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Investigating the Potential of Biogas Production from BIUST Wastewater Treatment Sludge by Co-Digestion with Slaughterhouse waste

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Abstract

Wastewater treatment is a necessity in any community and civilization particularly where water is a scarce natural resource. The Botswana International University of Science and Technology is habitat to a community of just under 5000 people and has its own dedicated wastewater treatment plant. Currently this plant is managed by the university and boasts of 7 ponds. The plant follows a conventional four stage process; starting off with screening and grit removal, then removal of suspended solids through sedimentation, breakdown of organic matter through biological processes, then lastly filtration, disinfection, and use of chemical treatment to ensure compliance with quality standards before final discharge. This research aims at the third stage of biological processing to explore potential for biogas production potential from BIUST wastewater treatment sludge (WTS). Presently the anaerobic digestion ponds are open to the atmosphere and therefore release methane to the atmosphere adding to greenhouse gas emissions. To investigate, four different ratios of sludge (SL) to slaughterhouse waste (SHW) (1:1, 1:3, 3:1, 2:3) were co-digested, and the two substrates mono digested. The experiment was conducted over a retention time of 32 days in 2L reactor vessels. The results for bio-methane potential revealed that sludge: slaughterhouse waste 1:3 accumulated the highest volume of biogas (10,446.4 NmL CH_4/gVS), sludge on its own accumulated the lowest volume of biogas (3,134.9 NmL CH_4/gVS). The ratio of 2:3 exhibited the most optimal physiochemical properties for biogas production, promising a high turnover of gas produced. The premeditated assumption was later discovered to be false, as the volume accumulated was relatively low (3435.8 NmL CH_4/ gVS) only increasing by 9.6% compared to the lone digestion of sludge. Ratio of 3:1 yielded a biogas of 5,686.1 NmL CH_4/gVS, showing an 81% increase in biogas yield compared to mono-digestion of sludge. Therefore, co-digestion of sludge with slaughterhouse waste at a 3:1 ratio shows great potential for biogas production from BIUST waste treatment sludge.

Keywords

Biogas, Biomethane Potential, Chemical Oxygen Demand, Carbon Nitrogen Ratio, Greenhouse gas, Wastewater treatment.

1. Introduction

Fossil fuels drove the Industrial Revolution, causing simultaneous technological, economic, and social advancements, however this negatively impacted and influenced the environment, e.g., climate change [1], hence the global drive to transition to renewable energy technologies. These are technologies which produce power, heat, or mechanical energy using biomass (energy crops, Agricultural waste, biogenic municipal waste, etc.), wind, solar (thermal and photovoltaic), hydro (river flow, tides, waves), and geothermal energy [2]. The global annual generation of waste was estimated at 1.3 billion tonnes by the World Bank in 2012 and is projected to double to around 2.2 billion tonnes per annum by 2025 [3]. Botswana's Waste Management Strategy [4] endeavours to ensure the sustainable and environmentally sound management of waste which would guarantee a significant extent the following: 1) Preservation, protection, and improvement of the quality of the environment; 2) Contribution towards the protection of human health; 3) Ensuring prudent and rational utilisation of the natural resources. Re-manufacturing, reusing and recycling, and using one industry's waste as another industry's raw material closes loops within a circular economy and minimizes waste. This approach holds several other advantages: improved resource efficiency, reduced health and environmental impacts, and lesser emissions of greenhouse gases [5].

The main disposal route for waste in Botswana is landfilling, which is the most discouraged level in the global best practices [6], [7]. This is because landfills take up large land space and have various environmental ramifications including the emission of methane. Botswana has identified various technologies to address environmental challenges related to wastewater and energy efficiency. The country recognizes the potential of technologies like activated sludge treatment plants for wastewater reuse, compact fluorescent lighting, and passive solar design for energy efficiency [6]. Wastewater sludge from treatment plants in Botswana is largely discarded by landfill and incineration, disregarding its potential as a fuel and fertiliser source. Sludge contains a high concentration of biodegradable components such as starch and proteins which makes it suitable for biogas production [3], [8]. Biogas is an emerging, versatile, and renewable source of energy that can turn out to be very useful in solving this challenge [9], [10]. The use of wastewater sludge as a source of energy and resource recovery is a good alternative for its management to mitigate the negative environmental impacts of its disposal. To maximise the methane potential of sludge, anaerobic co-digestion can be implemented to enhance the biodegradability of wastewater sludge [11], [12]. Slaughterhouse waste is also another waste stream which presents management problems but is rich in microorganisms essential for biomethane production. While biogas production processes related to wastewater sludge and organic wastes are very well documented, there is scarce information on co-digestion with slaughterhouse waste in Botswana. This research seeks to investigate biogas production potential from BIUST (WWTS) co-digested with slaughterhouse waste.

2. Methodology

Wastewater sludge from BIUST (WWTS) and SHW (from a local slaughterhouse) were used as substrates under mesophilic conditions to determine the optimum ratio of sludge to SHW for best biogas yield. The work was divided into four main areas: Substrate preparation, substrate characterization, running the BMP test, and digestate characterization. Substrate preparation to remove unwanted solid particles such as plastic and rubber. The final preparation step being combination of the two co-substrates to different mixture ratios (0:1, 1:0, 1:1, 1:3, 3:1 and 2:3). Proximate analysis were performed to determine moisture content, total solids volatile solids, fixed carbon, and ash content. The chemical oxygen demand was also measured using high-rate COD reagent vials. The Bio-Methane Potential (BMP) test was conducted by loading 2L reactors with co-substrates in a static bath connected to CO_2-absorption bottles in a purged environment. After the 32-day retention period, the digestate was characterized following a similar procedure to that used for the substrates.

