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Energy Potential from Waste Activated Sludge in Domestic Wastewater Treatment Plant South Jakarta

Marlita Elisa[1,] and *Nopa* Dwi Maulidiany[2*]

[1,2] Environmental Engineering Study Program, Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia

Abstract. Wasted activated sludge (WAS) a byproduct of wastewater treatment, holds significant untapped energy value. Conventional practice in DKI Jakarta involves collecting and directly disposing of WAS into landfill sites, overlooking the potential benefits of the sludge. Anaerobic digestion (AD) is a sustainable process that converts organic matter in the absence of oxygen offering a promising solution to harness this potential. The study aims to emphasize waste into energy by analyzing the volume of biogas through the Biochemical Methane Potential (BMP) value of WAS from the domestic WWTP in Setiabudi, South Jakarta. Characterization of WAS and its suitability for AD will be explored using DIN standards for 21 days. The experiment was duplicated into variants I1 and I2 and the parameters tested were pH, COD, TKN, VS, TS, concentration and volume of methane gas. In this study, the biogas yield from WAS obtained at 54,98 and 89,62 ml CH_4/g VS along with the composition of biogas determined through GC readings at 61,78% CH_4 and 56,08% CH_4 from I1 dan I2, respectively. By optimizing AD processes, this study seeks to contribute to sustainable waste management and renewable energy production. Further research is needed regarding pre-treatment that may influence the formation of biogas.

1 Background

One of the main by-products arising from the operations of Municipal Wastewater Treatment Plants (WWTPs) is commonly referred to as sludge. Sludge is closely associated with the removal processes targeting dissolved and insoluble solid contaminants in wastewater streams through diverse processing stages [1]. Waste-activated sludge (WAS) holds significant energy due to the large amount of organic matter contained in the sludge. The main source of sludge production in municipal wastewater treatment plants typically comes from the primary clarifier and secondary clarifier. Additional sludge production may result from the process of adding coagulants or flocculants, chemical precipitation, and tertiary filter backwash operations. In conventional WWTP, sludge is typically treated using thickening, digestion, conditioning, dewatering, and disposal processes [1]. However, in recent years new technologies have been developed to recover resources and reduce the

* Corresponding author: nd.maulidiany@ui.ac.id

quantity of sludge. Several emerging technologies such as hydrolysis or disintegration of solids in sludge (thermal, ozone, preoxidation, ultrasonic destruction) and nutrient recovery technologies keep developing to enhance anaerobic digestion processes [1]. This recovery means being able to restore nutrients and protein as well as digesting solids more optimally and efficiently to be able to recover energy as well as reduce the quantity of sludge.

Typically, anaerobic digesters require a type of waste rich in organic content. In addition to the high organic matter in WAS, the energy potential produced from WAS will be tested based on the anaerobic digestion (AD) process. Biological methane potential (BMP) method has recently been used in many studies to elucidate different substrates that produce a lot of biogases, especially through the BMP assays [2]. BMP serves as an indicator to depict the potential maximum volume of methane gas produced per unit mass of solids or readily volatile solid materials [6]. Current research has demonstrated that the biomethane output may be greatly increased by anaerobic co-digestion of waste-activated sludge (WAS) with lipid-rich waste ([3], [4], [5]). Therefore, the potential use of WAS as an AD substrate represents an opportunity over conventional immediate disposal waste.

The main objectives of this study aim to emphasize waste into energy by analyzing the volume of biogas through the Biochemical Methane Potential (BMP) value of WAS from the domestic WWTP in Setiabudi, South Jakarta. The object of the research focuses on the domestic wastewater treatment plant in Setiabudi, South Jakarta, Indonesia, which is estimated to collect sludge and currently employs conventional treatment methods, potentially overlooking the advantages of utilizing the sludge. Furthermore, the study involves the analysis of solid reduction, COD, and TKN through the BMP test, conducted to elucidate the mechanisms of the anaerobic digestion process. The experiment was performed using the BMP method to determine the accumulation of produced biogas, followed by biogas concentration testing using GC (Gas Chromatography). Through the conducted research, it is anticipated that WAS will serve as a promising substrate in the AD process, attributed to its high methane yield potential.

2 Method

The energy utilization of Waste Activated Sludge (WAS) from the Setiabudi WWTP will be tested using the DIN Standard by measuring biogas volumes (CH_4 and CO_2) from the biogas reactor, while the biogas concentrations measured using a GC (Gas Chromatograph). The experiment will be conducted over 21 days to observe and measure gas production within the biogas reactor. Meanwhile, gas concentrations will be measured using Gas Chromatography at the laboratory in the Chemical Engineering Laboratory of the University of Indonesia. The anticipated outcome of this research is the identification of potential energy within the sludge.

