



## Research article

## Bio methane potential of sludge from municipal sewer and exchange stations

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## ABSTRACT

Technologies with resource recovery alternatives are suggested in metropolitan settings. Anaerobic digesters (AD) are the most common. The use of microcrystalline cellulose and a variety of grocery products as control feed increases the cost of bio methane potential analysis (BMP). This limits its replication, especially in developing countries. As a result, this study looks into the use of milled paper as a control feed during BMP analysis of sludge from sewer and exchange stations.

A batch experimental study at 37 °C with hydraulic retention times of 23 and 24 days for exchange station and sewage sludge, respectively, was established for the assessment. The pH of the sewage sludge was acidic during the analysis. To avoid underestimating the total (TS) and volatile solid (VS) ratios, the VS should indeed be determined through temperature or pH adjustment. As a result, the preceding alternative was implemented in this work.

According to the findings of the online biogas application, the blank (milled paper) accurately keeps the required validation standards. Furthermore, the gas production potential of sludge from the exchange station (ES) and the sewage line (SS) is 2.4 and 1.6 NL/gVs, respectively. The generated gas has an electric potential of 8.81 and 3.35 KWH for ESS and SS, respectively. Interestingly, the calorific values of the investigated substrates were also nearly equivalent.

In brief, using milled paper as a control feed in BMP analysis reduces laboratory costs and encourages BMP test repetition, which is especially important in developing countries. This advances research on the use of AD in the search for alternative energy sources.

## 1. Introduction

Due to human actions, the consumption of sufficient water is unavoidable. A significant amount of used water is discarded as waste, 99.9% water and 0.1 percent solids (Muralikrishna and Manickam, 2017). Because this solid is a significant source of contaminants, it is necessary to seek effective treatment. According to a WHO fact sheet on sanitation in 2017, 45 % of the global population uses sanitation services that are safely managed. While two billion people lack access to basic sanitation (WHO, 2019).

The amount of waste produced increases in direct proportion to the amount of water demanded. As a result, the volume of wastewater discharged may be greater than the capacity of the pre-designed wastewater collection or treatment system. Because of this, approximately 80% of wastewater is now discharged untreated into

waterways, posing health, environmental, and climate-related risks, according to studies (Gill and Al-Shankiti, 2018; Wastewater Report 2018, n.d.).

This merely enhances the load of pollutants, which has major consequences for the environment, human health, and the quality of fresh-water sources. As a result, there is a greater concern for safe wastewater collection, transportation, treatment, and disposal/reuse.

Under this situation in terms of economies of scale, in metropolitan areas, a technology with energy recovery alternatives is advocated (Wikipedia, 2020). According to the International Energy Agency, global energy demand is expected to rise by 4.6 percent by 2021 (International Energy Agency, 2021). From this prospective, alternative energy sources are critical for managing energy demand and wastewater treatment. Decentralized technologies are viewed as eco-friendly solutions, particularly in rapidly urbanizing cities.

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To meet energy demand while also protecting the environment, anaerobic digesters (AD) are becoming a popular way to produce biogas from liquid and solid waste (Berhe et al., 2017; Lemma and Getachew, 2020; Sime, 2020). The AD system combines solid digestion with biogas production. Through the conversion of biomass energy into a useful fuel (biogas), a method for recycling organic wastes into stable soil additions, and waste treatment aimed at reducing their dangerous environmental consequences.

Because of the economic and environmental implications of AD technology and cues provided by a variety of agricultural policies and incentives, waste management, and renewable energy production, the application of AD varies greatly around the world, from small-scale household digesters in developing countries to large farm-scale or centralized digesters in developed countries (Vasco-Correa et al., 2018). Due to their economic elite, intensive research, and government subsidies for renewable energy and waste management solutions, China, Germany, the United States, Italy, the United Kingdom, and France are regarded as world leaders in the biogas sector (Akhiar et al., 2020).

The current application of AD in the biogas industry is categorized into three parts: micro digesters that use biogas, scale digesters that generate electricity, and scale digesters that produce biomethane. Micro digesters are widely used in rural areas of developing countries. They are regarded as an essential component of agriculture, waste management, and energy security. There are nearly 50 million micro-scale digesters in operation worldwide. The produced gas by these digesters is typically used in stoves for cooking or heating, replacing solid, high-emission fuels such as firewood and charcoal. A total of 50 million biogas stoves are used for cooking by approximately 126 million people. Furthermore, the generation of electricity from biogas is a well-established technology that is widely used all over the world. There are an estimated 132,000 small, medium, and large-scale digesters in operation. Similarly, upgrading biogas to biomethane for use as vehicle fuel or injection into local or national grids is a newer but now well-established technology. Over 606 upgrading plants are operational in Europe, with 203 in Germany, 96 in the United Kingdom, 69 in Sweden, 47 in France, and 53 in the Netherlands. Aside from Europe, the United States has about 50, China has 25, Canada has 20, and Japan, South Korea, Brazil, and India have a few. According to available data, 700 plants worldwide convert biogas to biomethane (Sarika, 2019; Yang et al., 2019; IEA, 2019; Canadian Biogas Association, 2021).

