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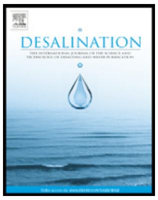

Theoretical study on feed water designs to reverse osmosis pressure vessel

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HIGHLIGHTS

- Single, central and end feed pressure vessels were investigated.
- Feed SDIs 5, 3 and 1 were simulated.
- Scale fouling was lower in single & central feeds than in end feed.
- Power consumption was lower in end feed than in the other designs.
- Capital cost was lower in the case of end feed design.

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ABSTRACT

Scale fouling and power consumption are one of the most important parameters in reverse osmosis (RO) desalination. To reduce scale problems in RO, single or central feeds to the pressure vessel were suggested instead of using end feed. In this paper Reverse Osmosis System Analysis (ROSA) software was used to simulate the differences between single, central and end feed designs. The effect of feed Silt Density Index (SDI) and number of the RO elements in the pressure vessel were investigated here. Feed SDIs 5, 3, and 1 were considered in this paper. To study the effect of the numbers of RO elements, 6 RO and 8 RO elements per pressure vessel were simulated. The simulation results showed that the power consumption in the end feed design was lower than in the single and central feed designs. The simulation results showed that Langelier Silt Index (LSI) and Stiff & Davis Stability Index (SDSI) were lower in the single than central feed design which in turn was lower than in the end feed design. These results indicated that although the power consumption in the single and central feed designs was higher than in the end feed design; the former designs were more efficient in rescuing the RO scale problems.

1. Introduction

Since commercialization in early 1970s, reverse osmosis (RO) membrane has been widely used in brackish and seawater desalination [1–4]. The wide applications of the RO technology were attributed to its efficiency and reliability in treating saline water. It has several advantages over the thermal processes which made it an attractive alternative in seawater desalination [4–6]. High salt rejection and recovery rate can be achieved in the RO processes but at lower power consumption than the thermal processes [4,7]. Furthermore, the membrane treatment has smaller footprint and can easily retrofit in an existing plant design [8,9].

In practice, seawater is pressurized and pumped into a pressure vessel that contains a number of RO membranes. Seawater enters the pressure vessel at one end while permeate and concentrate products are collected from the other end. Up to 8 RO elements are usually loaded in the pressure vessel in order to increase the recovery rate of the RO system [10]. The recovery rate in the RO system can reach up to 50% depending on the seawater salinity, pretreatment technique and temperature. Typically, seawater conversion rate decreases proportionally from the lead to the tail or the last element in the pressure vessel. Simultaneously, the feed salinity increases gradually from the lead to the tail elements. As a result the scaling potential of RO membranes increases towards the tail element, while the recovery rate is decreasing. There are some measures usually taken to prevent or reduce scaling problems of the tail elements including the use of anti-scalant, membrane treatment, and chemical softening of feed water [4,6,10,11]. Scale removal from seawater, however, tends to increase the desalination cost and hence it is not always economical. Alternatively, a central feed mode has been suggested to overcome scaling problems at the tail elements [12]. In the proposed design, feed water enters the pressure vessel through a central port at which it splits to feed the RO elements distributed evenly on both sides of the pressure vessel. Such design has the advantage of lowering the scale potential at tail elements and increasing the flux of element. But it requires a higher feed flow rate to meet the design criteria of membrane manufacturers.

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This study investigates the differences between central and end feed RO pressure vessel for seawater desalination. The importance of this study is to identify the key design issues and the advantages and disadvantages of each design. It is well known that the average system flux recommended by membrane manufacturing companies is dependent on the feed seawater quality which is in turn affected by the pretreatment process. This is due to the variation in the Silt Density Index (SDI) of seawater from different pretreatment processes. The better the pretreatment the lower the SDI of seawater and hence the higher average flux can be reached by the RO system [1,4,11–14]. Typically, feed water from NF/RO pretreatment has an SDI < 1 while an 1 < SDI < 3 can be obtained when MF/UF pretreatment is used [13,15–17]. For conventional seawater intake and conventional sand filtration pretreatment the SDI of the feed water is 3 < SDI < 5. In RO membrane desalination, SDI value is the common indicator of membrane fouling. For spiral wound membranes the recommended SDI of feed water should be less than 5, but lower SDI are preferable. In this paper the effects of three different SDI values on the performance of RO membrane, depending on the pretreatment method, were investigated. SDI values of 1, 3 and 5 were investigated for three types of feed water design; single, central, and end feed designs. Reverse Osmosis System Analysis (ROSA) software by Filmtec [18] was applied throughout this study to simulate these designs. The effects of each design on power consumption in terms of specific energy consumption, i.e. kWh/m^3, capital cost and scale potential in RO membranes were investigated.

