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# A Study on Reverse Osmosis Membrane Fouling and Its Control Strategies for Food Industries

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***ABSTRACT***
*Reverse Osmosis is now a day popular and effective treatment for sea water desalination and waste water treatment. However, Fouling is a major issues leads to reducing permeate, additional energy demand, frequent cleaning, shorter membrane life. Fouling has badly effect on the membranes performance. Fouling can occur inside or outside of the membrane and fouling differs from one type to other types of the membrane. Also depends on feed water characteristics. In the present work, RO membrane fouling types, its control strategies with latest development will be studied. Types of fouling are discussed in detailed. There are some types of fouling: a) Inorganic, b) Organic, c) Biofouling etc. Fouling control strategies like pre-treatment of feed water, membrane monitoring and cleaning, membrane surface and space modification etc are discussed in comprehensively. Identify technologies that are effective in fouling mitigation as well as eco friendly. Pre treatment is mostly used in practice to reduce load on RO. To improve the antifouling characteristics of RO membrane, surface modification by chemical and physical treatment. In present study, RO membrane pilot kit will be fabricated and used for study of membrane performance and it's fouling for wastewater generated from food industries.*

***Keyword:*** *Reverse Osmosis, Fouling, Antifouling, Surface Modification, Membrane*

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## I. INTRODUCTION

It is believed that 70 % of the earth is covered with covered with water. This makes a common person assumes that water is abundantly available on earth crust so no need to pay specific attention to the control on utility and reducing wastage of the water. However, it must be kept in mind that all water is not available for utilization. According to USGS(United States Geological Survey), About 97% of the water is available in oceans and seas with high total dissolved solids (> 30,000 mg/L) and only 3% is fresh water. Out of this 3%, only 0.8% is readily available fresh water resource due to location, physical state and natural distribution of hydrologic waters. The only water available for human consumption is about 0.77% which is approximately 10.7M Km3.

Water requirement and consumption rates are increasing with each passing days due to enormous increase in world population especially in developing countries, developing growth and economies, changing climatic conditions, and lifestyles. Global water demand is increasing with an increment of 1% per year and is expected to grow dramatically in the future due to above mentioned reasons. Industrial and domestic water requirements are increasing at faster rates, putting more pressures on existing fresh water resources. Relying on water conservation and storage strategies alone cannot serve the purpose.

This is resulting in search for new methods to obtain fresh water resources to combat with the emerging water scarcity issues. Desalination has been used for centuries to extract fresh drinking water out of saline sea water with the help of thermal distillation processes. Desalination removes dissolved salts from saline water turning it into fresh water. According to USEPA (United States Environmental Protection Agency), drinking water should have < 500 mg/L total dissolved solids. However these criteria varies from region to region and country to country.[1]

Polyamide RO membranes are the major technology for clean water supply, but the main barrier for universal application of these membranes is fouling. Also, these RO membranes are vulnerable to chlorine. These two factors can deteriorate membranes permeability, decrease in salt rejection, rising in energy consumption and shortening life of membranes. In this paper, surface modification of polyamide TFC RO membrane to improve fouling resistance, chlorine resistance and performance of membrane is reviewed over the years.

## II. Applications of RO

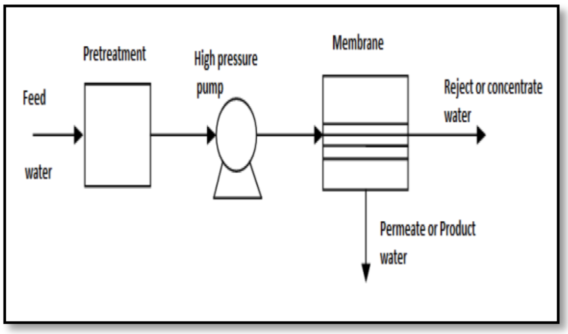
This technology has advantage of a membrane based process where concentration and separation is achieved without a change of state and without use of chemicals or thermal energy, thus making the process energy efficient and ideally suited for recovery applications.

The bibliographic review shows applicability of RO system for treating effluents from beverage industry, distillery spent wash, ground water treatment, recovery of phenol compounds, and reclamation of wastewater and sea water reverse osmosis (SWRO) treatment indicating efficiency and applicability of RO technology. RO systems are simple to design and operate, have low maintenance requirements, and are modular in nature, making expansion of the systems easy. Both inorganic and organic pollutants can be removed simultaneously by RO membrane processes. RO systems allow recovery/recycle of waste process streams with no effect on the material being recovered. [2]

The technology of RO has grown extensively over the recent years. As compared to the traditional cellulose acetate (CA) membranes, newer membrane materials have been developed that are more pH, temperature and chlorine resistant thereby resulting in many applications for the RO process.

