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Comparison of process stability in methane generation from palm oil mill effluent using dairy manure as inoculum

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HIGHLIGHTS

- This study investigated methane production from dairy manure as inoculum.
- Addition of dairy manure improved both the start-up time and rate of biogas production.
- Biogas production was achieved at ambient temperature.

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ABSTRACT

The potential of methane production in a continuously stirred tank reactor (CSTR) was investigated using dairy manure as inoculum at pH 6.8 and 37 °C temperature in this study. Two identical anaerobic bioreactors namely $CSTR_1$ and $CSTR_2$ filled with palm oil mill effluent (POME) as a carbon source were used. $CSTR_1$ was not added with the inoculum, while $CSTR_2$ was added with dairy manure as inoculum. Both the reactors were allowed to run for 5 days (d) in batch condition at hydraulic retention time (HRT) 10 d. The $CSTR_2$produced 0.85 L/d gas yield and 59% methane content compared to 0.39 L/d gas yield and 20% produced in $CSTR_1$, respectively. A better chemical oxygen demand (COD) reduction percentage of 48% was found in $CSTR_2$ compared to $CSTR_1$ with 33%. The investigation showed that dairy manure as inoculum has a marked influence on the start-up period and the biogas production rate.

1. Introduction

The increase in world's energy demand and depletion of energy reserve, strive biofuels as a favourable choice over fossil fuels due to their biodegradability, renewability and carbon neutrality (Krishnan et al., 2017a; Mishra et al., 2017). Methane production has a higher potential in the Asian countries due to the availability of agricultural and industrial waste water (Wang et al., 2014). The Methane production through anaerobic digestion is a promising strategy which got significant advantages over other forms of bioenergy production. It is because the anaerobic digestion is highly efficient in the organic removal while simultaneously generating renewable energy (Mamimin et al., 2015; Panpong et al., 2014). The by-products produced during the anaerobic treatment can also be used as further such as bio-fertilizers (El-Mashad and Zhang, 2010).

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Abbreviations: CSTR, Continuously stirred tank reactor; Dm, Dairy manure; HRT, hydraulic retention time; COD, Chemical Oxygen Demand; TS, Total Solids; VS, Volatile Solids; NH_3-N, Ammonia Nitrogen; CH_4, Methane

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Table 1
Chemical characteristics of raw POME.

Parameter[a]	Concentration (mg L^{-1})
pH	5.1± 0.2
Biochemical oxygen demand (BOD)	3,500 ± 500
Chemical oxygen demand (COD)	56,500 ± 300
Total carbohydrate	16,400 ± 200
Total nitrogen	960 ± 100
NH_4^+–N	810 ± 100
Total phosphorus	110 ± 1
Phosphorous	22± 1
Oil	109,000 ± 20
Total solids (TS)	32,000 ± 300
Volatile solids (VS)	26,000 ± 400
Volatile Suspended solids (VSS)	8,300 ± 200
Ash	4,500 ± 200

[a] All in mg L^{-1} except pH.

Table 2
Chemical characteristics of raw dairy manure.

Parameters	Concentration (mg L^{-1})
Total solids	186.8 ± 25
volatile solids	40 ± 0.5
COD	28,585 ± 500
NH3-N	610 ± 35
moisture	41.2 ± 1.5%
pH	7.2

[a] All in mg L^{-1} except pH and moisture.

Generally, the biogas constitutes 55%–60% methane (CH_4), 30%–35% carbon dioxide (CO_2), 5%–7% ammonia (NH_4) and a trace amount of H_2S (Zhu et al., 2015). Methane is a colourless, flammable, and high energy content natural gas with the calorific value ranges between 6 and 6.5 KWh m^{-3} (Sompong et al., 2012). Methane can be produced using wide range of organic wastes and also at various temperature such as psychrophilic (below 25 °C) (Cheng et al., 2013; Sims et al., 2010), mesophilic (30 °C and 37 °C), thermophilic (55 °C and 60 °C), and extremophiles temperature (above 65 °C) (Wang et al., 2009; Krishnan et al., 2017a; Gungor-Demirci and Demirer, 2004).

