urban sludge samples with substrates (agricultural residues) to create different C/N ratios from 16.6 to 32.5, then evaluating the quantity and quality of methane) the gas generated from the test pieces. This method not only solved the environmental problem but also had benefited from biogas produced from the digestion process. The initial results showed that the quantity of biogas from anaerobic co-digestion of sewage sludge and rice husk (ratio 4:1) are 160ml/g VS. Furthermore, the quality of methane can be up to 60% and near twice as much as mono-digestion. The study results estimate that the potential of recovering electricity from the sludge for the wastewater treatment plant of Binh Hung (Vietnam) is about 0.2 MW/year or higher.

1. Introduction
Nowadays, the management and treatment of sewage sludge produced from wastewater treatment plants is the most serious biological treatment challenge. Fresh and untreated sludge will have many pathogens and normally odorous, putrid. Sludge treatment accounts for half, even up 60% of the total wastewater treatment cost [1]. The challenge facing the sludge managers is finding a suitable solution, effective cost, and environmental and economical, and social benefits.
Currently, Ho Chi Minh City only has Binh Hung wastewater treatment plants, which treated 150,000m³ every day, and the wastewater treatment process will generate approximately 30 tons of sludge [2]. According to the sewage system plan by 2025 [3], 12 wastewater treatment plants will be completed with a total processing capacity of up to 2,912,000 m³/day; therefore, the amount of sludge generated can be up to nearly 200 tons/day. Nowadays, the sludge of Binh Hung Plant is treated by
stabilization, de-watering and drying process, this process was odorous, putrid and air pollution. The anaerobic digestion can be solved this problem - one of the challenges facing sludge treatment. The sludge treatment process by anaerobic digestion was accounted for about 38% of sewage sludge, the second most popular treatment process in India [4]. Anaerobic digestion seems to be the most popular stabilization method in European countries, applying in 24 countries [5]. Sewage sludge-treatment scenario with anaerobic digestion was the most environmentally and economically suitable method to treat sewage sludge because of energy recovery [6]. Simultaneously, a massive quantity of wastes from the agricultural process all over the world. These wastes account for a significant proportion of agricultural production. However, the treatment of agricultural wastes is disposed of by incineration or landfill. This process caused damage that affected the environment. Furthermore, agricultural wastes are valuable resources, which can be recovered and diverse economic, social and environmental purposes [7]. The increasing materials such as rice straw, rice husk, water hyacinth, and cassava peel can be paid more attention to researchers, especially recycling and waste to energy issues. Finding a suitable solution for sewage sludge and mixing materials is one of the most urgent challenges facing many countries [8]. Both anaerobic and aerobic techniques can be used for sludge treatment. However, anaerobic digestion has more advantages, such as it consumes little or even no energy. The feedstock can be stabilized, and the last stage’s product can be fertilizer to improve the soil [9]. Besides, it is one of the most suitable technology to produce renewable energy from wastes. This technique converts organic matter, which is in sludge and agricultural wastes, into biogas by microorganisms, and biogas is used for producing electricity by microorganisms.

2. Materials and research methods

2.1. Experimental materials

The sample of sewage sludge was taken from the wastewater treatment plant urban Binh Hung in Ho Chi Minh City (Vietnam) – urban wastewater treatment plant on the input material. All samples were mixed so that the C: N ratio could meet the desirable condition for anaerobic reactions is between 20 and 40 [10]. When the weight of substrate was changed, their rates would be adjusted respectively. The mixture's moisture was controlled at 65-70% for best decomposition [11] to produce methane gas optimally.

![Figure 1. The mixing materials after pre-treatment (A: rice husk, B: rice straw, C: rice husk charcoal, D: water hyacinth, E: cassava peel)](image-url)
The materials include rice husk, rice straw, water hyacinth, cassava peels were used in the research. Rice husk and rice husk were bought from the ornamental plant’s store, and water hyacinth was collected from the river; cassava peels are waste from Hung Duy Company - Cassava Starch Plant in Tay Ninh Province, Vietnam.

These materials were pre-treated before the experiment in many steps. In the first step, these materials were drying by solar. After that, they were cut into small pieces, which were dimensions from 1-3cm. Finally, they were grind out fine by QE 500 and sieved to the size of approximately 0.154mm.

