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A Comprehensive Review of Major Water Desalination Techniques from Saline Water

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Abstract*: In light of the critical challenge of global freshwater scarcity, this review paper underscores the paramount importance of ocean water desalination as a sustainable solution. While the majority of existing studies have concentrated on the technical aspects and efficiency of desalination techniques, this paper distinguishes itself by examining not only these operational principles and their cost-effectiveness but also by shedding light on the often-overlooked valuable mineral by products of the desalination process. We provide a comprehensive analysis comparing emerging desalination technologies, highlighting their environmental impacts alongside a novel perspective on the potential for valuable mineral extraction during desalination. This dual approach not only addresses the urgent need for fresh water but also introduces an innovative method for resource recovery, presenting a shift towards more sustainable and economically viable water management practices. Contrary to the common perception, our findings reveal that, except for the osmotically assisted reverse osmosis method, other common zero liquid discharge (ZLD) methods have shown better cost-effectiveness. Furthermore, we have investigated the most valuable minerals present in seawater and the common methods for their separation, indicating that focusing on mineral separation could significantly reduce if not completely remove, the costs associated with these desalination technologies. This paper aims to inform and influence decision-making in the field of water management, advocating for solutions that not only alleviate water scarcity but also enhance resource utilization for industry applications.*

Keywords: Desalination; Reverse Osmosis; Membrane Fouling; Brine Management

I. INTRODUCTION

Water is essential for life. Many countries around the world, especially developing countries and countries in the Middle East region, suffer from a shortage of fresh water. The United Nations (UN) Environment Programmed stated that one-third of the world's population lives in countries with insufficient freshwater to support the population. Consequently, drinking water of acceptable quality has become a scarce commodity. The total global water reserves are ∼1.4 billion km^3, of which around 97.5% is in the oceans and the remaining 2.5% is fresh water present in the atmosphere, ice mountains and ground water. Of the total, only ∼0.014% is directly available for human beings and other organisms. Thus, tremendous efforts are now required to make available new water resources in order to reduce the water deficit in countries which have shortages. According to World Health Organization (WHO) guidelines, the permissible limit of salinity in drinking water is 500 ppm and for special cases up to 1000 ppm. Most of the water available on the earth has a salinity up to 10 000 ppm and seawater normally has salinity in the range of 35 000–45 000 ppm in the form of total dissolved salts. Desalination is a process in which saline water is separated into two parts, one that has a low concentration of dissolved salts, which is called fresh water, and the other which has a much higher concentration of dissolved salts than the original feed water, which is usually referred to as brine concentrate. The desalination of seawater has become one of the most important commercial processes to provide fresh water for many communities and industrial sectors which play a crucial role in socio-economic development in a number of developing countries, especially in Africa and some countries in the Middle East region, which suffer from a scarcity of fresh water. There is extensive R&D activity, especially in the field of renewable energy technologies, to find new and feasible methods to produce drinking water. Currently, there are more than 7500 desalination plants in operation worldwide producing several billion gallons of water per day. Fifty-seven per cent are in the Middle East where large-

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scale conventional heat and power plants are among the region's most important commercial processes, they play a crucial role in providing fresh water for many communal and industrial sectors, especially in areas with a high density of population. However, since they are operated with fossil fuel, they are becoming very expensive to run and the environmental pollution they produce is increasingly recognized as very harmful to the globe. Moreover, such plants are not economically viable in remote areas, even near a coast where seawater is abundant. Many such areas often also experience a shortage of fossil fuels and an inadequate electricity supply. The development of compact, small-scale systems for water desalination is imperative for the population in such areas. Thermal solar energy water desalination is known to be a viable method of producing fresh water from saline water in remote locations; conventional basin solar stills with a relatively large footprint are an example of such simple technology. And using a clean natural energy resource in water desalination processes will significantly reduce the pollution that causes global warming. This article aims to present a review of the published literature on the various desalination technologies and their advantages and disadvantages in addition to their economics.

DESALINATION PROCESSES

Various desalination processes have been developed, some of which are currently under research and development. The most widely applied and commercially proven technologies can be divided into two types: phase change thermal processes and membrane processes both encompass a number of different processes. In addition, there are the alternative technologies of freezing and ion exchange which are not widely used. All are operated by either a conventional energy or renewable energy to produce fresh water.