In Malaysia, the palm oil mill effluent represents a constant environmental problem causing the high magnitude of hazards on the global environment (Krishnan et al., 2017b). Usually, the POME is acidic with high dissolved solids and difficult to degrade easily. Also, the huge amount of dairy manure produced nowadays by the feedlot farming is causing a major environmental damage (Forster-Carneiro et al., 2008). However, anaerobic digestion is carried out by microbial consortia and mainly depends on various factors like pH, temperature, HRT, and C/N ratio and it is a relatively slow process. Co-digestion is an important method to enhance biogas production. However, it is found that dairy manure is an outstanding co-substrate in anaerobic digestion because it contains eminent buffering capacity, rich in anaerobic bacteria and a wide range of essential nutrients for optimal microbial growth (Liu et al., 2013). Therefore, its supplementation as an additive with POME during anaerobic digestion is beneficial because it provides the energy source while concurrently resolving the pollution risk that is associated with dairy manure (Hniman et al., 2011). Previously, many researchers reported anaerobic co-digestion of POME using various substrates (Poh and Chong, 2009; Nasir et al., 2012). But the treatment of POME for methane generation using diary manure as inoculum (co-substrate) is very limited. In the present study, the potential of dairy manure as inoculum for the production of methane from POME with regulated pH and temperature was investigated. This experimental finding helps in wastewater management.

2. Materials and methods

2.1. Substrate preparations

Raw POME was collected from the final discharge point of Felda Palm Oil Industry, Lepar Hilir, Gambang, Malaysia and used as the substrate for methane production. The POME was stored at 4 °C in a 30 L container to prevent acidification and biodegradation prior use. The chemical characteristic of the POME used in this study is shown in Table 1. Fresh dairy manure was collected from Makmur Dairy Farm, Pahang, Malaysia and Bukit Tingi, Bentong, Malaysia. The dairy manure was scraped from the deposit directly and the samples were packed in polyethene bags and stored at 4 °C until use. The screening procedure removed sand, fibres, and straw from the raw POME and dairy manure. The chemical characteristic of the dairy manure used as inoculum in this study is shown in Table 2.

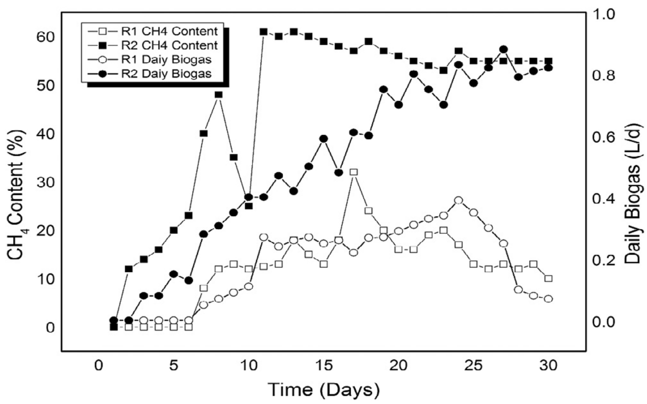

Fig. 1. Daily biogas production and methane content of the $CSTR_1$ and $CSTR_2$. In figures $CSTR_1$ is shown as R_1 and $CSTR_2$ is shown as R_2.

2.2. Experimental design

Two similar designs of glass made continuous stirred tank reactors $CSTR_1$ and $CSTR_2$ consists of a mixer motor, the top plate supporting a mixer, and multiple outlet sampling ports with an effective working volume of 7 L were used in this study. Bioreactors were set at 150 rpm, pH 6.8, temperature 37 °C, and the HRT of 10 d throughout this study. $CSTR_1$ was fed with 4 L POME as control reactor while $CSTR_2$ was fed with 4 L POME, and seeded with 1 L of dairy manure. The Nitrogen gas was flushed to remove Oxygen from the CSTR and the Oxygen concentration was kept below 5% throughout the anaerobic digestion. Once the steady-state is achieved, the biogas composition and volume produced were also recorded daily to evaluate the performance of the CSTR. The acclimatization process and start up period procedure was based on a study conducted by Sreekanth et al. (2009).

2.3. Analytical methods

The total biogas, biological Oxygen demand (BOD), total solids (TS), volatile solids (VS), chemical Oxygen demand (COD) and ammonia-nitrogen (NH_3–N) contents were determined according to standard APHA standards (APHA, 2015). The pH and alkalinity were measured using the electrometric method. The volume of the biogas was measured using water displacement method according to Wang et al. (2014). Total VFAs were measured by a modified titration method with standard 1 N HCl solution using a titration. The biogas composition was analyzed using GC9720 gas chromatography (Zhejiang Fuli Ltd, China) equipped with a Porapak N pillar and thermal conductivity detector. The helium was a carrier gas at a flowrate of 30 mL/min. The oven, detector, and injector temperatures were adjusted to 70, 120 and 120 °C respectively.

