

A MINI REVIEW ON CHALLENGES OF ANAEROBIC MEMBRANE BIOREACTORS FOR MUNICIPAL WASTEWATER TREATMENT PLANTS

Muhamad Asad Khokhar^{1*}, Ali Abbasi²

Institute of Chemistry, University of Sargodha, Punjab, Pakistan.
Department of Chemistry, TUM School of Natural Sciences, Technical University of Munich, Germany

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ABSTRACT

This paper provides an overview of the current state of co-digestion applications using Anaerobic membrane bioreactors in municipal wastewater treatment plants, along with a review of their environmental and economic implications. The transition from conventional energy practices to renewable energy is crucial for ensuring energy security and addressing climate change. Wastewater treatment plants contribute significantly to greenhouse gas emissions and are large energy consumers. By using energy-saving technology like anaerobic digestion, wastewater treatment plants can increase their energy efficiency. However, the majority of wastewater treatment plants currently in operation use sewage sludge in conventional anaerobic digesters, which results in a limited output of biogas. The low biogas output associated with mono-digestion has been effectively addressed by co-digestion. Anaerobic membrane bioreactors have also surfaced as a viable substitute for conventional anaerobic digesters.

Keywords: Wastewater treatment, anaerobic membrane bioreactor, sewage sludge, treatment plants

*Corresponding Author. E-mail: masad_khokhar@gmail.com

INTRODUCTION

Non-renewable energy sources pose a significant threat to global environmental health and safety. A key challenge today is balancing economic growth with the reduction of anthropogenic greenhouse gas emissions. In addition to the effects that present energy consumption patterns have on the environment, the unequal distribution of reserves makes the energy supply chain particularly vulnerable. Traditional economic institutions have been drastically shaken by recent global events and political unrest. Given the intricacy of the energy network and the number of nations dependent on outside resources, it is now evident that even regional changes can compromise energy security [1].

A greater emphasis on energy efficiency in a variety of engineering applications has resulted from the acceleration of the transition away from traditional energy sources like fossil fuels due to these overlapping global concerns. One area where energy consumption is notably high is wastewater treatment. The wastewater treatment industry accounts for about 3% of global electricity use, making energy efficiency in wastewater treatment plants crucial for enhancing a country's energy security. Furthermore, increasing wastewater treatment plants energy efficiency is consistent with the Sustainable Development Goals of the United Nations. Sewage sludge

and municipal wastewater handled in Wastewater treatment plants are regarded as biowaste because they contain a lot of organic materials that can be converted into energy through anaerobic digestion [2].

Microorganisms break down organic matter during anaerobic digestion to create biogas, which is a mixture of carbon dioxide and methane. This process has garnered significant attention for its potential to produce biogas, thereby contributing to energy neutrality in Wastewater treatment plants. Currently, many of the digesters employ mono-digestion, which utilizes a single substrate.

Mono-digestion in municipal Wastewater treatment plants has a notable drawback: it typically operates at low organic loading rates due to the low organic content of the feedstock. Additionally, biogas yields can be low because of various factors related to the characteristics of the mono-substrate [3-8]. As a result, conventional anaerobic digestion methods suggest that a typical wastewater treatment plants can achieve only up to 65% energy self-sufficiency. In contrast, co-digestion, which involves using multiple substrates, can enhance energy recovery during anaerobic digestion and improve the energy efficiency of Wastewater treatment plants. Furthermore, managing bio-wastes through co-digestion can lower overall waste management costs in a region. For instance, by diverting waste from traditional disposal techniques like landfilling, using food waste as a co-substrate in Wastewater treatment plants offers both financial and environmental benefits [9]. As a result, co-digestion techniques are now widely used in full-scale conventional anaerobic digesters at wastewater treatment plants across the globe. Biomass wash-out, poor reactor stability, and ineffective organic matter degradation are some of the major issues that Conventional anaerobic digesters in Wastewater treatment plants must deal with. These restrictions

make it more difficult for Conventional anaerobic digesters to attain energy neutrality in wastewater treatment plants [11-13].

