Application of the anaerobic co-digestion method to sewage sludge treatment toward recover green energy and utilize nutrients for agriculture

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Abstract. Sewage sludge after urban wastewater treatment needs to be treated intelligently to get maximum benefits. This study proposes a method of anaerobic co-degradation of agricultural sludge and residues to both solve environmental problems and recover a large amount of biogas and organic fertilizers. The results show the potential for energy recovery from biogas and impact assessment of the application directly on the rice fields. It is estimated that biogas recovery from sludge treatment from wastewater treatment plants gives a calorific value of about 76 × 10⁶ MJ/year. Results from the trial crop showed that fertilizer shows good supportability to the plant. The results show that the fertilizer from sewage sludge can be reduced and replaced by 50% to 100% of the number of chemical fertilizers but still give the same yield. The data show that the anaerobic co-digestion method is a suitable method for sludge treatment. The dual objective is to provide valuable benefits from recovered biogas and anaerobic digestion products.

1. Introduction
Along with the integration and development of urbanization in many regions in Vietnam, the drainage systems are being upgraded. Many wastewater treatment plants are being built to protect the urban water environment. According to the urban wastewater drainage system planning in major cities of Vietnam, the wastewater treatment plants will have a treatment capacity of up to five million m³ of wastewater/day and the amount of urban sludge discharged up to up to 1000 tons/day. Up to now, waste and sludge treatment plants in Vietnam are rare. The most common option for disposal is landfilling and it is increasingly proving ineffective. That sludge collected and delivered to the landfill or discharged directly to environment without treatment has arisen pollution matters such as heavy metal accumulation and odor, which lead to negative impact and risk to the environment and people health [1]. It is concerned that wasting sludge not only impacts the environment but also wastes valuable resources. The component of waste sludge contains high nutrition content such as organic carbon, N, P, K, and some multi-micronutrient [2], which are able to be applied as organic fertilizer for agriculture [3]. However, due to the toxic compounds such as pathogenic microorganisms and heavy metals in fertilizer from waste sludge [4], it is necessary to have appropriate assessment solutions for classification before applying to agriculture.

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In most developed countries, municipal wastewater sludge treatment is often applied with anaerobic biological treatment technology, which can help recover the maximum amount of energy from the sludge and minimize the amount of biogas released, causing air pollution. The disposal of waste in landfills is one of the significant contributors to greenhouse gases, accounting for about 5% of total global greenhouse gas emissions [5], with CH\textsubscript{4} being an important greenhouse gas [6], but also a valuable energy source combustion fuel. The utilization and recovery of biogas for electricity generation limits the problem of environmental pollution and greenhouse gas emissions and develops sustainable energy [7].

On the other hand, farmers in Vietnam and other countries are using too much chemical fertilizer. This will lead to an excess of nutrients in the soil, causing nutrient pollution to the surrounding water and so on; efficiency will decrease with the cost of fertilizer will be increased a lot. In the fruit orchards of Vietnam, as in Cho Lach - Vinh Long province, Vietnam was referring to a concept of "harmony combination" between chemical fertilizers and organic fertilizers. Initially, people here use 100% chemical fertilizer, for an early time, there will be excess productivity, but it will decrease as the later and increase plant diseases [8]. By contrast, other orchards are using a combination of chemical and organic fertilizers. Although they have a lifespan of 30 years garden is still lush. Therefore, combining harmoniously nutritional needs from organic and chemical fertilizers will be possible to bring positive effects to the soil [9]. This will reduce epidemic diseases, accompanied simultaneously by the amount of pesticide use, and the associated risks will be reduced. Besides the benefit from biogas, the treated sludge will open up a new direction in the management application for green manure sludge in agriculture and reduce the amount of chemical fertilizer use, which significantly impacts the environment and humans.

Hence, this study reports the effectiveness of the anaerobic co-digestion method applied to municipal sludge treatment. The expected products are biogas and organic fertilizers, green products that contribute to sustainable economic development. The study's data will be a reference for environmental managers and policymakers to have more options.

