



A short review on reverse osmosis pretreatment technologies



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HIGHLIGHTS

- Reverse osmosis (RO) water desalination has been getting very popular worldwide.
- Conventional pretreatment operational cost is lower than non-conventional systems.
- Non-conventional (membrane) pretreatment systems produce better water quality.
- Membrane pretreatment capital cost increased by 20–40% upon feed water quality.
- NF is a better pretreatment method when compared to conventional and UF.

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ABSTRACT

Recent research reports have underlined reverse osmosis (RO) as the most optimized technology for water desalination related applications. However, implementing this technology to seawater desalination is facing challenges of membrane fouling. This includes membrane biofouling, organic and inorganic fouling which adversely affect the process performance and overall treatment cost. To overcome these issues, pretreatment units ahead of the RO system are necessary to reduce RO membrane fouling and enhance its operational efficiency. This article aimed at reviewing the literature and summarizing relevant methods, mechanisms and novel developments which improve the performance of the RO systems when coupled with either conventional or non-conventional pretreatment units. Several studies suggested that the non-conventional pretreatment units were more efficient than the conventional systems for producing better water quality and minimizing the overall treatment cost. Ultrafiltration appeared to be a cost effective and efficient method of removing suspended solids (SS) and bacteria. The advent of nanostructured membranes nanofiltration has the potential of becoming preferred non-conventional desalination pretreatment over a wide range of salinity, total dissolved solids (TDS), inorganics, viruses, etc.

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1. Introduction

There're almost 26 countries that lack access to pure water resources to sustain agricultural and economic developments, and more or less one billion people have been deprived of pure drinking water. Middle East is among those regions where fresh water scarcity has severely affected agricultural capability and public life. Not to mention that the demand for pure water will dramatically increases according to the world statistics forecasting 40–50% population growth over the next 50 years. Thus, conservation and recycling of water for consumption can minimize the problem to some extent [76]. More or less, 98% of the available water in the world isn't available for direct consumption due to salinity. As water scarcity in many regions of the world is becoming an undeniable fact, efforts have been made to develop technologies for alternative water resources. Thermal desalination processes have been a great option, yet require high capital and operating costs due to installation, maintenance, and energy used. Toward minimizing the overall desalination cost, reverse osmosis membrane filtration (RO) has been widely used and is recently becoming an important alternative source of clean water [63]. There're more than 15,000 desalination plants around the world providing fresh water from saline water through which this number will continue to rise as researchers work to improve the process, both in terms of cost effectiveness and energy efficiency.

Desalination can be traced in history as back as in 1558. Giovanni Batista Della Porta (1535–1615) mentions three desalination systems in his books, *Magiae Naturalis* subsequently translated into French, Italian and German languages. During 1589, in the second edition, he described seven methods of desalination, including a solar distillation apparatus that converted brackish water into fresh water. He also explained a method to obtain fresh water from the air by dehumidification later reported by Delyannis [27]. The phenomenon of osmotic pressure was first observed by the French Cleric, Abb6 Nollet in 1748 [70], while the first semi-permeable membrane was prepared by traube in 1867. This gelatinous film of copper ferrocyanide supported on a porous clay frit displayed remarkable selectivity to dilute solutions of electrolytes had in fact pioneered the ultrafiltration as a technology. Many of the RO and nanofiltration (NF) membranes used these days are primarily condensation polymers whose origin began with the first synthesis of nylon.

Hassler [47] marked the beginning of membrane research at the university level. In his report, entitled "*The Sea as the Sea as a Source of Fresh Water*", Hassler mentioned the possibility of vapor transfer through sheets of cellophane. In a subsequent report, he described "salt repelling osmotic membranes" and "permselective films". It is believed that this historic unpublished document, dated August, 1950, introduced the first concept of membrane desalination. By the mid-1960s, two major chemical companies, Dow Chemical and DuPont, acknowledged the scope of large-scale membrane desalination. Both firms initiated R&D efforts which resulted in the development of hollow fiber desalination modules. The Dow concept involved cellulose acetate fibers as reported by Bray [16], while DuPont focused on polyamides. Due to the core problems faced during the operational performance of desalination systems; it was important to understand the membrane fouling—phenomenon, causes and mechanism.

