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The Use of Biofilter in Anaerobic Baffled Reactor to Improve Quality of Methane Concentration and Effluent as Liquid Organic Fertiliser

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ABSTRACT

The biofilter used is a simple technology in anaerobic digestion to remove pollutants from the substrate to enhance biogas production and nutrient effluent, which can be used as liquid organic fertiliser. This study aims to determine the effect of using a biofilter to improve biogas production and biogas effluent as an organic fertiliser material. The results show that the highest methane concentration is 60.64% at a dosage 200 $L \cdot day^{-1}$. The total solid (TS) content of biogas effluent exhibits a decrease of approximately 44% across all substrate doses, with respective percentages of TS of 0.16%, 0.03%, 0.025%, and 0.034% for 50 $L \cdot day^{-1}$, 100 $L \cdot day^{-1}$, 150 $L \cdot day^{-1}$, and 200 $L \cdot day^{-1}$, respectively. The use of biofilters in an ABR can significantly enhance the quality of biogas effluent, rendering it suitable for use as a liquid organic fertiliser. By capturing and biodegrading pollutants, the biofilter component can further enrich the nutrient content of the effluent, which already contains essential nutrients due to the anaerobic conditions and compartmentalised design of the ABR. The nutrient content in the biogas effluent mix with nutrition (AB mix) namely; N-total 262.5 $mg \cdot L^{-1}$, P-available 0.399 $mg \cdot L^{-1}$, Ca 4.08 $mg \cdot L^{-1}$, Mg 25.24 $mg \cdot L^{-1}$, Cu 0.032 $mg \cdot L^{-1}$, and Fe 13.09 $mg \cdot L^{-1}$ follows the standard organic fertiliser of the Minister of Agriculture of Indonesia.

Keywords: tofu industry, wastewater, renewable energy, anaerobic digestion, organic waste, fertiliser, nutrient content.

INTRODUCTION

Biogas is a renewable energy produced by anaerobic digestion and is considered one of the low-carbon fuel sources to meet the demand for energy in any way (Sawyerr et al., 2019). Many methods are used to obtain high-quality biogas production, such as a biofilter, to effectively increase the quality of methane and remove pollutants to improve the quality of biogas effluent (Dumont, 2015). The removal of substrate pollutants not only improves biogas production but also biogas effluent because it can decrease the smell, including pollutant gases such as H_2S, CO_2, nitrogen and heavy metal content (Hooton et al., 2019; Mielcarek et al., 2021). One of the suitable technologies that can face these challenges is the biofilter because it effectively removes volatile organic compounds and heavy metals in the substrate (Pachaiappan et al., 2022). Biofilter and biotrickling have the same principle: a gas stream is passed through a solid layer, then pollutant-degrading organisms are immobilised as a biofilm. H_2S is absorbed into sulphur (S) by metabolic activity of microorganisms in biofilms that depend on the available oxygen (Garcia-Peña et al., 2012). The combination of biofilter and activated carbon effectively removes 98.13% hexamethylcyclotrisiloxane, 96.61% Octamethylcyclotetrasiloxane, and 78.85% Decamethylcyclopentasiloxane (Yang and Corsolini, 2019). The use of a biofilter on a large scale with a mixed culture with specific bacteria strains in anaerobic digestion successfully removes 99% of 1,058 ppmv of H_2S (Kang et al., 2010). Furthermore, a biofilter in anaerobic digester in semi-continuous mode achieves the removal of COD 95% and sCOD 81.73%, with a methane concentration 55.089%, (Kang et al., 2010; Mawaddah et al., 2019). Biogas produces a by-product known as digestate for solids or effluent for liquids; the effluent can be utilised as an organic fertiliser due to its still high nutrient content (Devarenjan et al., 2019; Koszel and Lorencowicz, 2017). Several countries in the European Union have practised the application of biogas effluent as an organic fertiliser (EU), such as Germany, Denmark, Austria, Sweden, and Switzerland has taken a step toward concern and has been further implemented for the biogas sector developed (Al Seadi et al., 2013). Organic fertiliser from biogas effluent has been applied in many crops with significant results that can improve soil fertility and increase yield and productivity (Chang et al., 2022; Kefalew and Lami, 2021(Sürmen and Emre, 2022). The application of organic fertiliser from biogas effluent that is mixed with other amendments results in the equivalent yield of corn and mungbean which was applied with 100% recommended NPK fertiliser, and can also reduce 25% of the NPK fertiliser (Nghia et al., 2022). This study aims to determine the effect of using a biofilter to improve biogas production and biogas effluent as an organic fertiliser material.