As evidenced by literature from various countries, the use of AD is widespread. Many quantitative studies have been carried out to determine the amount of energy that can be produced as well as the economic contribution that it can make. During the analysis and validation of biomethane potential tests (BMP) in the Automatic Methane Potential Test System (AMPTS) or Online Biogas Application, cellulose or other grocery products are used as controls in all experiments (OBA). However, the use of milled paper as a control feed for the BMP analysis was investigated for the first time in this study. This reduces the cost of BMP analysis while also improving the BMP test's reputation. This promotes the use of BMP analysis in the search for alternative energy sources, particularly in developing nations.

Furthermore, throughout different investigators' studies of the AD system, samples were collected from a separate collection system or purely municipal sewage. As a result, in different studies, total solids (TS) concentration was carried out at a standard temperature of 105 °C. According to research, determining TS in acidic waste, such as kitchen waste analysis of volatile solids (VS), at a standard temperature of 105 °C reduces the VS concentration. In the AD system, this results in a kinetic disparity between acid formers and consumers. As a result, VS determination at 90 °C or through pH adjustment is advised.

For this investigational study, wastewater sludge samples were collected from exchange stations and sewage pipes. A temperature adjustment was made during the TS determination because during the analysis the pH of the sewage sludge was within the range of an acidic environment. Sample collection and testing runs for the exchange station

and sewage sludge were conducted throughout the dry season. As a result, the findings of this study's BMP analysis do not accurately reflect the potential for gas production during the wet season. Moreover, the BMP test was carried out without the use of headspace flushing.

## 2. Materials and methods

### 2.1. Sources of inoculum and substrate

The sludge (substrate) for the BMP study was carefully collected from Addis Ababa University's (AAU) College of Natural Science's existing wastewater sewage system, as well as official vehicles from exchange stations. Inoculum was also collected from AAU's College of Natural Science's existing biogas plant. It had been pre-incubated for three days.

### 2.2. pH determination

After two days of sample collection, the pH of the sampled municipal wastewater was determined in the laboratory. The pH-010 (ATC) folding three-in-one pH tester was used. During the analysis process, the manufacturer's working methods and a laboratory manual were also referred (Pillai, 2009).

### 2.3. Inoculum to substrate ratio

To determine the potential for methane production, the food-to-microbe ratio must be determined, which is computed using the organic matter content of the inoculum and the organic feed. As part of this study, TS and VS concentrations were measured. While performing the TS and VS measurement and calculation, the U.S.EPA standard laboratory guidelines and a book by Chunlong were used (USEPA, 2001; Chunlong, 2007).

To remove the water content of the sample, evaporating dishes with a given weight of the sample were dried at 105 °C for 24 h. The remnant was weighted after collecting and cooling it in a desiccator. After removing the volatile materials, the weighted sample was left to burn for an hour at 550 °C. The total and volatile solids were then computed using the weight measurement data obtained prior to and following each drying step. TS analysis from the sewer system was also done at 90 °C, taking into account the pH of the sample (Angelidaki et al., 2009). Finally, the VS fraction was determined using the VS ratio of the inoculum and substrate, as specified in the VDI 4630 guideline and the biogas handbook (VDI, 2016; Drosig et al., 2013).

### 2.4. Milled paper preparation

In numerous studies, the validity of BMP analysis is confirmed by using microcrystalline cellulose as a control feed. By considering the basic fact that cellulose fiber is the primary raw ingredient used in the making of paper (Edyta et al., 2020; ZX Printer, 2013), milled paper was used as the control feed during the experimental analysis. As a result, worn office paper was chopped into bits and soaked for 32 h. Every 10–12 h, the soaked paper was gently massaged with the palm to uniformly soak the pieces and further divide them. When it has been fully soaked, the residual paper muck is filtered through a cotton towel and allowed to dry at room temperature. The dry component was then processed with a grinder found at the mechanical laboratory.

### 2.5. Batch anaerobic digester experimental set-up

A bath experimental setup was used for the BMP test at the Addis Ababa Institute of Technology's Sanitary Laboratory (AAIT). During the complete BMP inspection, nine standard glass bottles were properly utilized as digesters. Three working sets of inoculums (blank), control,

and examined substrate were used during the detailed examination of the bio-methane potential of the collected sludge. For scientific significance, all the different groups were tested in triplicate.