Ning et al. [67] divided commonly occurring fouling scales into two major classes, a) hard scales and b) soft amorphous complexes. Among these typically brackish waters, scale foulants are calcium carbonate, calcium sulfate, strontium sulfate, barium sulfate, calcium

fluoride and calcium phosphate. Whereas amorphous gels consist of natural exocellular polysaccharides from microorganisms, hydrated silica, ferric and aluminum hydroxides, colloidal iron and manganese compounds and pretreatment polymers. Apart from these factors, silt particles, clay and filter mass such as activated carbon and manganese green sand from filters are damaging the membranes [67].

Scales result from super-saturation of the RO brine relative to the low solubility salts. At high total dissolved solids (TDS), natural crystallization rates and in the presence of seed crystals, scales can grow along and move forward from the back-end of the RO system (i.e. high concentration) toward the front (i.e. low concentration). With the advent of effective modern anti-scalants, scaling is a much smaller problem than colloidal fouling by coagulation of fine particles [69]. Natural waters contain suspended particles that are extremely small in size (<0.1 micron, defined as colloidal). At such sizes, surface to mass ratio is so much larger than visible particles causing them to agglomerate in indefinite patterns or undergo coagulation. The aggregation of particles and deposition on membrane surfaces results in what we observe in membrane autopsies as amorphous gels. Such foulants are complex mixtures and are difficult, sometimes impossible to clean.

Larger, visible particles if not removed from the RO feed water will naturally plug the feed flow channels in the membrane elements. To prevent such fouling, RO feed water needs to have turbidities of less than 1 NTU, and Silt Density Index (SDI), a flow rate over time through a 0.45 micron filter, of less than 4.0. Turbidity and SDI don't detect colloidal fouling potentials. To control scaling, anti-scalants are used to bind to nascent seed crystals preventing them from growing into scales and safely discharged with the reject water. For this reason, it is commonly called threshold inhibition mechanism. Antifoulants for controlling colloidal fouling work on the principle of keeping the colloidal particles from coagulating once formed on the membrane [67]. Colloidal iron and manganese compounds, due to their positively charged characteristics, are particularly sticky on the negatively charged membranes [67]. Special measures are required particularly on the mechanism of fouling by colloidal silica and silicates due to the spontaneous polymerization of monomeric silicic acid in all natural waters [69]. Silicic acid $[\text{Si}(\text{OH})_4]$ is the reactive silica species that can be detected by the molybdate colorimetric assay. It is spontaneously polymerized by elimination of water during RO concentration, generating in the RO concentrate a reaction mixture of oligomeric silica and silicates. The silica in the ultimate dehydrated state is found as SiO_2 (e.g. sand, quartz). When hydroxides of iron, aluminum, magnesium and calcium are involved in copolymerization with silicic acid, complex silicate oligomers are formed in the RO concentrate, some of which depending on their size may be deposited on the membrane surface [68].

Several studies [6,57,58,66] reported that biofouling has been one of the severe forms of membrane fouling affecting the performance of the RO membranes. It is caused due to the bacterial growth on the inner surfaces of the membrane pores forming a thick layer of biofilm clogging the membrane surface. Asif et al. [8] suggested that the biofilm behaves as a second membrane, thus promoting high concentration polarization, high salt passage, and low permeate flux. However, the scientific reason behind the rapid growth and accumulation of microbial communities on the RO membrane surface is still not well defined. Many research studies focused on improving the RO membrane desalination technology in conjunction with reducing membrane fouling. For instance, Flemming and Wingender [36], and Flemming [37] investigated the chemical composition of biofilm layers in the RO membranes. Xavier

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