
Biogas Production from Crude Glycerol Using an Upflow Anaerobic Sludge Blanket Reactor

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Abstract – The increased biodiesel production has led to an excess of glycerol, a byproduct with high organic content. While impurities limit crude glycerol's use in the chemical industry, it can be anaerobically digested to generate methane as an energy source. In this study, a laboratory-scale upflow anaerobic sludge blanket reactor was fed with crude glycerol from a biodiesel plant. The organic loading rate was gradually escalated from 2.0 to 10.0 kg COD/m³, and the crude glycerol dilution was reduced from 1:1,500 to 1:5. The UASB reactor was able to convert approximately 97.5% of the organic matter, producing 61.5 L of biogas per day, while maintaining a VFA/AlkHCO₃ ratio below 0.3, even with 14 g/L chloride in the system. Nutrient supplementation was essential to prevent system failure. Overall, the results suggest that crude glycerol can be an effective co-substrate to boost biogas yields during sewage sludge anaerobic digestion.

Keywords – Biodiesel, Crude Glycerol, Anaerobic Digestion, Biogas Production, Methane Generation.

I. INTRODUCTION

The biodiesel production process yields glycerol as a by-product, which contains impurities that impact industrial operations and heighten purification expenses. Specifically, for every kilogram of biodiesel generated, approximately 100 grams of glycerol is produced as a consequence of the transesterification reaction. [1], the global production of crude glycerol was approximately 3,000,000 metric tons in 2011, and is projected to increase to 4,600,000 metric tons by 2020 as biodiesel manufacturing capacity expands [2]. In recent years, crude glycerol has been utilized as an organic feedstock to synthesize various valuable biological products, thereby promoting its reuse and adding value to this residue [3], including methane for power generation [4]. Despite its high biodegradability [5], the crude glycerol contains high concentration of chloride, which can inhibit anaerobic digestion through cell plasmolysis [6]. Besides, [7] reported that the anaerobic digestion of glycerol can also be inhibited by the accumulation of metabolites due to the high COD concentration of glycerol.

This study aims to demonstrate the technical viability of using crude glycerol as a feedstock for biogas and energy generation, utilizing a laboratory-scale upflow anaerobic sludge blanket reactor operated at a high organic loading rate and with minimal dilution.

II. MATERIALS AND METHODS

The crude glycerol utilized in this study was manufactured at the R K College of Engineering biodiesel plant situated in Vijayawada, Andhra Pradesh State, India. It was obtained through the transesterification of a Waste Vegetable oil as shown in Fig. 1. This glycerol exhibited 82.4% purity, 1.4% non-glycerol organic matter, 0.048% methanol, 10% moisture, 6.2% ash, a pH of 5.5, 46.1 g/L chloride content, a chemical oxygen demand of 1,260 g/L, a biochemical oxygen demand of 851 gO₂/L, and an absolute density of 1.26 kg/L.

Fig. 1. Transesterification Setup



The lab-scale Upflow Anaerobic Sludge Blanket (UASB) reactor employed in this study was constructed using PVC tubing as shown in Fig. 2, with a diameter of 100 mm, a height of 1.82 m, and a working volume of 14.85 L. The biogas produced was measured using a Ritter gas meter, model TG05/05, and the methane content was determined through gas chromatography. The reactor was inoculated with a blend of three different sludges in equal proportions: a UASB reactor from a brewery, a UASB reactor for sewage treatment, and a lab-scale UASB reactor fed with sucrose and nutrients. The UASB reactor was operated in a temperature-controlled room at 35° C.

Two different nutrient solutions were employed throughout the 403-day operational period. The initial nutrient solution was utilized for the first 260 days, while a modified solution was implemented for the remainder of the study.

The UASB reactor operation was divided into three phases: I) a gradual transition from sucrose to glycerol as the main feedstock, II) a stepwise increase in the organic loading rate from 2 to 10 kgCOD/m³, and III) a reduction in the dilution of the crude glycerol from 1:1,500 to 1:5. Additionally, it was determined to subdivide phase II to accommodate a change in the nutrient solution.