2. Materials and research methodology

2.1. Biosolid treatment by anaerobic co-digestion method

Waste sludge is collected after the centrifugal dewatering process in the Binh Hung wastewater treatment plant (Ho Chi Minh City, Vietnam). The material is mixing with a ratio of C: N about 20-40 (suitable for anaerobic processes). However, the sewage sludge has an initial C/N ratio of 6-13 (humidity 80%), and a density of 800 kg/m\textsuperscript{3}, so independent sludge treatment by anaerobic incubation may not be feasible [10]. With the anaerobic co-degradation method, the above problem can be solved with the addition of a suitable material to increase the C/N ratio and the density of the mixture. Based on moisture, ToC, total nitrogen content, when the content of the substrates is changed, their ratio will be appropriately adjusted.

Previous research by Thanh Tran et al. has experimentally mixed with rice husks, coir mulch, sawdust, and rice straw, showing that samples mixed with coconut fiber and milled rice husk give the best results [11, 12]. Agricultural waste is used in mixing the rice husk, which is ground finely crushed and blended with a ratio of (MD) sludge with rice husk (2:1) and (MA) sludge with coconut coir (2:0.5) [12]. The moisture of the mixture was controlled at 65-70% [13] to co-digestion process optimally. The method of composting was processing under mesophilic (30-35°C) and thermophilic (55-60°C) temperature.

2.2. Method of estimating energy recovery from biogas

Method of measuring the amount of biogas produced: put the needle tip into the bottle cap, the tip of the tube into the cylinder filled with water to reverse. Then, open the valve to let the gas from the test bottle escape through the pipeline push the water in the tube measure out thanks to the pressure difference. The amount of gas in the cylinder is the amount of biogas produced during anaerobic digestion [12]. The process is described in Figure 1.
Note: (1) Flow control valve on air duct; (2) Plastic tube for air, one end attached to the needle for the sample bottle, (3) the other end into the cylinder filled with water; (4) Anaerobic digestion sample container; (5) The tank is filled with water, which is the gas collection medium; (6) 100 ml measuring cylinder filled with water. The biogas obtained during the digestion was analyzed using Agilent's AG 7890A machine mass spectrometer [14].

Annual CH$_4$ emission load (ton/year) converted to m3/year based on CH4 specific gravity of 0.71 kg/m3 [15]. The amount of CH$_4$ gas generated (m3) is estimated based on the amount of gas collected from the sludge treatment sample. The amount of electricity (kWh) generated based on the electromotive force of the gas turbine is 30% [16], and the lower heating value (LHV) of CH$_4$ is 35 MJ/m$^3$ [16, 17].

2.3. Experimental development in rice fields

Fertilizers were used empirically from sewage sludge was mixed with rice husk (ratio of 2:0.5), which be applied on soil preparation at the beginning of the rice crop with 1% and 3% of the landmass (calculated on the surface 15 cm). Fertilizers were analyzed nutritional indicators as N, P, K, TOC [18], and heavy metals such as As, Cd, Pb, Ni, Zn, Cu (SMWEW 3125) [19].

Place the rice field deployment of a typical farmer in Thanh Dien - Chau Thanh district, Tay Ninh Province, where the warm and humid climate is one of the provinces with the highest rice production in Vietnam. The rice variety used is OM4900. The trial was assessed through experimental plots, each pilot from 30 m$^2$, the number of replicates three times. The results were evaluated through 11 indicators: Germination rate (%), Height of rice plants (cm), The level of falling (exponentially), number of arista/m$^2$, number of firm rice grain/arista, Percentage of firm rice grain (%), Weight 1000 seeds (g), Rice yields at 13% humidity (t/ha), Percentage of head rice (%), Percentage clarity and turbidity grain (%), Percentage of milled rice recovery (%) [20].

3. Results and discussion

3.1. Assessing the impact of untreated sludge

Experiment assessing the impact of untreated sludge and treated according to two temperature conditions to the growth of rice to present the results as Figure 2. Sludge is decomposed in mesophilic conditions likely good support for the growth and development of rice germ. At concentrations from 6.25% to 75% rice germ are better developed than in the control sample. This can be seen when testing fertilizer from sludge decomposition after fertilizer on land, make enough workability and facilitate the growth of rice in the seedling stage. Thereby, we see the potential for the use of sludge decomposes at mesophilic conditions for agriculture.
Figure 2. Semilog graph for the difference between the untreated and treated sludge samples

For sludge decomposes under thermophilic conditions, it doesn't help agriculture and soil improvement. At concentrations of more than 12.5%, thermophilic sludge decomposition can cause adverse effects on the growth and development of coating, to concentrations of 25% and 50%, causing a strong impact similar to untreated sludge reasons. It can be explained when raising the temperature, the ion nitrogen is oxidized to nitrate and toxicity. Therefore, research thermophilic sludge decomposition is unappreciated in the following experiment.

