Research article

Performance of a Covered Lagoon Digester on Wastewater Treatments Obtained from Mango Processing in Kampong Speu, Cambodia

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Abstract: Cambodia exported more than 163,400 tons of fresh mangoes and 18,490 tons of processed, dried mangoes in 2022., Approximately 250–300 tons of dried mango are processed daily throughout the country. Mango processing produces wastewater which is a major concern and requires proper handling and treatment. This study aimed to assess the utilization of a lagoon digester on the mango processing wastewater including (1) ascertain the physio-chemical characteristics of mango processing wastewater; (2) estimate the biogas production and its quality; and (3) determine the potential greenhouse gas emission reductions available through this technology. The lagoon digester had a volume of 6,000 m^3. The study was carried out from July to November2023, at a mango processing factory located in the Kampong Speu province in Cambodia. The factory produced up to 300 m^3 of wastewater per day, which was diverted to the lagoon and then treated with NaOH and powdered calcium carbonate to raise the pH before feedstock was released into the lagoon pond. Three wastewater samples were obtained from the discharge pond of lagoon digester after a month of treatment to measure chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS) and pH. The biogas production was estimated and measured using the vortex flow meter, while a portable biogas analyzer was used to measure the biogas quality. The COD concentration of the wastewater before use of the digester was 35,000 mg/L which was above the standard of Ministry of Environment, Cambodia (<70 mg/L of COD for a public water discharging) which was reduced to 12,000 mg/L, or 65%, after treatment. It was estimated that the biogas yield from the lagoon digester was, on average, 2,296.9 Nm^3/day. While the H_2S concentration was over 5,000 ppm (above the permittable standard < 200 ppm) and the CH_4 content was 52%. In conclusion, this factory can lower the COD concentration of mango wastewater after discharging from the lagoon digester and further benefit from using biogas instead of LPG gas for cooking; by using the lagoon digester, the factory may be able to reduce greenhouse gas emissions by 1,5415.6 tCO_2eq/year.

Keywords lagoon digester, biogas, wastewater, treatment, Greenhouse gas, COD

INTRODUCTION

Mango is the highest produced and most valuable fruit grown by farmers in Cambodia. Over 100,000 hectares are cultivated for mango. Among Cambodia's 25 provinces, Kampong Speu produces the highest amount and the best quality mangoes in the country. (Pisei, 2019). In addition to this, over 163,400 tons of fresh mangoes are exported abroad. However, it decreased 30 percent of fresh mangoes export from the same period in 2021. According to the Ministry of Agriculture, forestry and fisheries, 99,800 tons were exported to Vietnam whereas, China imported only 27,400 tons from Cambodia in 2022 (Socheata, 2023a).

Cambodia processed and exported 18,490 tons of dried mangoes in 2022 which was over 3 percent increases compared to last year. Among the top three buyers, China imported 15,800 tons of dried mango from Cambodia (Socheata, 2023b). On a daily basis, 300 tons of mango are processed in five mango processing factories in Cambodia.(Vireak, 2020). This amount of processing capacity produces a large amount of wastewater which requires proper management and treatment. One case study showed that 50-100 tons of mango processing produced approximately 150-300 m^3 of wastewater with a high concentration of chemical oxygen demand (COD) which must be reduced below the permittable standards of Cambodia (Hin et al., 2023).

Wastewater treatment is a significant concern in Cambodia. Wastewater management appears to include discharge of treated wastewater, discharge of untreated wastewater, or by run off and natural purification processes in natural ponds or rivers in accordance with the environmental standards. In one study, the treated effluent had BOD and COD values (mg/L) that complied with the Ministry of Environment's regulations for wastewater effluent discharged into public waters and sewers, the standards of which are below 100 mg/L of COD and 80 mg/L, respectively (Prak and Savath, 2013). Generally, there are many options to remove COD from wastewater with both biological and chemical treatments. However, most livestock farms used the anaerobic digestion (AD) technology in terms of wastewater management and climate changes mitigation (Achinas et al., 2017).