MATERIALS AND METHODS

The research was conducted at the Laboratory of Management of Waste at the Faculty of Agriculture, University of Lampung, Indonesia. Tofu wastewater was collected from the tofu industry in Gunung Sulah district, Bandar Lampung City, Lampung Province, Indonesia. The inoculum was collected from the second biogas effluent pond in the Tapioca industry, Central Lampung Province, Indonesia.

Experimental set-up

The anaerobic digester used in this study is the anaerobic baffled reactor (ABR), the total volume is 0.927 m^3 (Fig.1). The ABR was inoculated with the 50% inoculum and the 50% substrate (1:1). The ABR was recirculated for 7 days to make the situation in all parts of the chamber stable with pH 7.16. The dosage of substrate is 50 kg $COD \cdot m^{-3}$ per day, 100 kg $COD \cdot m^{3\ -1}$ per day, 150 kg $COD \cdot m^{3\ -1}$ per day, and 200 kg $COD \cdot m^{3\ -1}$ per day. The total biofilter used in the chamber of the ABR is 700 balls with a total weight of 3.56 kg.

Data analysis

Tofu wastewater and inoculum

Tofu wastewater was analysed to determine the characterisation prior to treatment through ABR with a biofilter as initial data. COD and CODs were measured using a spectrophotometer, total solid (TS) was conducted using oven dry at 105 °C, and TSS with a muffle furnace based on weighing the dry mass after processing. The information about tofu wastewater and inoculum is provided in Table 1.

Biogas composition

Biogas composition was analysed two times namely in the first week and at the end of digestion. The composition of biogas and the quality of methane were observed to obtain the presentation of the gas composition (CH_4, CO_2, and N_2) using the Shimadzu Shincorbon ST 50-80 D-375 gas chromatography (GC) model. However, the

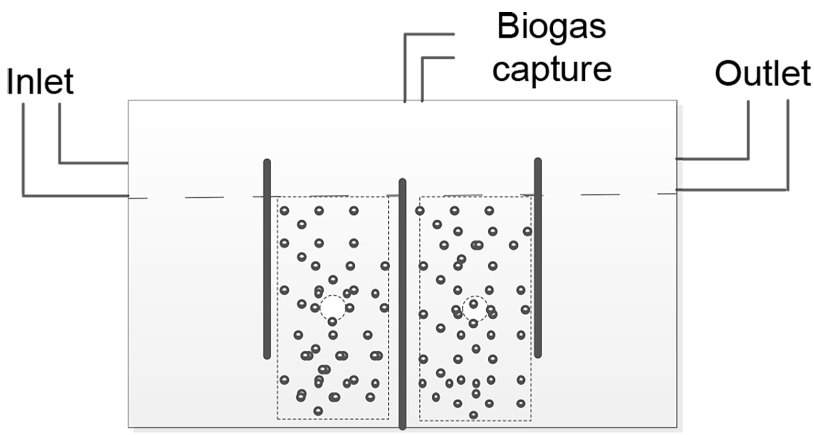

Figure 1. Design of anaerobic baffled reactor combined with biofilter

Table 1. Characteristics of tofu wastewater before treatment and inoculum

Parameter	Unit	Tofu wastewater	Inoculum
COD	$mg \cdot L^{-1}$	12400	–
CODs	$mg \cdot L^{-1}$	7150	–
N-Total	$mg \cdot L^{-1}$	–	–
TSS	$mg \cdot L^{-1}$	1188.25	–
TS	%	0.38	3.99
pH	–	5.17	7.95
Alkalinity	$mg \cdot L^{-1}$	280	800
VFA	$mg \cdot L^{-1}$	1500	1224
C/N ratio	%	–	4.66
VS	$mg \cdot L^{-1}$	–	1188.25

removal TS, TSS, and volatile solid (VS) was observed thrice in a week.

Biogas effluent

The biogas effluent was analysed to determine the nutrient content which can be used as liquid organic fertiliser. The nutrient analysed in this study is Nitrogen (N-total). P-available, Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Potassium (K), and C-organic. There are three treatments for biogas effluent, namely; 100% biogas effluent, a mixture of biogas effluent and nutrition (AB mix), and 100% nutrition (AB mix).