The experimental setup includes a heated water bath as an incubation tank, glass bottles as an anaerobic reactor, glass bottles as a CO<sub>2</sub> fixing unit, and graduated inverted cylinders as gas collection components, as illustrated in Figure 1. The AD system was permitted to run during the trial until the biogas generation was demoted.

### 2.5.1. Incubation unit with anaerobic bottles

To achieve optimal gas production, environmental conditions must be carefully managed. One of the most important factors is the digester's temperature. A heated water bath was used to maintain the bath's water temperature from ambient to a sufficient temperature within the anaerobic bottle. It was typically set to operate at 37 degrees Celsius. After inspecting the water level, the thermostatic water bath was replenished to its optimal level with tap water. Each anaerobic bottle in the thermostatic water bath was manually shaken twice a day for 2 min. This ensures that the inoculum and substrate are evenly mixed and that temperature gradients are avoided. This ensures a consistent mixture of inoculum and substrate in the anaerobic bottles and eliminates temperature gradient changes.

### 2.5.2. Carbon dioxide absorption units

Carbon dioxide gas is produced during the methanogenesis process. Nine conventional bottles containing a sodium hydroxide (NaOH) solution were used to absorb it. To properly create the 3 M NaOH solution, 510 L of distilled water and 561 g of sodium hydroxide pellets (Product code- GRM1183) from HI Media laboratories were used, according to the AMPTS II laboratory protocol (Bioprocess Control Manual, 2016).

### 2.5.3. Gas measuring unit

The volume of gas generated was measured using the water displacement method. The potential interaction between water and methane is exceedingly low since their chemical structures are so dissimilar. This strongly supports methane's insolubility in water. From the direct readings of the inverted graduated measuring cylinders, the corresponding volume of produced methane gas was estimated. The graded inverted cylinder was refilled with tap water before reaching the critical water level.

## 2.6. Data analysis

Microsoft Excel-2016 was used to organize the reading data from the graduated cylinders. Based on volumetric measurements, methane production was computed using the standard BMP technique, document number 201, file version 1.9 (Hafner et al., 2020).

### 2.6.1. Volume of methane produced from AD

By using the normalized methane concentration ( $xCH_4$ ) and the standardized biogas volume ( $V_{std}$ ), the cumulative methane production was calculated as shown in Eq. (1).

$$VCH_4 = xCH_4 \cdot n \cdot V_{std} \quad (1)$$

As indicated in the VDI 4630 manual, gas volume normalization was performed at a standard temperature of 0 °C and a pressure of 1 atm (VDI, 2016). Thus, to standardize the measured gas volume by accounting for pressure, temperature, and water vapor Eqs. (2) and (3) were used.

$$V_{std} = v \cdot \frac{(P - P_w) \cdot T_n}{P_n \cdot T} \quad (2)$$

$V_{std}$ : Standardized gas volume (ml)       $T_n$ : Standard temperature (273.15 K)

$P_n$ : Standard pressure (101.325 kPa)       $P_w$ : Saturation vapor pressure (kPa)

$T$ : Gas temperature (k)       $P$ : Gas pressure (kPa)

$v$ : Measured gas volume (ml)

The standard vapor pressure was calculated using Eq. (3).

$$P_w = 0.61094 \cdot e^{\left( \frac{17.625 \cdot T}{243.04 + T} \right)} \quad (3)$$

In addition, of the different techniques described in the standard BMP method document number 201, file version 1.9 method one was used to calculate methane production. Assume that the produced gas is made up entirely of methane and carbon dioxide. Eq. (4) was used to standardize the sum of these gases to one.

$$xCH_4, n = xCH_4 / (xCH_4 + xCO_2) \quad (4)$$

$xCH_4, n$ : The normalized methane volume fraction

$xCH_4$ : Measured methane concentration

$xCO_2$ : Measured carbon dioxide concentration

Further, this data was used as input to the web-based online biogas application (OBA) version 0.6.2. Additionally, using OBA, the total biogas output for all time was normalized and summarized by substrate mass. To calculate the background methane production of the inoculum from the mixture of examined substrate and inoculum, the mean volume fraction of bio-methane generation from it was removed using the AMPTS II manual (VDI, 2016).

### 2.6.2. Heat potential of the investigated substrates via AD

The amount of energy generated by an anaerobic digester from a given substrate can potentially be expressed in terms of net/low heat value (LHV). As shown in Eq. (5), LHV is calculated as the difference