APPLICATIONS OF ANAEROBIC MEMBRANE BIOREACTORS

MWW is characterized by low to medium organic matter content. The concentration of organic matter in MWW can decrease due to dilution from increased volumes of inflow, often caused by stormwater, groundwater infiltration, or seawater intrusion into the sewer system. In regions where sewer and stormwater lines are not separated, MWW may exhibit a low chemical oxygen demand (COD) concentration. During heavy rainfall, combined sewer systems can experience dilution rates of 8 to 10 times, leading to lower organic matter concentrations in the influent wastewater at wastewater treatment plants. Although numerous studies have examined the anaerobic treatment of low-strength MWW, typically characterized by 100–200 mg COD/L, recovering energy from such streams through anaerobic processes is often deemed impractical and infeasible [14]. The current practice of mono-digestion of sewage sludge is no longer viewed as an effective method for energy generation in Wastewater treatment plants. In contrast, co-digestion has emerged as a prominent method to enhance biogas production through anaerobic digestion. However, one of the challenges of co-digestion is the significant production of excess sludge from combined anaerobic digestion. Research indicates that excess sludge from anaerobic membrane bioreactors is considerably lower than that produced in co-digestion within conventional anaerobic digesters. Mass balance calculations suggest that daily input of 1 L of substrate results in the production of 0.25–0.50 L of excess sludge, accounting for 7% of the total COD in the feedstock [15-18].

CHALLENGES AND FUTURE PERSPECTIVES

The current scientific literature reveals significant research gaps regarding co-digestion applications using anaerobic membrane bioreactors. The high-quality permeate obtained from anaerobic membrane bioreactors presents attractive resource recovery options [19-24]. It has been noted that the excess sludge contains a high concentration of phosphorus, while the permeate from Anaerobic membrane bioreactors co-digesting microalgae and primary sludge has a high concentration of ammonia, both of which can be utilized in subsequent processes to optimize resource recovery. Nutrient recovery methods, such as cultivating microalgae in Anaerobic membrane bioreactors permeate and extracting phosphorus from excess sludge, are gaining traction. Several studies have successfully cultivated microalgae in the nutrient-rich permeate from Anaerobic membrane bioreactors using various feedstocks [25]. However, there is a notable lack of studies assessing the potential for microalgae cultivation using effluent from anaerobic membrane bioreactors. This represents a significant research opportunity to enhance bioenergy production and maximize resource recovery within the biorefinery framework.

The cost of membranes is a major operational expenditure in anaerobic membrane bioreactors for co-digestion and needs optimization to enhance the economic feasibility of these systems. In addition to optimizing membrane operation, utilizing low-cost membrane materials can further reduce expenses [26-30]. For example, recent advancements in Anaerobic membrane bioreactors technology have led to the adoption of direct membrane filtration, which is a cost-effective membrane application successfully implemented for co-digestion. In one study, low-cost stainless steel and nylon mesh were used as support materials for the direct membrane layer. Various researchers

have explored different low-cost support materials in anaerobic membrane bioreactors systems, including meshes and woven/non-woven fabrics. These low-cost materials have been effectively used in the digestion of SS, FW, and their co-digestion. For instance, polyester mesh was integrated into anaerobic membrane bioreactors for FW digestion, while Dacron mesh was utilized in a pilot-scale Anaerobic membrane bioreactors for SS digestion [31]. Researchers compared monofilament, multifilament, and staple filters in Anaerobic membrane bioreactors systems, finding that monofilament filters were more suitable for direct membrane filtration. On the other hand, staple filter cloths showed significant fouling. Because of the lower transmembrane pressure increases, decreased backwash frequency, and lower energy consumption shown with stainless steel, which indicate steady operating of Anaerobic membrane bioreactors for co-digestion, it was advised to utilize stainless steel rather than nylon mesh. In Anaerobic membrane bioreactors co-digestion applications, choosing the right support materials is essential to sustaining a steady permeate flux. It is necessary to assess performance in co-digestion applications using different support materials. The transition time between DM production and cake layer removal, which happens when physical cleaning is used because of decreased permeability, is a major disadvantage of direct membrane technology. During this transition, the large pore size of the support material can lead to decreased permeate quality and considerable biomass loss. Therefore, rapid direct membrane formation is essential to avoid low-quality permeate and biomass loss during this phase. After direct membrane formation, researchers have observed similar performance in both AnDMBR and anaerobic membrane bioreactors systems. Strategies aimed at reducing direct membrane formation

time in co-digestion applications represent a promising research avenue [32-36].

Despite its advantages for achieving energy-efficient wastewater treatment plants, membrane fouling remains a significant challenge for co-digestion applications using Anaerobic membrane bioreactors. To address this, electrochemical regulation has been integrated into Anaerobic membrane bioreactors to minimize membrane fouling. In this study, the implementation of electrochemical regulation led to a decrease in the membrane's transmembrane pressure. This approach has been shown to accelerate the mineralization of high molecular weight organics and reduce the membrane's fouling propensity. Although the application of voltage incurs additional operational costs, the increased methane recovery may offset these expenses and enhance the overall viability of the process. However, electrode efficiency can decline significantly due to the deposition of pollutants and the dissolution of ions. Additionally, the cost of electrodes can undermine the economic feasibility of co-digestion applications using Anaerobic membrane bioreactors. As a result, the practical application of electrochemical anaerobic membrane bioreactors for co-digestion remains challenging and requires further research [37].