RESULTS AND DISCUSSION

The effect of biofilter on biogas composition

The quality of biogas composition especially CH_4 depends on some factors such as pH, temperature, types of substrates, organic loading rate (OLR), HRT, and performance reactor (digester design) (Mawaddah et al., 2019; Li et al., 2020). Based on Table 2, the concentration of methane is increased gradually, but CO_2 and H_2S are still high. Hence, it can be indicated that the biofilter in ABR does not significantly affect in removal of the gas pollutant, but can increase methane concentration. The enhancement of methane is related to the nutritional content of tofu wastewater as the substrate. Tofu wastewater is rich in protein which has great potential to provide nitrogen as the main nutrient for anaerobic microorganism activities, and the neutralising effect of VFA through the formation of ammonia (Wresta et al., 2021).

Based on Table 2, the highest concentration of CH_4 is 60.64% at dosage substrate 200 $L \cdot day^{-1}$ and the lowest is 49.78% at 50 $L \cdot day^{-1}$. This is because of the effect of the dosage of the substrate that loads into anaerobic digestion. One of the factors that affect methane yield is the ratio of inoculum and substrate, however, during biodegradation process produces the production rate and synergetic effect (Corsino et al., 2021). Changing the dosage of substrate same as in nutrient content will affect the overall methane and biogas production process (Gokul Prasad, 2022). The effect of increasing cattle feed supplement from 543 $L \cdot kg^{-1}$ to 894 $L \cdot kg^{-1}$ VS is not affected in enhancing methane quality, however, significantly affects to biogas yield and cumulative biogas production rate, because the absence of a relationship between supplement addition and the methane content in biogas (Zieli et al., 2019).

Macro and micronutrient content in the substrate affects reactor performance, however,

Table 2. Biogas composition

Dosage of substrate ($L \cdot day^{-1}$)	Biogas composition			
	CH_4 (%)	CO_2 (%)	N_2 (%)	H_2S (ppm)
50	49.78	36.105	14.215	980
100	56.93	37.64	5.416	410
150	55.26	42.749	1.905	610
200	60.64	37.775	1.573	630

the content of nitrogen and phosphor in industrial wastewater is inadequate (Ravichandran and Balaji, 2020). Generally, biogas produced from dairy manures as feedstock has lower trace chemical concentrations, but the toxicity response of combustion is higher compared to other feedstock (Li et al., 2020). The high concentration of methane is the key to the quality of biogas because it has a high calorific value for combustion (Muntaha et al., 2022). However, based on the result in Table 2. the use of biofilters is not so effective in reducing the concentration of greenhouse gases, namely H_2S and CO_2, in this study the biogas composition ratio is still within reasonable limits which do not exceed the concentration of each gas. Generally, the range amount of H_2S in biogas is from 100 ppm to 10,000 ppm, as well as a CO_2 concentration of approximately 20–30%, depending on the type of substrate used, excessive concentration will affect the caloric value and corrosiveness during combustion (Silva and Mezzari, 2022). To remove the gas pollutant in biogas a special treatment is needed because the characteristic of the gas, a combination of monoethanolamine (MEA) as adsorbent and gas flow rate is 0.1963 cm^2 and 0.3 $L{\cdot}min^{-1}$ that can remove up to 0 ppm H_2S and 0.20%. CO_2 (Kalsum et al., 2022).

The effect of biofilter in the removal of pollutants

Total solid is one parameter to measure the quantity and quality of substrate solid waste and wastewater which impact anaerobic digestion performance through microorganism activities, it is because of the behaviour of microbial community in reactor related to TS in feedstock that influences the efficiency fermentation process (Shrestha et al., 2020; Yi et al., 2014). The high content of TS results low biogas production but increases biogas yield, because TS is linked to the substrate availability in reactor which can increase biogas yield (Jeppu et al., 2022).

In Figure 2. the removal of TS in each dose of substrate is provided. The highest TS removal is 95.95% in dosage 50 $L{\cdot}kg^{-1}$ per day from 0.74% to 0.03. TS removal in dosage substrate 100 $L{\cdot}kg^{-1}$ per day, 150 $L{\cdot}kg^{-1}$ per day, and 200 $L{\cdot}kg^{-1}$ per day respectively, are 42.86%, 100%, and 8.57%. The reduction in TS removal was caused by an increase in substrate dosage from 100 $L{\cdot}kg^{-1}$ per day, up to 200 $L{\cdot}kg^{-1}$ per day in reactor because the dosage of substrate is excessive and may cause the performance of the anaerobic digestion process not optimal in removing.