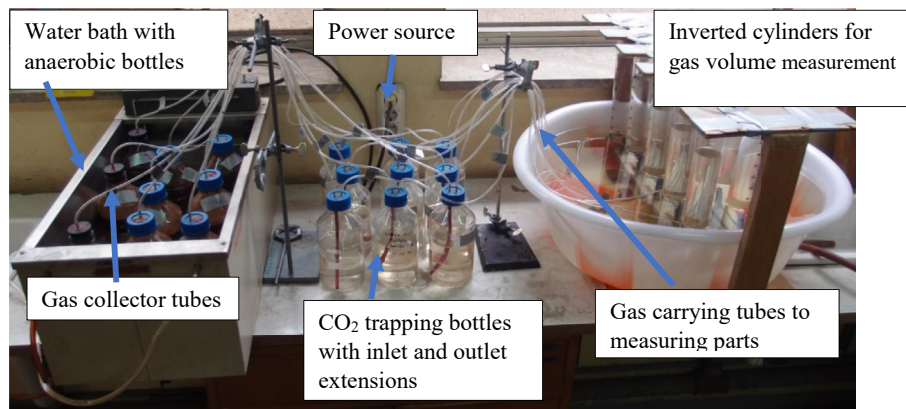


Figure 1. Anaerobic digester setup.

between the gross/high heat value (HHV) and that which is determined by the weight of the water ( $w$ ) and the enthalpy of vaporization (Charles, n.d.; Kuleape et al., 2014).

$LHV = HHV - \text{Energy to vaporize water}$

$$LHV = HHV - (2.766 * W)KJ / g \quad (5)$$

Furthermore, an empirical equation (based on a proximate analysis) developed by a research team that is applicable for defined ranges of VS and FS (60.84–82.64 % for VS and 17.36–39.16 % for FS) is used to compute HHV. Since the volatile solids (VS) and fixed solids (FS) values of the substrates used in this study were within the range, the authors' formula was used to determine HHV (Sahito et al., 2013).

$$HHV = 0.22551(VS) + 0.02505(FS) \quad (6)$$

### 2.6.3. Biogas to electricity

Eq. (7) was used to calculate the potential conversion of biogas to power. In a Malaysian and South Korean study, this was utilized to determine electric energy (Abdeshahian et al., 2016; Mudasar and Kim, 2017).

$$e_{\text{biogas}} = E_{\text{biogas}} * \eta \quad (7)$$

$e_{\text{biogas}}$  = The amount of electric power generated (kWH),  
 $E_{\text{biogas}}$  = Raw energy in the produced biogas (kWH) and  
 $\eta$  = Conversion efficiency of biogas to electricity (25–42%)

Eq. (8) demonstrates the calorific value of biomethane gas (6 kWh/m<sup>3</sup>), the amount of methane gas produced (total gas production (m<sup>3</sup>)), and the methane fraction that are all used to compute the raw electric energy (kWH) in the produced gas (percent).

$$E_{\text{biogas}} = EC_{\text{biogas}} * V_b * F_{\text{CH}_4} \quad (8)$$

## 2.7. Statistics

All results are presented as means  $\pm$  standard error, and comparisons were made using an unpaired t-test (two tailed) performed with Graph Pad Prism 9 software. P values of 0.05 were used to define statistical significance.

## 3. Results and discussion

### 3.1. Food to microorganism ratio

The AD system is the most effective method for sludge volatile solids (VS) stabilization. One of the factors influencing the performance of this activity is the food-to-microbe (inoculum) ratio. Such a measurement of the TS/VS ratio must be established (Bayhan and Erdirencelebi, 2020). According to previous research, the determination of TS should be based on the acidity or alkalinity of the sample effluent (Angelidaki et al., 2009). VS will be underestimated or overestimated due to the acidity or alkalinity of the sample wastewater. Because pH has such a strong

influence on microbial metabolism and the rate constant of hydrolysis (Borja and Rincón, 2017).

During this laboratory analysis, the pH of sample wastewater sludge from the sewerage system and exchange stations was found to be 5.1 and 6.9, respectively. A physicochemical analysis of 35 sewage sludge samples from different municipal wastewater treatment plants (WWTP) in Spain revealed a mean pH of 6.8 (Comesaña et al., 2018). Another study found that the pH of pure sludge is 7 (Liu et al., 2019). According to the findings of this study, the pH of sludge from exchange stations is similar to the mean value provided in the cited publications. The pH of sewage sludge, on the other hand, is vastly different. This could be due to the presence of pollutants from both point and non-point sources. As a result, the VS analysis has received special attention.

The average total solid, volatile solid (absolute and relative), and inoculum to substrate ratios were calculated using the masses of wet, dried, and burned samples, as shown in Table 1. The exact load of the feeds for the BMP analysis was then calculated using these inoculum substrate ratios (ISR). ISR values of 1.4 and 3.3 were obtained for sludge from exchange stations and sewage systems, respectively.

The study observed an inverse relationship between pH and ISR in the AD system, which was also mentioned in the analytical study on the effect of inoculum to substrate ratio in the AD system (Dixon et al., 2019).