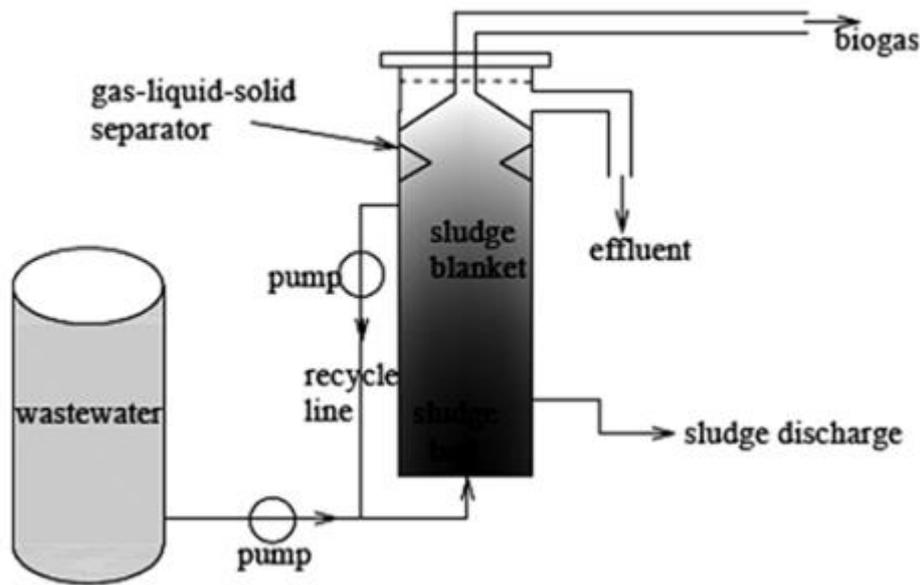


Fig. 2. Schematic of a UASB reactor

III. RESULTS AND DISCUSSION

3.1 Biogas Production (L) over Time (Days)

The biogas production exhibited significant fluctuations throughout the 365-day experimental period, as illustrated in the scatter plot in Fig. 3. The daily biogas yield ranged from approximately 14 L to 60 L, with noticeable variations correlating with changes in Organic Loading Rate and influent Chemical Oxygen Demand. This variability is expected in the biological process of anaerobic digestion, where factors such as feed composition, organic load, microbial activity, and nutrient availability directly impact gas production [8]

During the initial phase, biogas production remained relatively steady but low, around 14-15 L. This was likely due to the adaptation period of the microbial community as the reactor adjusted to utilizing crude glycerol as the feedstock [9].

During the mid-phase, from Day 100 to 250, biogas production began to increase, often exceeding 50 L per day and reaching a peak around Day 200. This increase likely corresponds to an optimized microbial population that was capable of efficiently digesting the organic matter and converting it into biogas [10].

Towards the end of the experiment, biogas production exhibited continued fluctuations, with values occasionally peaking close to 60 L per day. The system had likely become more robust in handling higher organic loads, which may have been connected to the final adjustments in operational conditions such as OLR and nutrient supply [11].