A covered lagoon digester is a popular AD method in Cambodia, In 2019, 44 units were reported to be in use for the treatment of wastewater mostly for commercial pig farms with some agro-processing factories using this method by construction of this type of lagoon digester inside their factory for wastewater management (NBP, 2019). With low construction costs, ease of usage, and suitability for wastewater with a dry matter (DM) level of 0.5-2%, lagoon digesters are popular (Rahman and Borhan, 2012) while the amount of DM in the wastewater from Cambodian pig farms is 0.9%, according to Hin et al. (2021). A cassava starch factory discharged the total wastewater about 800 m^3 for 50 tons of cassava starch processing daily and COD was analyzed on at least 3-4 times before construction and this results varied from 1,600 to 6,800 mg/L of COD and the covered lagoon digester was constructed to treat it properly and can be possibly 80% COD removal and it benefits the factory to generate biogas for electricity and boiling instead using of LPG gas. Our review demonstrates that only one mango processing factory in Kampong Speu attempted to solve their wastewater management problem after the existing systems were deemed inefficient at pollutant removal in wastewater. By installing and using a covered lagoon digester to treat approximately 200-300 m^3 of wastewater per day and generate 1,584 Nm3 of biogas for their daily consumption as well as it can reduce CO_2 emission by 9,540 tCO_2eq/year (Hin et.al, 2023).

Biogas, a byproduct of the lagoon digester, is a mixture of gases that consists of 60-70% of CH_4, 30-40% of CO_2 and other trace compositions (Okoro and Sun, 2019; Safferman et al., 2007). Methane (CH_4) is the main energy resource that can generate both heat and power generation. Nevertheless, biogas has a high content of hydrogen sulfide (H_2S) up to 3,500 ppm (Dumont, 2015). H_2S is poisonous to people and damaging to engines. H_2S levels for generator operation must be kept between 200 and 500 ppm (Rodriguez et al., 2014).

Given the importance of processing and exporting dried mangoes and in managing the resultant wastewater, the study aimed to (1) ascertain the physio-chemical characteristics of wastewater; (2) estimate the biogas production and its quality; and (3) determine the greenhouse gas emission reductions throughout the installation of the lagoon digester.

MATERIALS AND METHODS

The study was carried out between May and December 2023, at a mango processing factory located in the Treng Trayoeung commune, Phnom Srouch district, Kampong Speu province. This factory processes an average of 50-60 tons of fresh mango per day while the maximum processing is up to 100 tons daily.

The factory had applied two procedures to treat and manage the wastewater which had a chemical treatment and an anerobic digestion system or a simple lagoon digester. In principle, this mango-factory produced approximately 300 m^3 of wastewater daily with a high concentration of chemical oxygen demand (20,000 mg/L of COD) before being treated. A covered lagoon was a total volume of 6,000 m^3 for generating mango processing wastewater into biogas. In contrast to this, the factory used nitrogen hydroxide (NaOH) powder with an amount of 200 kg into a chemical treatment tank before discharging into lagoon digester.

Table 1 General description of the mango processing factory

Factory	Description
Name	Mango processing factory at Kampong Speu
GPS	11°19'50.0"N and 104°12'53.7"E
Years in operation	5
Daily processing capacity (tons)	50-60 tons
Operational period	10 months per year
Number of staff (persons)	140
Wastewater treatment	A Covered Lagoon Digester
Volume of digester	6,000 m^3
Maximum wastewater (per day)	300 m^3

