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Review

Emerging desalination technologies for water treatment: A critical review

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ABSTRACT

In this paper, a review of emerging desalination technologies is presented. Several technologies for desalination of municipal and industrial wastewater have been proposed and evaluated, but only certain technologies have been commercialized or are close to commercialization. This review consists of membrane-based, thermal-based and alternative technologies. Membranes based on incorporation of nanoparticles, carbon nanotubes or graphene-based ones show promise as innovative desalination technologies with superior performance in terms of water permeability and salt rejection. However, only nanocomposite membranes have been commercialized while others are still under fundamental developmental stages. Among the thermal-based technologies, membrane distillation and adsorption desalination show the most promise for enhanced performance with the availability of a waste heat source. Several alternative technologies have also been developed recently; those based on capacitive deionization have shown considerable improvements in their salt removal capacity and feed water recovery. In the same category, microbial desalination cells have been shown to desalinate high salinity water without any external energy source, but to date, scale up of the process has not been methodically evaluated. In this paper, advantages and drawbacks of each technology is discussed along with a comparison of performance, water quality and energy consumption.

Contents

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1. Introduction

Freshwater is a renewable resource, but increasing population growth and population density has strained the ability of many local supplies to sustain water quantity requirements at suitable levels of water quality. In response to the United Nations prediction that 2–7 billion people will face water scarcity by the middle of the century (Hameeteman, 2013), the water industry has become increasingly reliant upon desalination of ocean and brackish water supplies. Desalination processes are broadly categorized as thermal or membrane-based technologies (Greenlee et al., 2009). Although thermal desalination has remained the primary technology of choice in the Middle East, membrane processes, such as reverse osmosis (RO), have rapidly developed since the 1960's (Loeb and Sourirajan, 1963) and currently surpass thermal processes in new plant installations (Greenlee et al., 2009). The primary drawback with desalination is associated with costs (Subramani et al., 2011); those associated with electricity for seawater desalination using RO are 30% of the total cost of desalinated water. Higher energy consumption also translates to a corresponding increase in greenhouse gas (GHG) emissions (Raluy et al., 2005). Thus, reducing energy consumption is critical for lowering the cost of desalination and addressing environmental concerns about GHG emissions from the continued use of conventional fossil fuels as the primary energy source for seawater desalination plants.

During desalination with RO membranes, brackish water or seawater is pressurized against a semi-permeable RO membrane that allows water to pass through while rejecting salt. In order to produce desalinated water, the osmotic pressure of the feed water needs to be exceeded. The feed water to the RO is pressurized using a high pressure feed pump to supply the necessary pressure to force water through the membrane to exceed the osmotic pressure and overcome differential pressure losses through the system (Stover, 2007). In seawater desalination applications, an energy recovery device (ERD) in combination with a booster pump is used to recover the pressure from the concentrate and reduce the required size of the high pressure pump (Stover, 2007). In brackish water applications, ERDs are seldom utilized due to the low total dissolved solids (TDS) levels, while certain full-scale plants have installed turbochargers or isobaric devices to act as interstage booster pumps (Drak and Adato, 2014).

A theoretical minimum energy exists that is required to exceed the osmotic pressure and produce desalinated water. As the salinity of the feed water or as feed water recovery increases, the minimum energy required for desalination also increases. For example, the theoretical minimum energy for seawater desalination with 35,000 mg/L of salt and a feed water recovery of 50% is 1.06 kWh/m^3 (Elimelech and Phillip, 2011). However, the actual energy consumption is larger for full-scale plants. The energy required for desalination using RO membranes is a function of the feed water recovery, intrinsic membrane resistance (permeability), operational flux, feed water salinity and temperature fluctuations, product water quality requirements, and system configuration (Subramani et al., 2011). The lowest energy consumption reported for an RO system is 1.58 kWh/m^3 at a feed water recovery of 42.5% and a flux of 10.2 L m^{-2} h^{-1} (Seacord et al., 2006). In addition, pre- and post-treatment contributes to additional energy requirements (Wilf and Bartels, 2005). Typically, the total energy requirement for seawater desalination using RO (including pre- and post-treatment) is on the order of 3–6 kWh/m^3 (Semiat, 2008; Subramani et al., 2014a,b).