Moreover, researchers have explored vibratory membrane systems for municipal wastewater treatment to alleviate the fouling issue. Recent investigations have examined the use of vibration in Anaerobic membrane bioreactors to enhance dissolved methane recovery and mitigate membrane fouling. A similar study could be conducted for co-digestion with Anaerobic membrane bioreactors to improve economic feasibility [38-41].

Heating the bioreactor is a significant challenge in the anaerobic digestion process, and this issue also applies to co-digestion using anaerobic membrane bioreactors.

Generally, Anaerobic membrane bioreactors operate under mesophilic or thermophilic conditions, both of which require substantial energy for heating, leading to increased operational costs. In contrast, psychrophilic Anaerobic membrane bioreactors can effectively function at much lower temperatures, such as 15 °C, for municipal wastewater treatment. However, there is currently no research investigating co-digestion in psychrophilic anaerobic membrane bioreactors [42-45].

Utilizing psychrophilic conditions can notably reduce heating costs, thereby lowering operational expenditures for co-digestion applications. Nonetheless, operating under psychrophilic conditions presents significant challenges. The lower temperature range adversely affects microbial activity in the anaerobic digestion process, resulting in decreased biogas production. Several researchers have identified the hydrolysis step as the rate-limiting factor in the anaerobic digestion process at psychrophilic temperatures, which further limits the effectiveness of co-digestion in these systems by reducing methane conversion efficiency. Additionally, low hydrolysis rates can undermine the benefits of co-digestion in Anaerobic membrane bioreactors [46].

Membrane performance is another critical concern for co-digestion in psychrophilic Anaerobic membrane bioreactors. Studies have shown that membrane fouling rates are higher under psychrophilic conditions compared to mesophilic ones, primarily due to the accumulation of solids in the bioreactor resulting from reduced hydrolysis rates. Therefore, optimizing the hydrolysis rate could alleviate membrane fouling and enhance biogas production in psychrophilic conditions. Approaches such as enzyme addition or pretreatment may be incorporated into co-digestion strategies for psychrophilic Anaerobic membrane bioreactors.

A major challenge with psychrophilic Anaerobic membrane bioreactors is the potential decrease in volatile fatty acid degradation rates, which can lead to volatile fatty acid accumulation in the bioreactor. This accumulation may cause a drop in pH, posing a risk of inhibition for methanogenic archaea. Thus, maintaining the pH balance in co-digestion processes within psychrophilic Anaerobic membrane bioreactors is crucial, and ensuring adequate alkalinity is necessary for stable operation. Consequently, the stability of psychrophilic Anaerobic membrane bioreactors for co-digestion presents an important area for research [47].

While various researchers have reported efficient chemical oxygen demand removal in psychrophilic Anaerobic membrane bioreactors, most studies have focused on municipal wastewater. Therefore, examining the treatment efficiency of co-digestion in psychrophilic Anaerobic membrane bioreactors is a significant research opportunity.

Biogas generation was significantly enhanced by anaerobic membrane bioreactors compared to CAD under psychrophilic conditions. The membrane used in Anaerobic membrane bioreactors allows for a longer residence time for organic matter, which helps offset the low biogas generation efficiency typically seen in Conventional anaerobic digesters at lower temperatures. However, researchers noted that dissolved methane in the permeate stream can constitute up to 50% of total methane production, as lower temperatures increase methane solubility [48-51].

The high dissolved methane level in the permeate may significantly increase the environmental impact of Anaerobic membrane bioreactors and restrict their use, therefore environmental and economic concerns must be taken into account. In order to collect dissolved methane from the permeate stream, it is advised to investigate the possibility of integrated psychrophilic co-

digestion employing Anaerobic membrane bioreactors in conjunction with following membrane contactors. The examination of Energy Return on Investment may become a crucial field of study in the future since various factors affect total energy efficiency in psychrophilic co-digestion by anaerobic membrane bioreactors.

CONCLUSIONS

Compared to conventional techniques, co-digestion using Anaerobic membrane bioreactors achieves a better EROI through effective biomass valorization. The dynamics of the anaerobic digestion process are improved by the complementing qualities of various substrates. Improving energy security requires wastewater treatment facilities to rely less on conventional fuel sources. As a result, this integrated strategy can greatly increase Wastewater treatment plants' energy efficiency. Reviews of the literature show that co-digestion by Anaerobic membrane bioreactors is a viable substitute for mono-digestion by conventional anaerobic digesters based on economic and environmental evaluations.

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