Food processing is another important application area for RO technology. These applications in the food industry include water treatment applications, recovery of food products, recovery and recycling of the chemicals required in food processing and concentration and dewatering applications. Yet another important application of RO is in the production of ultra pure water for the semiconductor industry. [3]

The RO process is simple in design consisting of feed, permeate and reject stream. For feed water it is necessary to provide pretreatment in order to remove inorganic solids and suspended solid and using high pressure pump given feed through semi permeable membrane. Depending upon the permeate where it is used necessary post treatment is given. A schematic diagram of the RO process is shown FIG. 1.



Source: Garud R. M., Kore S. V., Kore V. S., Kulkarni G. S.“A Short Review on Process and Applications of Reverse Osmosis” Universal Journal of Environmental Research and Technology

## III. MATERIALS AND METHODS

### Organic Foulant

The organic Foulant used in this work was sodium alginate. Alginate has been extensively used in membrane fouling research to represent polysaccharides that constitute a major fraction of soluble microbial products in wastewater effluent. Sodium alginate was extracted from brown seaweed. Based on the manufacturer, the molecular weight of the sodium alginate ranges from 12 to 80 kDa. Sodium alginate as organic foulants were received in a powder form. A required Concentration of sodium alginate solution (100 mg/l) was prepared by dissolving of the foulants in deionized (DI) water. Mixing of the Sodium alginate solutions was performed for over 24 h to ensure complete dissolution. pH of the above prepared foulant solution was in the range of 7-8. Sodium Alginate solutions were stored in glass bottles at 4 °C.

### Chemical cleaning agents

The chemical cleaning agents used were NaOH (pH 11.0) as an alkaline solution, AR grade disodium ethylene diaminetetraacetate ($Na_2$-EDTA) as a metal chelating agent. Sodium Hydroxide and disodium ethylene diaminetetraacetate cleaning agents are the most common compounds in commercial cleaning products for organic-fouled membranes. The cleaning agent chemical solutions were prepared freshly by dissolving each chemical in deionized (DI) water. Cleaning with DI water served as a baseline. The pH of the disodium ethylene diaminetetraacetate cleaning solutions was adjusted with 1.0 M NaOH as needed.

**RO Membrane**

A standard polyamide thin-film composite (TFC) spiral-wound RO membrane element BW60-1812-75 (DOW FILMTECH) was employed in the fouling test. The effective surface area of the membrane is 0.001735 m2.

## IV. Filtration and cleaning operation

The experimental protocol developed for fouling and cleaning is as below:

- Permeate flux of deionized water,
- Membrane setting,
- Addition of organic foulant,
- Membrane cleaning, and
- Permeate flux of deionized water.

First, prior to each fouling test, the membrane was compacted with deionized water was filtered through the membrane element for approximately 1 h until the permeate flux become constant then collect the data of Deionized water permeability for 1 h to determine the pure water flux before fouling experiment.

Second, a feed water solution free of Foulant was filtered through the membrane to allow adjustment to the new conditions of salinity and pressure (90 psi and 1000 mg/L NaCl). After approximately 2 h of membrane setting.

Third, Thin film Composite Poly amide RO membrane was fouled by filtration 100 mg/l sodium alginate solution at an applied pressure of 90 psi. Fouling test was conducted for 3 hours.

Fourth, once foiling was achieved the fouling (sodium alginate) solution in the feed reservoir was disposed of and cleaning of the fouled membrane was performed by adding the chemical cleaning solution to the feed reservoir. The cleaning experiment was carried without an effective pressure. Finally, the membrane element was cleaned for 30 min by recirculating the above described chemical solutions. It is important to state that high pressure chemical cleaning of fouled membrane is not common inn practice. In view of this, all the cleaning experiments were operated without an effective pressure.

Fifth, at the end of the cleaning stage, the chemical cleaning solution in the reservoir was emptied, and the reservoir and the membrane cell were rinsed with Deionized water to flush out the residual chemical cleaning solution. RO membrane cleaning experiments was conducted for 15 minutes.