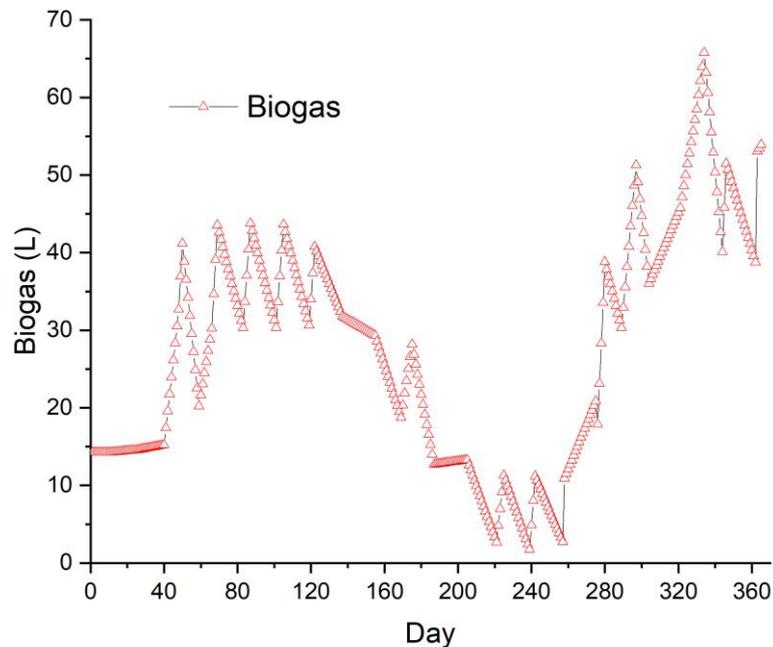


Fig. 3. Biogas Production Overtime

3.2 Influent and Effluent COD (g/L) over Time (Days)

The Chemical Oxygen Demand (COD) of both influent and effluent fluctuated over the experimental period as shown in fig 4, reflecting the treatment efficiency of the Upflow Anaerobic Sludge Blanket (UASB) reactor.

The influent COD fluctuated between 5 and 50 g/L, with periodic increases likely due to variations in the composition and concentration of the crude glycerol fed into the system. Higher influent COD levels were associated with increased organic loading [12], which stressed the microbial community but also increased the potential for biogas production.

The effluent COD followed a similar pattern to the influent COD, but remained consistently lower, indicating that the system was capable of removing a significant portion of the organic material [13]. However, there were fluctuations, especially in the early phases of operation, which might suggest that the microbial community was adjusting to the new feedstock and operational conditions.

Generally, there were instances where the effluent COD was comparable to or exceeded the influent COD, suggesting system instability or incomplete degradation of the organic matter [14]. This was particularly evident during the initial phase, when the system was still optimizing nutrient levels [15]. However, as the system matured, especially after Day 200, the effluent COD decreased significantly, demonstrating the reactor's enhanced treatment capacity [13].

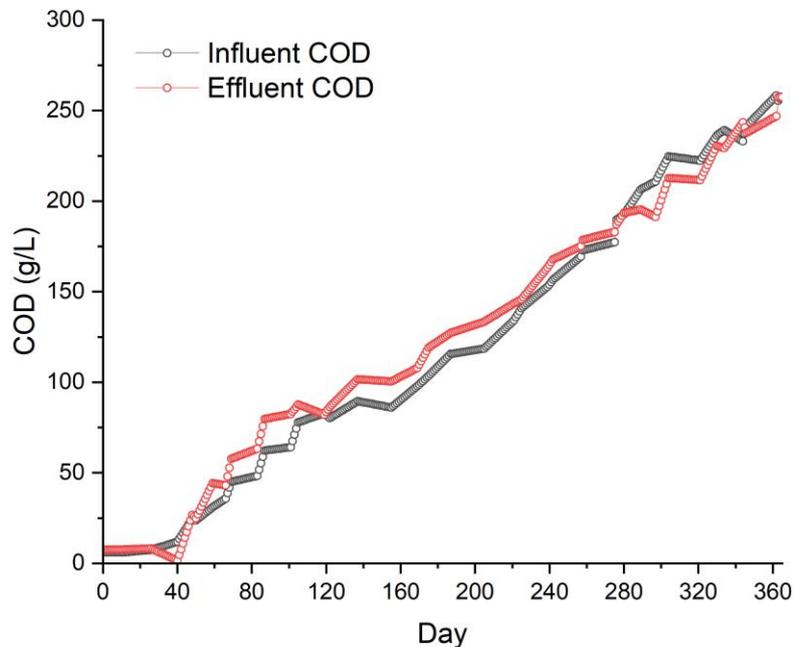


Fig. 4. Influent and Effluent Chemical Oxygen Demand (COD) over Time

3.3 Organic Loading Rate (OLR) (kgCOD/m³·d) over Time (Days)

The Organic Loading Rate is a critical factor that significantly influences the performance of an anaerobic digestion system. As illustrated in the scatter plot in Fig 5, the OLR fluctuated considerably, ranging from approximately 1 to 5 kgCOD/m³·d.

