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Membrane based desalination systems for seawater

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ABSTRACT

Desalination is a necessary supplement for the already existing natural resources to meet the growing demand of fresh water. It requires energy to separate the vast resources of seawater which contains around 3.5% of dissolved salts. Several technologies have been developed in recent years, besides the century old thermal desalination processes. This article provides an overview of the membrane technologies, particularly focusing on the most used Reverse Osmosis for seawater desalination.

INTRODUCTION

Ocean is the repository of many life-sustaining requirements available tangibly or intangibly. Energy can be obtained from the ocean in many ways; from within as waves, or outside as the wind. The ocean water is spread over about two-thirds of the earth's surface (Wang and Huo, 2022) and contains virtually all the mineral salts and valuable metals albeit in a very low concentrations. With increasing population, the demand for the fresh water has increased manifold to meet the needs of several life support systems including domestic, agriculture, food processing, pharmaceuticals, power generation, metallurgical industries, refinery operations etc. Only about 3.5% of annual precipitation is available for human use in rivers, ground water and lakes. Even in this, a significant fraction is rendered unfit due to anthropogenic contaminants. With reference to India, the per capita availability of fresh water has dwindled to about 1500 m^3/annum at present, down from 5000 m^3 in 1950, indicating water stress conditions. Being aware of these constraints, already a few desalination plants have been installed in parts of Gujarat and Tamil Nadu in late nineties. Since India is blessed with a long coastline of about 7,516.6 kilometers including about 5,422.6 kilometers in mainland and 2,094 kilometers in island territories, stretching across nine states and four union territories, Government of India has established the 'Desalination Mission' to adopt desalination in larger scales towards enhancing water security (Dhakal et al., 2022). Nature has illustrated the basic concepts of desalination processes; thermal and membrane based as seen from the evaporation – condensation–precipitation cycle using the thermal energy of the sun, while the plants separate the excess water through cell membranes for its removal through transpiration. In a similar manner the desalination technologies currently in vogue are either thermal, or membrane based.

Many variations of thermal energy-based desalination processes are in practice, in tune with capacity required, and locational logistics, exhibiting varying specific energy consumptions. Based on the form of energy the specific energy for seawater desalination varies from about 3 kWh/m^3 for reverse osmosis to about 15 kWh/m^3 for electro-dialysis, with the thermal processes in the middle depending on the type. However, the selection of an appropriate desalination technology is site specific, depending on the end use, economics, opportunity and logistic costs, thus accounting for the variety of desalination technologies in use.

Among the technologies available today, reverse osmosis is the most popular, as it operates under ambient temperatures with low specific energy consumption, and has a major share, dominating over hitherto popular, century old thermal desalination. The overall cost of water is also lower per m^3 and the modularity allow variable operating capacities. Constant development in the technologies, constituting the front-end and back-end components to provide sustainable performance, have made the process more attractive. This article provides an overview of the membrane-based electro-driven, concentration-driven, thermal- driven desalination processes, with particular focus on reverse osmosis with reference to seawater desalination including design philosophy, operational characteristics, limitations, and possible opportunities.

DESALINATION PROCESSES

Desalination means separation of pure water from its solution and can be achieved either by preferentially (which form the minor constituent ~ 3.5% in seawater and still lesser in most of the other saline waters) or water from the solution. The process requires energy to achieve the separation, which can be imposed externally as in thermal desalination, and the membrane based reverse osmosis (RO), or use the internally available energy in the system as in forward osmosis (FO) and membrane distillation. Unlike thermal desalination processes, membrane processes do not involve phase change, except membrane distillation, for the purpose of desalination.

MEMBRANE PROCESSES

Membrane processes are versatile as they can be used for desalination under different energy gradients such as reverse osmosis with mechanical energy (pressure), electro-dialysis with electrical energy (electric-potential), forward osmosis with chemical potential energy (concentration), and membrane distillation with thermal energy (thermal), but with different types of membranes. Among these processes, only reverse osmosis and the electro-dialysis have been found to be suitable for large scale deployment. Reverse osmosis has become the most preferred desalination process, particularly for seawater,