The substrate dosage is important to determine performance removal pollutants; the particle stability in any coagulant depends on the

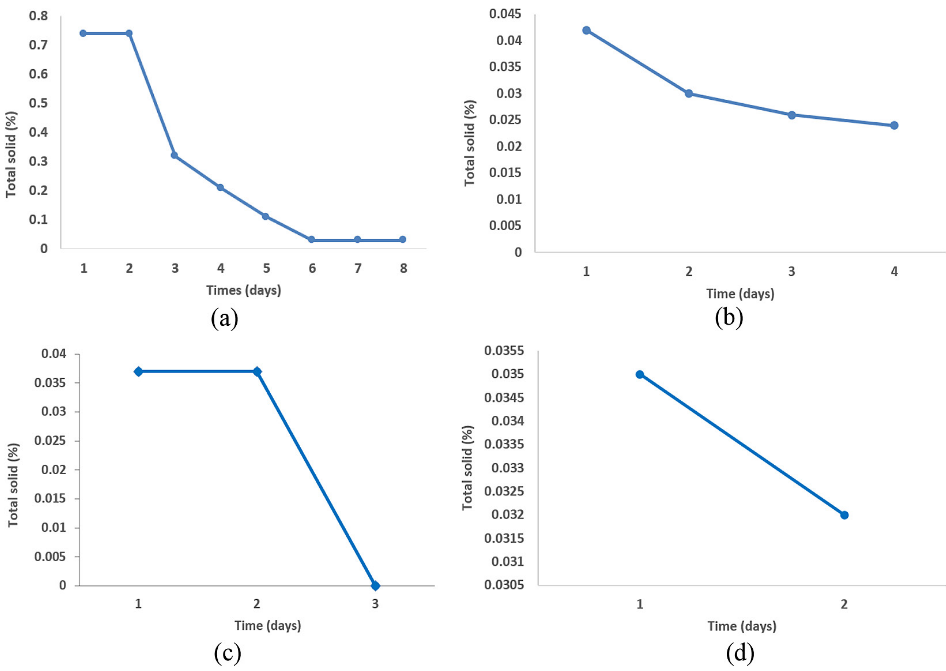

Figure 2. Total solid (TS) in biogas effluent; a) dosage substrate 50 $L{\cdot}kg^{-1}$ per day, b) dosage substrate 100 $L{\cdot}kg^{-1}$ per day, c) dosage substrate 150 $L{\cdot}kg^{-1}$ per day, and d) dosage substrate 200 $L{\cdot}kg^{-1}$ per day

substrate dosage, if a small amount of substrate is added, it will not affect the stability of the particles, however, the excessive dose added will have an effect like restabilisation and production of excessive sludge (Igwegbe and Okechukwu Dominic Onukwuli, 2019).In addition, the use of biofilters also affects the removal of pollutants in the anaerobic digestion process such as greenhouse gas (GHG), COD, and solid content in biogas effluent. The use of biofilter in ABR is because the biofilter has a high surface, a high void ratio, and low density that can preserve more biomass (Ravichandran and Balaji, 2020).

The use of quarts of sand biofilter reduces 91.9% TSS, 84.1% turbidity, 86.1% colour, 77.7% organic matter, and 81.9%, the effect in lowering TSS and turbidity is decreasing the consumption of coagulants in subsequent raw water treatment (Suprihatin et al., 2017). The result of TSS removal in each substrate dosage is shown in Figure 3. The efficiency of TSS removal for all dosages is 99.98%. The TSS content for each dosage at 50 $L \cdot kg^{-1}$ per day, 100 $L \cdot kg^{-1}$ per day, 150 $L \cdot kg^{-1}$ per day, and 200 $L \cdot kg^{-1}$ per day, respectively are 0.18 $mg \cdot L^{-1}$, 0.16 $mg \cdot L^{-1}$, 0.20 $mg \cdot L^{-1}$, and 0.25 $mg \cdot L^{-1}$.

