Journal of Membrane Science 366 (2011) 48–61

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

Effect of antiscalant degradation on salt precipitation and solid/liquid separation of RO concentrate

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ARTICLE INFO

Article history:
Received 5 May 2010
Received in revised form 1 September 2010
Accepted 21 September 2010
Available online 1 October 2010

Keywords:
Desalination
Antiscalant
Precipitation
Concentrate
Ozone

ABSTRACT

The key limitation to the application of reverse osmosis (RO) desalination on inland brackish waters is concentrate disposal. Due to precipitation of sparingly soluble salts ($CaCO_3$, $CaSO_4$, $BaSO_4$, $SrSO_4$), RO membrane recovery cannot be increased further; therefore, other strategies must be investigated. Antiscalants are often added to RO feed water to help prevent precipitation and increase RO recovery, but in concentrate treatment, antiscalants may prevent precipitation of problematic constituents. A three-stage process to treat brackish water RO concentrate was investigated; the stages include oxidation of antiscalants with ozone and hydrogen peroxide, precipitation at elevated pH, and solid/liquid separation. A model water concentrate was used to perform laboratory scale experiments for each treatment stage. Experimental results showed that the advanced oxidation process (AOP) of ozonation and hydrogen peroxide on phosphonate antiscalants allowed increased calcium precipitation as well as loss of the solubilizing effects of antiscalants as compared to precipitation without prior ozonation of the antiscalants. The AOP also removed the effect of antiscalant on precipitate particle size distribution and particle morphology. In some cases, the AOP also improved microfiltration performance for the solid/liquid separation stage. The concentrate treatment could increase overall recovery from 80% to 90% for non-ozonated, antiscalant-dosed concentrate and from 80% to 94% for ozonated, antiscalant-dosed concentrate.

1. Introduction

Reverse osmosis (RO) membrane technology has advanced dramatically over the past 40 years to become the primary technology for new desalination plant installations [1–9]. RO membrane desalination for drinking water uses either seawater or brackish water. Both seawater and brackish water plants must dispose of the RO waste stream (concentrate); the concentrate volumetric flow is much larger for seawater RO plants, but most such plants are coastally located and return the concentrate to the same seawater source. Brackish water RO plants have a much smaller concentrate volume, but compared to conventional fresh water treatment plants, concentrate volumes are quite high. Options for RO concentrate disposal include sewer disposal, evaporation ponds, deep well injection, irrigation, and surface water disposal [10,11]. However, each option has drawbacks and can be costly to implement; surface water and sewer disposal are typically the least expensive choices but both choices present issues with increased salinity in receiving waterbodies [12]. Therefore, concentrate disposal remains a key limiting factor for brackish water RO plants, particularly those built inland.

To reduce RO concentrate volume and increase recovery (the fraction of feed water that becomes product water), the concentrate can be treated to remove problematic precipitates, and most of the concentrate can be returned to the RO system for further desalination. Previous research on antiscalants and salt precipitation has demonstrated that the presence of antiscalants during precipitation reduces the extent of precipitation and may alter particle characteristics and subsequent filtration performance [13,14]. Accordingly, this study focuses on the novel three-stage concentrate treatment process shown in Fig. 1: antiscalant degradation, salt precipitation, and solid/liquid separation. Following concentrate treatment, the recovered water would be treated by a secondary RO or nanofiltration (NF) step, and the overall recovery of the system would be the combined recovery of the original RO stages and the secondary membrane treatment.

The key objective of this research was to evaluate the effect of antiscalant degradation on salt precipitation and solid/liquid separation (filtration). Data were obtained for the change in concentration of specific ions in solution, particle size distributions

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0376-7388/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.memsci.2010.09.040

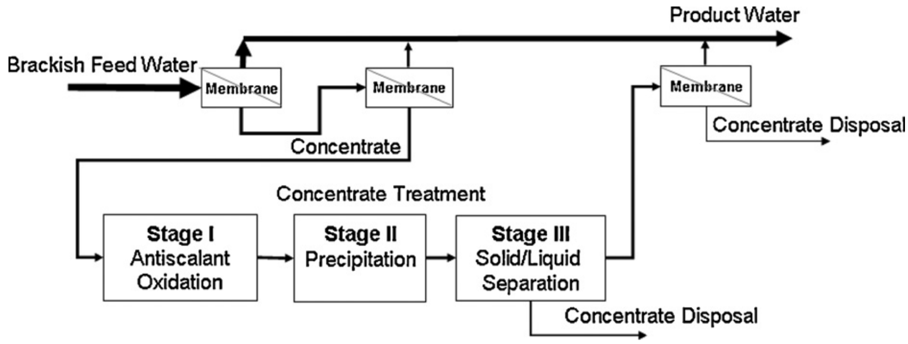

Fig. 1. Flow diagram of proposed brackish water desalination system including concentrate treatment.

of precipitates, particle morphology, elemental content of precipitates, and microfiltration of precipitated suspensions. The advanced oxidation process (AOP) of combined ozone (O_3) and hydrogen peroxide (H_2O_2), often called peroxone, was used to degrade organophosphonate antiscalants; the effects of several parameters, including ozonation time, antiscalant type, water composition, ratio of H_2O_2 to O_3, and normalized ozone dose (mg O_3/mg DOC), on antiscalant oxidation were evaluated. The results obtained from the combined ozonation–precipitation–separation experiments were used to calculate the increase in predicted overall RO recovery.