3. Results and discussions

3.1. Biogas production

The daily biogas production rate in both $CSTR_1$ and $CSTR_2$ during the operational period is shown in the Fig. 1. During biogas production, the lag phase of 6 d and 1 d was observed in $CSTR_1$ and $CSTR_2$ respectively. Such extended and longer lag phase in the $CSTR_1$was due to the presence of high lignin content of POME and no activity of methane producing bacteria which caused decreased substrate degradation rate. But $CSTR_2$ was enriched with the methanogenic bacterial consortium for early biodegradation of biomass and biogas production. As a result, the lag phase of $CSTR_2$ was shorter. It was reported by Walter et al. (2015) that dairy manure contains anaerobic bacteria that are able to improve the degradation of waste in an anaerobic environment. Similarly, Gungor-Demirci and Demirer (2004) shown that high biogas production rate during the fermentation of dairy manure and broiler at the initial phase, was due to the consumption of easily degradable COD. The biogas produced in $CSTR_1$ was continued to increase up to 0.39 Ld^{-1} on day 24 and decreased to 0.25 L^{-1} over a 3 d period. The methane production only started from day 6 with methane content was below 33%. It fluctuated until day 22 and methane stabilized at 20% which further decreased to 15% towards the day 30. The $CSTR_1$ showed a marked decrease in biogas production rate due to reduced bacterial growth activity. In contrast, $CSTR_2$ showed a steady increase in daily biogas and methane production from the second day onwards. The methane content was high and peaked at 59% on day 15. The methane content was stable throughout the experiment and slightly decreased to 55% towards the end of the experiment. These results also indicated that the substantial amount of biogas was produced in $CSTR_2$ which in turn reflects the efficiency of bioreactor operation and fermentation rate (Lateef et al., 2014). These methanogenic bacteria's were shown to produce biogas in $CSTR_2$ with shorter lag phase. The reason for higher biogas production rate and less lag phase was also probably

Table 3
Changes in substrate content during anaerobic digestion.

Digestion Composition	NH_3–N (mg/L)		COD reduction(%)	VS reduction (%)	Methane content	Maximum Gas Yield (L/d)
	Initial	Final				
POME + Inoculum	600	380	48	58.5	59%	0.85
POME	580	780	33	34.5	20	0.39

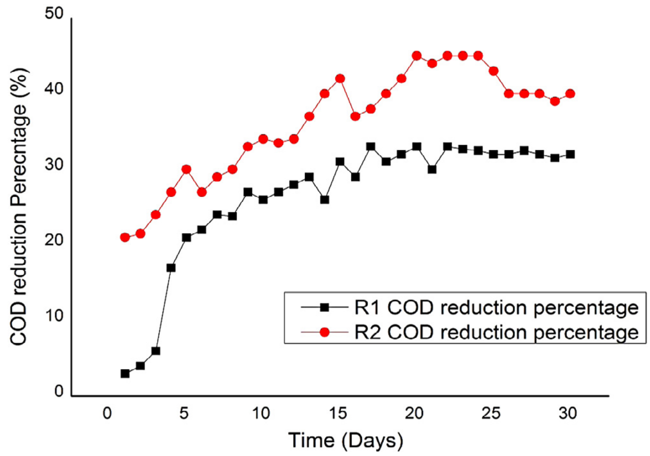

Fig. 2. COD reduction percentage of $CSTR_1$ and $CSTR_2$. In figures $CSTR_1$ is shown as R_1 and $CSTR_2$ is shown as R_2.

attributed to the inoculum which acted as a buffering system during bioreactor start up. These results were similar those reported by Siddique et al. (2014), which showed that bioreactor operated without inoculum produced less biogas compared to bioreactor seeded with inoculums. Dairy manure contributes in the buffering capacity of the mixture due to the result of its neutral pH (7.24 ± 0.18) and alkalinity in high levels (12.38 ± 0.32 g $CaCO_3$/L). It is also vital to take consider the alkalinity factor to be high enough in order to prevent destabilization of the system caused by volatile fatty acids accumulation. This is in consonance with earlier study reporting increase in methane yield and biomass degradation rate with the inoculum addition (Elbeshbishy et al., 2012).

3.2. Chemical Oxygen demand (COD) removal

The total percentage of COD reduction for both $CSTR_1$ and $CSTR_2$ is shown in Fig. 2. The COD concentration in $CSTR_1$ was gradually decreased from 51,000 mg L^{-1} to 40,000 mg L^{-1} over a period of 22 d and stabilized at 40,000 mg L^{-1} COD concentration on day 30. Despite, the percentage of total COD reduction was 33%. Such lower COD reduction was due to the absence of inoculum in the bioreactor. In contrast, higher COD concentration in inoculum has increased the total concentrations above 60,000 mg L^{-1}in $CSTR_2$. This was due to the increase in MLSS concentration. The COD reduction was peaked at 48% and declined to 40% towards the end of the experimental period. The fluctuation in $CSTR_1$ and $CSTR_2$ indicates unstable nature of the microbial community in dairy manure due to ambient temperature (37 °C) adopted. However, the COD removal efficiency was high and it was associated with VFA production during the experiment. The average COD removal efficiency in $CSTR_2$ was above 48% compared to $CSTR_{1.}$Similarly, Walter et al. (2015) achieved COD removal efficiency of 51% in a co-fermentation study of cattle slurry with palm empty fruit bunches.