The removal efficiency of TS, TSS, and VS in this study is due to the substrate was filtered in the first step before loading into ABR, it is to reduce the hydraulic retention time (HRT) of organic matter in the anaerobic digestion process and increase the production of biogas and the methane quality. The HRT and the dosage of the substrate affected the performance of the reactor and the removal of pollutants. The TS and VS content also influences reactor performance in the substrate due to the microbial activity involved in the efficiency of anaerobic digestion (Orhorhoro et al., 2017). Increasing HRT from 17 to 34 hours affects all parameters including reducing the concentration of TSS and VSS are 75% and 90% of COD removal (Hassan et al., 2022).

Figure 4 shows that VS removal for all the dosages of the substrate, the highest VS removal is 66.80% at dosage 150 $L \cdot kg^{-1}$ per day from 0.89 $mg \cdot L^{-1}$ to 0.74 $mg \cdot L^{-1}$. VS removal at dosage 50 $L \cdot Kg^{-1}$ per day, 100 $L \cdot Kg^{-1}$ per day, and 200 $L \cdot Kg^{-1}$ per day, respectively are 48.18%, 58.69%, and 41.16%. Based on the result in Fig 4. the decrease of VS removal can be initiated because of the excessive-high dosage substrate load into ABR. The effect of increasing the OLR in the reactor is reduce the efficiency of VS removal (Blasius et al., 2020). The highest VS removal is 75% at OLR 1 g $VS \cdot L^{-1}$ per day at 55 °C, but when the OLR increased in the maximum dosage at 7 g $VS \cdot L^{-1}$ per day the VS removal gradually decreased to 44% (Gou et al., 2014). The combination temperature and OLR also influenced the removal of VS, mesophilic treatment is more efficient in waste treatment than thermophilic for the removal of COD and TS, methane yield and biochemical methane potential value, TVS removal at OLR 0.15 and 0.30 g $TVS \cdot L \cdot d^{-1}$ is 79.5% and 80.1%. However, TVS removal at OLR 0.45, 0.60, and 0.90 g

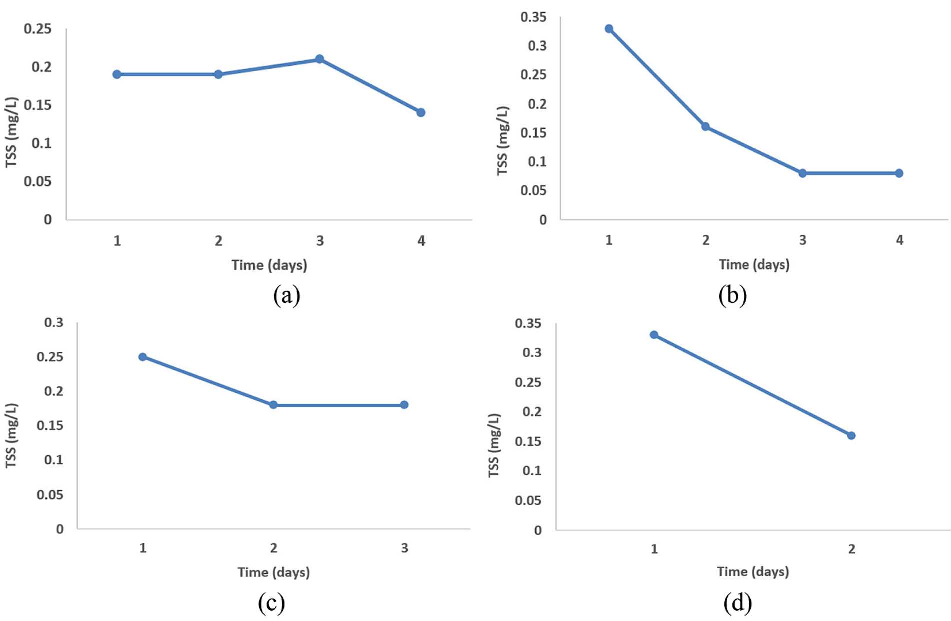

Figure 3. Total solid suspended (TSS) in biogas effluent; a) dosage substrate 50 $L \cdot kg^{-1}$ per day, b) dosage substrate 100 $L \cdot kg^{-1}$ per day, c) dosage substrate 150 $L \cdot kg^{-1}$ per day, and d) dosage substrate 200 $L \cdot kg^{-1}$ per day

