PRODUCTION AND PURIFICATION OF BIOGAS OBTAINED FROM ANAEROBIC DIGESTION OF URBAN SOLID WASTE

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ABSTRACT

Energy management is crucial for the future, demanding economic and sustainable solutions. Biogas emerges as a promising alternative, meeting energy demand while reducing waste and greenhouse gas emissions. Produced via anaerobic digestion, it utilizes biomass to generate renewable energy and organic fertilizer, influenced by factors such as temperature, pH, and organic load composition. Raw biogas contains methane, carbon dioxide, and impurities that need removal to enhance its quality. Purification techniques, such as physical and chemical absorption, and membrane separation, are employed for this purpose, with physical absorption being common to remove CO_2 and H_2S, often requiring increased pressure to improve efficiency. This study focused on modeling and simulating anaerobic digestion of urban solid waste using Aspen Plus software. Purification was simulated using water scrubbing in a packed column, varying pressure and water flow rate. The results showed a biogas production of 9307.2 m³/day and a methane volumetric fraction of 56.13%, validating the importance of modeling in optimizing anaerobic digestion and biogas purification processes.

Keywords: Energy. Biogas. Modeling. Simulation. Purification.

1 INTRODUCTION

According to the International Atomic Energy Agency (IAEA), energy and energy availability are issues of utmost importance for the future. The need to provide energy in an economically and environmentally viable manner over the long term represents a significant challenge for researchers. In this perspective, the search for alternative resources that provide a lower negative environmental impact has become one of the greatest challenges in the energy sector (Miranda *et al*., 2019).

Biogas, a renewable energy resource, presents itself as an alternative solution to the growing global energy demands while contributing to the reduction of waste and greenhouse gas (GHG) emissions when used correctly. Biogas is considered carbon-neutral because the carbon in it comes from organic matter that captured atmospheric CO_2 in a relatively short period (Awe *et al*., 2017).

Anaerobic digestion for biogas production ($BioCH_4$) is an economical process that uses biomass as the main raw material and generates renewable energy and organic fertilizer (Gautam et al., 2020). In this process, various operational factors affect biogas production, such as temperature, residence time, quantity and characteristics of organic load, pH, reactor volume, feeding pattern, inclusion of aqueous medium, and carbon-to-nitrogen ratio (C/N), among others (Bhatt, 2020).

Raw biogas from anaerobic digestion of sewage sludge, livestock manure, and agro-industrial biowastes mainly contains methane (55-70%) and carbon dioxide (30-45%), along with traces of other compounds (Awe et al., 2017). CO_2 and impurities reduce biogas quality, and H_2S can damage equipment (Lins et al., 2022). Therefore, biogas purification before use is essential. Key purification techniques include physical absorption, pressure swing adsorption, chemical absorption, cryogenic separation, membrane separation, and biological methane enrichment (Awe *et al*., 2017). Physical absorption, using water or organic solvents, is a common method to remove CO_2 and H_2S, often requiring increased pressure to enhance the solubility of polluting gases (Gantina *et al*., 2020).

Actual research aimed to improve the modeling and simulate anaerobic digestion of urban solid waste using Aspen Plus, version 12. This was achieved through reactions cataloged in the literature and estimation of binary interaction parameters, typically overlooked in current literature, which were estimated by regression within Aspen itself. Simulation data were compared with literature-available data. Additionally, the purification of this process by the water scrubbing method in a column packed with Pall rings was studied, varying the operating pressure and water flow rate.

2 MATERIAL & METHODS

Reactions involved in the anaerobic digestion process were described by Rajendran et al. (2014). During this study, the following assumptions were adopted: carbohydrates were represented by cellulose, hemicellulose, dextrose, and starch; lipids were represented by triolein, tripalmitin, SN-1-palmito-2-olein, and SN-1-palmito-2-linolein; proteins were represented by hypothetical pseudo-components, protein and insoluble protein (PI); and lignin was represented by an inert hypothetical pseudo-component.

Simulating the anaerobic digestion (AD) process in Aspen Plus, version 12, utilized the flowchart proposed by Rajendran *et al*. (2014). This flowchart consists of a stoichiometric reactor for hydrolysis reactions and a continuous stirred-tank reactor (CSTR) for acetogenesis, amino acidogenesis, acidogenesis, and methanogenesis phases, with a residence time of 18 days. NRTL thermodynamic model was selected to represent binary interactions between the components involved in the simulation due to its ability to describe mixtures containing highly polar compounds at low pressures. The main difference from Rajendran *et al*. (2014) in this study lies in considering all binary interaction parameters among system components, estimated via regression using the UNIFAC model.

Research focused on the anaerobic digestion of urban solid waste (USW) as the substrate, with an inlet flow rate of 150 $m^3 \cdot day^{-1}$, residence time of 19 days, and reactor volume of 3000 m^3. The resulting biogas production was 9600 $m^3 \cdot day^{-1}$. A ratio of 15% total solids (TS) and 85% volatile solids (VS) in %v/v was applied (Borås Energy and Environment AB, 2012; Rajendran *et al*., 2014).

Purification of biogas obtained within Aspen Plus, an absorption column was configured using the RadFrac module, operating in countercurrent mode. The biogas from anaerobic digestion was injected at the base of the column, while water was introduced at the top. The simulated column was of the packed type, utilizing 0.625-inch Pall rings made of plastic. The water flow rate (absorbent) varied between 5000 and 100000 kg/day, with a fixed height of 2 meters. The column diameter was adjusted according to the water flow rate used. Operating pressures ranged from 10 to 40 bar, and the feed temperature was maintained at 30°C.