Finally, the cleaned RO membrane was subjected to the second baseline performance with Deionized water for 2 h to determine the pure water flux again. The operating conditions at this stage were identical to those applied during the initial baseline performance, so as to determine the cleaning efficiency by comparing the pure water fluxes determined before fouling and after cleaning. Throughout all the fouling and cleaning experiments, the feed water in the reservoir located on top of a magnetic stirrer was mixed vigorously to ensure complete mixing of the feed water and cleaning solution.

Cleaning efficiency varies with respect to the conditions applied during cleaning, namely, type of cleaning agent, cleaning solution pH, cleaning agent dose, cleaning time, and cleaning solution temperature. Furthermore, cleaning efficiency, even at fixed cleaning conditions, is also influenced by the conditions applied during fouling. For a systematic investigation on the role of physical and chemical interactions in cleaning of fouled reverse osmosis membranes, it is necessary to isolate cleaning conditions from the influence of fouling conditions, thus focusing solely on the influence of cleaning conditions on cleaning efficiency. Therefore, all the fouling runs subjected to cleaning experiments were performed at the same fouling conditions in terms of feed solution chemistry (i.e., 100 mg/l sodium alginate) and operating conditions (i.e., 90 psi); these conditions yielded similar flux decline profiles.

## V. Results and Discussion

### 5.1 Determination of Clean Water flux with Deionized Water

Before start of the fouling experiments, the pure water permeability of the RO membrane was evaluated using Deionized water. Flat sheet RO membrane filtration by Deionized water at an applied pressure 90 psi. Clean water flux with deionized water test was conducted for 2 hours. The average volume of permeate of Deionized water was shown in figure 2.

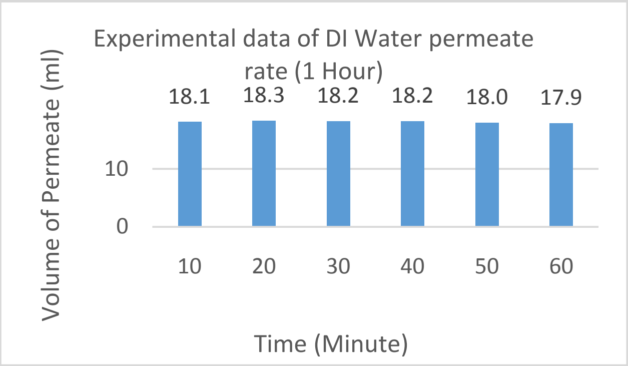


**Figure 2 Experimental data of DI Water permeate rate (1 Hour)**

### 5.2 Determination of % Salt Rejection and NaCl (1000 mg/l) Compaction Behaviour

A feed water solution free of Foulant was filtered through the membrane to allow adjustment to the new conditions of salinity and pressure (90 psi and 1000 mg/L NaCl). The average volume of permeate of Deionized water was shown in figure 3. Also measure conductivity of Feed water and RO membrane permeate. Conductivity of Feed water is 1.56 mS/cm and permeate water is 0.04 mS/cm. Salt rejection was observed 97.44 %.

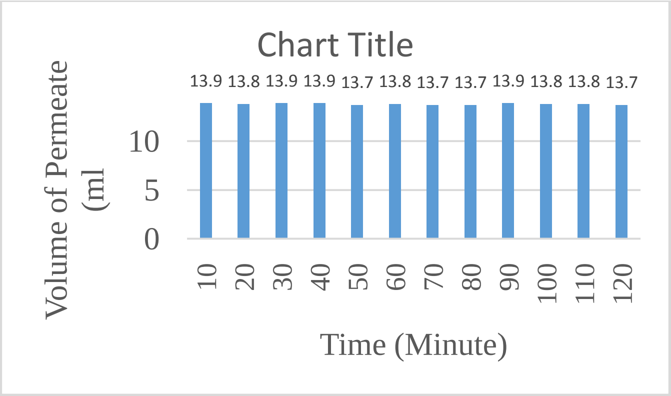


**Figure 3 Experimental data of 1000 ppm NaCl Solution for Feed Adjustment (2 Hour)**

### 5.3 Fouling behavior of RO Membrane with Sodium Alginate

A typical profile of the permeate flux with time is shown in figure 4. during the fouling stage, the flux declines quickly in the initial stage and then declines slowly with time until the fouling run ended after 3 hours. It means the foulant, sodium alginate gel layer becomes dancer and more compact which lead to a considerable increase of hydraulic resistance.