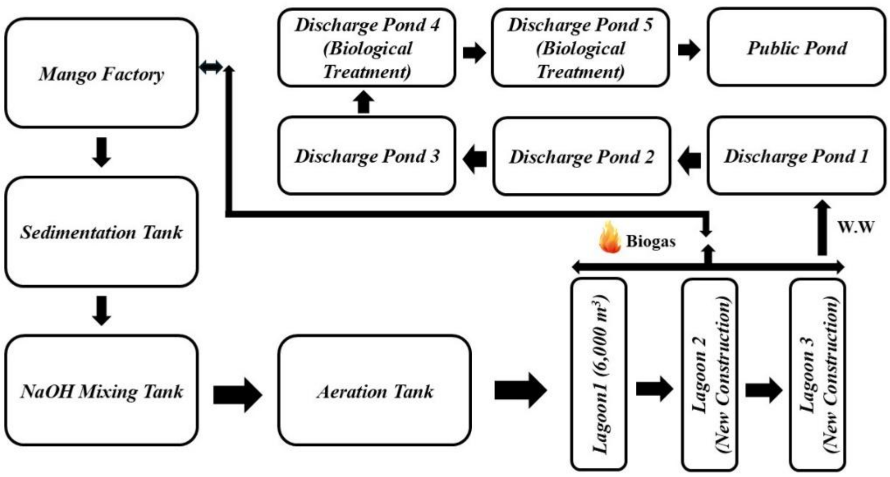

Fig. 1 Diagram of wastewater treatment at the mango processing factory

Materials

A Geotech 5000 biogas analyzer was used to measure biogas quality (Hin et al., 2021; Mean et al., 2022). A vortex flow meter (was used to measure what?) with a range of 20-880 Nm^3/hr. was connected to the main pipeline of the lagoon. The desulfurizing system consisted of 4 desulfurizing tanks which stored and used iron oxide (Fe_2O_3) with an amount of 30 kg in each. Iron oxides replacement occurred monthly to make sure that H_2S concentration remained below 200 ppm.

Data Sampling

To determine the physio-chemical properties of wastewater (COD, BOD, TS, TSS, pH and TOC), there were three samples of wastewater taken from different sites including, the first sample was collected in sedimentation tank; the second sample was collected in a NaOH powder mixing tank and the third sample was taken from a discharge pond 1. For daily biogas consumption was recorded twice per day from the vortex flow meter whereas, the biogas quality was measured by Geotech 5000 biogas analyzer for three times per month before and after desulfurized when biogas was consumed for boiling and cooking.

Total Biogas Estimation

Technically, 1kg of COD can be removed from 1 liter of wastewater converted into 0.35 $Nm^3$of methane volume (CH_4) and mainly the methane concentration varied from 50-60% in biogas from mango processing factory (Deublein and Steinhauser, 2010). Additionally, to estimate the total biogas production was based on the efficiency of COD removal from the total wastewater after discharging from the lagoon digester.

$$TBP\ (Nm^3) = TW(m^3/day) \times COD(kg/m^3) \times 0.35 \times COD_{removal}\ (\%)/\ \%CH_4 \quad (1)$$

Whereas, TBP represents the total biogas production and TW presents the total wastewater and COD removal represents the efficiency of COD reduction in biogas production.

The Estimation of GHG Emission Reduction

To calculate CO_2 reduction equivalent (tCO_2 eq.) by avoidance of CH_4 emission reduction throughout the operation of lagoon digester for the wastewater treatment is based on the CH_4 density which is 0.717 kg/m^3 whereas, the conversion of CH_4-to-CO_2 is 30 times more potential in causing the global warming (Mean et al., 2022).

$$CO_2 \text{ by avoidance of } CH_4\ (tCO_2eq./year) = Q_{CH4} \times D_{CH4} \times CH_4\text{-to-}CO_2/1{,}000 \quad (2)$$

Where Q_{CH4} represents the total methane production annually (Nm^3/year), D_{CH4} represents the methane density (kg/m^3).

Data Analysis and Interpretation

Data were prepared in table and bar charted in Microsoft Excel and Descriptive statistics were employed in each parameter to determine mean, standard deviation (SD), standard error (SE) and p-value in R studio version 4.3.1.