2. Background

Seawater sources have a total dissolved solids (TDS) content between 30,000 and 45,000 mg/L, while the TDS of most brackish waters ranges from 1000 to 10,000 mg/L [12]. The salt content limits its recovery for seawater RO systems to approximately 50%, while brackish water systems can achieve 70–90% recovery; however, recoveries greater than 80% are rare except for waters with an influent TDS of less than 1500 mg/L [15]. Brackish water RO membrane recovery is primarily limited by sparingly soluble salts that could precipitate and deposit on the membrane surface, creating an impermeable layer of scale. Low-solubility salts include calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), barium sulfate ($BaSO_4$), strontium sulfate ($SrSO_4$), and silicates. When each salt reaches its respective solubility limit during RO treatment, precipitation can occur, and irreversible membrane scaling causes either decreased permeate flow or increased feed pressure. Salt precipitation can be controlled using a combination of pH and chemical addition; chemicals called antiscalants are often used to limit precipitation [16–18]. While antiscalants allow RO recovery to increase above the point of salt saturation, precipitation can still occur in the presence of antiscalants at high values of supersaturation. As a result, novel RO concentrate treatment is necessary to increase RO recovery and decrease concentrate volume.

Various alternative strategies to conventional concentrate disposal have been investigated, including coupled membrane technology (RO combined with ultrafiltration or concentrate treated by seawater RO membranes), evaporation combined with salt production, and pre- or inter-stage treatment through salt precipitation [10,15,19–22]. The work on interstage salt precipitation has shown that a large portion of target ions (primarily Ca^{2+}) can be removed from the concentrate, enabling further RO treatment of the concentrate and increased overall recovery (from 90% to 97% for Colorado River water) [15]. However, the effect of antiscalants on the precipitation process has not been evaluated; although precipitation can be achieved when antiscalants are present, the chemicals are expected to have an influence on salt precipitation.

Two common classes of antiscalants are used in drinking water RO applications. One class is based on phosphonates alone and the other is based on acrylic acid with or without phosphonate blending. The four antiscalants used in this study, shown in Fig. 2, were chosen because they are often used in drinking water applications [23].

Little research has been done on the oxidation of antiscalant compounds [24]. Yang et al. used the Fenton process [24] to degrade antiscalants successfully, but this process would not be easily applied in municipal drinking water treatment systems because

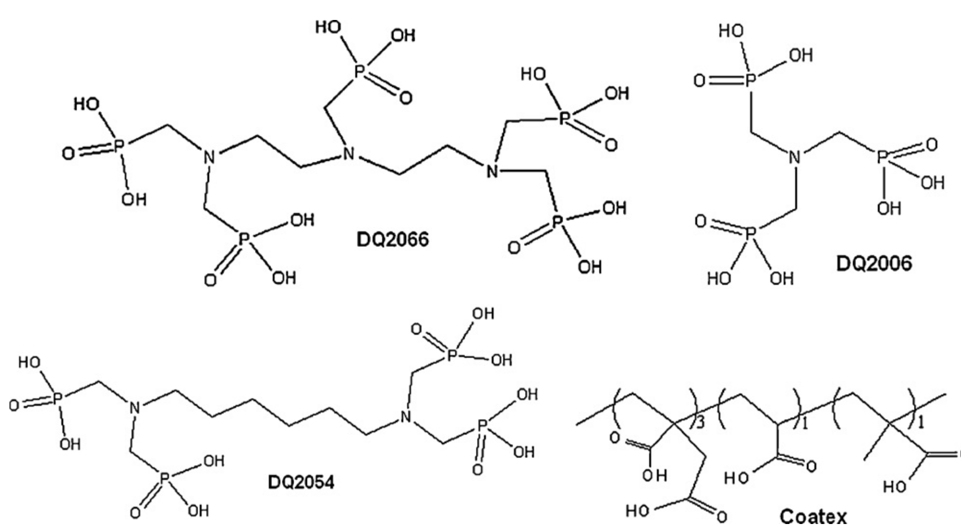

Fig. 2. Chemical structures of antiscalants DQ2066, DQ2006 (recommended for general metal ion control), DQ2054 (recommended for calcium sulfate control), and Coatex.