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Anaerobic Digestion Potential in Traditional Boarding School

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Abstract. There are approximately 36,600 religious boarding schools in Indonesia accommodating a student population of 3.4 million. Traditional religious boarding school is one of the most significant contributors to waste generation after housing. This study is aimed to measure waste generation and the potential to implement anaerobic digestion in traditional boarding schools. At Al Hikam Boarding School, with a population of 265 residents, the average daily waste generation was measured at 33.6 kg/day, with organic waste constituting 41.8%. Over three months, the study included the stages of seeding, acclimatisation, and operation of anaerobic digestion using organic waste generated by the boarding school and traditional buffet. With an input of 7.6 kg/day, the results showed that organic waste used had a pH, total solid (TS), volatile solid (VS), chemical oxygen demand (COD), and temperature of 6.1±0.38, 25±0.092%, 95±0.0054%TS, 453±188 g/L, and 29.5±1.12°C, respectively. The digester reported a volatile solid destruction (VSD) and chemical oxygen demand (COD) reduction of 91±0.015% and 89±0.081%, respectively. This produced biogas volume and methane yield of 805±219 L/day and 292±130 L.methane/kg.VS. So, anaerobic digestion with a *Toren* Biogas reactor is the recommended technology to manage organic waste at traditional boarding schools, with a potential reduction factor of 54%.

Keywords: Anaerobic digestion; Biogas; Boarding school; Organic waste treatment

1. Introduction

By the end of 2017, Indonesia had generated 65.8 million metric tons of waste, of which 60% was dominated by organic waste (Ministry of Environment and Forestry, 2020). Then, a landfill is dominated by organic waste and the degradation of that waste causes methane gas production, potentially resulting in landfill fires that are harmful to humans and the environment (Amritha and Anilkumar, 2016). Management of organic waste results in reduced financial expenditures and serves as a crucial measure to mitigate adverse environmental impacts (Kharola *et al.*, 2022). Therefore, the challenges of managing organic waste can be handled when appropriate technology is implemented.

The management of organic waste is best done at the source to avoid waste

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transportation. Thus, it is strategic to target waste producers with a high amount of organic waste. In Indonesia, there are 36,600 religious boarding schools with 3.4 million students and 370,000 teachers (Ministry of Religious Affairs, 2022). Therefore, traditional boarding schools play an important role in contributing to Indonesia's journey towards achieving 100% effective waste management.

The most highly recommended method for processing organic waste is anaerobic digestion, which produces digestate rich in nutrients and could potentially be used as fertilizer and biogas for cooking (Abdillah, 2017). Anaerobic digestion is waste-to-energy technology that adopts bacteria to degrade organic content of solid waste into biogas (Wainaina *et al.*, 2020). However, the technology must be compatible to ensure long-term use. The implementation is hindered by financial constraints, limited awareness, and the productivity of available technologies (Dhanya *et al.*, 2020). Furthermore, the characterization of the substrate plays an essential role in the successful application of anaerobic digestion technology (Bartocci *et al.*, 2021). This study aimed to examine waste generation and composition at Al Hikam Boarding School. A pilot-scale experiment was carried out to use anaerobic digestion technology to process organic waste and to study the operating conditions directly.

2. Methods

Al Hikam Boarding School, located in Depok, West Java, has at least 265 residents and still lacking the technology of organic waste processing and management (Pramadita *et al.*, 2021). Currently, school focuses on the management of inorganic waste processing, with no corresponding efforts for organic waste processing. Appropriate management is critical in reducing environmental contamination and greenhouse gas emissions caused by disposal in landfills (Kustiasih *et al.*, 2014).