3.2. Effective treatment of urban sewage sludge by anaerobic co-digestion method

Figure 3 showed that the treatment process by anaerobic co-digestion under mesophilic conditions.

Figure 3. Biogas generation of control samples and co-anaerobic samples (MA, MD) over the period treatment time

According to the results of recent studies show treatment MD (2:0.5) used crushed rice husk with a size smaller than 2 mm and MA (2: 1) using coir mulch are two treatments that have significantly different from other treatments in mesophilic conditions.

Under Mesophilic conditions, the MA and Control samples graphs began to reduce gas production when the incubation time reached about 45 days. In comparison, the MD samples at an incubation time of up to 60 days, the gas production still showed no sign of decreasing down, and this proves that the nutrients in the MD are still enough to supply the anaerobic process for some more time while MA and Control are exhausted. The results show that using anaerobic tanks with a retention time of about 30 - 45 days is suitable for MA and Control samples. MD can extend the time even further to optimize biogas
production or use a combined method such as composting for optimal disposal. Table 1 shows the technical properties of Control, MA, and MD samples before incubation and after anaerobic digestion for 60 days.

**Table 1.** Compositional properties of sludge samples before and after treatment

| Evaluation criteria                        | M_control | MA (2:1) | MD (2:0.5) |
|-------------------------------------------|-----------|----------|------------|
| **Before treatment**                      |           |          |            |
| C/N                                       | 10        | 30       | 20         |
| VS (%)                                    | 64        | 57.33    | 67.33      |
| Specific weight (kg/m³)                   | 800       | 740      | 450        |
| Humidity (%)                              | 80        | 60       | 60         |
| **After treatment**                       |           |          |            |
| VS (%)                                    | 55        | 29       | 35         |
| Amount of reduction VS (%)                | 14        | 60       | 70         |
| Reduced sludge volume (%)                 | 8         | 11.6     | 10.5       |
| Reduced sludge mass (%)                   | 20        | 27       | 35         |
| Humidity (%)                              | 50 - 60   | 20 - 30  | 40 - 50    |

The control sample after 60 days had a relatively low reduction in VS amount (14%), while the VS amount of treatment MA and the MD after 45 days decreased by 60% and 70%, respectively. The result exceeded the minimum requirement of the anaerobic process of a minimum reduction of 38% VS [21]. At the same time, it can be commented that the treatment efficiency when co-degradation is much higher than that of independent decomposition. Milled rice husks also show a much better decomposition rate than coir mulch when reducing VS to 70% in just 45 days, while coir mulch takes up to 60 days to reduce only 60%. Control and MD samples (2:0.5) after incubation still have a relatively high moisture content, so the treatment process applied to these two samples requires an additional step of water separation or heat drying to reduce the amount of water and reduce the volume and weight of the product. MA (2:1) is the only model that, if applied in practice, would not require an additional water separation procedure.

### 3.3. Potential energy recovery from biogas

According to anaerobic digestion technology under Mesophilic conditions, the anaerobic tank operates in a continuous form to be fed continuously after 45 days of acclimatization. The samples showed that the total gas yield was as high as 18400 ml biogas/200g sludge in the experiment. On average, the gas yield was 92 ml biogas/g sludge, estimated at 92 m³ biogas/ton sludge.

Currently, the treatment capacity of the Binh Hung plant is 469 000 m³/day, the average amount of sludge generated is about 200 tons/day. With the amount of sludge generated 150 tons/day and 1 year = 365 days, we can calculate the amount of gas collected in 1 year: 92 x 200 x 365 = 6.716 x10⁶ m³ biogas/year. This result is still low compared to the methane yield from pulp waste for 400 m³ CH₄/ton VS of: 400 m³ CH₄/ton VS from sisal production wastewater; 650 m³ CH₄/ton VS with solid waste coffee; 730 m³ CH₄/ton VS with coffee Arabia; and 450 m³ CH₄/ton VS with corn [22]. This is explained because the test sample is too small, about a few hundred grams, the ability to recover biogas has not been properly evaluated. If applied on a larger scale, more biogas will be obtained.