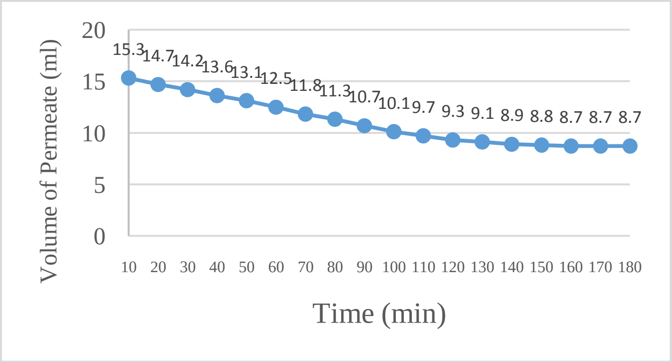


**Figure 4 Flux behavior during the fouling experimental. Condition for the fouling experiments: sodium alginate solution 100 mg/l**

**5.4 Cleaning of RO Membrane (Chemical Aspects of Cleaning)**

The chemical aspects of cleaning – cleaning solution type, cleaning solution pH, and cleaning agent dose have been systematically investigated to find out the favorable cleaning conditions in terms of chemical reaction between the cleaning agent and foulants. Cleaning experiments presented in this section were performed at fixed physical conditions so that only the chemical aspects of cleaning could be investigated.

**Effect of cleaning solution type**

The cleaning efficiency with different cleaning solutions NaOH (pH 11) and EDTA is compared in Fig. 5. Deionized water was also used to serve as a baseline for comparison with the cleaning solutions. Because fouling runs prior to each cleaning experiment were performed under identical conditions, the flux behavior of each run was almost identical, except the DI Water permeate volume obtained after cleaning. The efficiency of each cleaning solution, determined by comparing the deionized water permeate volume before fouling and after cleaning (the initial and final DI water) permeate volume are shown in Fig. 6.

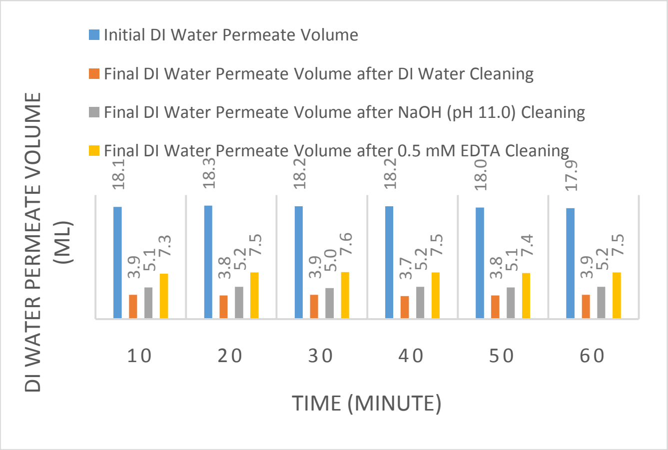


**Figure 5 Initial and final DI water Permeate volume after DI Water, NaOH (pH 11.0) & 0.5 mM EDTA cleaning**

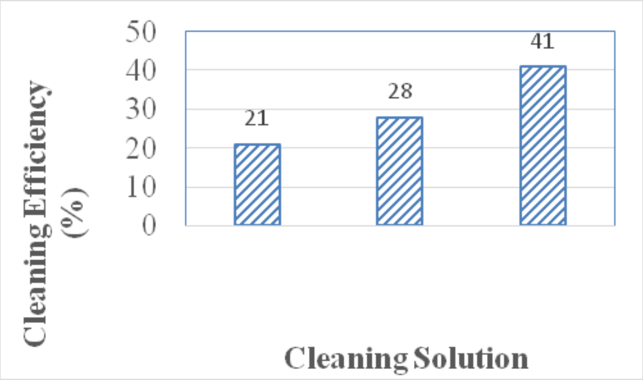


**Figure 6 Various cleaning efficiency with respect to cleaning solution type. Condition for the cleaning experiments: cleaning time 15 min.**

The cleaning efficiencies with Deionized Water and NaOH (pH 11) were 21 and 28%, respectively. This points out that NaOH cleaning performed at these experimental conditions was ineffective since the cleaning efficiency with Deionized water was already 21%. Cleaning with 0.5mM EDTA was relatively more effective compared to Deionized water and NaOH, the cleaning efficiency 41% was two times higher than that of Deionized water.