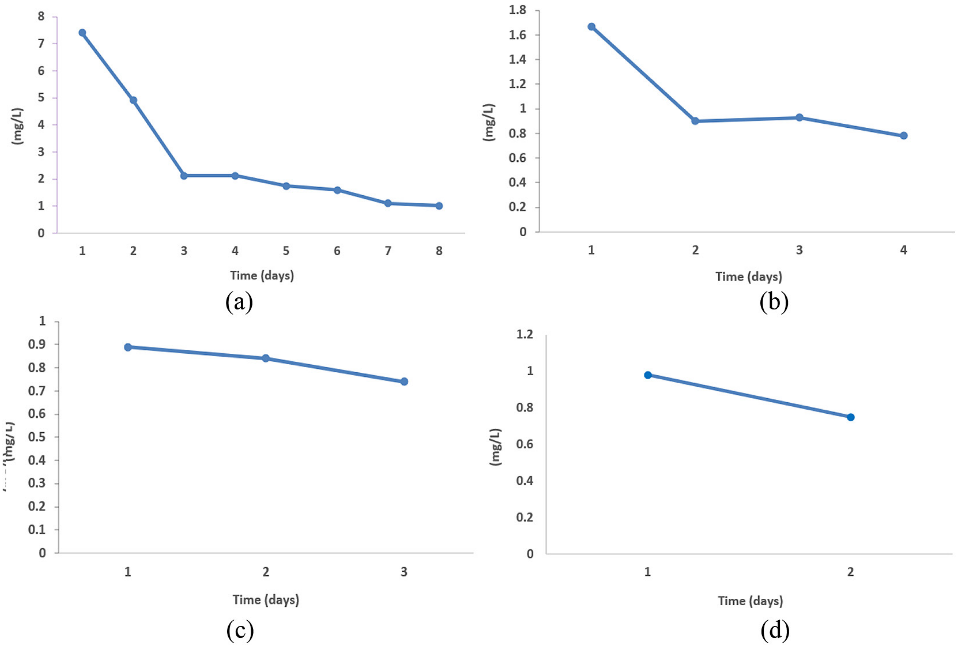

Figure 4. Volatile solid (VS) in biogas effluent; a) dosage substrate 50 L·kg^{-1} per day, b) dosage substrate 100 L·kg^{-1} per day, c) dosage substrate 150 L·kg^{-1} per day, and d) dosage substrate 200 L·kg^{-1} per day

TVS·L·d^{-1} respectively is 54.4%, 44.4%, and 32.7% (Blasius et al., 2020).

The use of biofilters in anaerobic digestion process is a promising and economically friendly solution for the physical and chemical disinfection of wastewater (Maurya et al., 2020). In a biofilter system, acidogenic and methanogenic microorganisms adhere to and colonise the surface of the biofilter, forming a biofilm layer that facilitates the conversion of organic matter to methane (Damayanti et al., 2020). Consequently, the biofilter system not only excels in removing pollutants from wastewater but also enriches the quality of the biogas effluent, which possesses significant potential as a valuable organic fertiliser.

The effect of biofilter on biogas effluent

The anaerobic digestion process yields biogas as its primary product and a nutrient-rich liquid digestate as a by-product. This liquid by-product, characterized by its high nutrient content, can be effectively utilized as a liquid organic fertilizer or a nutrient source for hydroponic plant cultivation. The elemental composition of the biogas effluent reveals a significant presence of carbon (37.92 wt%), hydrogen (4.113 wt%), nitrogen (46.287 wt%), oxygen (1.56 wt%), and sulphur (0.047 wt%). This distinctive elemental profile makes the biogas effluent a valuable resource with considerable economic potential for further utilisation and product development (Qian et al., 2022). The biogas effluent is a valuable organic material that can be used as a high-quality fertiliser, rich in essential nutrients such as nitrogen, phosphorus, and potassium, which are vital for plant growth (Chang et al., 2022). The characterisation of the biogas effluent is shown in Table 3.

Based on Table 3 the macronutrients in the biogas effluent are still high and are not very different from the commercial AB mix of nutrients for hydroponic plants. Therefore, it can be indicated that it is worthy of being used as organic fertiliser or nutrients for hydroponic plants. The use of biogas effluent as fertiliser is a wise solution for both environmental and economic aspects because the product is useful in improving soil fertility, including microorganisms in the soil, and can replace synthetic fertiliser to improve biodiversity (Farghali et al., 2022). The use of biogas effluent is needed to obtain additional material that can increase the nutrient content for the growth of plants and meet the Regulation of the Minister of Agriculture of the Republic of Indonesia. The standard of liquid organic fertiliser based on PERMENTAN No. 70/permentan/SR.140/10/ 2011 is provided in Table 4.