2.1 Substrates

The WAS used for this experiment was obtained from Setiabudi Wastewater Treatment Plant (WWTP) (South Jakarta, Indonesia) which uses a Moving Bed Biofilm Reactor (MBBR) with a processing treatment capacity up to 85 L/s. The sampling of sludge is conducted before the sludge treatment process at the wastewater treatment plant, which involves the drying and pressing of the sludge. After collection, the samples were transported to the laboratory using a jerry can by following the standard for sampling containers from SNI 6989.59 (2008) and stored at $4^oC \pm 2$ freezer for no more than 3 days before use.

2.2 Experimental setup

The biogas reactor used in this experiment is one of the biogas volume tests based on the development of the VDI batch fermentation method using the concept of liquid transfer (liquid displacement) [6]. The concept of liquid displacement measurement is a volumetric method of measuring biogas by transferring the volume of biogas to an equivalent external collection system, in this case, the volume transfer is represented by a vessel filled with liquid [7]. The gas volume in the reactor is measured using a eudiometer, ambient thermometer, and ambient pressure gauge. Gas production measurement takes place for 21 days according to the DIN 38414 (Part 8) standard. Two reactors are utilized with each substrate sample contain 50 mL of WAS while still leaving space for the headspace area of the storage bottles in the reactor. The headspace volume based on the test standard is 40% of the total storage bottle container.

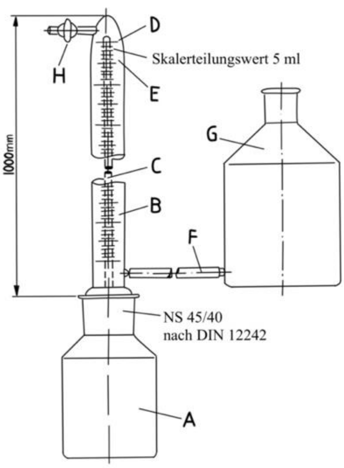

Fig 1. Biogas Reactor

The experiment using the DIN basis commences with the preparation of the reactor sealing solution. The sealing solution comprises 30 ml of sulfuric acid mixed with 1 liter of distilled water, which is then homogenized. Subsequently, the solution is added with 200 grams of sodium sulfate decahydrate ($Na_2SO_4*10H_2O$) or equivalent to 88.268 grams of Na2SO4. In a separate container, a methyl orange solution is prepared by mixing 0.1 grams of methyl orange sodium salt into 100 ml of distilled water to serve as the solution's dye. Then, the methyl orange solution is blended into the sulfuric acid solution. The next step involves filling the measuring bottle (G) through the connecting tube (F) until the zero mark on the eudiometer is reached. The addition of the sealing solution is carried out until the bottle is filled up to one-fourth of its capacity with the stopcock (H) open, followed by closing the stopcock. Subsequently, the eudiometer tube (B) is installed, and air replacement in the storage bottle (A) is conducted using nitrogen. These steps are undertaken to ensure an anaerobic reactor environment. The apparatus setup is then stored in a dark room, covered with a lid.

2.3 Characteristic Test

The initial test aims to determine WAS characteristic data such as COD, TS, VS, TKN, and pH to see changes in the characteristics of the substrate after the formation of biogas. Consideration of parameter measurements is based on literature reviews to test and analyze pH, COD, Total Solid (TS), Volatile Solid (VS), Total Kjeldahl Nitrogen (TKN) as a representation of protein content in substrate [6]. TS and VS were analyzed using the USEPA Gravimetric method, COD was analyzed using the USEPA Reactor Digestion Method, and TKN was analyzed using the Nessler method. The characteristic test was held at the University of Indonesia's Environmental Engineering Laboratory.

3 Result and discussion

3.1 Characteristics of WAS

The characterization of the substrate in the BMP process is carried out by testing the initial parameters of the substrate. The results of parameter testing before the experiment can help to identify the content of the samples and the correlation between each parameter/variable and the settlement with the formation of biogas. The results of the test parameters from the study are divided into COD, pH, TKN, Total Solid (TS), and Volatile Solid (VS) which can be seen in **Table 1**.

