THE ROLE OF ELECTROCOAGULATION IN IMPROVING MEMBRANE BIOREACTOR PERFOMANCE FOR TEXTILE EFFLUENT TREATMENT: A LITERATURE REVIEW

Maiara H. Simone[1], Amanda Dalalibera[1], Letícia S. Kruze[1], Marcelo O. Heiderich[1], Nathalia A. Lupetti[1], Tiago Z. Massambani[1], André A. Battistelli[1], Tiago J. Belli[2], Maria E. N. Hassemer[1].

[1] Water Reuse Laboratory, Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Florianopolis, Brazil.
[2] Department of Civil Engineering, Santa Catarina State University, Ibrirama, Brazill.
**Corresponding author's email address: maiarasimone14@gmail.com*

ABSTRACT

The textile industry, while economically significant, generates highly polluted wastewater, predominantly containing azo dyes, such as Remazol Brilliant Violet (RBV-5R). These dyes are difficult to remove due to their low fixation to fibers and pose serious environmental and health risks. Membrane bioreactors (MBRs) have shown promise in treating such wastewater, achieving over 80% chemical oxygen demand (COD) removal and 70% color removal. However, membrane fouling remains a significant problem. This review examines the role of electrocoagulation (EC) as an alternative to improve MBR efficiency. EC, by producing metal hydroxides that aggregate contaminants, can significantly improve color removal and reduce fouling. Studies by Ravadelli, Belli, and Tohid show that combining EC with MBR systems significantly improves dye removal, bacterial activity, and energy efficiency, despite some operational challenges. Optimal configurations of EC and MBR, particularly in terms of electrode material and current exposure, show great potential for sustainable textile wastewater treatment.

Keywords: Eletrochemical processes. Dye removal. Electric Current. Efficiency. Membrane fouling.

1 INTRODUCTION

The textile industry is vital to the economies of many countries, but it generates highly polluting wastewater. Among the various dyes used, azo dyes are the majority, accounting for approximately 65-70% of global dyes due to their low cost, stability and variety of colors. A common example is Remazol Brilliant Violet (RBV-5R), which has low fixation on textile fibers, resulting in significant losses in wastewater. This creates serious environmental problems, as many dyes and their by-products are carcinogenic. Due to the negative impact on the environment and public health, the removal of dyes from wastewater has been widely studied[1].

In recent decades, the use of membrane bioreactors (MBRs) for the treatment of industrial and municipal wastewater has increased. MBRs combine membrane filtration with traditional biological wastewater treatment and differ from conventional methods by separating activated sludge from the treated effluent. The modeling of MBR systems varies by biological process due to the wide range of possible biological responses. In textile wastewater, MBRs have been shown to be effective, recovering more than 80% of chemical oxygen demand (COD) and 70% of color [2,3]. However, membrane fouling is a common limitation. Research suggests that combining coagulation with membrane bioreactors can improve control of this fouling[3]. In this context, the present review provides a detailed analysis of the role of electrocoagulation as an alternative to different membrane separation processes.

2 MATERIAL & METHODS

The literature review on the performance of textile wastewater treatment in a membrane reactor supported by electrocoagulation was conducted using scientific databases such as *ScienceDirect* and *Google Scholar*. Articles published between 2019 and 2025 were included, and keywords such as "membrane electrobioreactor" and "dye" were used.

3 RESULTS & DISCUSSION

Electrocoagulation (EC) is a process in which the anode electrolytically dissolves, producing charged metal hydroxides that can attract and accumulate contaminants of varying charge. The efficiency of EC systems is affected by several factors, including the initial concentration of the contaminant, the type of material used in the electrodes, the distance between the electrodes, their configuration, the current density applied, the conductivity and pH of the solution, as well as the duration of electrolysis, retention time, electrode passivation, and the type of power supply used. During the process, chemical reactions occur in the vicinity of the anode and cathode, resulting in the formation of metal hydroxides. These reactions affect both the electrodes and the solution [4].

The Table 1 highlights three studies that share the common approach of combining electrochemical processes with membrane reactors to increase the efficiency of pollutant removal, optimize energy consumption, and improve the quality of the treated effluent.