RESULTS AND DISCUSSION

The Physio-chemical Characteristics of Wastewater

The wastewater primarily originates from various stages of mango processing, including washing fresh mangoes, syrup production, steaming, mango pearl processing, and other operations along the production line. For laboratory analysis, the wastewater quality was considered with three different sites in anaerobic digestion. Table 2 showed the physio-chemical characteristics of wastewater in this factory contained 3.6-4.2 pH in acidity state which was strongly affected by the fermentation of the wastewater in the covered lagoon. Additionally, the COD reduced from 35,000 mg/L to 19,400 mg/L after being treated with NaOH powder while it further decreased to 12,000 mg/L after discharged from the lagoon digester for which we compute a COD removal efficiency of 65%. However, the COD standard for water area and sewer was lower than 300 mg/L in Cambodia whereas, the COD standard for protected public water was below 120 mg/L according to (MoE, 2018).

In contrast, one study found that mixing NaOH with wastewater was effective in reducing COD from 5,000 mg/L to 1,200 mg/L, while also adjusting the pH from 6.5 to 9.5 with a 0.5 M NaOH concentration (Amor et al., 2019). Additionally, the BOD_5 concentration in wastewater before treatment was 17,540 mg/L, which decreased to 7,810 mg/L and further reduced to 6,030 mg/L after treatment in the lagoon digester. However, the permissible BOD_5 standard for sewage discharge pond is set below 200 mg/L (MoE, 2018).

Table 2 The Physio-chemical characteristics of wastewater (WW)

Parameters	Units	Testing results		
		WW before treatment	WW + NaOH before treatment	WW after treatment
pH	-	3.6	3.8	4.2
Chemical oxygen demand (COD)	mg/L	35,000	15,600	12,000
Biochemical oxygen demand (BOD_5)	mg/L	17,540	7,810	6,030
Total organic carbon (TOC)	mg/L	1690	6,990	5,995
Total nitrogen (TN)	mg/L	112	228	346
Total suspended solids (TSS)	mg/L	480	188	64

The Estimation of Biogas Production from Mango Processing wastewater

Table 3 shows the potential biogas produced from mango processing, and it was estimated to produce approximately 2,296.9 Nm^3/day with an average of 150 m^3wastewater treatment daily. For full processing, the factory produced a maximum of 300 m^3 wastewater and treated it in the lagoon digester. So, the biogas potentially produced 4,593.8 Nm^3/day daily in terms of 65% COD reduction efficiency in this lagoon digester. Additionally, Table 4 described the biogas quality and it resulted as 52% of CH_4, 40.8% of CO_2, 1.1% of O_2 and 4.1% of N_2, respectively whereas, it was observed that H_2S concentration contained above 5,000 ppm or an average of 5,040 ppm in biogas which needed to treat it properly and reduce below 200 ppm if the factory preferred to generate it with a cooking stove, boiling and electricity generation in avoidance of erosion and a short life-time of uses.

Table 3 Description of biogas potential produced from mango processing

Description	Unit	Average
Total wastewater	m^3/day	150
Daily Biogas Production	Nm^3/day	2,296.9

Table 4 Description of Biogas quality in lagoon digester

Biogas compositions	Unit	Mean	S. E
Methane (CH_4)	%	52	0.5
Carbon dioxide (CO_2)	%	40.8	1.2
Oxygen (O_2)	%	1.1	0.3
Hydrogen sulfide (H_2S)	ppm	5,040	150
Nitrogen (N_2)	%	4.1	0.2

In the meantime, biogas production from cassava wastewater in the same anaerobic digestion (covered lagoon digester) found that the biogas potential was estimated to produce 5,500 Nm^3/day within amount of 400 m^3 wastewater treated daily in terms of 80% COD removal efficiency after discharged from lagoon. Furthermore, its biogas quality contained 50% of CH_4, 41.7% of CO_2, 0.1% of O_2 and 3.8 of N_2, respectively whereas, H_2S varied from 260-450 ppm (Hin and Sokhom, 2020).

