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Review

Treatment technologies for reverse osmosis concentrate volume minimization: A review

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ABSTRACT

Reverse osmosis (RO) is a well-established technology for treatment of impaired water sources and production of potable water. One of the major drawbacks with RO is the volume of concentrate (reject) produced during the process. Several technologies and process configurations, which are available for further treatment of RO concentrate, reduce the reject volume. In this paper, a comprehensive review of treatment technologies for treating RO concentrate from municipal and industrial sites to enhance the overall feed water recovery is presented. Treatment technologies are discussed according to their classification as membrane-based, thermal-based, or emerging technologies. All categories are capable of reducing RO concentrate volume, and in combination, can achieve zero liquid discharge. Membrane-based technologies are less energy intensive when compared to thermal-based technologies, but when the concentrate water quality is complex, such as with industrial effluents, the use of membrane-based technologies is restricted. Thermal-based technologies are capital intensive, consume a significant amount of energy and are not suitable for large flow rates. This review also addresses emerging technologies, such as forward osmosis (FO) and membrane distillation (MD) that show promise to efficiently treat RO concentrate, but these technologies are still under development and operational data on large scale facilities are limited. Selection of the best available technology for concentrate volume minimization will depend on several factors including the treated water quality, energy consumption, costs and technological development stage.

Contents

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1. Introduction

The production of potable water has become a worldwide concern today. Less than 3% of the earth's 330 million cubic miles of water is fresh and it is very unevenly distributed across the planet. For many communities, projected population growth and demand exceed fresh water resources [1]. It is estimated that over one billion people are without clean drinking water and approximately 2.3 billion people live in regions with water shortages [2]. As a result of demographic expansion, many areas in the world face the challenge of meeting ever-increasing water demands. In order to cope with this increasing water demand, many municipalities and other water suppliers are turning toward RO for desalination to supplement dwindling freshwater sources. Global and domestic implementation of RO technology has risen dramatically in recent years [1,3]. Apart from energy consumption, a key criterion for implementation of RO technology is the volume of concentrate produced during the process. The volume of concentrate generated is even more critical for inland RO plants located in areas far away from the ocean [4].

Common disposal options for RO concentrate are surface water discharge, deep well injection, evaporation ponds and land application [5]. Disposal of concentrate is site specific and the availability of any option depends on the concentrate quality and quantity. The cost of disposal is an important factor that needs to be taken into account before considering which option to employ [6–8]. Disposal options to surface waters include discharge to rivers, bays, tidal lakes, brackish canals, or oceans [9]. Faced with extensive and costly permit reviews, some plants have avoided surface water discharge in favor of other options [10]. Dilution or blending of high ionic strength residuals with other wastewaters is another option. In addition, concentrate blended with industrial or municipal wastewaters can undergo further treatment or be disposed by release to publicly owned treatment works (POTW) [10,11]. Deep-well injection enables concentrate to be pumped into porous subsurface rock formations with well depths varying from a few hundred feet to several thousand feet depending on the geological conditions at the site [12,13]. Evaporation ponds are another disposal option. They are most appropriate for small flows and for regions having a relatively warm, dry climate with high evaporation rates, level terrain and low land costs [5]. Land application methods for concentrate disposal consist mainly of disposal to creeks and ponds [14].

In order to reduce the volume of RO concentrate and disposal costs, several zero liquid discharge (ZLD) and near-ZLD (feed water recovery of 95–98%) technologies have been utilized in the past. ZLD technologies have been considered as an uneconomical option and were employed in limited cases in the past [4]. However, with the development of new ZLD technologies, more cost-effective options are now available. Treatment of concentrate from nanofiltration (NF) and RO processes was reviewed by Van der Bruggen et al. [15]. Different system configurations for reuse, treatment and discharge of concentrate were discussed but detailed information on concentrate treatment technologies was not provided. More recently, various types of concentrate volume minimization approaches were reviewed by Pérez-González et al. [16], but the work primarily focused on treatment of RO concentrate during municipal and wastewater treatment with limited focus on system configurations used for other applications. Thus, in the current review, an up-to-date comprehensive review of technologies and system configurations are provided that can be applied for the treatment of RO concentrate generated from both municipal and industrial water treatment plants.

2. Characteristics of RO concentrate

Feed water recovery of RO is dependent on the concentration factor (CF) defined below [17,18],

$$C_F = \frac{C_c}{C_F} = \left(\frac{1}{1-R}\right)[1 - R(1 - R_s)] \quad (1)$$

where C_C and C_F are the retentate and feed concentrations, respectively. R is the fractional feed water recovery and R_S is the nominal salt rejection. The concentration factor increases sharply as the feed water recovery increases above 80% [19]. Thus, it is essential to evaluate the solubility limits of scaling ions of concern to determine the treatment option for RO concentrate. Treatment of RO concentrate depends on the concentration of contaminants present in the water. For concentrate generated from desalination of brackish groundwater, the primary constituents of concern are calcium, barium, silica and sulfate [20,21]. Presence of high concentrations of calcium, barium and sulfate will result in exceeding the saturation limits of calcium carbonate ($CaCO_3$), calcium sulfate ($CaSO_4$), and barium sulfate ($BaSO_4$), thereby restricting the feed water recovery of the RO process. When concentrate from wastewater treatment plants is utilized, scaling due to the calcium phosphate ($CaPO_4$) will result in restricting the feed water recovery.

Typically, up to a Langelier Saturation Index (LSI) of 3.0 for $CaCO_3$, 6000% saturation of $BaSO_4$ and 250% saturation of $CaSO_4$ in the concentrate can be handled using antiscalants [17,18,20,21]. For controlling $CaCO_3$ and $CaPO_4$, a low feed pH with acid addition along with antiscalants is necessary to prevent scaling of the membranes [22,23]. Unlike $CaCO_3$, scaling due to $CaPO_4$