**Effect of cleaning solution pH**

Variation of solution pH from pH 5.0 to pH 11.0 on the cleaning efficiency of 0.5 mM EDTA is shown in Fig. 8. It is shown that cleaning efficiency increased noticeably from 29 to 59 % with increasing pH from 5.0 to 11.0 for EDTA. The increase in the chelating ability of EDTA at pH 11.0 resulted in a more effective. Consequently, the alginate gel layer was broken down relatively more easily compared to lower pH and thus resulted in a higher cleaning efficiency. Deionized water permeate volume before fouling and after cleaning (the initial and final DI water) permeate volume are shown in Fig. 7.

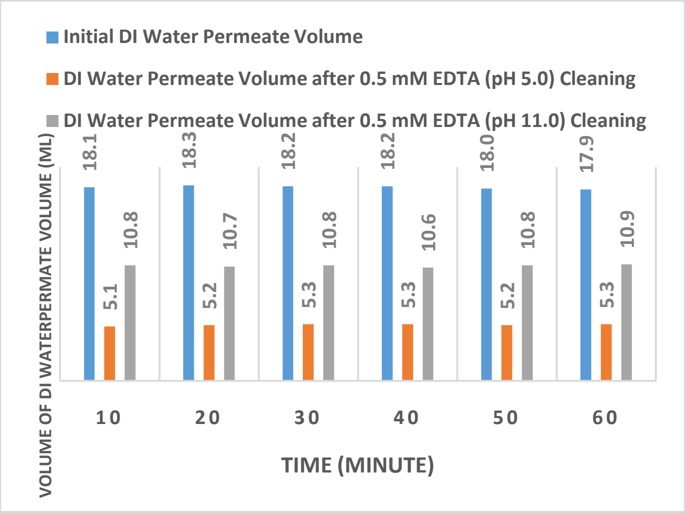


**Figure 7 Initial and final DI water Permeate volume after Cleaning of 0.5 mM EDTA solution at pH 5.0 and pH 11.0**

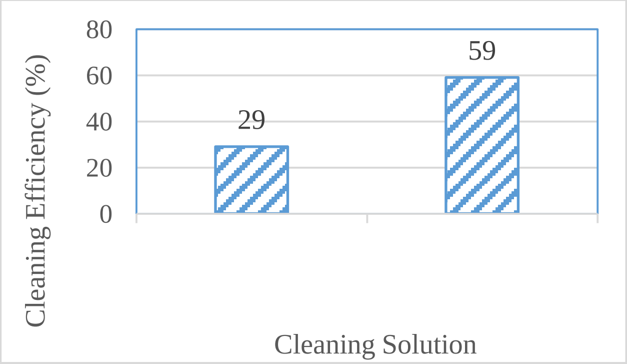


**Figure 8 Variation in EDTA cleaning efficiency as a function of cleaning solution pH.**

### Effect of cleaning chemical dose

Cleaning experiments were also performed with cleaning solutions containing different doses of EDTA (at the pH 11), as presented in Fig. 9. The results clearly show that cleaning efficiency with EDTA cleaning increased with increasing cleaning agent dose. For EDTA, cleaning efficiency increased proportionally with EDTA concentration and reached near 100% efficiency at 2.0 mM EDTA. Deionized water permeate volume before fouling and after cleaning (the initial and final DI water) permeate volume are shown in Fig. 10.

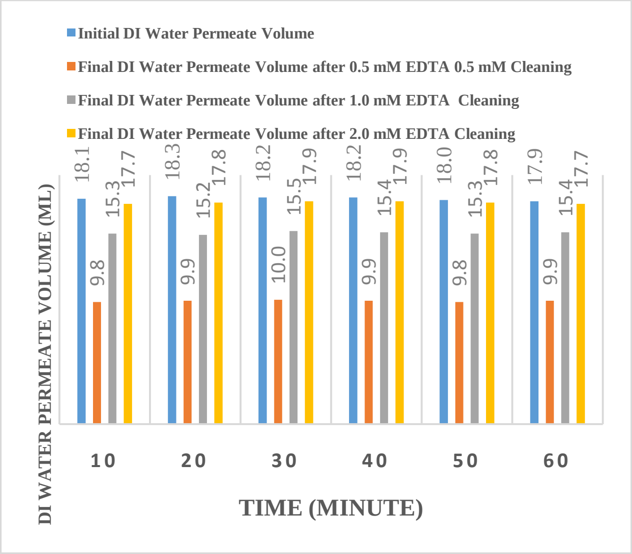


**Figure 9 Initial and final DI water Permeate volume after Cleaning of 0.5 mM EDTA , 1.0 mM EDTA and 2.0 mM EDTA solution at pH 11.0**