2.2. Experimental design
The mixing materials and sewage sludge were analyzed about total organic carbon (TOC), total nitrogen (TN), volatile solids (VS), total phosphorus (TP), humidity, drying coefficient (K). The results were shown in Table 1.

| Structure                  | Humidity | K   | TOC (%) | TN (%) | TP (%) | VS (%) |
|----------------------------|----------|-----|---------|--------|--------|--------|
| Sewage sludge              | 74       | 1.74| 17      | 1      | 0.29   | 47.6   |
| Rice husk                  | 13       | 1.13| 22      | 3      | 0.12   | 75.2   |
| Rice husk charcoal         | 2        | 1.02| 21      | 2.6    | 0.20   | 4.64   |
| Rice straw                 | 8        | 1.08| 29      | 0.2    | 0.10   | 92.7   |
| Water hyacinth             | 60       | 1.90| 23      | 1.6    | 0.11   | 84.5   |
| Cassava peel               | 12       | 1.12| 21      | 5      | 0.34   | 81.6   |

Experiment 1: Analyzing nutrient ingredient of materials and chose ratio for mixing the sample

Experiment 2: Comparing the quantity of the biogas produced from the mono digestion and co-digestion with various materials.

Experiment 3: Comparing the quality of the biogas produced from the mono digestion and co-digestion with various materials.

2.3. Experimental conditions
After mix controllably in about 70% moisture, samples were kept in a sealed glass bottle 300ml which are placed in Yamato incubator with mesophilic condition 30°C in total time experiment. Each ingredient had ten glass bottles with the same conditions about the weight of sewage sludge and mixing materials, temperature.

The digestion ability of samples was shown through the volume of generated biogas per total volatile solids (TVS) (ml/g VS). Biogas was collected every two days. C/N ratio, biogas generation performance (ml/g VS), and time for biogas generation were criteria to evaluate the experimental design. Biogas is collected by equilibrating the ambient pressure when water in turned-over bottles is pushed out. CH₄ is analyzed immediately after collection.

Biogas was analyzed by IMR 2800P equipment – combustion gas analyzes equipment. IMR 2800P can be continuously and simultaneously measured up to 18 parameters such as temperature, CO₂, O₂, CO, H₂S, hydrocarbon, CH₄, NO₂, NO.
3. Results and discussion

3.1. Nutrient ingredient analysis of samples

The sewage sludge and mixing material ratio was 4:1, which had a C/N rate suitable for anaerobic digestion. The result of the analysis was shown in Table 2.

Table 2. Different of the structure on the mixture in anaerobic co-digestion about TOC, TN, TP, Humidity, K, VS, and C/N ratio

| Code | Sample | Ingredient                            | Humidity | K   | TOC% | TN% | TP (%) | VS (%) | C/N  |
|------|--------|---------------------------------------|----------|-----|------|-----|--------|--------|------|
| M1   | Sewage sludge |                                        | 78%      | 1.74| 20   | 1.2 | 0.26   | 37.6   | 16.67|
| M2   | Sewage sludge and rice husk            | 61%      | 1.61| 52   | 1.6 | 0.32   | 62.1   | 32.5 |
| M3   | Sewage sludge and rice husk charcoal   | 64%      | 1.61| 55   | 2.1 | 0.58   | 48.9   | 26.19|
| M4   | Sewage sludge and rice straw           | 68%      | 1.68| 63   | 3   | 0.25   | 63.3   | 21   |
| M5   | Sewage sludge and water hyacinth       | 76%      | 1.76| 69.7 | 2.7 | 0.34   | 51.4   | 23.23|
| M6   | Sewage sludge and cassava peel         | 61%      | 1.61| 76   | 3.8 | 0.53   | 65.2   | 20   |

3.2. Comparison of the quantity of the biogas producing from the mono digestion and co-digestion with various materials.

Based on initial results, mono-digestion generated a more little biogas volume than co-digestion with various materials. The detailed result was shown in Figure 1. Therefore, in the perspective of performance digestion, anaerobic co-digestion was more effective than mono-digestion and brought significant economic value.
Figure 4. Diagram of the cumulative biogas yields of samples

Figure 4 presents the daily biogas production results from anaerobic co-digestion of sewage sludge and various material under mesophilic conditions until the end of the process. From the figure, the higher volume of the biogas yields was found to be M3 and M5, about 160 ml/g VS and 130 ml/g VS, higher than M1 (single digestion – only sewage sludge). From the figure, it is clear that the cumulative biogas yields from anaerobic co-digestion of sewage sludge and various material though 51 days are higher than that was obtained from single digestion. After the day of 51st, biogas speed generate is decelerated, so we finish this experiment.