Reverse osmosis

The RO process is relatively new in comparison to other technologies and was introduced as a successful commercialized technology in water desalination in the early 1970s. RO is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane without the need for heating or phase change. The major energy required is for pressurizing the feed water [6]. It can also be described as a process of forcing a solvent from a region of high solute concentration through a membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure, as shown in Figure . Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behindwith an increase in salt concentration.

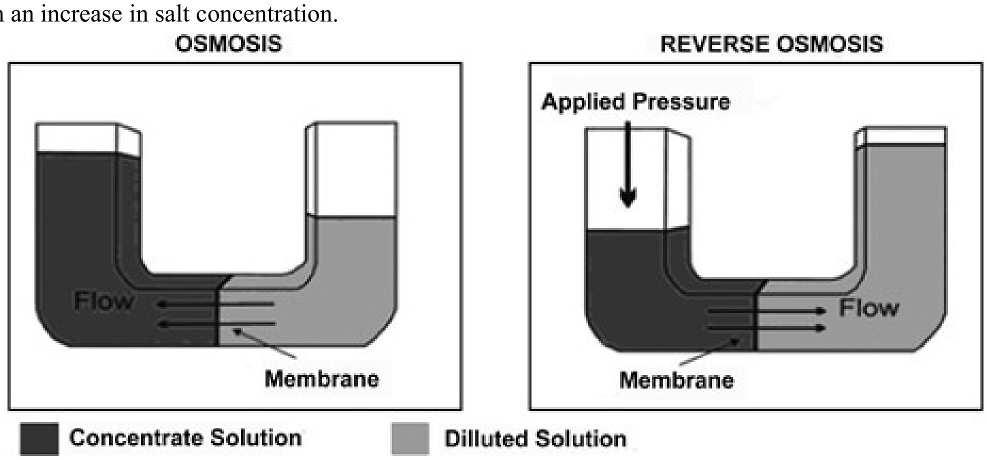

Fig: Osmosis and RO processes

A typical large saline water RO plant consists of five major components, a saline water supply system, a feed water pre-treatment system, high-pressure pumping, RO modules (membrane separation) and post-treatment system. In the recent years, the largest RO desalination plants have been built in the Middle East and particularly in Saudi Arabia. A plant in Jeddah produces 15 million gallon per day (MGD), while the Al Jubail and Yanbu RO plants have capacities of 24 and MGD, respectively.

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Synthetic membranes were first introduced in separation processes in the 1960s, but they began to play an increasingly crucial role in water desalination in the 1980s. Originally, membrane applications were limited to municipal water treatment such as microfiltration and desalination but, with the development of new membrane types, uses have expanded to cover not only the water industry but also high return processes such as chemical separations, enzyme concentration and beverage purification. This technology uses a relatively permeable membrane to move either water or salt to induce two zones of differing concentrations to produce fresh water. These processes are also useful in municipal water treatment; RO and electrodialysis (ED) are replacing phase change desalting technologies for supplying water to coastal and island communities all over the world. RO, in particular, is becoming an economical alternative to the traditional water softening processes .Membrane technology includes several processes, but the principal difference between them lies in the size of the entities, ions, molecules and suspended particles that are retained or allowed to pass through the membranes. Typical separation processes are nano-filtration, ultra-filtration, micro-filtration and filtration used in the pre-treatment stages of desalination to remove large particles, bacteria, ions and for water softening. Figure 2 shows the effective range of membrane processes and applications.

