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IMPROVEMENT OF AQUACULTURE WASTEWATER CO-DIGESTION PERFORMANCE BY CATTLE DUNG USING A THERMOPHILIC PILOT REACTOR AND FERTILISER RECOVERY

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Abstract: The fundamental challenge to balancing the fuel demand is the risk of process instability. Research on energy recovery from aquaculture effluent addresses energy demands and environmental pollution concerns. The current study examined the effectiveness of anaerobic co-digestion of aquaculture effluent in a 45 L thermophilic reactor without utilising chemical catalysts. The partially digested cow manure created a substantial buffering capacity in this co-digestion process that balanced the volatile fatty acids (VFA). The methane produced was 0.45 m^3 CH_4/kg VS, whereas 71% of the chemical oxygen demand (COD) was removed. Thermophilic wet co-digestion was used to shorten the digestion and co-digestion phases. The results showed the highest methane was produced after 5 days (0.085 m^3 CH_4/(kgVS. day), and 81% of total methane potential was attained after 9 days. The system proficiency for eliminating volatile solids was more than 36% after 6 days. Sludge recovery was 0.08 m^3 sludge/m^3 wastewater and water recovery was 0.85 (m^3 sludge/m^3 wastewater). It is suggested that wet co-digestion at a thermophilic state was favourable for the commercial application of co-digestion of aquaculture wastewater.

Keywords: Anaerobic co-digestion, methane production, anaerobic reactor, aquaculture wastewater.

Introduction

Globally, huge amounts of aquaculture wastewater are constantly being produced (Syukor *et al.*, 2015). Typical landfilling of these wastes produces gas and leachate that may cause health risks and environmental pollution (Cao *et al.,* 2019). Anaerobic methane production of these wastes can offer a promising technology for the waste minimisation process (Ajeng *et al.*, 2022). Indeed, this technique may provide many energy, ecological and economic advantages (Khalid *et al.,* 2019). This technology permits the generation of fresh and renewable energies (Krishnan *et al.,* 2017). This technique contributes to the development of air and soil quality. This may be combined with sectors that are unlike energy (Nasrullah *et al.,* 2014). Therefore, an anaerobic co-digestion system of aquaculture wastewater may be more financially reasonable than other treatment operations for its simultaneous energy and fertiliser production. In addition, this technology is more environmentally beneficial than incineration.

Studies on anaerobic co-digestion of organic wastes are numerous and alienated on the investigational and modelling mechanism (Jia *et al.,* 2019). Still, the anaerobic co-digestion of aquaculture wastewater is vague as it relies on several parameters. Indeed, methane productivity can vary for different reasons, mainly because of waste characteristics, seeding variations, system alignments, operating conditions, and inhibitory constraints. The previous studies reported the influence of unlike animal dung as seed on bio-methane generation and kinetics for food waste anaerobic co-digestion (Bhatnagar *et al.,* 2022). The result indicated that cattle dung inoculum was apposite to food waste co-digestion compared to other animal wastes, as a high bio-methane generation was attained (Huang *et al.,* 2019). The co-fermentation of food wastes with manure and sewage sludge might be helpful because of the buffering capability, dilution with toxic substances, improvement of nutrient balance, and synergistic influence of microbes (Kabouris *et al.,* 2009). This technology appears to be favourable for improving system performance and economic feasibility.

In single-tank systems, where pH management at neutral levels is necessary to maintain the biological reaction, over-acidification becomes a problem (Khalid *et al.,* 2021). Two bacterial processes must occur simultaneously for anaerobic digestion to occur: transforming the feed's organic stuff into simple, tiny molecules and converting CH_4 and CO_2 from these molecules (Michal *et al.,* 2017). Each stage has different ideal pH ranges, with the first being preferred at lower pH values and the second at higher ones. If the pH significantly falls below 6.5 during the initial phase, the methanogenic organisms cannot survive and methane production ceases. The procedure is then referred to as being hindered, and in severe cases, it may take many months to get it back to fully working levels.