Figure 1 Biomethane Potential Test setup.

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3. Results and Discussion

3.1 pH

Results in Table 1 show that the ratio of 2:3 showed the largest increase in pH from 6.43 to 7.96 along with the ratio 3:1 increasing from 6.76 to 7.96. The observation of pH increase reflects the transformation of the organic matter and the production of biogas. Anaerobic digestion is affected by the strength of hydrogen ions, that is the pH, of this digestion setup. A high degree of acidity would thus impede digestion since concentration of hydrogen ions affects microbial action. Methanogens, responsible for methane production, have been known to die in acidic environments; they thrive best in a setup with a neutral to slightly alkaline. The optimum system pH would fall between 7 and 8.5, although it can still perform well at a pH of about 7 when the process is strictly anaerobic [13]

Table 1- substrate and digestate pH values.

Sludge/Paunch matter Ratio	pH before digestion	pH after digestion
0:1	6.17	6.73
1:0	5.77	6.46
1:1	6.07	5.97
1:3	5.94	6.57
3:1	6.76	7.84
2:3	6.43	7.96

Table 2 - COD analysis results

Sludge/Paunch matter Ratio	RAW COD (g/L)	Digestate COD (g/L)	COD Removal efficiency (%)	COD/VS Ratio (g COD / g VS)
0:1	9.76	0.13	98.7	0.75
1:0	9.16	0.56	93.8	0.56
1:1	9.70	1.27	86.9	0.78
1:3	13.65	9.61	29.6	0.82
3:1	13.76	8.35	39.3	1.10
2:3	14.42	0.37	97.4	1.36

3.2 COD removal efficiency, COD/VS Ratio

Error! Reference source not found. demonstrates a relatively high COD removal efficiency, which suggests a significant conversion of organic matter to biogas, but the lower efficiencies imply a longer retention time is required, however this will also demand a larger reactor for the same material flow which also then bear on capital costs due to material costs and heat loses accompanied with the large design [14], [15]. The ratio 0:1 exhibits the highest removal efficiency at 98.7%, followed by the ratios of 2:3 and 0:1 at 97.4% and 93.8% efficiency respectively. The optimal COD/VS ratio for anaerobic digestion ranges between 1.2 to 1.6 g COD/g VS [16], with 2:3 being the most efficient at 1.36 g COD/ g VS. The typical trend of low COD/VS ratios is associated with a greater potential for biogas production and higher methane yields [17].

3.3 Biogas Production

Biomethane production results Figure 2 revealed that sludge: slaughterhouse waste 1:3 accumulated the highest volume of biogas (10,446.4 NmL CH_4/gVS), sludge on its own accumulated the lowest volume of biogas (3,134.9 NmL CH_4/gVS). Ratio of 3:1 yielded a biogas of 5,686.1 NmL CH_4/gVS, showing an 81% increase in biogas yield compared to mono-digestion of sludge. Sludge on its own was slow to produce biogas owing to the lack of methanogens which are readily available in paunch matter [18]. The increase of biogas production rate increases almost directly to the increase in paunch matter fraction digested with SHW.

4. Concluding Remarks

BIUST wastewater sludge has a better potential for biogas production when co-digested with paunch matter in a shorter retention time. It will be worth repeating the same experiment at longer retention time, to observe if an increase in biogas production rate would yield more gas. The ratio of 1:3 accumulated the highest volume of biogas summing up to 10 446.4 NmL CH_4/gVS, whereas the ratio of 2:3 exhibited the most optimal physiochemical properties for biogas production. Contrary to that, the volume accumulated was relatively low (3435.8 NmL CH_4/ gVS) only increasing by 9.6% compared to the mono-digestion of sludge (Figure 3). Thus, co-digestion of sludge with slaughterhouse waste at a 3:1 ratio demonstrates a significant promise for biogas production from BIUST waste treatment sludge, as it results in an 81% increase in biogas yield compared to the digestion of sludge alone.

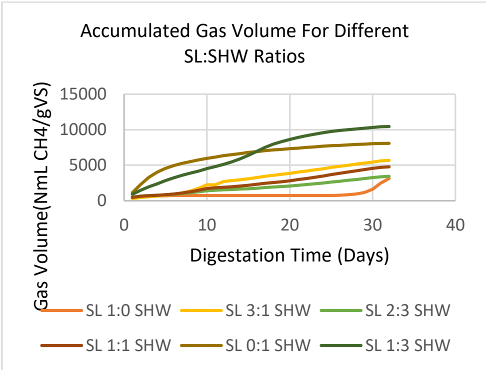

Figure 2 Biomethane Production rate against retention time in days.

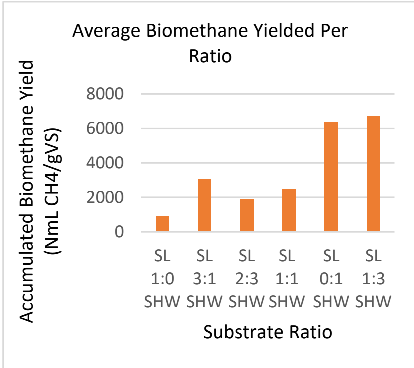

Figure 3 Average biogas yield per ratio.

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