However, the biogas produced from M4 and M6 was low, and the process that produced the biogas was ended soon, approximately ten days. These results were conformable with the C/N ratio of M4 and M6 because this ratio of about 21 and 20 was not suitable with the anaerobic digestion process, which is 20-40 [11]. M6 is the mixture of sewage sludge and cassava peels; furthermore, the cassava peels had cyanide. This cyanide can be inhibited the convert organic matter into biogas of a consortium of microorganisms. So that, cassava peels need to cyanide treated before mixing with sludge.

According to research abroad, the quantity of the biogas producing of the anaerobic digestion was 310 ml/g VS after 30 days [12]. However, in Vietnam, the study about the anaerobic digestion of sewage sludge was not well-known. Thus, the quantitative review of our research in the country is promising, but the research is still undergoing different stages to increase biogas production.

3.3. Comparison of the quality of the biogas producing from the mono digestion and co-digestion with various materials.

Choosing the samples M3 and M5 which the biogas' quantity was the highest cumulative biogas yields, were analyzed and compared with single digestion.
Figure 5. Results of the quality of biogas in three samples

The cumulative methane yields from the M3 sample were 58.7%, and the M5 sample was 56.2%, higher than M1 sample – 39.5%. The initial result showed the quality of methane from co-digestion was twice as much as mono-digestion. It can be seen that energy recovery of sewage sludge treatment by anaerobic co-digestion is potential.

3.4. Estimating the potential of electricity recovery

In this experiment, the highest volume of biogas producing was about 4800 ml biogas/200g sewage sludge and time digestion was 45 days; approximately 0.5 m³ biogas/ton sewage sludge/day. Binh Hung wastewater treatment plants can be produced 120-ton sludge every day.

Estimate the quantity of biogas obtained in 1 year [10], the estimated parameters including calorific value and performance of electricity production of methane

120 (tons sludge/day) x 0.5 (m³ biogas/ton sludge/day) x 45 (days for digestion) x 365 (days/year) x 75% (methane/biogas) = 739125 (m³ methane/year) ≈ 740.000 (m³ methane/year).

The methane's calorific value is 37.78 MJ/m³, and the conversion factor from CH₄ to 1 kWh electricity is 30%. [13]

Estimate the amount of electricity that can be obtained from methane

740.000 (m³ methane/year) x 37.78 (MJ/m³ methane) x 30% = 8387160 (MJ/year) = 2330 (MWh/year) = 0.2MW

So, the plant electrification project, which capacity is 0.2 MW, potential can be set up. 20% of electricity from this plant can be used to heat for the anaerobic digestion process and operate this plant. About 80% of electricity can be used to demand wastewater treatment system of Binh Hung Plant for reducing operating costs.

4. Conclusion

The analyses results of the C/N ratio of mono – digestion sample was not good enough to treat the sewage sludge by anaerobic digestion, so the cumulative biogas yields were medium volume (58 ml/g VS) and lower than the mixture of sewage sludge and rice husk charcoal and water hyacinth, is 160 ml/g VS and 130 ml/g VS respectively which the ratio of the sewage sludge and mixing material is 4:1. The cumulative methane yields producing from anaerobic co-digestion with rice husk charcoal and water hyacinth can be up to 56 – 59%, the potential electrification plant project can be set up, which a capacity is 0.2 MW/year. The next step of the study is to research the microorganism, which can be support for faster digestion process and higher quality of methane. Then, we will utilize sewage
sludge after treatment for agriculture application. Although the research is still undergoing different stages, its benefits of economy and environment are promising.

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