Nevertheless, aquaculture wastewaters are generated continuously, so the thermophilic state is more apposite to digest a high amount of wastes in short HRT and produces buffering capacity to pH drop (Fountoulakis *et al.,* 2010). Besides, the thermophilic state decreases the pathogen microbes in the effluent, which enables it to improve for further application. Nevertheless, consequences on the methane potential of aquaculture wastewater are limited due to the complexity of such waste and the system's sensitivity to some factors. Indeed, the hazard of degradation imbalance and process instability represents the main obstacle concerning the commercialisation of the system. Besides, most studies are carried out with tiny reactor sizes and full-scale operations are limited.

Therefore, the current study aims to examine the anaerobic co-digestion of aquaculture wastewater at a thermophilic state by an improved pilot reactor. The finding from the pilot-scale system performance benefits the probability of increasing energy recovery. Moreover, the feasibility of using sludge as an agricultural input with heavy metal content can also be evaluated.

Materials and Methods

Digested cow manure and raw aquaculture wastewater were taken from a commercial farm in Terengganu, Malaysia. The reactor was seeded with sludge obtained from cow manure co-digestion at thermophilic states (Fountoulakis *et al.,* 2010). To achieve the desired co-digestion qualities, 10 kg of digested manure was diluted with tap water to create the inoculum. The properties of cow manure are shown in Table 1. The high quantity of volatile solids and the impartial pH of the reactor permitted an optimum start-up. The feed waste utilised after seeding is prepared from wet wastes taken from the different kitchens. They were manually separated to eliminate non-biodegradable and then ground with the help of a grinder. Indeed, the tiny size of ground waste (< 9 mm) may enhance the digestion rate and abridge the hydraulic retention time. The entire quantity fed in the reactor was 3.99 kg of wet waste and the final substrate-to-seed proportion was 1:8.

Table 1: Characteristics of cow dung used in this study

	Organic Loads (kg)	**pH**	**TS (%)**	**VS (% of TS)**
Cow dung	11	6.1	18	78
Digester set up	35	7.4	5.4	78

Trials were performed in a pilot digester of 45 L volume (Figure 1). The digester was armed with a pH meter, a gas flow meter, an electric stirrer, and a heater (Khalid *et al.,* 2020). The food-to-mass ratio used in this study was 0.2. Substrates were presented from the reactor inlet. Reactor and stirrer combinations are necessary to enhance blending efficiencies. The task was to confirm a completely integrated reactor with a suitable mixing speed. The stirrer was armed with 15 paddles set around the alliance with a 4 cm interval between every paddle. The arrangement of such a blender with a flat cylindrical chamber helps remove gravitational influences and increases reactor homogeneity. A nonstop blending at 50 rpm and a thermophilic state were selected to perform the co-digestion of wastes. A double-jacketed water heater performed the warming to keep the temperature at (54 ^{o}C). A PC was linked to the reactor to observe the reaction tank's pH and temperature. The whole investigational setup was run till biogas generation. The entire biogas volume was assessed under 1 atm and 20 ^{o}C.

For monitoring the co-digestion system, effluent samples were collected from the digester sample collection port whereas the digester was uninterruptedly blended to obtain a homogeneous mixture. The period of sampling and assay depended on the determined parameter and their influence on the co-digestion efficiencies. The acid and alkalinity were determined every day at starting. The COD was defined as the generation of biogas was noteworthy.

Results and Discussion

In the present part, results of cow dung co-digestion with aquaculture wastewaters were shown for 2 trials in the batch thermophilic state. Unlike phases of co-digestion, include sets of microbes with their sensitivity to environmental conditions. The methanogenic phase was mainly sensitive to acidosis and alcalose as they involved a trivial group of anaerobic microbes. Nevertheless, acidosis was frequently the consequence of numerous inhibitions as any distressed stage in the co-digestion system may lead to the accretion of volatile fatty acids and a fall in pH. Therefore, controlling several parameters like acidity, alkalinity, ammonia concentration, and C/N, may decrease the procedure inhibition and circumvent system failure. For optimum methane generation, the favourable recommended pH is around 6.5 to 7.5 (Davidsson *et al.,* 2008). The proportion of VFA to the total alkalinity (VFA/TA) is considered a significant tool to determine the pH constancy and buffer capability of the reactor. It has been recommended that the proportion should be less than 0.51 (Luostarinen *et al.,* 2009). During co-digestion with cow dung, this value was 0.9 at the acidification stage and decreased after the steadiness of co-digestion to stay lower than 0.31 for the rest of the system.