### 3.2. Gas production potential of sludge

Sewage sludge can be treated using biochemical, thermochemical, or mechanical methods (Grosser and Celary, 2019). For the study, the biochemical strategy's anaerobic digester was used to investigate the biodegradability of municipal sludge collected from various sources. In the presence of microorganisms, the anaerobic digester follows a multi-step procedure. Among them, hydrolysis is the bottleneck stage. According to a review report, domestic sewage contains both particulate and dissolved organics. These particulate organics are mostly found in the form of organic polymers, which degrade at a slower rate (Rajagopal et al., 2019). Domestic sludge's gas generating potential is so reduced. The potential for sludge from the sewer system to generate gas, as seen in Figure 2, is a perfect representation of this. Before the 16th day, the gas production from the exchange station exceeded that of the sewage sludge.

The type of microbes in the examined substrate/inoculum, as well as the working environment, have a significant impact on the capacity for gas production. As shown in Figure 2, gas production from the ES and SS begins within 24 h of turning on the AD system. ESS, however, produced more gas than SS ( $p$  value < 0.0001). This is most likely due to the availability of anaerobic bacteria. Regardless of sewer operating conditions, according to research on sewage sludge structure and composition, proteobacteria types are the most prevalent phylum in municipal sewage sludge (Nascimento et al., 2018). As per Marín, this type of bacteria is facultative (Marín, 2014). As a result of the time they spend queuing up at the exchange station, they are able to be active and grow in population. As a matter of fact, the AD system can generate gas right away. The sewer system's holding period is far too short in comparison to the exchange station. As a result, the MO may be limited in its ability to fully activate in order to increase population density.

**Table 1.** Inoculum substrate ratios for ESS and SS.

Parameter	Unit	ESS	Paper (1)	Inoculum (1)	SS	Paper (2)	Inoculum (2)
pH		6.9	-	7.3	5.1	-	7.5
TS	%	4.44	93.87	3.24	1.66	100	8.65
VS (Absolute)	Gram	0.15	2.24	0.21	0.1	0.3	0.33
VS relative to TS	%	69.07	100	58.95	66.67	100	67.68
ISR	gram VS of Inoculum/gram VS of Substrate	1.42	0.1	-	3.33	1.11	-
Total working mass	Gram	800					