Sampling of solid waste was carried out for 8 days by using load count analysis to calculate the loads during a specific period. The procedure refers to SNI 19-3964-1994 concerning Methods of Taking and Measuring Samples of The Generation and Composition of Urban Waste. This study continued with organic waste processing through anaerobic digestion using *Toren* Biogas, also known as TORBI, is anaerobic digestion reactor produced by AIUEO Kreasi Energi Co. Ltd. TORBI, as shown in Figure 1, had design patent P00201910803 with a processing capacity of 1200 L and was made of LLDPE (Linear Low-Density Polyethylene) (Cahyono, Priadi, and Abdillah-Ayik, 2023). This particular reactor shows favorable characteristics for implementation and offers ease of use, affordability, and portability (Ismaniari, 2020). The mass of organic waste needed for feeding anaerobic digestion referred to the results from the sampling of solid waste.

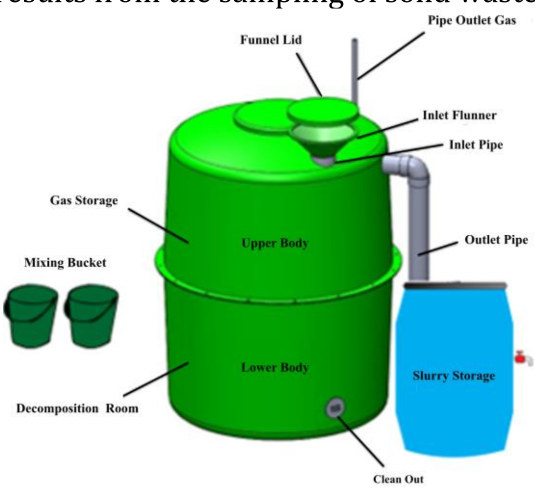

Figure 1 Design Patent of *Toren* Biogas

To mitigate the uncertainty related to the results acquired a triple-sample testing process was implemented, including substrate and static conditions. Furthermore, the data analysis was conducted using the IBM SPSS Statistics 22 software. The analysis of solid waste was obtained through a descriptive method, followed by anaerobic digestion data using efficiency values and correlation tests. Additionally, this attempt aims to derive relevant conclusions.

The following is the process carried out at *Toren* Biogas:

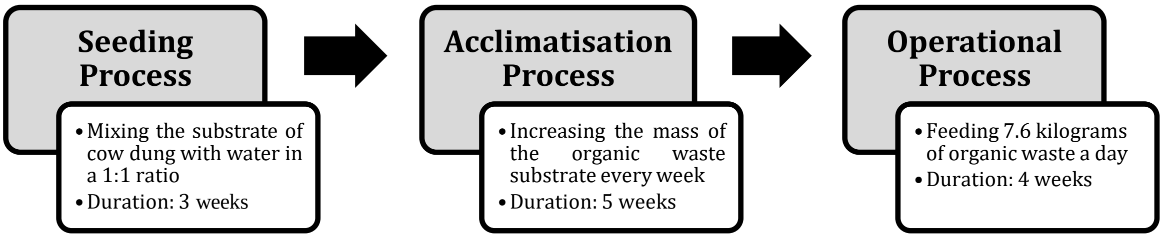

Figure 2 *Toren* Biogas Process

2.1. Seeding Process

The seeding process is a starter with cow dung and water in a ratio of 1:1 as substrates. In this study, a homogenous mixture was prepared by mixing 7 liters of cow dung and water in an immense bucket placed into the TORBI. The feeding procedure takes place for approximately three weeks on each working day, accompanied by periodic observations of gas production.

2.2. Acclimatisation Process

The process of acclimatisation covers around five weeks and includes the use of organic waste derived from Al Hikam Boarding School complemented with waste from traditional buffet, such as *nasi uduk* and *warteg*. The total mass required refers to the amount of organic waste generated, which is 7.6 kg each day. Subsequently, it is important to raise the proportion of total mass waste to avoid shock loading and promote optimal adaptation of microorganisms. In the initial week, the quantity of newly generated waste constitutes 20% of the total mass. However, this percentage incrementally increases by 20% to achieve a value of 100% by the end of the fifth week. The substrate was crushed to a particle size of 20 mm as part of an effort to improve the production of biogas and anaerobic digestion process based on (Silvestre, Bonmatí, and Fernández 2015). This can occur due to the greater contact between susbtrates and microbes, leading them to produces a higher methane yield (Arifan *et al.*, 2022). The reactor is controlled by measuring pH, temperature, TS, VS, and COD in TORBI effluent using standard methods. Meanwhile, biogas volume is measured regularly using a flow meter and gas bags on-site.

