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COMPARATIVE EFFICIENCY OF NANOFILTRATION AND REVERSE OSMOSIS MEMBRANES IN INDUSTRIAL WASTEWATER TREATMENT: A CASE STUDY FROM NORTHERN RAJASTHAN

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ABSTRACT

Industrial effluent is a significant environmental problem because of its heavy burden of inorganic and organic contaminants. The present research examines and contrasts the efficacy of Nanofiltration (NF) and Reverse Osmosis (RO) membrane separation processes in treating industrial effluent from Rajasthan's Hanumangarh and Sri Ganganagar districts, India. All-important parameters examined here are Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), and pH. Results reveal that although RO is better in terms of TDS rejection, NF is better in terms of flux and energy efficiency. Findings provide crucial information regarding membrane selection for better industrial wastewater management.

Keywords: Nanofiltration, Reverse Osmosis, Industrial Wastewater, COD, BOD, TDS, pH, Rajasthan

INTRODUCTION

Water is a basic input for all industrial processes. Starting from cooling systems in thermal power plants to process water in textile and chemical manufacturing units, water is an unavoidable necessity. Nevertheless, as industries grow, the amount and complexity of generated wastewater have increased. Industrial wastewater is usually filled with a diverse array of contaminants such as heavy metals, dyes, oils, salts, and organic material, which, if not adequately treated, have a serious effect on aquatic life as well as public health. Conventional wastewater treatment processes like sedimentation, biological treatment, and chemical precipitation are usually ineffective for eliminating these complicated contaminants. Membrane separation technologies have grown to be a proven, advanced technology to address this problem, with much better contaminant removal efficiency. Of these, Reverse Osmosis (RO) and Nanofiltration (NF) are two technologies that are leading the way using pressure-driven membranes to demultiply contaminants from water. RO can remove nearly all dissolved solids and salts and is thus best suited for high-purity applications. NF provides selective separation, particularly good at removing divalent and larger organic molecules at lower pressures and

energy input than RO. With the growing pressure on industries to meet environmental regulations and promote sustainable water management, knowing how efficient RO and NF compare under actual operating conditions is essential. This research focuses on comparing and assessing the performance of these two technologies for treating industrial effluent from Hanumangarh and Sri Ganganagar districts in Rajasthan, which have booming industrial activities and scarce freshwater resources. Based on the evaluation of important parameters for water quality like Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), and pH, this study presents data-driven evidence to inform effective wastewater treatment measures. This article intends to contrast the effectiveness of RO and NF under conditions in two industrially developed districts of Northern Rajasthan.

MATERIALS AND METHODS

StudyArea

Hanumangarh and Sri Ganganagar are agriculturally rich districts with growing agro-processing and textile industries. Industrial effluent in these districts includes dyes, salts, oils, and organic load.

Equipment and Membranes

RO systems operated at 60–100 psi, while NF systems worked between 40–60 psi. Thin Film Composite (TFC) Polyamide membranes were used in both cases.

Methodology

- COD: Standard dichromate digestion method
- BOD: 5-Day Incubation Method (Dilution Method using Winkler's titration)
- TDS: Gravimetric analysis
- pH: Digital pH meter

Sampling and Analysis

To conduct a comprehensive performance evaluation of Nanofiltration (NF) and Reverse Osmosis (RO) membrane technologies, a total of 30 composite wastewater samples were systematically collected from selected textile dyeing and food processing units in the industrial zones of Hanumangarh and Sri Ganganagar districts, Rajasthan. The sampling sites were chosen based on their industrial effluent volume and diversity of pollutants.

Samples were collected in clean, sterilized containers and immediately stored at lower temperature to prevent any chemical or biological changes prior to laboratory analysis. Each sample was divided into three aliquots: one for baseline analysis (raw effluent), one to be treated with an RO membrane, and one with an NF membrane.

The treatment process involved passing each aliquot through RO and NF membranes under their respective operating pressuresRO at 60–100 psi and NF at 40–60 psi. Membrane units used Thin Film Composite (TFC) Polyamide membranes configured in cross-flow mode.