In the early phase, the OLR was maintained at relatively low levels. This controlled approach allowed the microbial community to gradually adapt to the organic load of crude glycerol [16]. Consequently, the biogas production remained low and steady, consistent with the lower OLR [17].

During the mid-phase, the OLR was gradually increased, likely in line with the reactor's increased stability and successful microbial adaptation [17]. The OLR reached peaks near 5 kgCOD/m³·d during this period, corresponding to the spikes in biogas production. This suggests the reactor was able to handle higher organic loads without significant drops in performance, indicating the microbial community had successfully acclimated to the conditions [16].

In the final phase of the experiment, the OLR remained high, fluctuating between 4 and 5 kgCOD/m³·d. Despite the elevated organic loading, the system continued to perform well, maintaining consistent biogas production and showing minimal increase in effluent COD [18]. This suggests the reactor had stabilized, and the microbial community was functioning optimally, even under the higher organic loading [19].

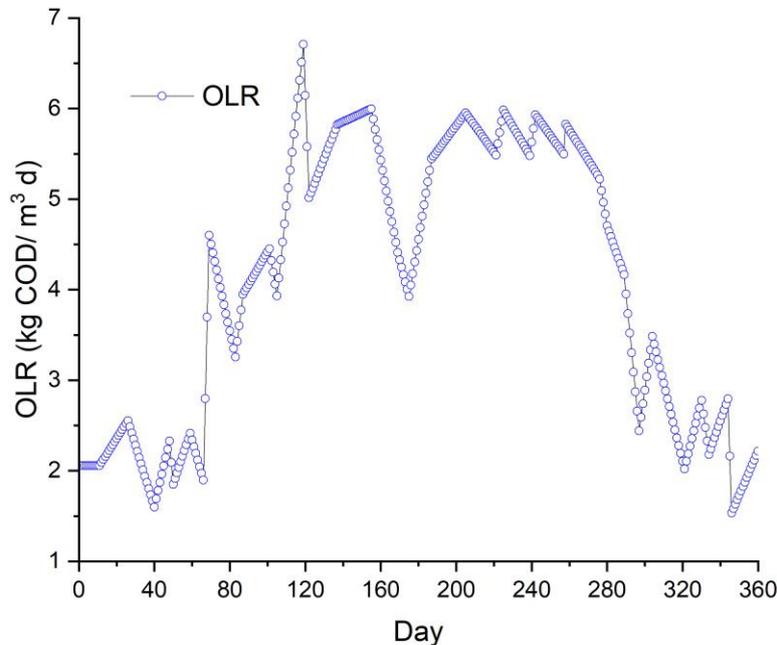


Fig. 5. Organic Loading Rate (OLR) over Time

3.4 Correlation Between Biogas Production, COD, and OLR

Biogas Production and COD: The relationship between biogas production and COD is well-established in anaerobic digestion processes. As the OLR and influent COD increased, biogas production also tended to increase, particularly when the system reached a more stable operational phase. However, during periods of instability, fluctuations in biogas production could be observed as the system struggled to cope with higher COD levels.

OLR and Biogas Production: The observed correlation between OLR and biogas production suggests that the reactor's biogas output is heavily influenced by the amount of organic matter fed into the system. As the OLR increased, the microbial community had more organic material to degrade, resulting in greater biogas production. However, this relationship is not strictly linear, as other factors such as nutrient availability, temperature, and microbial community composition also play critical roles in determining the system's performance.

3.5 Operational Phases and System Stability

Phase I (Days 1–100): During the initial phase, the system experienced a gradual but steady start. Biogas production remained relatively low, and COD removal efficiency had not yet reached its full potential. This phase was characterized by the microbial community's acclimatization and the optimization of nutrient levels.