Table 1 Performance of Reactors in Electrocoagulation-Assisted Textile Wastewater Treatment.

Reactor – configures	Dye/ Effluent	Applied Current	Efficiency	Ref.
Anoxic/Oxic Membrane Bioreactor assisted by Electrocoagulation	RBV5R	10 A/m²	94.9%	Ravadelli et al.[1]
Anoxic/Oxic Membrane Bioreactor assisted by Electrocoagulation	Remazol Brilhant Violet (RBV)	10 A/m²	94.3-98.2%	Tavangar et al.[5]
Nanofiltration Membrane Reactor preceded by Electrocoagulation	Textile Wastewater	20 mA/cm ^{2}	93.0%	Belli et al.[4]

Ravadelli et al. [1], in their research, studied the use of an anoxic-oxic electro-membrane bioreactor (A/O-EBRM) to treat wastewater containing an azo dye (RBV5R). During the research period, results without and with the application of electrocoagulation were compared. At the beginning of the study (period I), without electrocoagulation, the dye removal in the A/O-EBRM bioreactor was about 52%. This means that about half of the dye present in the effluent was removed by the process. However, after the introduction of electrocoagulation (period II), with a current of 10 A m^{-2} and an electric current exposure mode of 6′ON/30′OFF, there was a significant improvement in this removal, reaching almost 95%. This indicates that electrocoagulation played a crucial role in increasing the efficiency of the treatment process, resulting in a much more effective dye removal. In addition, nitrification activity, which is important for wastewater treatment, increased during period II. This suggests that the presence of electrocoagulation not only improved dye removal, but also promoted more favorable conditions for other important bacterial activities in the treatment process.

Despite these benefits, there was an increase in membrane fouling during period II due to the increased suspended solids content. This may present a challenge for long-term system maintenance and may require additional strategies to mitigate the problem. However, despite this challenge, the energy efficiency of the process improved significantly during Period II. There was a 17.2% reduction in average energy consumption per mass of dye removed, indicating a more efficient use of energy in the treatment process. In summary, the introduction of electrocoagulation in the A/O-EBRM bioreactor resulted in significant improvements in several performance metrics, including dye removal, bacterial activity, and energy efficiency, despite the challenges associated with increased membrane fouling[1,2,4].

Like Ravadelli et al.[1], Belli et al.[4] conducted a detailed analysis of the performance of an anoxic-oxic membrane bioreactor with electrochemical support (A/O-EBRM) as a viable solution for the treatment of textile wastewater contaminated with the azo dye Remazol Brilliant Violet. The research employed a rigorous experimental approach, testing three different operating conditions that varied the solids retention time (SRT) and the electric current application modes (6′ON/30′OFF and 6′ON/12′OFF). The results showed remarkable dye removal efficiencies under all conditions tested, with average efficiencies ranging from 94.3% to 98.2%. In addition, the study observed a direct correlation between SRT and dye removal rate, indicating that the amount of biomass present significantly affects the removal efficiency. Electric current exposure was also found to be a critical factor, significantly affecting dye removal efficiency and suggesting possible mechanisms of biodegradation inhibition[4].

Batch activity tests showed that the dye removal rate (DRR) decreased significantly by 39% (from 16.8 to 10.2 mgRBV-5RL^{-1}h^{-1}) when the SRT was reduced from 45 to 20 days. In addition, the DRR decreased dramatically by 91% (from 16.8 to 1.5 mgRBV-5RL^{-1}h^{-1}) when the electric current exposure mode was changed from 6′ON/30′OFF to 6′ON/12′OFF. This significant reduction in DRR under prolonged electric current exposure suggests a possible inhibitory effect on dye removal via biodegradation. On the other hand, the mixed liquor filterability improved under conditions of higher electric current exposure, resulting in a lower membrane fouling rate. However, this 6′ON/12′OFF exposure mode inevitably required more energy, estimated at 43.6 kWh per kilogram of dye removed[4].

Overall, the study suggests that the combination of a longer SRT (45 days) with a shorter electric current exposure time (6′ON/30′OFF) is more advantageous for the treatment of wastewater containing azo dyes in an A/O-eMBR system. This combination offers lower operating costs and efficient removal of COD and N-NH_4^+ as well as dye removal. The energy demand for this mode was estimated to be between 21.9 and 22.6 kWh per kilogram of dye removed, which is almost half of the energy consumption observed in the 6′ON/12′OFF mode[4].