Table 1. WAS Sample Characteristics

Parameters	I1	I2
COD (mg/L)	22600	20500
pH	6	6
TKN (mg/L)	14.4	2.4
TS (%)	4.6	8.6
TS (gr)	0.4818	0.094
VS (%)	79.4	88.9
VS (gr)	0.3826	0.0836

Notes:
A: Sample I1 (Waste Activated Sludge sample 1)
B: Sample I2 (Waste Activated Sludge sample 2)

Both of the samples have COD values that were quite close to each other indicating a similar organic content from two samples that were taken at different times (see **Table 1**). When compared to previous research utilizing WAS in a study with a co-digestion system [2], it can be stated that the findings of this research have a higher COD value than the previously reported, which is 12700 ± 0.8 mg/l. Given the COD content, it is possible to achieve a cumulative methane potential value of nearly 200 mL/g VS. This indicates that the organic content in sludge from the WWTP in Setiabudi is relatively high. Consequently, this situation could potentially increase biogas production or energy generation. As for the acidity level in this experiment, both samples have a neutral to acidic sludge content with a pH value of 6. This may be due to the mixing of the addition of flocculants and coagulants in the waste treatment process [1]. Nevertheless, these recorded pH values consistently fall within the optimal range required for the anaerobic digestion (AD) process [7].

Another tested parameter is the TKN value, which can represent the protein content within the substrate [9]. It can be observed that sample I1 has a higher TKN value compared to I2. This indicates the presence of distinct characteristics among the sludges produced at the WWTP. A high TKN value indicates that the sample is rich in proteins making it a suitable sample as a substrate for the methanogenesis process [10]. However, the quality of the gas produced is not only influenced by the amount of proteins but also by fats, which yield a higher quantity of methane.

TS and VS testing were conducted to assess the biodegradability of the organic content in the samples. The TS and VS values in **Table 1** closely approach the TS and VS testing of from the WWTP sludge in previous study[10], which ranges from 2.29% to 4.49% TS and 62.2% to 71.6% VS [11]. In that case, a high VS value along with COD has the potential to generate a substantial accumulation of biogas during the AD process, as both parameters can represent the overall testing effectiveness [6]. According to all the tested parameters, it can be inferred that the WAS samples hold significant potential as a substrate for the AD process.

3.2 Analysis of Cumulative Biochemical Methane Potential

The investigation of energy potential in WAS was conducted through the biogas reactor to monitor the accumulation of biogas formation from the samples. This was followed by gas composition and concentration readings using GC. Methane gas measurement, employing the DIN standard-based method, was performed by observing the volume changes of the locking solution daily for 21 days or until the volume change was less than 1%.

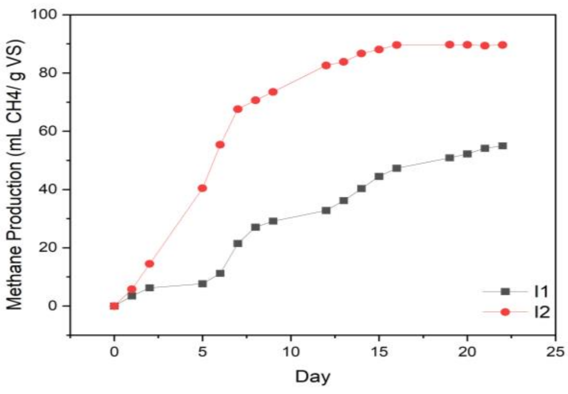

Fig 2. Cumulative Methane Gas Production

The methane yield values are presented in the diagram in **Fig 2** which illustrates one of the gas components, CH_4 within biogas. Through experiments that were carried out on WAS samples from the Setiabudi WWTP, the methane yield values for samples I1 and I2 were 54.98 and 89.61 mL CH_4/g VS, respectively. In a study by Koch, Lippert, and Drewes (2017) [11], the methane yield from WWTP sludge ranged from 250 to 290 mL CH_4/g VS. When compared to the findings of this research, the obtained values are notably lower, but noted that in this experiment no inoculum was added as a starter for AD. Thus, it may affect the biogas accumulation as a result.

Based on the obtained methane yield values, the conversion of biogas into a fuel source can be pursued, employing an assumed estimated calorific value of 6 kWh per 1 m^3 biogas volume [12], the calculated calorific values for I1 and I2 were 0.000534 kWh/m^3 and 0.00095 kWh/m^3, respectively. The values obtained remain within a narrow range when compared to the calorific values of conventional fuel sources such as wood, cow dung, coal, plant residues, and natural gas [12]. However, based on the earlier statement that WAS does not employ a starter during the AD process, its outcomes cannot be directly compared to other studies that utilize inoculum. Other than that, considering the distinct characteristics and organic content among different components, the challenges in biogas production will also vary for each substrate [13]. Furthermore, discrepancies between the biogas yields observed in testing and those reported in the literature can be attributed to several influencing factors, including microbial activity, environmental conditions, and experimental errors [6].