2.3. Operational Process

After completing the acclimatisation procedure, the operating process may continue for approximately four weeks. The TORBI feeding process uses 7.6 kg/day of organic waste from Al Hikam and traditional buffet restaurants in a ratio of 1:1.5. The substrate must be crushed and not contain any waste that has potential to interfere with the degradation process, such as corn weevils, chicken bones, beef bones, fruit seeds, banana peels, and twigs or wood (Shodiq, 2020). The parameters of pH and temperature were measured directly using a Hanna pH meter and a termometer every day. Total solids, volatile solids, chemical oxygen demand, and ammonia were measured in the Environmental Engineering Laboratory, Universitas Indonesia, while biogas volume was obtained using a flow meter. That parameter was measured every two days for four weeks. The sample of biogas was stored in a 1 L tedlar bag to analyze biogas composition in the Chemical Engineering Laboratory, Universitas Indonesia.

The factor reduction potential can be calculated according to the equation (1).

$$\text{Potential Reduction Factor} = \frac{\text{Mass of organic waste}}{\text{Total organic waste requirement}} \tag{1}$$

3. Result and Discussion

3.1. Waste Generation and Composition

Based on Figure 3 below, the mass generation at Al Hikam Boarding School fluctuates. On the seventh day, Al Hikam Boarding School's "*Haul*" activity, which comprised a full day of activities for residents and guests, generated 65.9 kg of waste. Meanwhile, the lowest waste of 11.5 kg was discovered on the fifth day due to inactivity. This study produced 33.6 kg/day, or 0.127 kg/person/day of waste, showing that the volume fluctuates. Due to the "*Haul*" activity, school produced the largest and lowest volumes on the seventh and eighth days, at 1220 L/day and 354 L/day. Therefore, waste volume in this study was 683 L/day, or 2.58 L/person/day. The generation and volume depend on the size of waste, the activities, and the habits of residents at Al Hikam Boarding School in Depok City.

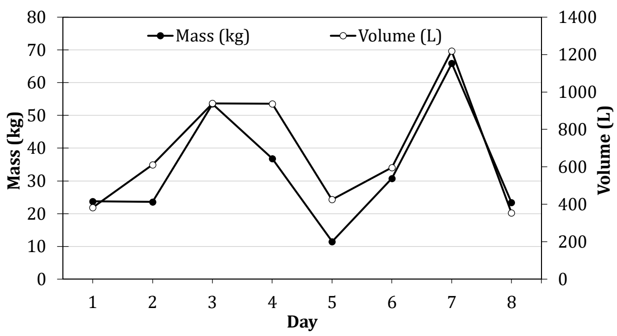

Figure 3 Waste Mass at Al Hikam Boarding School Depok City

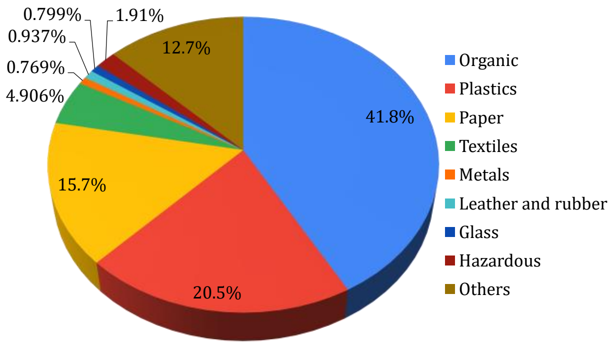

Figure 4 Waste Composition at Al Hikam Boarding School Depok City

Based on Figure 4, the composition is dominated by 41.8%, 20.5%, and 15.7% of organic, plastic, and paper waste. The presence of organic waste shows potential for implementing eco-friendly waste management such as anaerobic digestion. Meanwhile, the large amount of plastic waste shows the importance of reducing plastic consumption and promoting responsible disposal. The paper waste can be recycled to reduce landfill waste while fostering environmental awareness within school community. The sustainable practices for these categories can significantly minimize school's environmental effects and promote a culture of responsibility among students and staff.