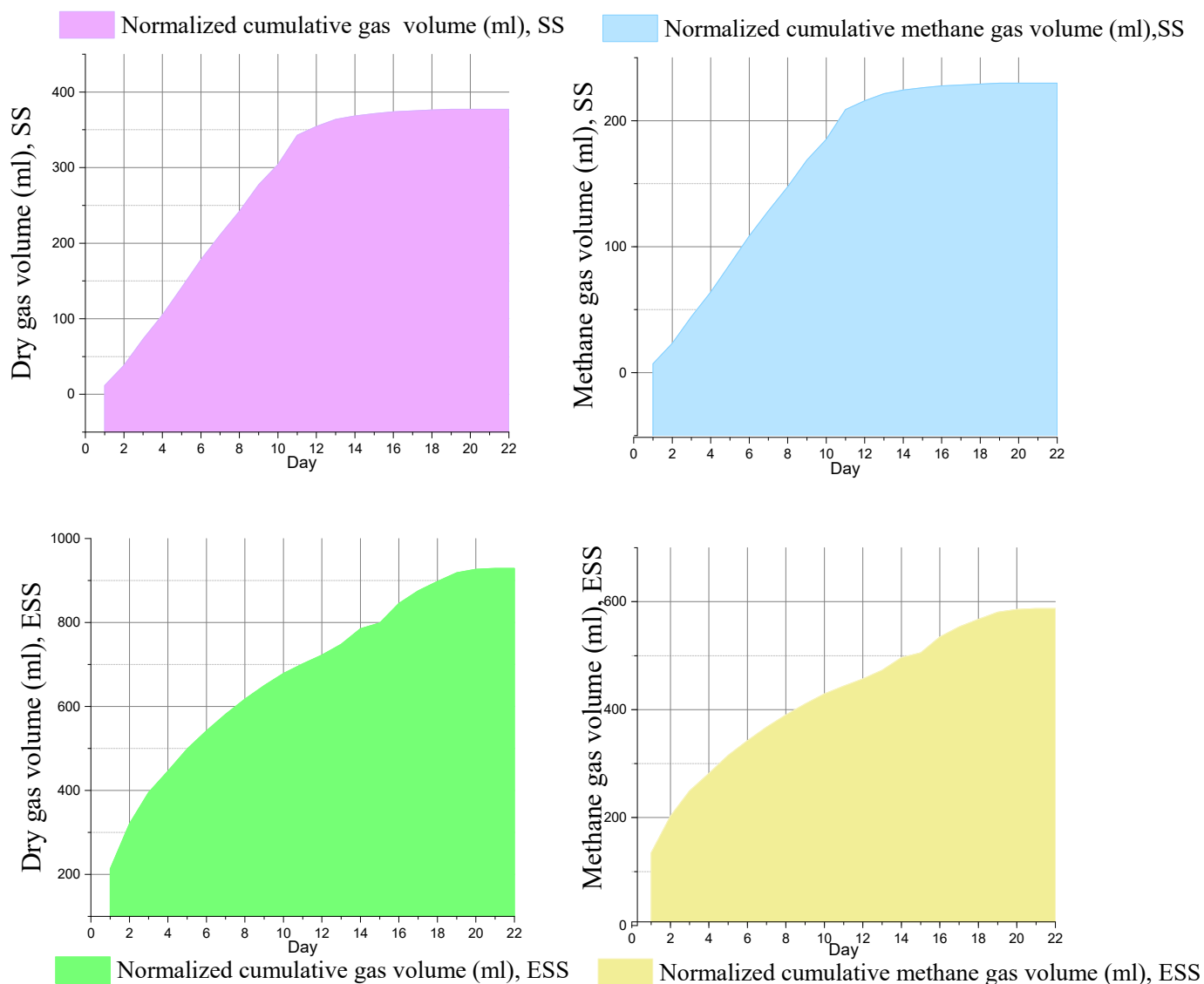


Figure 2. Normalized total and methane gas production from SS and ESS.

Furthermore, retaining sludge at exchange station sites prior to desludging reduces the time required for the hydrolysis step within the AD system. In this case, it could be regarded as a pre-hydrolysis stage, and the established AD process would function as a two-stage system. This has also been demonstrated in studies on the effects of pre-hydrolysis presence and absence on sewage treatment using an AD system. According to the study (Rajagopal et al., 2019), this pre-treatment improves bio-methane potential, solid reduction, and digestate disposal.

According to research findings, gas production from a two-stage AD system surpasses that of a single-stage AD system. Organic materials have more opportunities for break-down and grain size reduction in a two-phase AD system. This improves the solubilization of organic waste, and the increased bacterial activity results in the release of hydrolytic enzymes. This significantly increased biogas production by doubling or tripling it (Pilli et al., 2020; Owusu-Agyeman et al., 2021).

Furthermore, a comparison study of thermal and biological hydrolysis at various temperatures conducted in Ontario, Canada, found that the working temperature had a significant impact on the VSS concentration (Beraki et al., 2018). As a result, the pre-hydrolysis step's duration must be limited based on the examined substrate's operating temperature and composition. Otherwise, the amount of methane that can be caught may be underestimated. Thus, for effective gas and nutrient extraction, it is

preferable to keep the sludge residence time at a minimal level for anaerobic acidification (Chen et al., 2021).

The standardized volume of methane produced from ESS and SS is depicted in Figure 3. For comparison with other studies, the produced methane gas was normalized at a standard temperature and pressure. The average gas production of sludge from ES and sewage was 693.47 and 273.42 Nml, respectively. The volume of gas produced by sewage sludge is nearly equal to the Sudanese findings. A 30-day lab report using a five-liter digester and household sludge from the wastewater treatment plant at Soba municipal station (south of Khartoum, Sudan) produced a volume of 270.25 Nml gas (Haroun et al., 2020). However, the gas production potential of ES sludge deviates significantly from this result. On the other hand, a South Arabian study confirmed that the annual biogas output capacity of a biogas plant with a digestion tank size of 500 m<sup>3</sup> was expected to be 20–36 10<sup>3</sup> Nm<sup>3</sup> (Ayhan et al., 2016). Further, as per Subiaco's (Western Australia) experimental results, sludge samples had a biogas production capacity of 0.6 m<sup>3</sup>/VS. This variation deviates significantly from the study's findings. This could be due to differences in the volatile solid concentrations of the sludges (Pong, 2013).

The statistical results of mean and residual standard deviation (RSD) obtained from OBA, presenting the measured volume of gas production from ESS, SS, and milled paper, are summarized in Table 2.

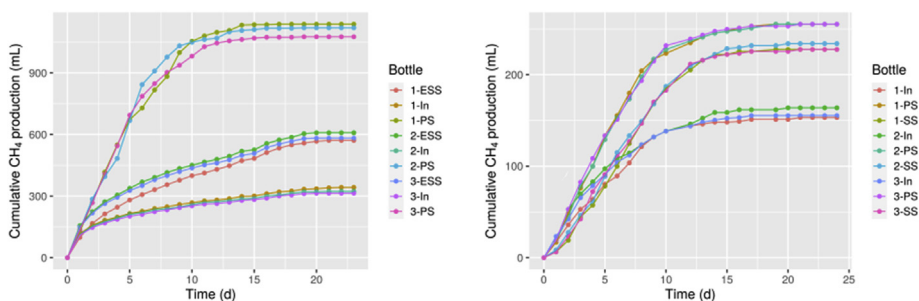


Figure 3. Standardized methane gas production from ESS and SS, a graph from OBA.