According to the standard organic fertiliser in Table 4. That biogas effluent can be combined with various materials to meet the standards as organic fertilizer. These materials include fish emulsion, coal, slag, sugarcane husk charcoal, and organic garbage, Additionally, other organic materials such as manure, food waste, and shale

Table 3. Macronutrient content of biogas effluent treat with commercial nutrition

Parameter	100% nutrition	100% effluent	Mix effluent and nutrition (AB mix)	Unit
Nitrogen (N-total)	202.75	175.63	262.5	$mg \cdot L^{-1}$
P-available (P)	1.22	0.675	0.399	$mg \cdot L^{-1}$
Calcium (Ca)	1.02	1.83	4.08	$mg \cdot L^{-1}$
Magnesium (Mg)	20.83	24.25	25.24	$mg \cdot L^{-1}$
Copper (Cu)	< 0.007	< 0.007	0.032	$mg \cdot L^{-1}$
Iron (Fe)	8.7	9.53	13.09	$mg \cdot L^{-1}$
Potassium (K)	830	140	440	$mg \cdot L^{-1}$
C-Organic	0.088	0.39	0.49	%

Table 4. Standard organic fertiliser (The regulation of Minister of Agriculture of Indonesia, 2011)

Parameter	Unit	Standard organic fertilizer
C-organic	%	Min 15
pH	–	4–9
Macronutrient N P_2O_5 K_2O	 % % %	 Min 4 Min 4 Min 4
Micronutrient Total Fe Available Fe Mn Zn Cu Mo Na Cl	 ppm ppm ppm ppm ppm ppm ppm ppm	 Max 9000 Max 500 Max 5000 Max 5000 Max 5000 Max 20 Max 2000 Max 5000

can also be used (Nghia et al., 2022; Nurweni et al., 2019). The combination of these materials with biogas effluent can enhance its nutrient content and make it suitable for use as an organic fertiliser. However, information is missing on the specific proportions of these materials that should be added to the biogas effluent to meet the standards. The utilisation of biogas effluent as an organic fertilizer can positively impact farmers' ability to achieve the highest net profit by reducing the dependence on synthetic fertilizers (Hooton et al., 2019). Biogas effluent can be an effective substitute for approximately 25% of the chemical fertilizer NPK 1 $ton \cdot ha^{-1}$ as the recommended application dose, as it provides essential nutrients for plant growth (Nghia et al., 2022). This substitution can lead to cost savings for farmers, as biogas effluent is a readily available and renewable resource. Furthermore, the use of biogas effluent as an organic fertiliser can contribute to a more circular economy and reduce the environmental impact of synthetic fertiliser usage (Chojnacka and Moustakas, 2024). Mixing biogas effluent with 100% nutrients (AB mix) increases the nutrient content so that it meets the liquid organic fertiliser standards required by PERMENTAN No. 70/permentan/SR.140/10/2011, which can be applied to plants using soil or hydroponic growing media, however, several things must be considered in its application apart from nutrition, pH and heavy metal content are also taken into consideration (Bergstrand et al., 2020). However, information on the specific economic benefits of using biogas effluent as a substitute for chemical fertilisers is lacking in terms of net profit. Further research is needed to quantify the economic advantages of this practice under different farming conditions.

CONCLUSIONS

The use of biofilters with variations of substrate dosage in anaerobic digestion is very efficient in removing the pollutant and increasing the nutrient content of the biogas effluent that can be used as an organic fertiliser. The highest removal of TS is 95.95% at a dosage 50 $L \cdot kg^{-1}$ per day, the removal of TSS is 99.98% for the entire dosage of substrate, and the removal of VS is 66.80% in the dosage of substrate 150 $L \cdot kg^{-1}$ per day. Treatment of biogas effluent with a nutrition mix (AB mix) improves the nutrient content by increasing the concentration of phosphorus, nitrogen and other essential micronutrients, making it compatible with the standard of organic fertiliser as specified in the Indonesian Ministry of Agriculture Regulation, PERMENTAN No. 70/permentan/SR.140/10/2011.

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