3.2. Analysis of Anaerobic Digestion Implementation

Examining the characteristics of the substrate before the feeding process is crucial. This is important since these characteristics have a significant influence on the subsequent operation of the reactor. The characteristics have a pH, temperature, TS, VS, and COD of 5.9±0.058, 30±0.15°C, 23±0.022%, 97±0.021%TS, and 357±38.4 g/L. Based on its characteristics, the substrate has an organic loading rate (OLR) value of 1.4 kg.VS/m^3.day. After that, the acclimatisation process takes place on the 1^{st} to the 35^{th} days, while the operational process lasts on the 36^{th} to the 58^{th} days.

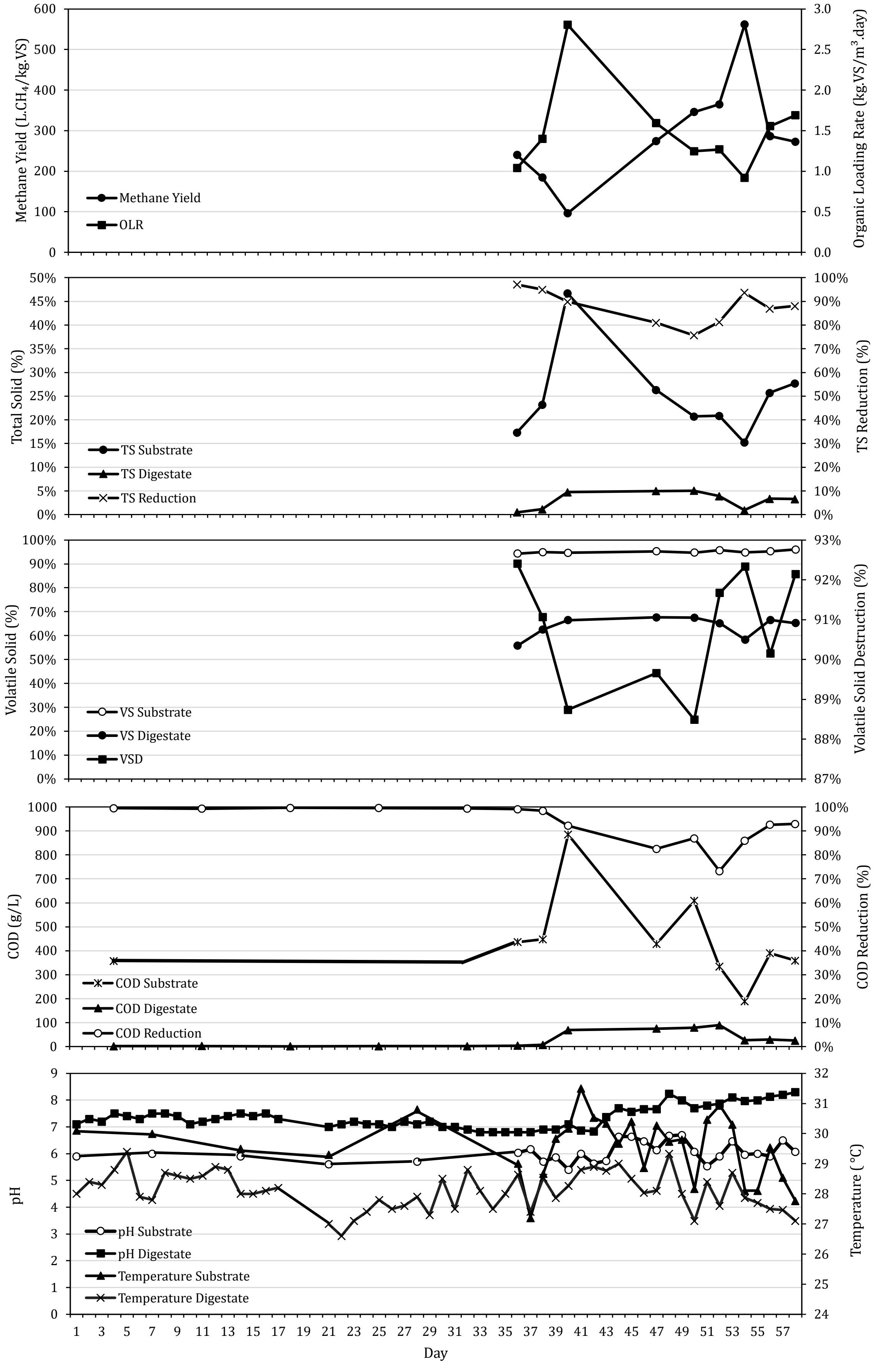

Figure 5 The Parameters Result During Acclimatisation and Operational Process

Figure 5 shows that the pH of the substrate and digestate remains relatively stable during the acclimatisation process, with pH substrate concentration ranging from 5.6-6 and 6.8-7.5. The acclimatisation process is complete when the substrate mass has reached 100% and the pH has fluctuated by less than 10% for three consecutive days. During the operating process, the pH levels of both fluctuated. Furthermore, the pH concentration of the substrate and digestate range from 5.4 to 6.7 and 8-8.3, with an average concentration of 6.1±0.38 and 7.6±0.53, respectively. The concentration of pH digestate is classified as a phase in the process of methanogenesis (Khalid *et al.*, 2011). The pH changes the transition from substrate to digestate due to bacterial adaptation. An imbalance between acid-forming and methane-forming bacteria disrupts the effective breakdown of acid into methane. This imbalance results disrupts acetic acid fermentation and subsequently causes a decrease in pH (Rizal, Mahidin, and Ayyub, 2015).

Based on the data in Figure 5, there are slight fluctuations in the temperature and digestate of the substrate during the acclimatisation process, which ranges from 29-31°C and 26°C- 29°C, respectively. The concentrations of both the substrate and the digestate fluctuate during the operational process, ranging between 27–32°C and 27–29°C. The temperature of the digestate is lower than the substrate because of the growth and metabolic processes of microbes (Rizal, Mahidin, and Ayyub, 2015). The acetogenesis and methanogenesis phases influence digestate fluctuations in temperature during acclimatisation and the operational process. The current study is in the mesophilic phase, which is relatively stable due to the slower rate of methane production and the longer detention time of 32 days.