3 RESULTS & DISCUSSION

Results obtained from the simulation of anaerobic biodigestion in this study are shown in Table 3. It can be observed that the simulated value of biogas production (9307.2 m^3/day) is in agreement with the experimental value (9600 m^3/day) obtained by Borås Energy and Environment AB (2012), with a slight underestimation and a relative absolute error (|ARD|) of 3.0%. In contrast, the biogas production simulated by Rajendran *et al*. (2014) was 10,176 m^3/day, showing a higher |ARD| of 6.0% compared to the experimental value. Regarding the volumetric methane fraction simulated in the biogas stream, a value of 56.13% was obtained, while the corresponding experimental value was not provided by Borås Energy and Environment AB (2012) or Rajendran *et al*. (2014). Therefore, a better agreement is observed with the simulation conducted in this study, attributed to the inclusion of binary parameters.

Table 1 Comparison between simulated and experimental results.

Parameter	Value	|ARD|(%)
Experimental Biogas Production	401 L/kg_{SVrem}	—
Simulated Biogas Production[a]	436.7 L/kg_{SVrem}	8.9
Simulated Biogas Production[a]	448 L/kg_{SVrem}	11.9
Experimental volumetric fraction of CH_4	66%	—
Simulated volumetric fraction of CH4[a]	59.6%%	9.7
Simulated volumetric fraction of CH4[b]	—	—
Experimental Biogas Production	401 L/kg_{SVrem}	—
Simulated Biogas Production[a]	436.7 L/kg_{SVrem}	8.9

[a] Actual work.

[b] Rajendran et al. (2014).

Figure 1(a) depicts how the molar fractions of CH_4 and CO_2 vary under different operational conditions. Decreasing the molar fraction of CO_2 leads to a corresponding increase in CH_4. At lower pressures, such as 10 bar and 20 bar, significant increases in water flow rate are required to substantially reduce the molar fraction of CO_2 and increase the purity of CH_4. At higher pressures, such as 30 bar and 40 bar, the efficiency in CO_2 removal improves significantly, and small increases in water flow rate result in a much higher molar fraction of CH_4. Figure 1(b) shows polynomial function fittings for different operating pressures, demonstrating how the diameter of the absorption column varies with water flow rate. This analysis is crucial for the subsequent design and optimization of the system.

Furthermore, with the pressure variations applied in the system, it was possible to determine the Henry's constant through linear regression using the generalized Henry's law. High value obtained for R^2 indicates a good model fit to the experimental data. As shown in Figure 2, the Henry's constant determined was 0.017 (Kmol/hr.bar).

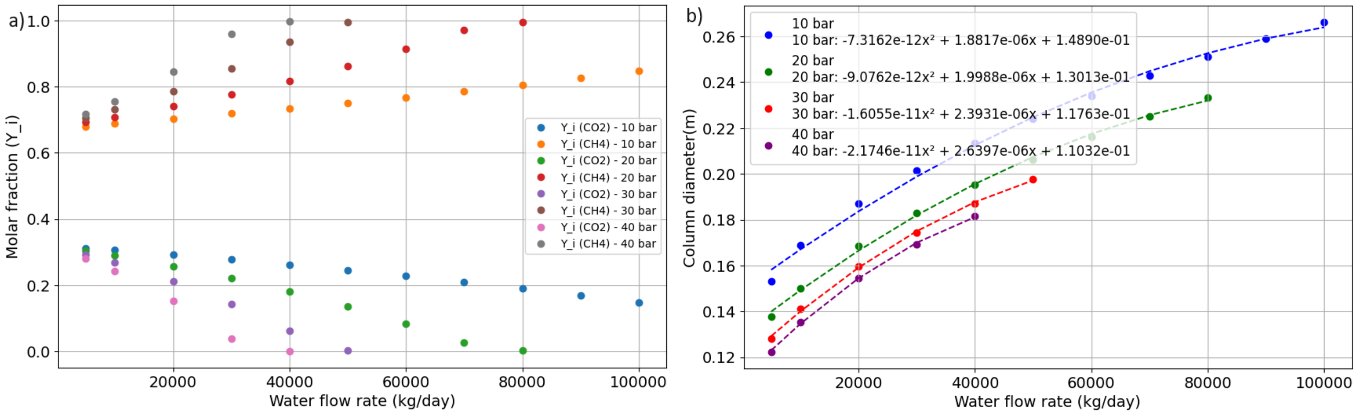

Figure 1 Analysis of Biogas Purification by Water Scrubbing.

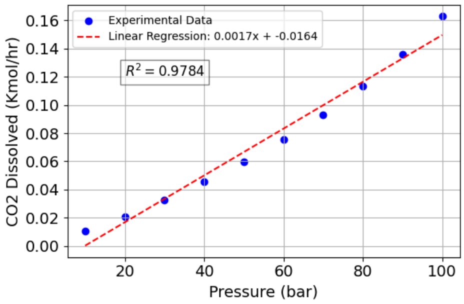

Figure 2 Experimental data and determination of the Henry's constant for the absorption system.

4 CONCLUSION

Research emphasized the importance of modeling and simulation in the development and optimization of anaerobic digestion processes and biogas purification, using Aspen Plus software. Applying the NRTL thermodynamic model to account for binary interactions between components made it possible to accurately simulate biogas production, validating results obtained with experimental data available in the literature. Additionally, simulations were conducted for the biogas purification process, revealing promising results at higher pressures (30 and 40 bar).

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