The amount of COD swiftly decreasing by the initial 9 days may be described by the fast hydrolysis of cattle manure in the thermophilic rather than the mesophilic state. By the 3rd week, a substantial reduction was observed

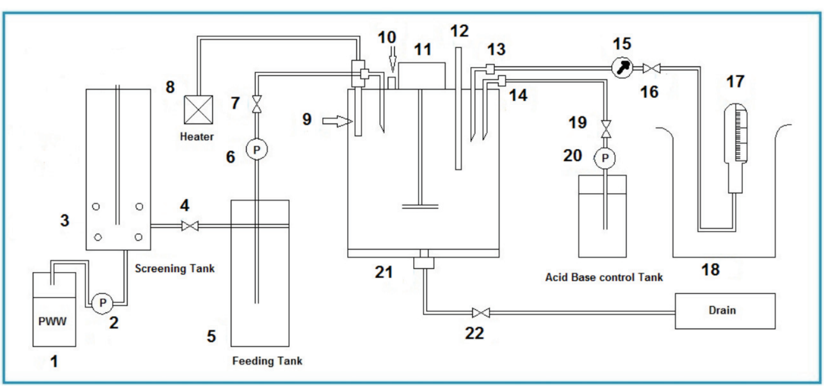

Figure 1: Schematic diagram of the present study

again. A mean COD removal of 71% was observed after the fermentation process. TS and VS were attained at 3.5% and 62%, respectively. It is related to the volatile solid's removal of 43%. The cumulative biogas generation shown in Figure 2 defines the unlike phases of co-digestion. From the start, a tiny increment in a generation was detected, then an enhancement of generation that relates to the exponential state was observed, and lastly, a stationary stage was attained.

1-Raw wastewater Feeding zone; 4,7,16,19,22- control valve; 3-screening tank, 5-feeding tank; 2,6,20-peristalic pump;8-heater; 9-temperature sensor; 10-pressure controller; 11-stirrer motor with stirrer; 12- pH sensor; 13-Gas collection wire; 14-acid base control wire; 15-biogas flow meter; 17-biogas collection tank; 21-Process reactor (capacity 5 L); 18-water displacement system.

In the case of the starting proportion of cow dung, the general production attained 441 L of biogas and 191 L of methane. It refers to a 141 L CH4/kgVS methane production that was deliberated as a significant potential for cow dung at the pilot operating states. Aquaculture wastewater comprised of the digested cow dung was fed into the reactor as inoculum. The presence of this seeding confirmed an outstanding medium to digest other wastes. Results of alkalinity and buffering capability demonstrated that the used media may provide the appropriate states for methane production of substrates, providing a quick acid liberation. The primary properties of aquaculture wastewater and the final properties after co-digestion treatment are listed in Table 2. It attained 0.71 at the start of the system and quickly reduced after the system balance (between 0.31 and 0.21). This low ratio indicates the buffering capability in the reactor causing an alkalinity and acidity balance without any additives that can decrease the waste processing expense for commercial applications. Therefore, this system was operated steadily and a pH of around 7.99 was observed by the end of co-fermentation.

Digestion of proteins and lipids during aquaculture wastewater's hydrolysis and acidification stage refers to the development of different VFAs (Luostarinen *et al.,* 2009). The biogas generated was observed to increase quickly after 5 initial days of the co-digestion. Subsequently, a trivial reduction of the biogas generation was then noted until the 10th day,

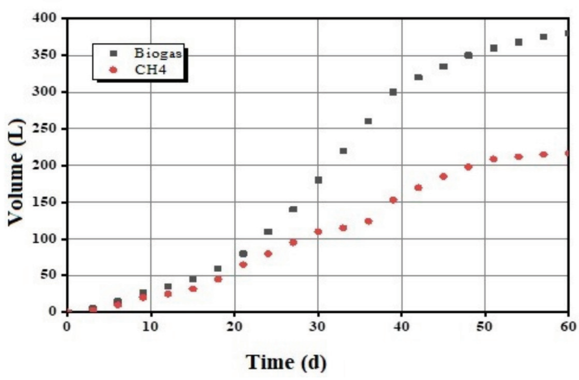

Figure 2: Cumulative volume of biogas and biomethane produced from cattle manure

Table 2: Characteristics of aquaculture wastewater used in this study.

