Effect of Operating Pressure on Reverse Osmosis Permeate Quality in a Hybrid MBR–RO Treatment of Textile Wastewater

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Introduction

The textile industry generates complex wastewaters with high concentrations of organic matter, salts, dyes, and surfactants. Conventional treatment processes often do not meet the water quality standards required for safe discharge or reuse. Hybrid systems that combine biological treatment with membrane separation process have emerged as effective strategies to achieve higher removal efficiencies and support water reuse [1,2]. This study evaluates the performance of a hybrid membrane bioreactor–reverse osmosis (MBR–RO) system for treating real textile wastewater (TWW), with a specific focus on the influence of reverse osmosis (RO) operating pressure on permeate quality and membrane fouling. Understanding the relationship between pressure, flux, and pollutant removal is essential for optimizing system performance and minimizing energy consumption.

Materials and Methods

Real TWW was collected from the equalization tank of a cotton knitted fabric in Croatia. The wastewater was first treated in a laboratory-scale aerobic MBR, and the MBR permeate was subsequently fed to a laboratory-scale membrane RO unit.

RO performance was assessed at operating pressures of 10 bar, 12 bar, and 14 bar. The following parameters were monitored in both feed and permeate: chemical oxygen demand (COD), turbidity (NTU), electrical conductivity, and total nitrogen (TN). Long-term membrane separation tests were conducted to observe flux decline. Physical rinsing with water and chemical cleaning (Nalco PermaClean 98 (PC98) and Nalco PermaClean PC77 (PC77)) were applied as needed, and reference measurements with demineralized water were performed out to estimate intrinsic membrane performance.

Results and Discussion

RO consistently produced high-quality permeate at all operating pressures. COD removal remained high but showed limited improvement above 10–12 bar: at 10 bar, 71.5 → 12.6 mg/L; at 12 bar, 56.2 → 10.2 mg/L; and at 14 bar, 70.3 → 11.2 mg/L. This indicates that pressure plays only a minor role in further COD reduction within this range. Turbidity was already low after MBR and decreased further after RO: at 10 bar, 1.04 → 0.22 NTU; at 12 bar, 0.74 → 0.49 NTU; and at 14 bar: 1.14 → 0.22 NTU. Conductivity showed a clearer dependence on pressure: at 10 bar, 6730 → 116.9 µS/cm; at 12 bar, 6720 → 111.8 µS/cm; and at 14 bar, 6790 → 78.3 µS/cm. Higher pressure improved salt rejection; however, the benefit from 12 to 14 bar was relatively small compared with the expected increase in energy demand [2]. Total nitrogen decreased modestly, confirming that nitrogen removal was primarily achieved in the biological step: at 10 bar, 4.73 → 3.23 mg/L; at 12 bar, 2.04 → 1.22 mg/L; and at 14 bar: 2.27 → 1.50 mg/L. Overall, permeate quality suggests strong potential for water reuse applications.

During long-term operation, the clean-water flux decreased from about 140 LMH to approximately 80 LMH when treating the MBR permeate. Rinsing with water did not improve performance. Chemical cleaning with PC98 and PC77 did not restore the flux, instead, the post-cleaning flux stabilized at 75–73 LMH [3,4]. This behavior indicates the presence of persistent (partly irreversible) fouling and/or membrane compaction rather than purely reversible deposits [3].These findings emphasize the importance of optimized cleaning protocols and selecting of operating pressures that balance permeate quality, fouling development, and energy use [4,5].

Conclusions

The hybrid MBR–RO system showed excellent performance in treating real TWW, producing permeate suitable for potential reuse.

Key conclusions include:

- operating pressure strongly influences salt removal,
- improvements above 10–12 bar are limited relative to energy costs,
- fouling is the dominant factor constraining flux, and
- optimal operating conditions are likely within 10-12 bar.

The results provide practical guidance for designing and optimizing hybrid membrane systems in TWW treatment and reuse schemes.

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