3.3. Volatile solids and ammonia-nitrogen concentration

From the Fig. 3, VS content was observed to be decreased at higher rate after 3 d of the anaerobic digestion and slightly increased after day 7. This was probably due to the adaptation of the microbial community in the system (Saidu et al., 2013; Brown et al., 2012). However, the VS removal achieved in total was higher during the experiment. The comparison of COD removal, VS concentration, and gas yield between $CSTR_1$ and $CSTR_2$ are presented in Table 3. During the fermentation, the VS reduction in the $CSTR_2$ was significantly improved by 1 to 2 times using inoculum. Fig. 4 shows the NH_3–N of the $CSTR_1$ and $CSTR_2$ during anaerobic digestion. On the day 3, NH_3–N concentrations in $CSTR_2$ increased up to 780 mg L^{-1} and decreased thereafter from day 4. It was also observed that NH_3–N concentration was decreased in the $CSTR_1$ until day 16, and then gradually raised up to about 800 mg L^{-1} on day 30. But, the $CSTR_2$ found to be stabilized all through the period of the experiment. Zeeman et al. (1985) found that NH_3–N ranged between 700 mg L^{-1} to 1100 mg L^{-1} inhibited adapted anaerobic digestion of manures. In this study, that there was no sign of inhibition due to NH_3–N in CSTR2. Meanwhile, in $CSTR_1$ shown accumulation of NH_3–N which is near moderate inhibition on microorganisms resulted to lower biogas yield.

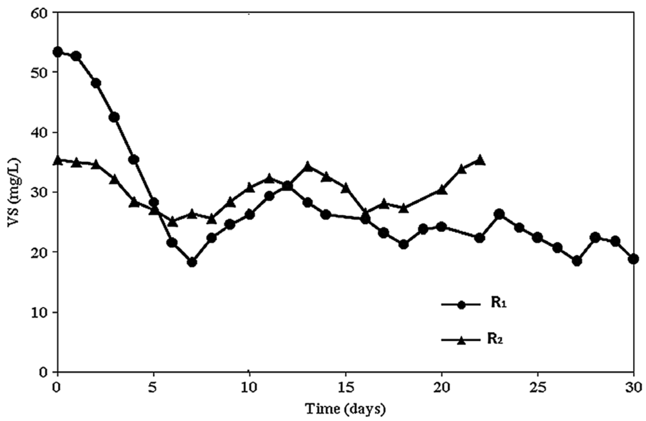

Fig. 3. VS concentrations in $CSTR_1$ and $CSTR_2$ during anaerobic digestion. In figures $CSTR_1$ is shown as R_1 and $CSTR_2$ is shown as R_2.

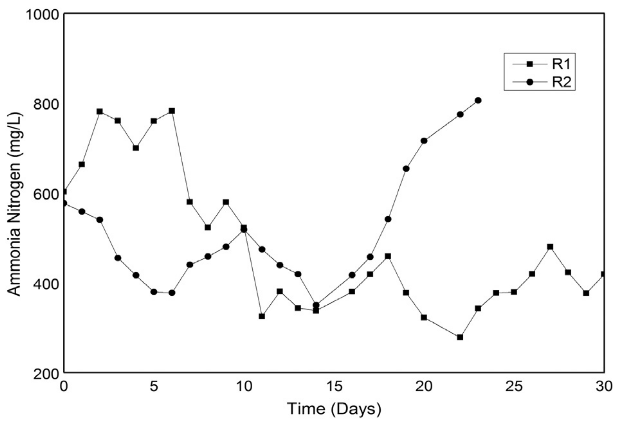

Fig. 4. Ammonia-nitrogen concentrations in $CSTR_1$ and $CSTR_2$ during anaerobic digestion. In figures $CSTR_1$ is shown as R_1 and $CSTR_2$ is shown as R_2.

4. Conclusions

The findings presented here showed that dairy manure has practical application potential in enhancing methanogenesis and the COD removal. The utilization of dairy manure as inoculum in anaerobic digestion of POME showed higher methane content of 59%, less lag time and better COD removal reduction of 48%. This result reflects the efficiency and influence of dairy manure on $CSTR_2$ start-up time and biogas production.

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