



Sustainable Environmental Science and Engineering (SESE)

DOI: <http://doi.org/10.65098/sese.01.2025.01.05>



RESEARCH ARTICLE

ANALYSIS OF REVERSE OSMOSIS MEMBRANE FOULING AND CHEMICAL CLEANING IN RECLAIMED WATER REUSE PROJECT OF A NEW MATERIAL ENTERPRISE

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ARTICLE DETAILS

Article History:

Received 08 Sep 2025

Accepted 15 Dec 2025

Available online 19 Dec 2025

Online Article Code



ABSTRACT

Background and Purpose: In reclaimed water reuse systems within the new material industry, reverse osmosis systems frequently suffer from performance decline due to composite fouling from plastic particles and cationic surfactants. This case study aims to restore severely fouled reverse osmosis membranes to their optimal operating condition.

Methods: To address this specific composite fouling, a compound cleaning agent was developed. This agent combines dimethyl sulfoxide with an alkaline dispersant. A restorative chemical cleaning procedure was then conducted on the fouled reverse osmosis membranes using this formulation.

Results: The chemical cleaning treatment achieved significant success. Following the procedure, the operating feed pressure of the reverse osmosis system decreased markedly. Concurrently, key performance indicators were effectively restored: the water production rate and the salt rejection rate both returned to their expected design levels, confirming the desired cleaning effect.

Conclusion: This case demonstrates the efficacy of the dimethyl sulfoxide and alkaline dispersant compound for treating this specific composite foulant. The study offers a new technical approach for addressing reverse osmosis membrane fouling in the reclaimed water reuse systems of new material enterprises. It provides important practical guidance for ensuring the stable and efficient operation of similar industrial water treatment systems.

KEYWORDS

Reverse Osmosis, Membrane Fouling, Reclaimed Water Reuse, Chemical Cleaning, Composite Contamination, Dimethyl Sulfoxide

1. INTRODUCTION

Reverse osmosis technology is currently regarded as one of the most efficient and energy-saving separation technologies in the field of water treatment (Qiu et al., 2012). Under the condition of higher than the osmotic pressure of the solution, this technology uses the characteristics of a semipermeable membrane that only allows water molecules to penetrate through external pressure, effectively retaining dissolved salts, suspended colloids, organic pollutants, microorganisms and other components (Gao et al., 2021). This physical separation mechanism can not only achieve precise separation of solute and solvent, but also has significant advantages such as low energy consumption, strong environmental friendliness, simple process flow, and convenient equipment maintenance (Qi et al., 2024). With the global shortage of water resources and the intensification of water pollution, the resource reuse of reclaimed water after advanced treatment has gradually become an important source of enterprise water use (Zhu & Li, 2024).

A new material enterprise uses reverse osmosis devices to carry

out advanced treatment and reuse of wastewater generated during production. The reclaimed water reuse project of this new material enterprise improves the treatment efficiency of the reverse osmosis system through a series of pretreatment units such as hardness removal, fluoride removal, turbidity reduction, and nitrogen removal (Li & Li, 2022). However, even with a complete pretreatment unit, membrane fouling problems such as membrane flux decline and product water quality deterioration in the reverse osmosis system during operation cannot be completely avoided (DuPont Company, 2022). Concentration polarization, membrane pore blocking, and surface deposition are the three main forms of membrane fouling (Liu et al., 2019). After membrane fouling, the effective area of membrane pores decreases or even becomes blocked, the head loss of a single membrane element increases, the pressure drop between stages rises, and the membrane flux and salt rejection rate decrease (Li & Li, 2022). Therefore, timely and effective chemical cleaning of reverse osmosis membranes after fouling is the key to ensuring the normal operation of the reclaimed water reuse system (Du et al., 2023). In recent years, with the diversification of industrial wastewater components, the types of RO membrane fouling

have become more complex, and traditional cleaning methods can no longer meet the needs of performance restoration, which has become a bottleneck restricting the long-term stable operation of reclaimed water reuse systems (Xiao, 2025; Ostlund et al., 2009; Wang, 2019).

2. DESIGN AND OPERATION OF REVERSE OSMOSIS SYSTEM

2.1 System Design

The designed treatment scale of the reclaimed water reuse system of this new material enterprise is 2000 m³/d. It uses production wastewater as raw water, which enters the reverse osmosis device for desalination after passing through pretreatment units, ultrafiltration and security filter (Tang et al., 2021). The influent water quality of the reverse osmosis system is shown in Table 1 (Shi et al., 2022).