Phase II (Days 100–250): As the microbial community adapted to the glycerol feedstock, the system demonstrated improved performance. The increased organic loading rate resulted in higher biogas production, and the chemical oxygen demand removal efficiency also improved.

Phase III (Days 250–365): During the final phase, the reactor reached its peak performance. Stable biogas production, low effluent COD, and consistent OLR fluctuations indicated that the system had

fully adapted to the operating conditions. The microbial community proved robust, able to handle higher organic loads without significant system disturbances.

The experiment demonstrates that a UASB reactor can effectively degrade crude glycerol, converting it into biogas while maintaining stable performance despite fluctuations in OLR and influent COD. The microbial community in the reactor adapted to changes in organic load and nutrient levels, leading to improved biogas production and COD removal efficiency over time. The findings suggest that with proper management of OLR and nutrient supply, UASB reactors can provide a sustainable solution for treating glycerol-rich waste streams.

IV. CONCLUSION

This study demonstrated the feasibility of using crude glycerol, a byproduct of biodiesel production, as a substrate for anaerobic digestion in a UASB reactor. The results showed that the UASB reactor was able to operate stably at an organic loading rate of 10 kgCOD/m³, with high organic matter removal efficiency (97.5%) and significant biogas production (61.5 L/d with 59% methane).

The key findings included:

- The UASB reactor performance was improved by adjusting the nutrient solution to match the increased organic loading rate, highlighting the importance of nutrient supplementation for optimal anaerobic digestion.
- The system was able to tolerate high concentrations of chlorides, up to 14 g/L, without a significant impact on its efficiency.
- The observed biogas production closely matched the theoretical values calculated based on mass balance, indicating a well-functioning methanogenic process.

REFERENCES

- [1] B. W. Gebreegziabher, A. A. Dubale, M. S. Adaramola, and J. Morken, “Advancing Anaerobic Digestion of Biodiesel Byproducts: A Comprehensive Review,” *BioEnergy Research*, vol. 18, no. 1. Springer Science+Business Media, Jan. 21, 2025. doi: 10.1007/s12155-025-10820-4.
- [2] G. Martínez, N. Sánchez, J. M. Encinar, and J. F. González, “Fuel properties of biodiesel from vegetable oils and oil mixtures. Influence of methyl esters distribution,” Mar. 03, 2014, Elsevier BV. doi: 10.1016/j.biombioe.2014.01.034.
- [3] S. Goyal, N. Hernández, and E. W. Cochran, “An update on the future prospects of glycerol polymers,” Feb. 27, 2021, Wiley. doi: 10.1002/pi.6209.
- [4] H.-J. Choi and S. Yu, “Influence of crude glycerol on the biomass and lipid content of microalgae,” Mar. 06, 2015, Taylor & Francis. doi: 10.1080/13102818.2015.1013988.
- [5] J. . Pradima, R. M. Kulkarni, and A. Narula, “Review on enzymatic synthesis of value added products of glycerol, a by-product derived from biodiesel production,” Apr. 26, 2017. doi: 10.1016/j.refit.2017.02.009.
- [6] H. Tokumoto, K. Kurahashi, and S. Yoshihara, “Effective Utilization Process of Crude Glycerol Using Anaerobic Microorganisms,” Jan. 01, 2017. doi: 10.5650/oleoscience.17.295.
- [7] M. B. Viana, A. V. Freitas, R. C. Leitão, and S. T. Santaella, “Biodegradability and methane production potential of glycerol generated by biodiesel industry,” Sep. 05, 2012, Pergamon Press. doi: 10.2166/wst.2012.455.
- [8] Jiang, J., He, S., Kang, X., Sun, Y., Yuan, Z., Xing, T., Guo, Y., & Li, L. (2020). Effect of Organic Loading Rate and Temperature on the Anaerobic Digestion of Municipal Solid Waste: Process Performance and Energy Recovery. In *Frontiers in Energy Research* (Vol. 8). <https://doi.org/10.3389/fenrg.2020.00089>
- [9] Tasnim, A., Mamun, M. R. A., Hossen, Md. A., Rahman, M. T., & Soeb, Md. J. A. (2022). Comparison Effect on Biogas Production from Vegetable and Fruit Waste with Rumen Digesta Through Co-Digestion Process. In *European Journal of Energy Research* (Vol. 2, Issue 1). <https://doi.org/10.24018/ejenergy.2022.2.1.38>
- [10] Masinde, B. H., Nyaanga, D., Njue, M., & Matofari, J. W. (2020). Optimization of Biogas Production in a Batch Laboratory Digester Using Total Solids, Substrate Retention Time, and Mesophilic Temperature. In *International Journal of Power and Energy Research* (Vol. 4, Issue 2). <https://doi.org/10.22606/ijper.2020.42001>
- [11] Guimarães, C. de S., & Maia, D. R. da S. (2023). Development of Anaerobic Biodigester for the Production of Biogas Used in Semi-Continuous System Bioprocesses: An Efficient Alternative for Co-Digestion of Low Biodegradability Biomass. In *Biomass* (Vol. 3, Issue 1). <https://doi.org/10.3390/biomass3010002>