Based on Figure 5, the TS concentrations of the substrate, digestate, and reduction show fluctuations during the operational process. The concentration of the substrate varies from 15%-47%, with an average of 25±0.092%. A high and low TS concentration means that the substrate contains solids and water, respectively. The substrate has a water content ranging from 53%-85%, with an average of 75±0.092%. There is an associated rise in the rate of decomposition of organic waste when the water content increases (Tanimu *et al.*, 2014). Meanwhile, the TS concentration of the digestate varies between 1%-5%, with an average of 3±0.02%. The reduction in the substrate ranges from 76% to 97%, with an average of 88%±0.072%.

Figure 5 shows that VS concentration of the substrate shows a high level of stability within the range of 94–96%TS, with an average of 95±0.0054%TS. The presence of organic molecules in the solid material can explain the higher VS concentration (Sarwono, Subekti, Widiarti, 2018). The fluctuation, ranging from 56%-68%TS, with an average concentration of 64±0.042%TS, is related to the impact of organic compound decomposition. VSD concentrations are 88-92%TS, with an average of 91±0.015%TS. The presence of fluctuations is caused by a high concentration of organic material in the substrate, which leads to an accumulation of inhibitors, increased ammonia, and a decrease in temperature due to bacterial activity during the hydrolysis process.

As shown in Figure 5, COD of the substrate and digestate is 357 g/L.COD and 1.3-2.4 g/L.COD. Based on the data obtained, the average percentage is 99±0.0013%. During the operational process, there is a decrease in COD substrate to digestate due to the decomposition of organic matter. In the operational process, the concentration of substrate and digestate fluctuates between 189-885 g/L and 3.8-89 g/L.COD, with an average of 453±188 g/L.COD and 45±34 g/L.COD. Therefore, a COD reduction of 73%-99% is realized and organic matter reduction greater than 50% leads to stable conditions (Akhiar *et al.*, 2017).