In contrast, the biogas production in fattening pig farms was an average of 415 Nm^3/day in terms of 140 m^3 wastewater treatment in a covered lagoon digester daily. Meanwhile, its biogas quality resulted 59.5% of CH_4, 31.5% of CO_2, 1.3% of O_2 and 2,256 ppm of H_2S, respectively (Hin et al., 2021).

Biogas Desulfurization (H_2S) Reduction

Figure 2 illustrates the comparison of H_2S concentration before and after desulfurization between one week and four weeks of full biogas consumption. It was observed that H_2S gas decreased dramatically from over 5,000 ppm to 37 ppm (below standard) within a week of use whereas H2S increased gradually by 4,700 ppm over a month. Similarly, a few commercial pig farms use iron pellets to treat H_2S and normally, they prefer to change iron pellets monthly with a flow rate of 150-250 Nm^3/hr. (Mean et al.,2022). Meanwhile, this amount of H_2S dramatically increased after a month of full consumption (cooking and boiling) with a flow rate of 30-80 Nm^3/hr. which caused the iron pellets (120kg) in the desulfurizing tanks to be less efficient to remove H_2S from biogas. Technically, According to Lor et al. (2021), H_2S removal was observed with 4 kg of pellets, as H_2S levels decreased to above 2,500 ppm.

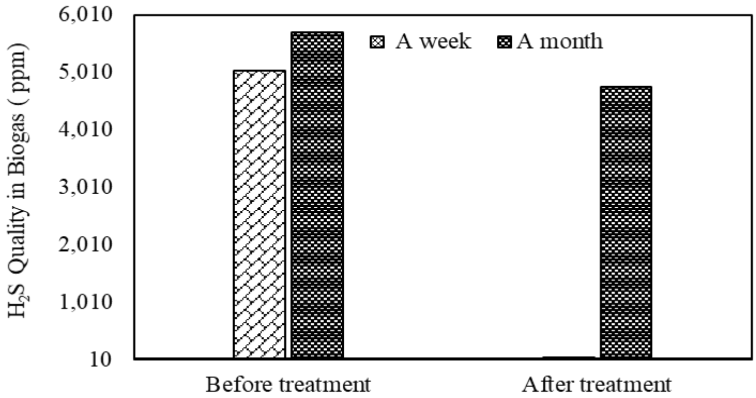

Fig. 2 Comparison of H_2S concentration after desulfurization between a week and a month

Estimation of Annual CO_2 Emission Reduction

Table 5 shows that the annual biogas production was 1,378,125 Nm^3/year, with methane production at 716,625 Nm^3/year. The factory's full biogas utilization can significantly reduce CO_2 emissions by 15,415.6 tCO_2eq/year. Compared to commercial pig farms, this represents a substantial reduction in CO_2 emissions. Hin et al. (2021) reported that CO_2 emissions from pig farm wastewater treatment can be reduced by 2,832 tCO_2eq annually.

Table 5 The avoidance of CO_2 emissions throughout the promotion of lagoon digestion

Description	Unit	Value
Annual biogas production	Nm^3/year	1,378,125
Annual methane production	Nm^3/year	716,625
Annual CO_2 reduction	tCO_2eq./year	15,415.6

CONCLUSION

The lagoon digester was the most effective option for wastewater treatment, as it not only reduced COD concentration but also generated biogas for on-site use. Additionally, it helped the factory mitigate foul odors and minimize complaints from neighboring villagers. Furthermore, the treatment process contributed significantly to CO_2 reduction. However, the COD levels remained above the standard even after treatment. To enhance wastewater treatment efficiency and further reduce pollutants, it is recommended that the factory construct two additional lagoon digesters. This would also increase biogas production, which could replace LPG and diesel for boiling and electricity generation.

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