The accumulation of biogas and methane results in an exponential graph as the gas volume increases until the graph reaches a stationary phase or a point of insignificant gas production volume. The biogas composition in this experiment consists of several gases represented by CH_4 and CO_2. The ratio of CH_4 to CO_2 volumes is associated with the stages of the AD process, namely the microbial activity in biogas production [12]. A higher CH_4 content will lead to a more efficient energy utilization from the AD process [14]. The stages of organic matter degradation in the AD process can be observed in **Fig 2.**

The initial stage of anaerobic degradation involves microorganisms that operate through a series of fermentation processes to hydrolyze solid residues, yielding simpler organic acids that are subsequently digested to produce acetic acid [13]. When connected to the hydrolysis stage, this can be observed in the biogas accumulation graph, particularly from day 1 to day 4, during which there is minimal change in biogas volume. An increase in biogas becomes evident from day 5 onwards. In the stages of the AD process, the acidogenesis process begins to produce CO_2 and H_2, suggesting the onset of secondary biogas production from that day onwards. Following day 5, a significant and sustained increase in biogas occurred until day 15. This might be due to the degradation of organic content progressing from acetogenesis to methanogenesis, resulting in the production of more CH_4 and CO_2 until the bacteria can no longer degrade the organic content. This is consistent with the findings of Li et al. (2022) [10], where rapid organic matter degradation and favorable environmental conditions provide sufficient nutrient substrate and a suitable environment for methanogenic bacteria to metabolize methane. As digestion continues, the available substrate gradually decreases [10]. Consequently, methane production gradually declines, as seen from day 15 to 21, or until no significant gas production occurs.

At each stage, the conversion of organic matter into biogas will impact the accumulation of biogas at the end of the experiment [6]. When the environmental conditions for microorganisms are unstable, the degradation of organic content may not proceed optimally, affecting the production of both CO_2 and CH_4 [15]. The production of CO_2 in all samples notably increases until day 15. This was consistent with findings similar to those of Kavuma (2013), where carbon dioxide production increased during the initial days of digestion, reaching its peak on day 15 and subsequently decreasing significantly due to gas conversion. However, it's unavoidable that experimental errors, such as sample leakage during GC testing or changes in gas composition due to variations in air pressure during sample transport to the Chemical Engineering Laboratory at FTUI, can occur and influence the results of this experiment.

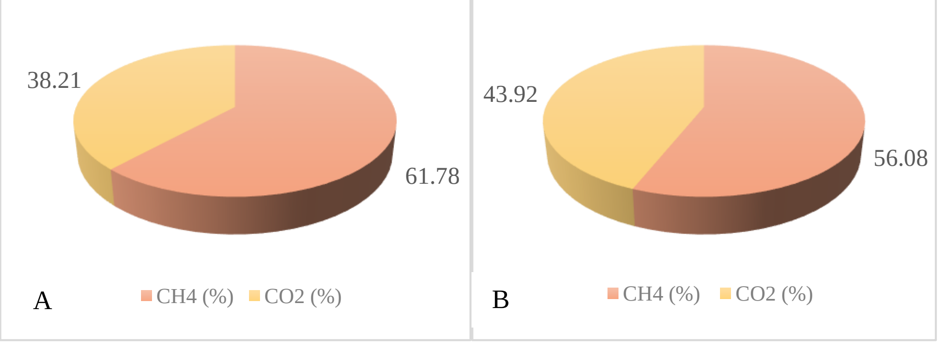

Fig 3. Biogas Composition A (I1) and B (I2)

Samples I1 and I2 in this study produced 61.78% CH_4; 38.21% CO_2 and 56.08% CH_4; 43.92% CO_2, respectively, which falls within a range similar to the experiment conducted by Wan, Zhou, Fu, & Li (2011) [16] with 65.1±1.9% CH4 and 28.1±1.2% CO_2 (see in **Fig 3**). Observing the significant differences in methane and carbon dioxide compositions compared to the standard AD biogas, various possibilities arise regarding the influence of suboptimal AD factors. The elevated CO_2 production could be due to inhibition in the fermentation process or hindered methane production caused by other gases such as hydrogen sulfide, which restricts methane-producing bacteria [17]. Moreover, the proportions of methane and carbon dioxide continually vary due to the duration and rate of biomethanation during retention time [17]. This phenomenon occurred in a study using sludge from wastewater and fats, oils, and grease (FOG), which experienced digestion failure due to a relatively short hydraulic retention time of 10 days, allowing microorganisms insufficient time to fully degrade the organic matter [16].

