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A novel ammonia–carbon dioxide forward (direct) osmosis desalination process

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Abstract

A novel forward (direct) osmosis (FO) desalination process is presented. The process uses an ammonium bicarbonate draw solution to extract water from a saline feed water across a semi-permeable polymeric membrane. Very large osmotic pressures generated by the highly soluble ammonium bicarbonate draw solution yield high water fluxes and can result in very high feed water recoveries. Upon moderate heating, ammonium bicarbonate decomposes into ammonia and carbon dioxide gases that can be separated and recycled as draw solutes, leaving the fresh product water. Experiments with a laboratory-scale FO unit utilizing a flat sheet cellulose tri-acetate membrane demonstrated high product water flux and relatively high salt rejection. The results further revealed that reverse osmosis (RO) membranes are not suitable for the FO process because of relatively low product water fluxes attributed to severe internal concentration polarization in the porous support and fabric layers of the RO membrane.

Keywords: Forward osmosis; Direct osmosis; Osmosis; Desalination; Ammonium bicarbonate; Draw solution; Osmotic pressure; Internal concentration polarization

1. Introduction

Freshwater scarcity is a growing problem in many regions in the world. Unchecked population growth and the impairment of existing freshwater sources cause many countries and communities in dry regions to turn to the ocean as a source of freshwater. Current desalination technologies are, however, prohibitively expensive and energy intensive. Reverse osmosis (RO), a commonly used desalination technology, is significantly more expensive than the standard treatment of freshwater for potable use. Less expensive methods of desalination are needed to make desalination technologies more competitive with freshwater treatment.

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To reduce the cost of existing desalination technologies, it is prudent to focus on what makes current technologies so expensive. Energy is indisputably the most significant contributor to the cost of desalination [1]. Hence, reduction in energy usage is the primary objective to making desalination more affordable.

Forward (or direct) osmosis (FO) is a process that may be able to desalinate saline water sources at a notably reduced cost. In forward osmosis, like RO, water transports across a semi-permeable membrane that is impermeable to salt. However, instead of using hydraulic pressure to create the driving force for water transport through the membrane, the FO process utilizes an osmotic pressure gradient. A "draw" solution having a significantly higher osmotic pressure than the saline feed water flows along the permeate side of the membrane, and water naturally transports across the membrane by osmosis. Osmotic driving forces in FO can be significantly greater than hydraulic driving forces in RO, potentially leading to higher water flux rates and recoveries.

In RO, typical seawater recoveries are between 35–50% [2]. The remaining salt solution, now concentrated brine, is discharged back to sea. This is a critical environmental drawback to RO and also limits its use to coastal areas since brine from brackish groundwater desalination cannot be disposed of inland in an economical manner. At a high recovery from typical seawater, the salt may be induced to precipitate, eliminating the need of this environmentally harmful brine discharge. RO cannot achieve this high recovery due to hydraulic pressure limitations of the pumps and membrane housings. However, with the use of a suitable draw solution, as in our novel FO process described in this paper, very high osmotic pressure driving forces can be generated to achieve high recoveries that, in principle, can lead to salt precipitation.

In this paper we describe a novel forward osmosis process for seawater and brackish water desalination. The novel process operates by using a concentrated ammonium bicarbonate solution to extract water from a saline feed stream across a semi-permeable membrane. Laboratory-scale experiments with a semi-permeable cellulose triacetate membrane demonstrate that the new FO process yields high water flux with very limited salt passage.

2. Previous forward osmosis efforts

Several attempts to use forward osmosis as a means of desalting saline waters have been reported in the past four decades. These methods involved the generation of an osmotic pressure difference across a semi-permeable membrane by use of a draw solution at the permeate side. The resulting osmotic pressure difference induces transport of water through the membrane from the feed (saline water) side to the permeate side. A variety of methods to generate the osmotic pressure difference have been used. The relevant previous forward osmosis efforts for desalination — mostly presented as patents with limited technical details and performance data — are summarized below.

Batchelder [3] described a process of adding volatile solutes, such as sulfur dioxide, to seawater or freshwater to create a solution which may be used in a forward osmotic process to extract water from seawater. The suggested membrane to be used in this process was cellulosic in nature. Other examples in the patent described the use of carrot root as a membrane material. The process is carried out until the draw solution is sufficiently dilute, at which point the volatile solute is removed by heating and/or air stripping. The patent, however, only determined that positive water flux occurred in the experiments and did not quantify the flux or salt rejection.

Glew [4] expanded on this idea by describing a method of forward osmosis using a mixture of water and another gas *or* liquid. This mixture is intended to lower the "activity" of the water solution to the point that a net flow of potable water will be induced from the seawater, after