2. Theory

In conventional RO membrane system, seawater is fed into membrane elements packed in a pressure vessel through one end, while product water and brine is collected from the other end (Fig. 1). Up to 8 RO elements can be loaded in the pressure vessel for seawater desalination. Such design is efficient to increase the recovery rate of the RO system but it also has some disadvantages such as high scale potential and low recovery rate in tail elements (Fig. 1). Alternatively, single and central feed design pressure vessels have been proposed to reduce fouling potential in the tail elements. However, the recovery rate of RO system in the single and central feed designs are lower than that in the end feed design. As a result, the capital cost of the RO system could be different in each design. This issue should be taken into account in the system design as most companies try to reduce the capital cost. But the maintenance cost of the RO system can be reduced in the central feed design because of the lower fouling propensity of the tail elements.

In this study three RO systems are considered. The first system represents the end feed design, the second system is the central feed design, and third is the single feed design. In the latter design each RO element in the pressure vessel has its own feed stream. Three pretreatment options were considered throughout this study. These are:

1. Open seawater intake in which a conventional pretreatment in which sand filters followed by cartridge filters are used for seawater treatment to give SDI < 5
2. MF/UF pretreatment to produce feed water to RO of SDI < 3
3. NF permeate which usually has SDI < 1.

The first and second options are normally used in conventional seawater pretreatment to RO membranes while in the third option NF pretreatment is applied to remove scale ions from seawater. While in option three, the end and central feed designs were mainly challenged for their efficiency to reduce the capital cost, options one and two were applied to reduce the fouling potential in tails elements of the RO system. Therefore, feed water to RO system in options one and two contained divalent ions as well as monovalent ions. Because it is NF pretreated, the feed water to RO system in option 3 will be free from scale ions and they were assumed to be Na & Cl ions only. The compositions of feed waters are listed in Table 1.

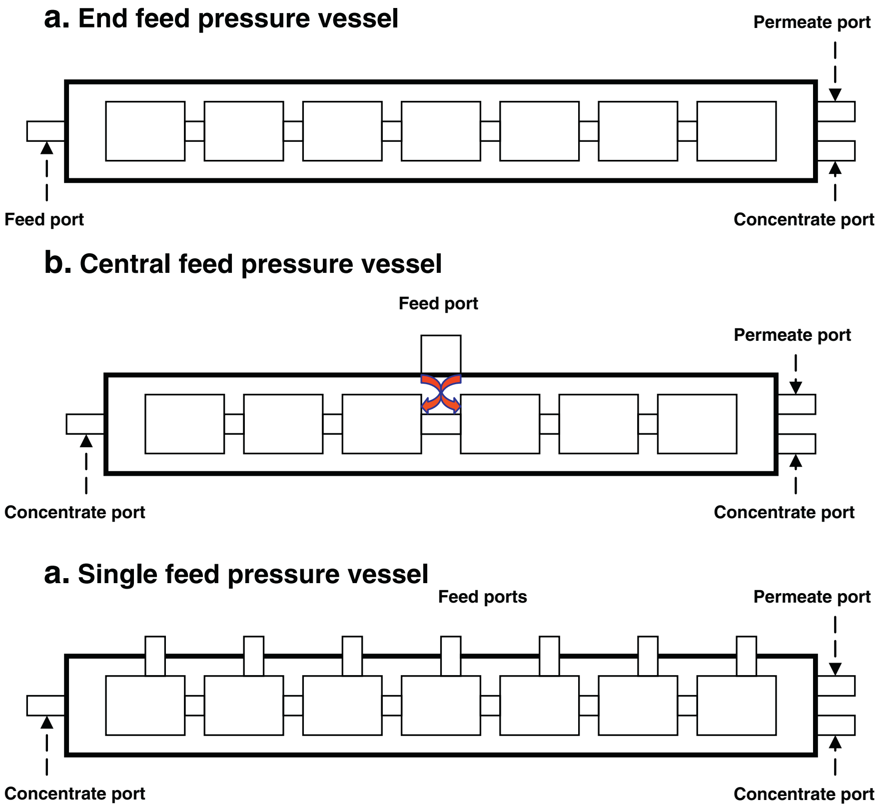

Fig. 1. Schematic diagram of end and central feed pressure vessel.