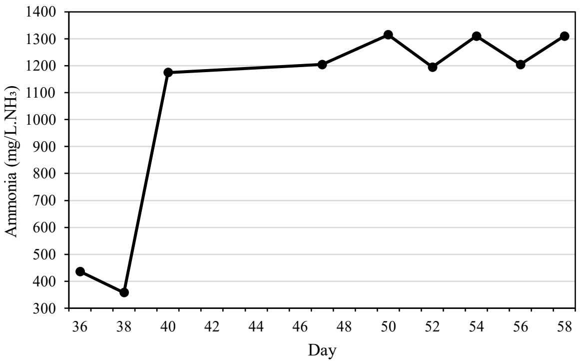

Figure 6 Ammonia During Operational Process

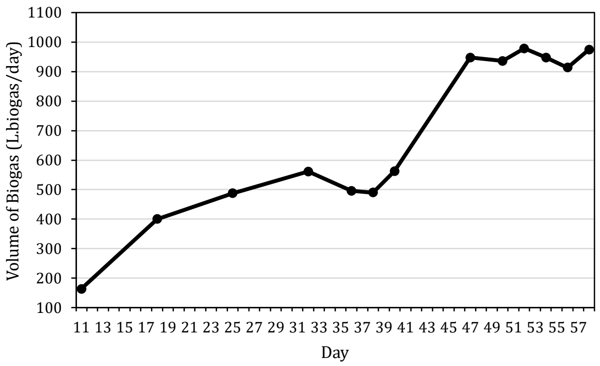

Figure 7 Volume of Biogas During Acclimatisation and Operational Process

As seen in Figure 6, the ammonia concentration of the digestate increases initially before stabilizing. The concentration ranges from 358-1315 mg/L.NH_3, with an average of 1057±378 mg/L.NH_3. Therefore, ammonia is below the specified range of 1500-3000 mg/L.NH_3 (Rajagopal, Massé, and Singh, 2013), providing an acceptable nutrition source for microorganisms and preventing disturbance to anaerobic digestion process.

Based on Figure 7, the volume of biogas during the acclimatisation process shows a continuous increase. This can be attributed to the adaptation of bacteria, with an average of 163-561 L.biogas/day. Subsequently, during the operating phase, there is an increase in the volume of biogas, which tends to stabilize within the range of 496-975 L.biogas/day. This occurs because the methanogen bacteria reached the optimum conditions for activity (Dong *et al.*, 2015). The presence of the volume of biogas indicates that biogas produces, so it can be observed the concentration of the biogas (Hapsari *et al.*, 2019). Based on the analysis of biogas composition, we know that the biogas is composed of 59±0.035% methane and 41±0.035% carbon dioxide.

According to the data shown in Figure 5, the methane yield concentration has an average concentration of 292±130 L.CH_4/kg.VS. Furthermore, TS of the substrate has a significant impact on determining the yield of the gas during the operational process. On May 13, 2023, the highest and lowest TS were 47% and 97 L.CH_4/kg.VS. On May 27, the lowest TS concentration of 15% corresponded to the highest methane yield of 562 L.CH_4/kg.VS.