Table 2. Mean and standard deviation of gas production.

	ESS	Paper (1)	SS	Paper (2)
Mean BMP (ml/gVS)	2401	382	1596	350
RSD (%)	6.03	3.9	2.79	5.13

According to the RSD results, the observed values are comparable to the theoretical values of methane production from sewage sludge. As a result, the data set was statistically valid. Moreover, the gas production from the inoculum must be deducted to obtain the particular gas production from the examined substrate. It must also be adjusted by substrate VS mass. The normalized gas production employing substrate mass from the exchange station and sewage sludge is provided as 2.4 and 1.6 NL/gVS, respectively, in Figure 4.

To see if there is a statistical difference in gas production between exchange station sludge and sewage sludge, a two-tailed statistical analysis was performed. As illustrated in Figure 5, the volume of biogas (A) and methane gas (B) produced from the exchange station sludge and sewage sludge differs significantly.

### 3.3. Validation of BMP analysis

A biomethane potential test nowadays is used to estimate the methane production potential of organic materials, solid or liquid. Even when performed in accordance with similar standards and guidelines, BMP from the same substrate has significant inter-laboratory test variability. To address this major challenge and improve test replicability, a common validation criteria design was established, as recommended by a standardization study (Holliger et al., 2016).

In addition, a study was conducted to categorize the sources of variability and refine the validation criteria by putting the standardized BMP technique to the test in a variety of inter-laboratory projects. The BMP

results from this study were validated using the test's validation criteria and document number 100 from the collection of standard BMP techniques (Hafner et al., 2020; Holliger et al., 2020). OBA is used to quickly generate the validation findings in Table 3.

According to the validation requirements for ending a BMP experiment, gas production must be less than 1% of the net collected volume of methane from the substrate for three consecutive days. As a result, the time span chosen to accomplish the BMP analysis was ideal. Furthermore, the criteria were developed with cellulose as a control. During this study, however, a rough milled paper was used as a control, which met the validation criteria. As a result of the findings, milled paper can be used as a control in the absence of cellulose, which is especially beneficial to developing countries.

### 3.4. Energy potential of biogas and its economic value

The biogas generated by the AD system can be used to generate heat or electricity. The electric potential of gas produced from sewer and exchange station sludge is 3.35 and 8.81 kWh, respectively. The variation in methane fraction and amount of raw produced biogas results in a noticeable change in the electric power potential of the produced gas. According to the Electricity Prices Data, as of a March 2021 report, the cost of electricity in Ethiopia for residential users is 0.007 US \$ per kWh (Global Petrol Prices, 2021). As a result, the exchange stations' and sewage sludge's electric potential had monetary values of \$0.06 and \$0.02, respectively.

For comparison purposes, the electric price takes into account the global average price as published in the global electric price report (0.136\$). With this value, the monetary values will be 1.2\$ and 0.46\$ for ESS and SS, respectively. This price of ESS generated electricity is nearly identical to a study conducted in Spain (Gómez et al., 2010).

In another case, the biogas produced can be converted into heat through the combustion process. The enthalpy of combustion or calorific

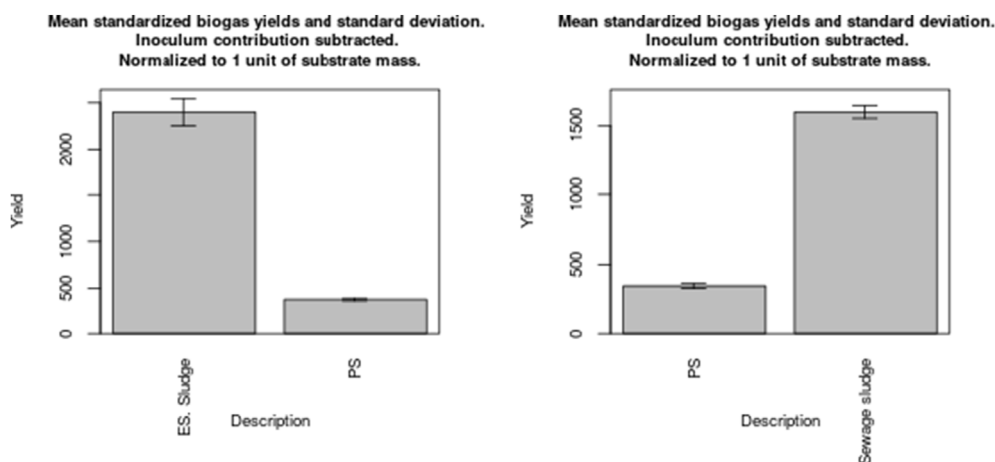


Figure 4. Normalized gas volume by substrate VS mass.