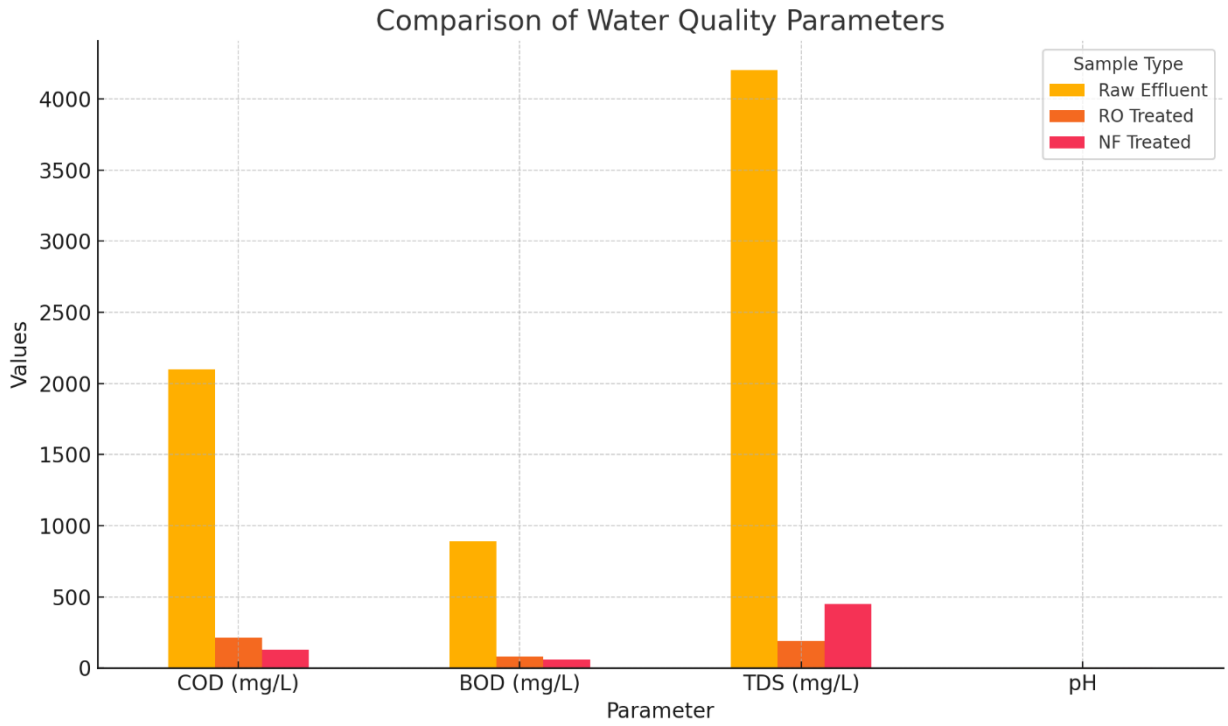
Post-treatment, the following parameters were analyzed:

- **COD (Chemical Oxygen Demand):** Determined by open reflux digestion method
- **BOD (Biological Oxygen Demand):** Assessed using 5-day incubation method
- **TDS (Total Dissolved Solids):** Measured using standard gravimetric method
- **pH:** Recorded using a calibrated digital pH meter

Results

Each sample was evaluated in three stages: untreated (raw effluent), post-treatment with Reverse Osmosis (RO), and post-treatment with Nanofiltration (NF). The results are focused on four critical water quality indicatorsCOD, BOD, TDS, and pHto determine and compare the efficiency of the two membrane technologies. The findings provide insight into the pollutant removal capabilities of each treatment process and are supported by tabulated data and graphical representations. The variations in pollutant concentrations before and after treatment reflect the relative performance of RO and NF in handling high-strength industrial effluent originating from textile and food-processing sectors

Parameter	Raw Effluent	RO Treated	NF Treated
COD (mg/L)	2100	210	130
BOD (mg/L)	890	80	60
TDS (mg/L)	4200	190	450
pH	5.2	6.9	6.7



DISCUSSION

The comparative analysis of NF and RO technologies reveals key differences in their performance across all evaluated parameters. In terms of COD and BOD reduction, NF-treated water showed slightly superior performance compared to RO. This suggests that NF membranes are more effective at removing medium to high molecular weight organic pollutants typically found in effluents from textile and food processing industries. This could be attributed to the semi-permeable nature of NF membranes, which allows for the selective retention of divalent ions and large organics while permitting monovalent ions to pass. Conversely, RO exhibited the highest TDS removal efficiency among all samples, validating its recognized role in applications requiring high levels of desalination. RO membranes, with smaller pore sizes and tighter rejection profiles, efficiently blocked dissolved salts, resulting in treated water with significantly reduced TDS levels. However, the energy and pressure demands of RO systems remain notably higher, necessitating advanced pretreatment and regular maintenance to minimize fouling and scaling. The pH values of both NF and RO-treated water were near neutral, indicating the stability of both membranes in moderating acidic or basic raw effluents. While both technologies achieved acceptable pH levels post-treatment, NF's lower pressure requirement and higher flux rate demonstrate its advantage in scenarios where partial treatment or reuse of water is acceptable.

CONCLUSION

This comparative study reveals that both RO and NF have unique advantages in industrial wastewater treatment. RO excels in TDS removal, while NF offers better energy efficiency and organic pollutant reduction. Selection between the two should be based on specific effluent characteristics and reuse objectives. Policymakers and industry leaders should consider hybrid models and closed-loop systems to optimize treatment and sustainability.

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