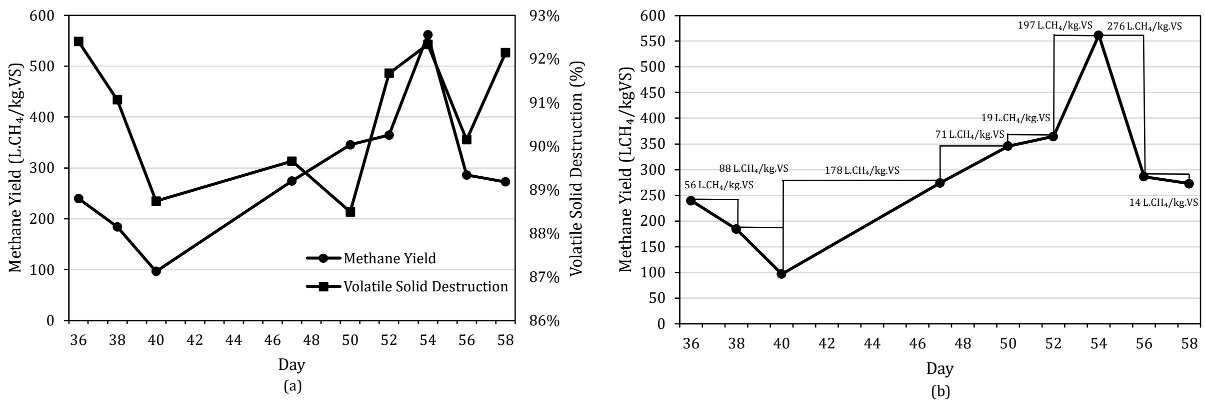

Figure 8 (a) Correlation of Methane Yield and Volatile Solid Destruction; (b) Correlation of Organic Loading Rate and Methane Yield

According to Figure 8a, there is a correlation between the methane yield and VSD concentration using the ICM SPSS Statistic 22 application. On May 20, 2023, a decrease in VSD and VS concentrations of digestate occurred simultaneously.

Figure 5 shows the fluctuations of the OLR, with a range of 0.9-2.8 kg.VS/m^{3}days. Subsequently, a reversal in the relationship between OLR and VSD was observed. According to the literature (Babaee and Shayegan, 2011), an increase in the OLR concentration was correlated with a decrease in VSD. An increased TS concentration of the substrate and a constant VSD led to an increase in the OLR. Therefore, a reduction in the VS digestate concentration is observed despite a constant concentration of VS substrate, leading to a decrease in VSD.

Based on the data presented in Figure 8b, the highest increase in methane yield, reaching 197 L.CH_4/kg.VS, was on May 25, 2023. The decrease occurred when the OLR concentration was 1.3 kg.VS/m^3.day. A negative correlation was also carried out between OLR and methane yield using the ICM SPSS Statistic 22 application.

High-generation organic waste has the potential to be used in the production of new products (Windraswara and Prihastuti, 2017). The total mass of organic waste required is 14.07 kg/day, while the mass based on quartering methods is 7.6 kg/day. This means that the percentage of organic matter at Al Hikam Boarding School while using anaerobic digestion is 54%. The value is higher than the recovery factor for organic waste, which has a value of 32.6% (Hartono, Kristanto, and Amin, 2015).

4. Conclusions

In conclusion, waste generated at Al Hikam Boarding School was measured to be 33.6 kg/day, which was equivalent to 0.127 kg/person/day. Furthermore, the quantity of waste amounted to 683 liter/day or 2.58 liters/person/day. The composition of organic, plastic, paper, residue, textiles, B3, leather and rubber, glass, and metal waste was 41.8%, 20.5%, 15.7%, 12.7%, 4.906%, 1.91%, 0.937%, 0.799%, and 0.769%, respectively. During the operating procedure of the anaerobic digestion, the typical substrate has a pH of 6.1±0.38, TS of 25±0.092%, VS of 95±0.0054%TS, COD of 453±188 g/L, and temperature of 29.5±1.12^{o}C. Meanwhile, the concentration of ammonia, VSD, and COD reduction was 1057±378 mg/L, 91±0.015%, and 89±0.081%. The parameter data affected biogas volume and methane production, which had a concentration of 805±218 L/day and 292±130 L.CH_4/kg.VS. The gas was composed of methane and carbon dioxide, with a concentration of 59±0.035% and 41±0.035%. Thus, anaerobic digestion with a TORBI rector had the potential to reduce organic waste at boarding school by about 54%, with a communal setting where fluctuations were complemented by waste from surrounding areas such as restaurants. This method reduced waste going to landfills and produced biogas, which might be used for cooking regularly. Further study could conduct controls on the type of substrate used to identify the optimal methane yield value.

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