The calorific value of CH₄ is 37.78 MJ/m³ and the biogas consumption coefficient to produce 1 kWh of electricity is about 30%. The electricity amount can be generated from the above biogas is 6.716 x 106 m³/year x 37.78 MJ/m³ x 30% = 76 x 106 MJ/year. The total cumulative equivalent electricity value is 6.34 million kWh of electricity. Typically, a family uses an average of 300 - 400 kWh of electricity/month [23]. This electricity is enough for 1320 - 1760 households to use electricity in a year.

### 3.4. Assessing the impact of organic fertilizer from waste to rice plants

Results of analysis of the quality of the fertilizer are described in Figure 4 and Table 2.
The nutritional indicators of organic fertilizer from waste (sewage sludge)

The treated sludge product has organic content, total nitrogen, and potassium minerals reaching the permissible threshold of (QCVN 01-189:2019/BNNPTNT on fertilizer quality). However, there are some heavy metals in the sludge that need to be considered. Some heavy metals can be used as multi-micronutrients for plants. However, metals such as As, Cd, or Pb over the permissible levels can harm the environment, plants, and humans. The results of the heavy metal analysis are reported in Table 2.

### Table 2. Results of the analysis indicate heavy metals in fertilizers

| Heavy metals | As (mg/kg) | Cd (mg/kg) | Pb (mg/kg) | Ni (mg/kg) | Zn (mg/kg) | Cu (mg/kg) |
|--------------|------------|------------|------------|------------|------------|------------|
| Fertilizers sample | 0.85       | 1.515      | 67.96      | 27.45      | 1201.5     | 241.425    |
| Standard QCVN 50:2013/BTNMT | 40         | 10         | 300        | 1400       | 5000       | -          |

The analysis results from Table 2 show that although heavy metals are present in the sludge sample after treatment, it is still at a safe threshold. Toxic metal concentrations were much lower than the standard of the National Technical Regulation on Hazardous Thresholds for Sludges from Water Treatment Process. Therefore, the treated sludge can be qualified for agricultural purposes according to the reference standard from EPA 503 [24].

The process of testing organic fertilizers from wastewater sludge is evaluated in 4 stages of rice: Seedling, tillering, and stem development, which brought forth fruit of the rice plant and harvest. In the seedling stage 14 days after sowing, through accreditation Independent-samples T-Test with fertilizer concentration of 3% and not used (0%) showed the value of Sig (2-tailed) = 0.000 with 95% confidence intervals. It can conclude that there are significant differences in the overall average height of rice land use organic fertilizer 3% compared with the control sample. To further evaluate the differences in the growth of rice plants through three concentrations of 3%, 1%, and 0% (no use) in other stages, used the test One-Way ANOVA.

Over the tillering and stem development stage to assess the impact of fertilizer on rice plants growth with Sig value = 0.000 <0.05 with 95% confidence interval. It can conclude that there are significant differences in the average dimension high rice plants 21 days after sowing time among three concentrations of organic fertilizer 3%, 1%, 0% (no use). The average height respectively in the concentrations of 3% (68.567cm), 1% (61.667cm), 0% (59.097cm), so the height rice plants in this phase with the concentrations 3% is still dominant. Simultaneously, the influence of fertilizer on tillering shows the value Sig = 0.725> 0.05 with the 95% confidence interval. It can conclude that there is no difference in the average number of tillers among the three concentrations fertilizer experiments. Thus
the use of fertilizer experiments with the concentrations 1% and 3% for good tillering efficiency, achieving an effective amount of branching for rice plants.