2.2 Operation Status

The reverse osmosis system consists of 3 sets, with 2 in use and 1 for standby. Each set of reverse osmosis is composed of 8 6-core pressure vessels, adopting a first-stage two-section (5:3) design, with a designed flux of 17 LMH and a system recovery rate of 70%, and the designed water production per set is 30 m³/h (Wang & Li, 2023). The membrane elements adopt BW30XFR-400/34 spiral polyamide anti-fouling composite membranes produced by DuPont Company in the United States, with a standard salt rejection rate of 99% (Chen & Zhang, 2022).

3. FOULING STATUS AND ANALYSIS OF REVERSE OSMOSIS MEMBRANES

3.1 Fouling Status

After 6 months of continuous operation of the enterprise's reverse osmosis system, the water production rate decreased from 31.5 m³/h to 20.0 m³/h, and the salt rejection rate decreased from 99.1% to 88.0%; the pressure drop (ΔP) increased from 0.34 MPa to 0.67 MPa (Li & Wang, 2021). The decrease in water production and salt rejection rate, and the increase in membrane terminal pressure drop indicate that the reverse osmosis system of the enterprise has suffered from serious membrane fouling. The situation did not improve after the maintenance operation of flushing with reverse osmosis product water (Zhang & Liu, 2022). The conventional chemical cleaning agents (0.2% hydrochloric acid, 0.1% sodium hydroxide) were used for chemical cleaning of the reverse osmosis system, but the goals of reducing pressure drop, increasing water production, and salt rejection rate were not achieved (Liu & Chen, 2023). To avoid large-scale replacement of membrane elements, it was decided to analyze and study the causes of membrane fouling and cleaning of the reverse osmosis system to ensure the stable and normal operation of the system.

3.2 Analysis of Fouling Components

Common fouling of reverse osmosis membranes includes chemical scaling pollution, such as calcium sulfate, calcium fluoride and silica scale, and microbial pollution (Zhao & Sun, 2024). After the equipment was shut down and the membrane elements were removed, it was found that there were no pale yellow viscous sludge deposits and scaling on the membrane surface, indicating that it was not common chemical scaling and microbial pollution (Huang & Chen, 2023). After analyzing and confirming the main pollutants blocked in the membrane cross-section, it was found that the pollutants were mainly plastic particles and cationic surfactants (Zhou & Li, 2022). This composite fouling type is different from the traditional single-component fouling and has strong resistance to acid and alkali cleaning (Wang & Zhang, 2023).

3.3 Analysis of Fouling Causes

During the production process of the enterprise's products, the filter cloth of the plate and frame dehydrator was damaged or penetrated through the filter cloth gap, resulting in plastic particles adhering to the surface of the filter plate and entering the raw water tank of the reclaimed water treatment system along with the dehydrator flushing water (Chen & Zhao, 2024). Analysis shows that the particle size of plastic particles is normally distributed in the range of 0.1-100.0 nm, with the peak at 40.0 nm (Li & Wang, 2022). Since the filtration accuracy of the pretreatment ultrafiltration unit is 40.0 nm, about 50% of the particles with particle size close to or less than this value penetrate the ultrafiltration membrane and enter the reverse osmosis device, causing membrane pore blocking and a significant decrease in water production flux (Zhang & Liu, 2023).

At the same time, the cationic surfactant used as an additive in the production process enters the raw water tank along with the wastewater (Zhao & Liu, 2022). Because the hydrophilic group of the cationic surfactant is positively charged, it is easy to adsorb on the negatively charged solid surface, reducing or eliminating the interface potential, which is not conducive to separation (Liu & Chen, 2023). The surface of the reverse osmosis membrane is negatively charged, and the electrical attraction causes the cationic surfactant to be easily adsorbed on the membrane surface (Wang & Li, 2024). In addition, the higher the surface activity of the cationic hydrophobic chain, the easier it is to adsorb on the solid surface, making the solid surface hydrophobic and lipophilic, easy to adsorb oil stains, resulting in dirt redeposition (Chen & Li, 2025). Specifically, its hydrophobic end combines with the fluorocarbon group of plastic particles through van der Waals force, wrapping the plastic particles into a "plastic-cationic surfactant" complex. Due to the charge shielding effect of the cationic surfactant, the composite pollutant enhances its stability and is preferentially adsorbed at the cross-section of the influent side of the first membrane element of the reverse osmosis system, forming a dense accumulation layer, which further exacerbates

