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Energy efficiency of direct contact membrane distillation

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ABSTRACT

Membrane distillation (MD) is a promising technology due to its ability to function using low temperature differences and low-quality heat sources, thus allowing it to operate on solar or waste heat. The flux and energy efficiency of MD are influenced by temperature and concentration polarization, process conditions, and membrane-related parameters like thickness, tortuosity, thermal conductivity, pore size, and porosity. To date, a comprehensive review of membrane and distillation parameters on energy consumption has not yet been conducted. Accordingly, this review introduces the central energy parameters for MD (e.g., energy efficiency, gained output ratio, etc.) and discusses the reported impacts of membrane properties, mass and heat transfer, feed water properties, and system parameters on the energy parameters. The application of solar energy to direct contact MD (DCMD) is also discussed. A critical analysis of the energy efficiency of DCMD processes will help to establish its strengths and limitations and provide a road map for the development of this technology for both large-scale and portable applications.

1. Introduction

The large-scale desalination industry is currently dominated by multi-stage flash distillation, multiple effect distillation, and reverse osmosis (RO) techniques [1,2]. Although reverse osmosis has lower energy requirements relative to the other leading technologies, the method is known to be expensive for small-scale water purification purposes. Membrane distillation (MD) is a promising technology that operates based on the partial vapor pressure difference developed across a membrane. This technique utilizes a porous hydrophobic filter that is capable of preventing feed liquid entry into the pores while allowing the volatile vapors to cross to the distillate side. This characteristic makes MD unique among common water purification technologies as it can completely separate inorganic and non-volatile compounds without the use of traditional distillation techniques. However, the fabrication of a purely hydrophobic membrane that resists internal wetting while maintaining high vapor throughput is a continuing challenge.

In terms of energy efficiency, MD is an attractive technology due to its ability to function using low temperature differences and low-quality heat sources. Thus, it is an economically viable large-scale purification technology because it can utilize either solar thermal energy [3], waste heat, or natural temperature gradients. In fact, the heat requirement for MD is so low that Baghbanzadeh et al. [4] have recently suggested the notion of zero thermal energy input membrane distillation (ZTIMD), where the natural temperature difference between the sea surface water (at 30 °C) and the sea bottom water (at 10 °C) can be used as the process driving force without the need for preheating and zero waste production, which contrasts the seawater reverse osmosis (SWRO) process. Further, a simulation study has suggested that the specific energy consumption of ZTIMD would be in the range of 0.45 kW h/m^3, which is comparable to commercial SWRO processes [4].

The low energy requirement of MD techniques makes it competitive with RO; moreover, it can also be applied to high temperature applications where RO is not suitable. In fact, direct contact MD (DCMD) is a thermally driven process that can operate at temperature above 100 °C, making it a more energetically efficient method for use in onsite wastewater desalination [5]. The US oil and gas industry generates approximately 3.3 billion m^3 of wastewater annually, with salinity concentrations almost 7 times higher than seawater. Onsite desalination using steam assisted gravity drainage (SAGD) systems that produce wastewater have been proven to be more environmentally friendly and economically viable than disposal through deep well injection technology. The energy consumption of wastewater desalination has been

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