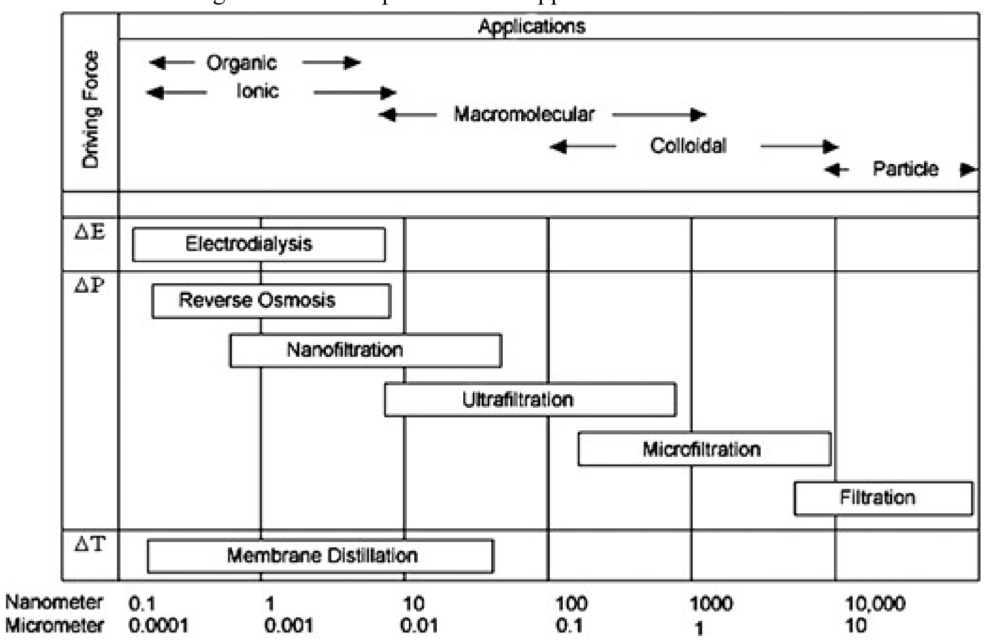

Figure 2. Effective range of membrane processes and applications .

Advantages and disadvantages of RO process

1-Material corrosion problems are significantly less compared with MSF and MED processes due to the ambient temperature conditions

2-Polymeric materials are utilized as much as possible rather than the use of metal alloys.

3-Two developments have also helped to reduce the operating cost of RO plants during the past decade.

4-The development of operational membranes with high durability and lower prices.

5-The use of energy recovery devices that are connected to the concentrated stream as it leaves the pressure vessel. The concentrated brine loses only ∼1–4 bar relative to the applied pressure from the high-pressure pump. The devices are mechanical and generally consist of turbines or pumps that can convert a pressure difference into rotating energy that can be used to reduce energy costs.

RO units sold for residential water filtration require very large quantities of water since they recover only 5–15% of the feed water that enters the filter. In seawater systems, for every 5 gallons of usable water, 40–90 gallons of water are sent to the wastewater system .

Membrane scaling caused by the precipitation of salts is a common problem in the RO process, but it is less than in MSF.

Membranes are liable to be fouled (plugged) by large particles, but this can be avoided by pre-filtering the feed water through a 5–10 µm cartage micro-filter. Biological fouling can be caused by the formation of micro-organism colonies and by entrapping dead and live organisms. Colloidal fouling is caused by the settlement on membrane surfaces of colloids from an accumulation of aluminum silicate and clays and from soap detergents and organic materials.

II. CONCLUSION

The number of desalination plants worldwide is growing rapidly, and as the need for fresh water supplies grows more acute, desalination technologies improve and unit costs are reduced. Desalination processes should aim to be environmentally sustainable. Most drinking water applications use WHO drinking water guidelines as water quality specifications. 'WHO Guidelines for Drinking-water Quality' cover a broad spectrum of contaminants, including inorganic and synthetic organic chemicals, disinfection by-products, microbial indicators and radionuclides, and are aimed at typical drinking water sources and technologies. Currently, WHO says that existing guidelines may not fully cover the unique factors that can be encountered during the intake, production and distribution of desalinated water. Hence, it imposes stringent guidelines not only for drinking water quality but also for environmental protection issues. This is in order to assist with the optimization of both proposed and existing desalination facilities, and to ensure that nations and consumers will be able to enjoy the benefits of the expanded access to desalinated water with the assurance of quality, safety and environmental protection. Obviously, the intake and pre-treatment of seawater, as well as the discharge of the concentrate reject water produced, have to be adapted to the specific conditions at the site of each desalination plant. Hence, it is necessary to consider and evaluate the criteria that help to select the best available technology and the optimal solution for the intake and outfall system at each plant.

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