3.3 WAS characteristics of BMP performance Analysis

From the results of the two samples, it can be proven that there was a reduction in the initial COD parameter, as depicted in **Fig 4**A. The reduction of COD values before and after the AD process can represent the outcome of organic content degradation within the substrate, serving as an indicator of the organic content's biodegradability [8]Generally, the treatment of biowaste through AD leads to a decrease in COD [12]. After the calculation, the percentage reduction in COD for I1 and I2 was determined to be 73% and 22% respectively. The maximum COD reduction can reach 88% from the initial testing, as indicated by a study utilizing an AD reactor with the addition of FOG substrate [18]. However, in this particular testing, only about 22%-73% of the COD in the WAS substrate was reduced after the BMP process. This could possibly be due to insufficient degradation of organic matter, influenced by factors such as inhibited microbial decomposition activity [6].

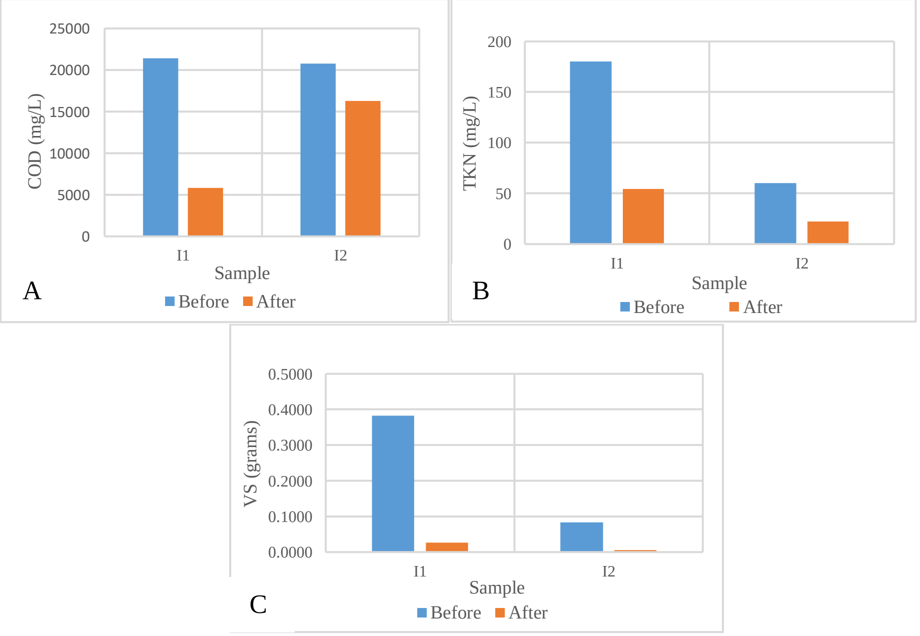

Fig 4. Initial and End Parameter Testing

Regarding the TKN values (**Fig 4**B), it can be determined that reductions of up to 70% and 63% occur for samples I1 and I2, respectively. Based on the study by [19], proteins and carbohydrates can be converted into biogas with methane content ranging from 50% to 58%, whereas fats can be converted into biogas with methane content ranging from 66% to 73%. Although fats generate a higher amount of methane gas, it can be concluded that the level of degraded protein content is considerable enough to produce methane gas. In terms of volatile solids (VS) reduction, both samples achieve percentages exceeding 90% (**Fig 4**C), which can be considered quite high. This is consistent with the high VS content in WAS prior to the experiment, providing more opportunities for the degradation of volatile solids. In comparison to the study [20] utilizing high-rate mesophilic AD, which reported a range of 56%-65.5%, it can be noted that the percentage reduction in this experiment remains relatively high. This indicates that the level of solids (VS) stabilization in WAS is also quite substantial.

4 Conclusion

The biogas production from Waste Activated Sludge (WAS) at the WWTP in Setiabudi, South Jakarta, indicates a relatively modest energy potential based on methane yield values of 54.98 mL CH_4/g VS for sample I1 and 89.61 mL CH_4/g VS for sample I2, in comparison to the methane yield from lipid-rich waste. Despite WAS demonstrating a reduction in organic content by 93-94% for VS and 73% for COD, several factors can impact microbial activities in the degradation of organic content into biogas. These factors include sample heterogeneity, reactor retention time, suboptimal substrate ratios, and acidic pH. Furthermore, the measurement of biogas concentrations for samples I1 and I2 resulted in respective values of 61.78% CH_4 with a calorific potential of 0.000534 kWh/m^3 and 56.08% CH_4 with a calorific potential of 0.00095 kWh/ m^3. Further research is needed related to bacterial environment suitability.

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