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- [12] Subramanyam, R. (2020). Evaluation of UASB Reactor Performance During Start-Up Operation Using Glucose Bearing Synthetic Wastewater. In International Journal of Environment (Vol. 9, Issue 1). <https://doi.org/10.3126/ije.v9i1.27432>
- [13] Hou, Y., Liu, M., Tan, X., Hou, S., & Yang, P. (2021). Study on COD and nitrogen removal efficiency of domestic sewage by hybrid carrier biofilm reactor. In RSC Advances (Vol. 11, Issue 44). <https://doi.org/10.1039/d1ra03286k>
- [14] Shin, S. G., Kim, S. I., & Hwang, S. (2022). Startup of Demo-Scale Anaerobic Digestion Plant Treating Food Waste Leachate: Process Instability and Recovery. In International Journal of Environmental Research and Public Health (Vol. 19, Issue 11). <https://doi.org/10.3390/ijerph19116903>
- [15] Phanwilai, S., Noophan, P., Li, C., & Choo, K. (2020). Effect of COD:N ratio on biological nitrogen removal using full-scale step-feed in municipal wastewater treatment plants. In Sustainable Environment Research (Vol. 30, Issue 1). <https://doi.org/10.1186/s42834-020-00064-6>
- [16] Pera, A. L., Sellaro, M., Bianco, M., & Zanardi, G. (2021). Effects of a temporary increase in OLR and a simultaneous decrease in HRT on dry anaerobic digestion of OFMSW. In Environmental Technology (Vol. 43, Issue 28). <https://doi.org/10.1080/09593330.2021.1952312>
- [17] Sprafke, J., Ekanthalu, V. S., & Nelles, M. (2020). Continuous Anaerobic Co-Digestion of Biowaste with Crude Glycerol under Mesophilic Conditions. In Sustainability (Vol. 12, Issue 22). <https://doi.org/10.3390/su12229512>
- [18] Yanqoritha, N., Turmuzi, M., Irvan, I., Batubara, F., & Abdullah, I. (2018). Acclimatization Process on Hybrid Upflow Anaerobic Sludge Blanket Reactor (HUASBR) using Bioball as Growth Media with OLR Variation for Treating Tofu Wastewater. In Oriental Journal Of Chemistry (Vol. 34, Issue 6). <https://doi.org/10.13005/ojc/340654>
- [19] Pramanik, S. K., Sujá, F., Porhemmat, M., & Pramanik, B. K. (2019). Performance and Kinetic Model of a Single-Stage Anaerobic Digestion System Operated at Different Successive Operating Stages for the Treatment of Food Waste. In Processes (Vol. 7, Issue 9). <https://doi.org/10.3390/pr7090600>.