Table 3. Describe the difference in the One-Way ANOVA analysis

| Sum of Squares | Df | Mean Square | F     | Sig. |
|----------------|----|-------------|-------|------|
| **Height 21 days after sowing time** |     |             |       |      |
| Between Groups | 1438.958 | 2 | 719.479 | 42.414 | .000 |
| Within Groups | 1475.803 | 87 | 16.963 |       |      |
| Total | 2914.761 | 89 |       |       |      |
| **The degree of tillering 21 days after sowing time** |     |             |       |      |
| Between Groups | .156 | 2 | .078 | .323 | .725 |
| Within Groups | 20.967 | 87 | .241 |       |      |
| Total | 21.122 | 89 |       |       |      |
| **Height 42 days after sowing time** |     |             |       |      |
| Between Groups | 282.482 | 2 | 141.241 | 8.103 | .001 |
| Within Groups | 1516.462 | 87 | 17.431 |       |      |
| Total | 1798.944 | 89 |       |       |      |
| **Firm rice grain/arista** |     |             |       |      |
| Between Groups | 1814.378 | 2 | 907.189 | 1.234 | .293 |
| Within Groups | 169849.007 | 231 | 735.277 |       |      |
| Total | 171663.385 | 233 |       |       |      |

The brought forth fruit stages study assessed the number of grains seed by One-Way ANOVA test the height of rice at 42 days after sowing time. Results showed Sig value = 0.001 <0.05 with a 95% confidence interval, we conclude that there is a significant difference in the average height of rice plants between 3 concentrations of fertilizers. On the other hand, the analysis of ANOVA LSD gives results that the concentration of 3% and 1% difference with 0%, simultaneously the concentration of 3% no different from 1%. In Table 3, the concentration of the organic fertilizer of 1% combined with chemical fertilizers is equivalent to 3% treatment.

![Figure 5](image.png)

Figure 5. (A) Weight of 1000 seeds after harvest. (B) The height growth of 2 samples with 0% (not used) and 3% from organic waste.

Finally, the harvest stage is the decisive phase of yield after one crop. The yield of the sample 0%, 1%, and 3%, respectively, 6.8, 6.7, and 6.8 tons/ha (reference yield of OM4900 rice varieties is 5 - 7 tons/ha). We use the One-Way ANOVA test the number of firm rice grain/arista harvest with three levels of fertilizers applied to the soil 3%, 1%, 0%. Results showed that Sig = 0.293 > 0.05 with 95% confidence interval, we conclude that there is no difference in the average firm rice grain/arista in three experimental samples 3%, 1%, 0%. Thus the use of fertilizers experiments with concentrations of 3% and 1% is still guaranteed yield harvest.
3.5. Evaluation of fertilizer savings when using organic fertilizers from the waste

In the process of growing, the rice should be added nutrients for every stage of growth through fertilization. Fertilizer programs are divided into four main stages, and they may be similar to the four stages of development of rice depending on nutritional requirements. They were assessed according to the experiences of farmers in the experimental area. The dose and number of different fertilizers can be changed to ensure an adequate supply of nutrients macro to rice plants.

| Table 4. Description rice cultivation process applied to each case |
|---------------------------------------------------------------|
| Fertilizer use                  | Stages 1 | Stages 2 | Stages 3 | Stages 4 |
| Chemical fertilizers (control) |          |          |          |          |
| 3% organic fertilizers         | ✔️       | ✔️       | ✔️       | ✔️       |
| 1% organic fertilizers         | ✔️       | ✔️       |          |          |

Note: ✔️ Chemical fertilizers ✔ Organic fertilizers from waste

The results showed that using organic fertilizers from the waste applied phase 1 saves 100% of additional chemical fertilizer for soil samples using concentrations of 3% and 50% of soil samples using a concentration of 1% organic fertilizer experiments. Although loop untested, but initial also shows potential economic benefits for farmers.

With a sample of 3%, the yield guarantee compared with the control sample without added fertilizer can be explained by the excess fertilizer from the previous crop, which has supported the development of the next rice crop. Therefore, the first experiments should perform repeatedly, but at the moment, they should be considered using a ratio of 1% and a harmonious combination with chemical fertilizers for better productivity.

4. Conclusion

Untreated sewage sludge can cause adverse effects on the ecosystem environment. However, the co-anaerobic decomposition method mixed with rice husk (ratio 2:0.5) and use with 3% volume concentration, trace elements can be used as trace elements stimulate plant growth. The potential to recover the benefits of electricity from biogas obtained after treatment in a year is about 6.34 million kWh. With yields guaranteed by the control sample, the cost savings over-farming by reducing fertilizer use from 50% to 100% also shows the potential benefits of fertilizer from waste. However, it should be tested for a long time to assess the growth of beneficial microorganisms and change the concentration of nutrients in the soil. It will be the foundation for the development of agriculture green.

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