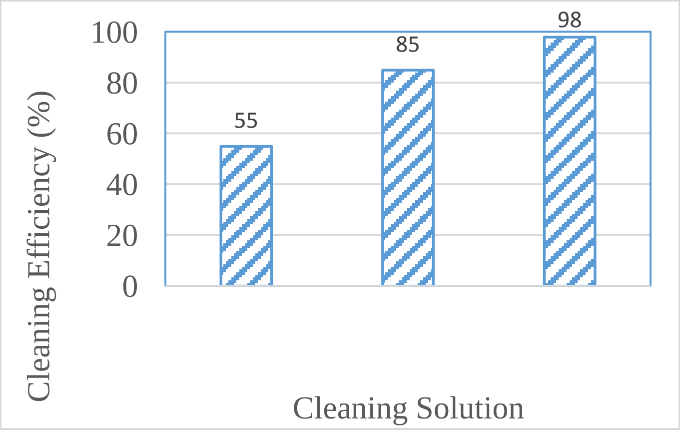


**Figure 10 Variation in EDTA cleaning efficiency with EDTA concentration.**

### 5.5 Cleaning of RO Membrane (Physical aspects of cleaning)

In this section investigate the physical aspects of cleaning time, and temperature to determine the favorable conditions for effective mass transfer. During cleaning, mass transfer of foulants from the fouling layer to the bulk solution takes place after the chemical reaction between the cleaning agent and deposited foulants has weakened the structural integrity of the fouling layer.

Cleaning experiments following fouling runs carried out under identical conditions were performed at fixed chemical conditions, thus focusing on the physical aspects of cleaning. However, it is important to note that cleaning time and temperature also affect chemical reaction between cleaning agent and foulants since contact time (between cleaning agent and fouling layer) and solution temperature influence the extent and rate of reaction. While investigating the influence of a certain physical factor on the efficiency of a cleaning agent, all other physical factors are kept constant.

### Effect of cleaning Time

The influence of cleaning time on the efficiency of each cleaning agent was investigated. The flux behaviors during the fouling and cleaning runs and the resulting cleaning efficiencies with NaOH (pH 11) and 0.5mM EDTA (pH 11) are shown in Fig. 12 and Fig. 14. In all cases, the results are compared for cleaning performed for 15 and 60 min.

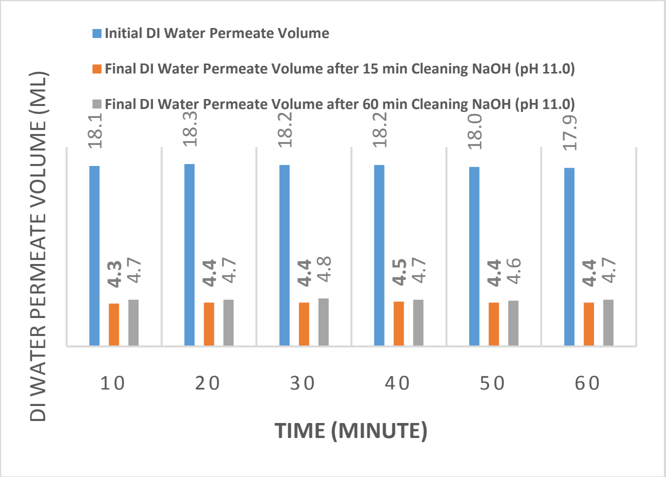


**Figure 11 Initial and final DI water Permeate volume after Cleaning of NaOH solution at pH 11.0 for 15 minute and 60 minute.**

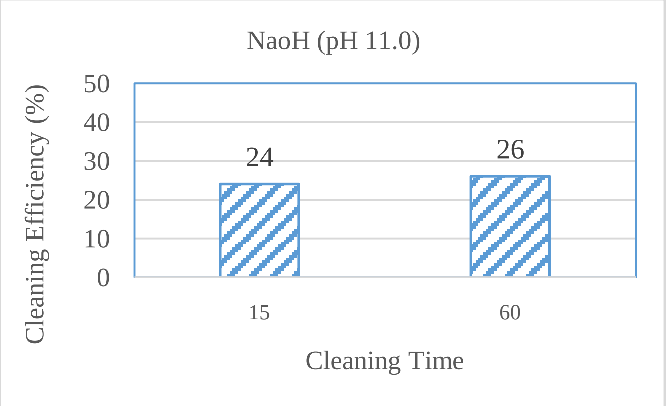


**Figure 12 Variation in NaOH cleaning efficiencies with respect to cleaning time**

It is shown in result negligible difference observed in cleaning efficiency. Cleaning efficiency increased from 24% to 26% with increasing time from 15 to 60 minute for cleaning NaOH at pH 11.0. Therefore, NaOH is not a suitable cleaning agent for membranes fouled by organic matter.