Finally, on the other hand, Tavangar et al.[5] conducted a study to understand the influence of the choice of electrode material on the results for the treatment of real textile wastewater. In the hybrid electrocoagulation-nanofiltration (EC-NF) system, the operation was based on two complementary stages. First, in the electrocoagulation stage, with a density of 20 mA/cm² and a pH of 7, iron (Fe), aluminum (Al) and titanium (Ti) electrodes were used to promote redox reactions that precipitated the pollutants and formed flocs that facilitated their subsequent removal. Then, in the nanofiltration stage, membranes were used to retain the remaining contaminants while allowing the passage of ions and smaller molecules. In this hybrid EC-NF system, the color, COD and turbidity removal performance of the three electrocoagulants follows the order: aluminum (Al) with the best performance, followed by iron (Fe) and lastly titanium (Ti). The aluminum (Al) electrode, considered the most efficient, was able to remove approximately 93% of the color, 64% of the COD and 99% of the turbidity [5].

Another critical aspect of the research was the issue of membrane fouling, which is a common problem in the membrane filtration process. EC pretreatments were found to be effective in reducing this fouling and improving permeate flux. In particular, EC pretreatment with Al electrodes resulted in a significant increase in final NF membrane flux, approximately 37% and 76% compared to Fe and Ti electrodes, respectively. Furthermore, EC pretreatment with Al, Fe, and Ti electrodes improved the final NF membrane flux by 616%, 420%, and 305%, respectively, compared to NF filtration of raw wastewater without any pretreatment. This can be attributed to the formation of a thinner cake layer and higher porosity in aluminum electrodes, providing more pathways for water molecule transport [5].

4 CONCLUSION

It can be concluded that the research by the cited authors demonstrates significant advances in the treatment of wastewater containing azo dyes through different approaches and technologies. Ravadelli et al.[1] showed that electrocoagulation can dramatically increase the efficiency of dye removal and improve bacterial activity in the A/O-EBRM bioreactor, despite the challenges of membrane fouling. Belli et al.[4] corroborated these findings by evaluating the influence of solid retention time and current application modes on the performance of the A/O-EBRM, highlighting the importance of balancing energy and operational efficiency with dye removal rates. Tavangar et al.[5], in turn, demonstrated the efficiency of aluminum as an electrode material in the hybrid electrocoagulation-nanofiltration system, highlighting the reduction in fouling and increased permeate flux as additional benefits.

These complementary studies indicate that electrocoagulation, combined with bioreactor and nanofiltration techniques, offers a promising solution for textile wastewater treatment that addresses both contaminant removal efficiencies and operational challenges. The choice of electrode material, current exposure time, and proper management of solids retention time are critical factors in optimizing system performance, balancing contaminant removal efficiency and energy consumption. In summary, these technological innovations have the potential to significantly contribute to the sustainability and efficiency of wastewater treatment processes in the textile industry.

REFERENCES

[1] RAVADELLI, M., COSTA, R. E., LOBO-RECIO, M. A., AKABOCI, T. R. V., BASSIN, J. P., LAPOLLI, F. R., BELLI, T. J. 2021. J. Environ. Chem. Eng. 9(4).105286.
[2] MONEER, A. A. 2023. Egypt. J. Aquat. Res. 49(3). 269-282
[3] UDDIN, M., KHAYRUL, M. I., DEV, S. 2024. Heliyon 10. e31358
[4] BELLI, T. J., BASSIN, J. P., VIDAL, C. M. de S., NAGEL-HASSEMER, M. E., RODRIGUES, C. LAPOLLI, F. R. 2023. Environ. Sci. Pollut. R. 30. 58412–58427
[5] TAVANGAR, T., JALALI, K., AMIN, M. A. S., KARIMI, M. 2019. Sep. Purif. Technol. 216. 115-125

ACKNOWLEDGEMENTS

Thank CNPq for granting a scholarship at the Water Reuse Laboratory – LaRA.