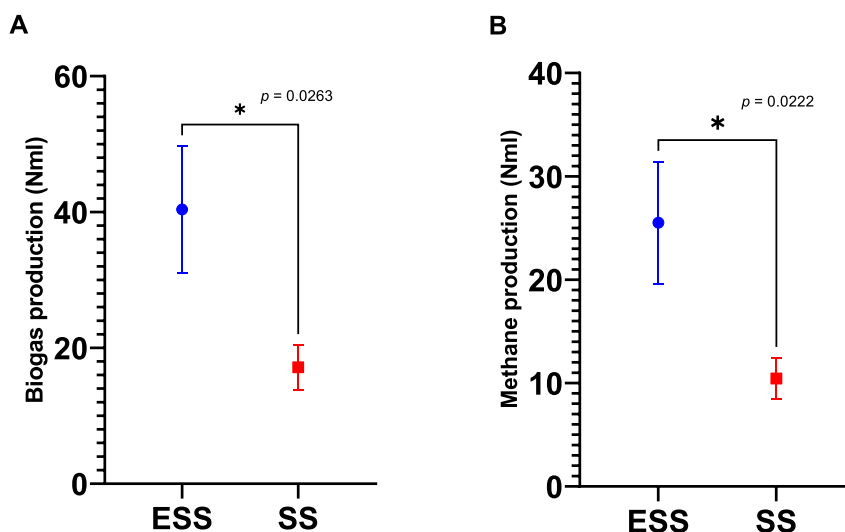


Figure 5. Statistical analysis of total and methane gas production.

Table 3. Validation of BMP results.

Validation criteria, ESS		Validation criteria, SS	
Criterion	Result	Criterion	Result
Duration (1% net 3 d)	✓ OK	Duration (1% net 3 d)	✓ OK
Cellulose BMP (340–395 mL/g): 382 mL/g	✓ OK	Cellulose BMP (340–395 mL/g): 350 mL/g	✓ OK
Cellulose RSD (<6%): 3.9%	✓ OK	Cellulose RSD (<6%): 5.1%	✓ OK
Overall validation (OK or fail)	✓ OK	Overall validation (OK or fail)	✓ OK

Table 4. Calorific values of sludge from Sewage and Exchange station.

Source of sludge	TS %	VS Relative to TS (%)	FS (%)	HHV (MJ/Kg)	HHV (MJ/KgVS)	Sludge water content (WC) (%)	WC/VS	Energy required to vaporize water (MJ/KgVS)	LHV (MJ/KgVS)
Exchange station	4.44	69.07	30.93	16.35	23.67	95.56	1.38	3.83	19.85
Sewage sludge	1.66	75	25	17.54	23.39	98.34	1.31	3.63	19.76

value (CV), of a given substrate determines its energy potential. As shown in Table 4, the HHV of exchange station sludge and sewage sludge is initially estimated to be 23.67 and 23.39 KJ g<sup>-1</sup>VS, respectively.

According to the European Parliament and Council, waste storage is the final and least necessary method of waste processing. According to regulations governing the criteria and procedures for allowing waste to be disposed of in specific types of dumpsites, domestic waste with a heat of combustion value greater than 6 MJ/kg on a dry matter basis cannot be kept and must instead be used for energy recirculation (Journal of Laws, 2015). According to the findings, sludge from the exchange station and sewage can be used as a source of heat for the community. The findings are consistent with values mentioned in various literature (Schauum et al., 2016; Ostojski, 2018; Yahya, 2018; Abusoglu et al., 2019; Hanum et al., 2019; Hu et al., 2021).

#### 4. Conclusion and recommendation

The rapid urbanization of cities, combined with population growth, places a strain on existing wastewater management systems. As a result, waste treatment and resource recovery technologies are highly demanded, particularly in developing countries. In a batch experimental setup, the biomethane potential of wastewater sludge from sewer and exchange stations was investigated in this study using a laboratory scale AD system.

In addition, the use of milled paper as a control feed during the BMP analysis of sludge from sewer and exchange stations was investigated.

The results show that BMP from milled paper is equivalent to cellulose BMP. This strongly supports the use of milled paper as a control feed during BMP analysis. It thus significantly reduces the cost of BMP analysis and spreads its application, particularly in developing countries. Sludge from sewer and exchange stations, on the other hand, has an electric potential of 3.35 and 8.81 kWh, respectively. Furthermore, based on the calorific value of sludge, we can conclude that sludge from municipal sewage and exchange stations is a potential source for energy recycling.

More research into the digestate's composition and re-use potential is recommended. Domestic sludge must also be co-digested with food, solid waste, and kitchen waste. In addition, the energy potential and monetary value of co-digestion methane should be studied.

#### Declarations

##### Author contribution statement

Selamawit M.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Agizew N.: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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##### Data availability statement

Data will be made available on request.

### Declaration of interests statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

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