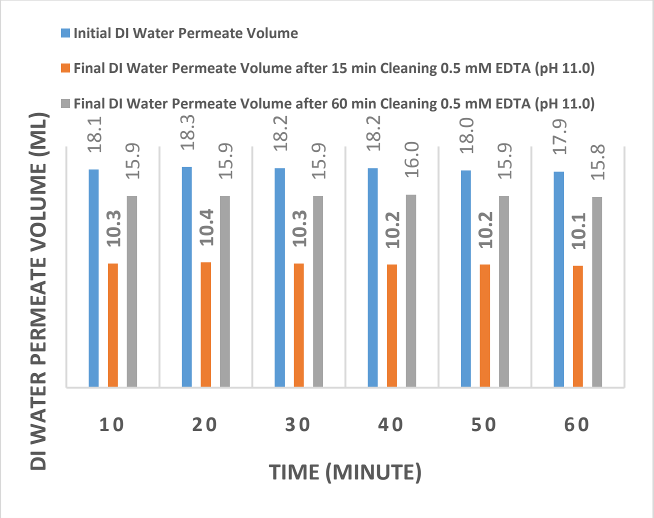


**Figure 13 Initial and final DI water Permeate volume after Cleaning of 0.5 mM EDTA solution at pH 11.0 for 15 minute and 60 minute.**

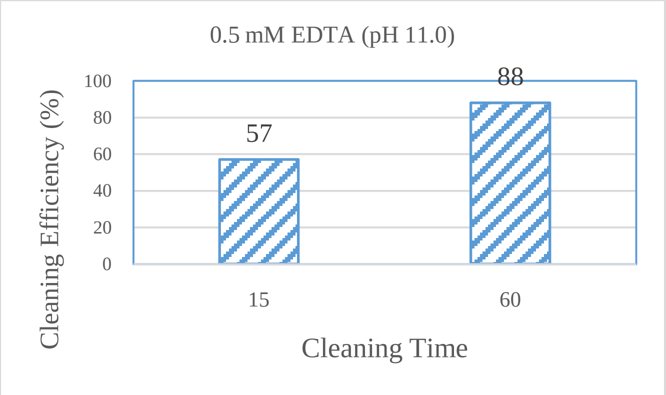


**Figure 14 Variation in 0.5 EDTA cleaning efficiencies with respect to cleaning time**

It is shown that cleaning efficiency increased from 57 to 88% with increasing time from 15 to 60 minute for EDTA. When considering the cost and environmental impact of cleaning chemicals, pumping energy, plant shutdown time aspects of membrane cleaning cycle, the optimization of cleaning cycle time is very important for membrane separation process. An optimum membrane cleaning time reduces the operational cost and also plant shut down.

## Effect of Temperature

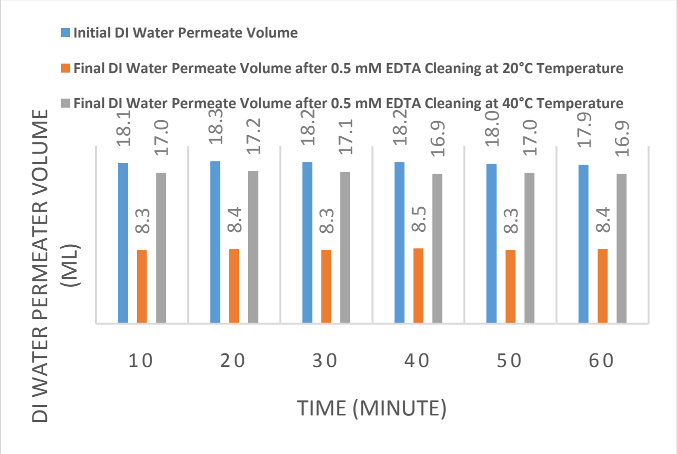


**Figure 15 Initial and final DI water Permeate volume after Cleaning of 0.5 mM EDTA solution at pH 11.0 for 15 minute and 60 minute.**

The results for EDTA cleaning performed at different temperature are presented in Fig. 16. In both cases, the pure water flux after cleaning was determined at 20 °C and 40°C. The cleaning efficiency with 0.5 mM EDTA (pH 11) increased dramatically with increasing cleaning temperature from 20 to 40 °C.