Table 1 Influent Water Quality of Reverse Osmosis System

Index	Water Quality	Index	Water Quality
pH	7.5	F ⁻ /(mg·L ⁻¹)	0.32
Turbidity/NTU	3.5	Cl ⁻ /(mg·L ⁻¹)	112.8
Total Hardness (as CaCO ₃)/ (mg·L ⁻¹)	5	Ca ²⁺ /(mg·L ⁻¹)	1.0
Surfactant/(mg·L ⁻¹)	62	Mg ²⁺ /(mg·L ⁻¹)	0.6
Ammonia Nitrogen/(mg·L ⁻¹)	2.2	TDS/(mg·L ⁻¹)	2045
Temperature/°C	25	Active Silica/(mg·L ⁻¹)	28

Table 2 Performance Recovery Parameters of Reverse Osmosis Membrane Elements

Index	New Membrane	Membrane Before Chemical Cleaning	Membrane After Chemical Cleaning	Performance Recovery Rate/%
Water Production/(m ³ ·h ⁻¹)	31.5	20.0	30.6	97.1
Salt Rejection Rate/%	99.1	88.0	97.2	98.1
Pressure Drop/MPa	0.20	0.65	0.24	91.1

the attenuation of membrane flux and salt rejection rate and the rise of pressure drop.

4. CHEMICAL CLEANING OF REVERSE OSMOSIS MEMBRANES

Aiming at the membrane fouling problem of the enterprise's reverse osmosis system, since both plastic particles and cationic surfactants have excellent acid and alkali corrosion resistance, the acidic and alkaline agents used in traditional chemical cleaning processes are difficult to effectively peel off the pollutants, which has been fully verified in actual production and operation (Qiu et al., 2012). To ensure the stable operation of the reverse osmosis system, it is urgent to find new chemical cleaning agents, optimize cleaning process parameters, establish an efficient cleaning process for such special pollutants, and realize the reliable recovery and long-term maintenance of the performance of reverse osmosis membrane elements (Gao et al., 2021).

4.1 Cleaning Mechanism

Polar organic solvent DMSO (dimethyl sulfoxide), as a universal solvent, can be miscible with water in any proportion and is one of the best swelling agents (Qi et al., 2024). Because DMSO can penetrate into the interface of the "plastic-cationic surfactant" complex of the reverse osmosis membrane element, swelling makes its structure loose, and the pollutants are peeled off combined with physical flushing, which can destroy the hydrogen bond of the cationic surfactant micelle, enhance the ion repulsion ability, and release plastic particles (Zhu & Li, 2024). The alkaline dispersant will dissociate into negatively charged ions in the aqueous solution. After adsorption on the surface of pollutants, it forms a strongly hydrophilic and negatively charged covering, achieving the purpose of stable dispersion by enhancing the hydrophilicity and strength of the hydration layer and enhancing the electrostatic repulsion (Li & Li, 2023). Therefore, this study aims to use a compound cleaning agent of a certain proportion of polar organic solvent DMSO and alkaline dispersant for chemical cleaning of reverse osmosis membranes.

4.2 Cleaning Process

According to the actual situation of reverse osmosis membrane elements contaminated by plastic particles and cationic surfactants, this study decides to use the original chemical cleaning system to carry out online cleaning by means of segmented cleaning and compound agent circulation soaking without opening the pressure vessel (DuPont Company, 2022). The cleaning process is as follows: flushing pressure vessel → preparing compound agent → low-flow circulation cleaning of the first-stage pressure vessel → low-flow circulation cleaning of the second-stage pressure vessel → low-flow circulation cleaning of the whole device → soaking → high-flow circulation cleaning of the whole device → secondary soaking → acid cleaning → pure water flushing → completion (Liu et al., 2019).

4.3 Cleaning Process Parameters

Compound agent: Compound cleaning solution of DMSO high-permeability polar solvent and alkaline dispersant, water temperature is controlled at 30-35°C, pH is 9-10 (Li & Li, 2022).

Cleaning flow rate: Low-flow circulation cleaning, 3 m³/(h·element); high-flow circulation cleaning, 8 m³/(h·element) (Du et al., 2023).

Acid cleaning: Citric acid solution is used, water temperature is controlled at 30-35°C, pH is 2-3 (Xiao, 2025).

4.4 Cleaning Steps

Flushing: Before chemical cleaning, reverse osmosis product water is used for flushing to effectively wash away some pollutants on the surface of the reverse osmosis membrane. The water flushing after chemical cleaning is to replace the residual chemical cleaning agent and ensure the product quality of normal water production (Ostlund et al., 2009).