	Organic Loads (kg)	pH	TS (%)	VS (% of TS)
Aquaculture wastewater	5	6.54	23	77
Digester set up	38	7.6	5.3	73

with the last decrease in 2.1 L/day between day 9 and day 61 (Figure 3). The operating period was abridged considerably at our reactor operating states and no prolonged lag stage seemed. The quick hydrolysis stage was due to the thermophilic state and the suitable reactor blending (Pellera & Gidarakos, 2017). Besides, the methanogenesis phase was more quickly started in a thermophilic reactor than in a mesophilic reactor (Borthakur *et al.*, 2021). The amount of biogas generated during this co-digestion of aquaculture wastewater with an inoculum of 0.062 m^3 /kg of raw waste of 0.026 m^3 of CH_4/kg. Consequently, the methane production attained 0.45 m^3 of CH_4/kg of VS at 1 atm and 20 ◦C which remained very promising compared to the other literature outcomes.

However, outcomes of methane potential depended on some parameters and it was very important to weigh them for identical operating states. Nevertheless, most research was carried out on small digesters that may decrease the waste's present ability and increase the co-digestion efficiencies (Syukor *et al.,* 2015). Therefore, for identical operating states of thermophilic wet co-digestion, (Bougrier *et al.,* 2018) reported 0.33 m^3 CH_4/kgVS in the reactor of 8 L, whereas (Cai *et al.,* 2021) studied 0.35 m^3 CH_4/kgVS in the reactor of 5 L working volume. Using an identical working volume pilot reactor as the current one, (Zaied *et al.,* 2019) studied 17 wastes where biomethane production was observed to be 0.28 and 0.42 Nm^3 CH_4/kgVS. It was noticed that the methane potential projected at the present operating condition was the maximum compared to the others. Besides, the operational period of 10 days was adequate to attain 81% of the total methane potential (Figure 4), which may save time and energy.

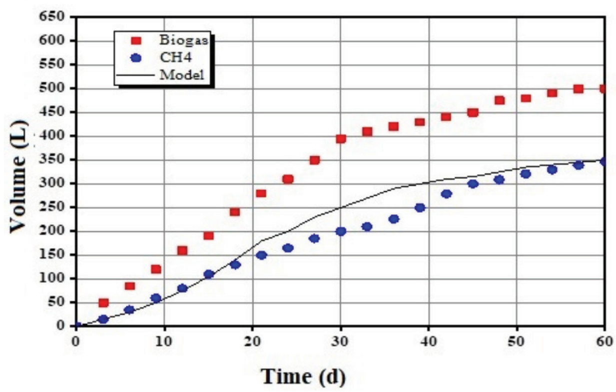

Figure 3: Cumulative production of biogas (L) and CH_4 (L) during the aquaculture wastewater digestion process

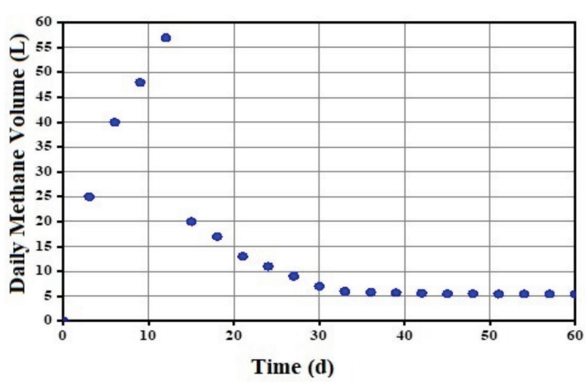

Figure 4: Daily production of CH_4 (L) during aquaculture wastewater digestion process