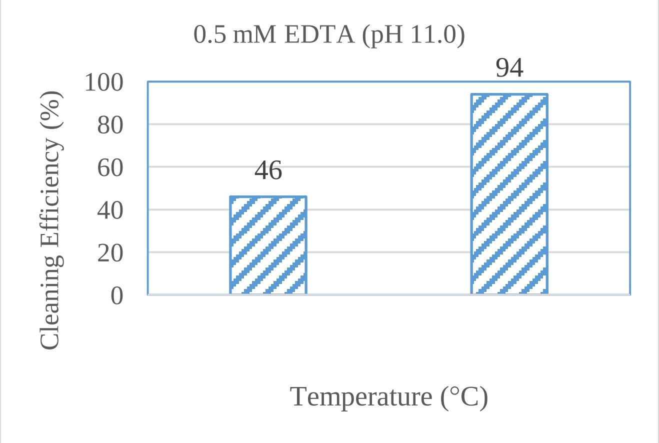


**Figure 16 Variation in 0.5 EDTA cleaning efficiencies with respect to cleaning solution temperature.**

## VI. CONCLUSIONS

RO membrane technology is one of the best technologies for drinking water domestic and industrial water treatment. Poly amide RO membrane is widely used in industrial RO applications because it has major advantages like high salt rejection and water permeability, broad temperature and pH operating range. Depending on feed water quality, membrane properties and operation conditions one or several types of fouling could occur, such as biofouling, organic fouling, inorganic scaling and colloidal fouling.

There are various types of fouling control methods currently applied in practice, e.g., membrane pretreatment, membrane monitoring, cleaning, and membrane surface modification and these techniques are a very important role in reducing RO fouling.

During Fouling Experiments Permeate Flux declined quickly in the initial stage and then decline slowly. It mean that the foulant sodium alginate gel layer become denser and more compact with leads to be a considerable increase of hydraulic resistance. Fouling and subsequent cleaning of RO membrane with sodium alginate, NaOH and EDTA, respectively using a laboratory-scale cross flow RO setup. EDTA cleaning is found to be very effective in cleaning of RO membrane fouled by organic foulant, while NaOH cleaning resulted in poor cleaning efficiency due to its limited reactivity with deposited foulants.

Cleaning efficiency increased noticeably from 29 to 59% with increasing pH from 5.0 to 11.0 for EDTA. Cleaning efficiency increased proportionally with EDTA concentration and reached 98% efficiency at 2.0 mM EDTA.

For NaOH at pH 11.0 cleaning efficiency increased respectively 24% to 26% with increasing time from 15 to 60 minute. For 0.5 mM EDTA at pH 11.0 cleaning efficiency increased from 57 to 88% with increasing time from 15 to 60 minute.

The cleaning efficiency with 0.5 mM EDTA at pH 11.0 dramatically increased from 46 % to 94 % with increasing cleaning solution temperature from 20 to 40 °C.

## REFERENCES

[1]. Nida Maqbool, Zubia Saleem and Yousuf Jamal “A Short Review on Reverse Osmosis Membranes: Fouling and Control” Open Access Journal of Waste Management & Xenobiotics ISSN: 2640-2718

[2]. Garud R. M., Kore S. V., Kore V. S., Kulkarni G. S. “A Short Review on Process and Applications of Reverse Osmosis” Universal Journal of Environmental Research and Technology

[3]. Ankoliya, Dipak, Bhargav Mehta, and Hiren Raval. "Advances in surface modification techniques of reverse osmosis membrane over the years." Separation Science and Technology 54.3 (2019): 293-310.

[4]. Barker, Duncan J., et al. "Soluble microbial products in ABR treating low-strength wastewater." Journal of Environmental Engineering 126.3 (2000): 239-249.

[5]. Jarusutthirak, Chalor, Gary Amy, and Jean-Philippe Croué. "Fouling characteristics of wastewater effluent organic matter (EfOM) isolates on NF and UF membranes." Desalination 145.1-3 (2002): 247-255.