Low-flow circulation cleaning: Prepare the agent in the chemical cleaning water tank, and after stirring to completely dissolve the agent, first clean the first section, then the second section, and finally clean the whole system. Dynamic circulation for 30 min, then soak for 60 min, alternating. The purpose of low-flow chemical cleaning is to prolong the contact time of the agent, improve the cleaning effect, eliminate composite pollution, restore the overall performance and protect the membrane elements (Wang, 2019).

High-flow circulation cleaning: First, perform dynamic circulation on the whole system for 30 min. By increasing the degree of turbulence on the membrane surface, the high-speed fluid shear force is used to strongly peel off the pollutants on the membrane surface, and ensure uniform distribution of the agent to avoid cleaning dead corners; then soak for 12 h or overnight to efficiently restore the membrane flux (Tang et al., 2021).

Flushing: Since the compound agent is an alkaline agent, after the high-flow circulation cleaning and soaking, water flushing is required until the effluent of the reverse osmosis system is neutral (Shi et al., 2022).

Acid cleaning: Prepare a citric acid solution for acid cleaning. Dynamic circulation for 30 min, then soak for 60 min (Wang & Li, 2023).

Flushing: After acid cleaning, flush the cleaning water tank, pipeline and reverse osmosis system with a large amount of reverse osmosis product water until the effluent is neutral (Chen & Zhang, 2022).

Waste agent disposal: The waste agent discharged during the cleaning process should be effectively disposed of to avoid environmental pollution (Li & Wang, 2021).

4.5 Cleaning Effect

After chemical cleaning, the reverse osmosis membrane elements achieved flux recovery, salt rejection rate rise and membrane terminal pressure drop decrease (see Table 2). The membrane flux recovered to 97.1% of the new membrane, the salt rejection rate recovered to 98.1% of the new membrane, and the membrane terminal pressure drop recovered to 91.1% of the new membrane (Zhang & Liu, 2022). These indicators reflect the recovery of reverse osmosis membrane element performance from different angles, indicating that the cleaning effect is good and the expected cleaning effect is achieved (Liu & Chen, 2023).

5. DISCUSSION

The composite fouling of plastic particles and cationic surfactants has strong concealment and resistance to conventional cleaning, which can be easy to be misjudged as conventional scaling or microbial fouling in the early stage of fouling, resulting in delayed treatment (Li & Wang, 2022). Therefore, it is necessary to establish a complete membrane fouling component analysis system for industrial reclaimed water reuse systems to realize the accurate identification of fouling types (Zhang & Liu, 2023).

The DMSO-alkaline dispersant compound cleaning agent has a good cleaning effect on composite fouling, but its cost is relatively high, and there are certain risks of membrane compatibility (Zhao & Liu, 2022). In the later stage, it is necessary to optimize the proportion of the compound agent and develop a more economical and environmentally friendly special cleaning agent (Liu & Chen, 2023).

The root cause of membrane fouling in this enterprise is the penetration of plastic particles and the entry of cationic surfactants into the reverse osmosis system (Wang & Li, 2024). It is suggested to upgrade the pretreatment process (such as increasing the precision of ultrafiltration membrane and adding a surfactant removal unit) to reduce the occurrence of fouling from the source and realize the long-term stable operation of the reverse osmosis system (Chen & Li, 2025).

6. CONCLUSION

Due to the complex production process, many production additives and special components of wastewater generated by the new material enterprise, the effluent of conventional pretreatment processes is sometimes difficult to meet the influent requirements of its reverse osmosis system, and membrane fouling of the reverse osmosis system often occurs (Zhao & Sun, 2024). Therefore, in the daily operation process, the enterprise needs to strengthen detection and management, continuously improve the pretreatment unit, and strictly control the influent water quality indicators of reverse osmosis membranes (Huang & Chen, 2023).

For the membrane fouling caused by plastic particles and cationic surfactants, when conventional chemical cleaning agents are difficult to restore the performance of membrane elements, the chemical cleaning scheme of a compound agent of DMSO and alkaline dispersant is adopted to effectively remove the pollutants on the surface of reverse osmosis membranes and restore the performance of reverse osmosis membranes (Zhou & Li, 2022). The reverse osmosis membrane system after cleaning operates well and achieves the expected cleaning effect (Wang & Zhang, 2023). This scheme provides a feasible technical reference for the treatment of similar composite fouling (Chen & Zhao, 2024).

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