Figure 5 depicted that chemical oxygen demand (COD) decreased quickly over time. Total COD-eliminating efficiency of 62% and 73% were noted after 9 and 19 days, respectively. Consequently, COD values stayed between 11,001 mg/L and 12,001 mg/L±8% at the end of the 20th day of co-digestion which was in the limit of seeding time COD. These outcomes established that aquaculture wastewater could be transformed into gas after 9 days of co-fermentation. The VS remained at 26 mg/L, referring to a total removal of 36%. In conclusion, the co-digestion of aquaculture wastewater and cow dung produced biogas and biomethane after an abridged operating period. The biogas generation was quick by this co-digestion. It may be because of the configuration of aquaculture wastewater containing a huge portion of biodegradable organics and an advantageous operating condition comprising huge buffering capability, proper blending, and less solid presence (Michael *et al.,* 2017). These promising circumstances may confirm an encouraging sustainable system for energy generation and organic waste processing. Co-fermentation of organic substrates might result in irrigation liquid and fertiliser for agriculture.

As a result, Table 3 shows the qualities of the fermented waste. From the fermented waste, sludge recovery was 0.08 m^3 sludge/m^3 wastewater, and water recovery was 0.85 (m^3 sludge/m^3 wastewater). To assess their prospective

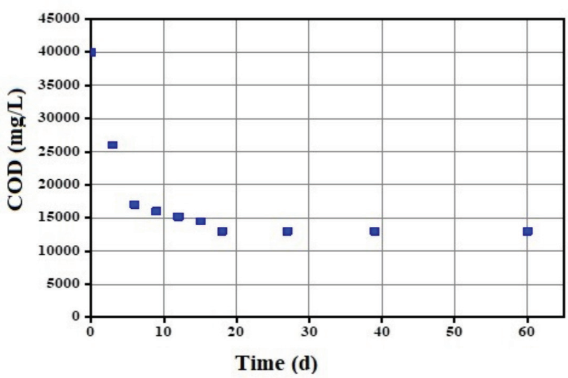

Figure 5: COD reduction profile for aquaculture wastewater digestion process

Table 3: Characteristics of fermented slurry

	Solid Portion		Water Portion
	Cow dung aquaculture wastewater		Cow dung-aquaculture wastewater
Recovery of sludge (m^3 sludge /m^3 substrate)	0.08	Recovery of water (m^3water m^3substrate)	0.85
Moisture (%)	94.95	COD (g/L)	0.29
Zn (g/kg dry weight)	0.57	Turbidity (unfiltered turbidity, UNF)	1289
Ni (g/kg dry weight)	0.17	Suspended solids (g/L)	0.04
Cu (g/kg dry weight)	0.18		
Cr (g/kg dry weight)	0.02		
Hg (g/kg dry weight)	0.002		
Pb (g/kg dry weight)	$7.2*10^{-3}$		
Cd (g/kg dry weight)	$2.5*10^{-4}$		

usage, the qualities of the sludge were compared to the requirements established in the current Malaysian guidelines. Sludge can be used as an agricultural input if the heavy metal content is within the limitations outlined in Appendix K3 of the Environmental Quality Regulations 2009 (PU (A) 433) (Environmental Requirements, 2010) (Qasim *et al.,* 2015). The fermented slurry may be used as fertiliser, and the generated liquid can be used for irrigation.

Conclusion

The co-digestion of aquaculture wastewater seeded by digested cow dung in the thermophilic pilot reactor was assessed by methane potential, COD removal, and operating period. The methane generation of aquaculture wastewater attained 0.45 m^3 CH_4/kg VS. This operation period was very abridged and required only 5 days to attain the highest methane generation [85 L CH_4/ (kgVS. day)] and 9 days to reach 81% of the total methane potential. The digested cow dung as seeding confirmed an outstanding buffering capability and a suitable co-digestion of the examined proportion of aquaculture wastewater without additives. The detected alkalinity of the reactor demonstrated that the cattle dung co-digestion may produce the appropriate environments for methane production. This system efficiently eliminated 71% of COD and more than 36% in volatile solids. The effluent of cow dung and aquaculture wastewater constituted a performant fertiliser for farming exploitation.

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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