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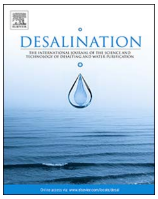

Theoretical analysis and auxiliary experiment of the optimization of energy recovery efficiency of a rotary energy recovery device

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ABSTRACT

A rotary energy recovery device (RERD), as the energy saving equipment of seawater desalination system, has a great significance on reducing the energy consumption and permeate cost of the system. The high or low energy recovery efficiency directly determines whether the engineering application of the RERD can be widely used. In this paper, firstly, based on the calculation formula of energy recovery efficiency, the main impact factors of efficiency were analyzed theoretically, including processing capacity, the high and low pressure differentials, and the leakage of the device. Secondly, in order to carry out some required auxiliary tests smoothly, a new RERD was designed and manufactured, and a complete SWRO desalination system was also established. The results depicted that the energy recovery efficiency reached the maximum and the corresponding optimal processing capacity was about 12.15 m^3/h when the pressure of the low pressure seawater was 1.0 bar, that of the high pressure brine was 60.0 bar, and leakage of the device was 0.6 m^3/h. Furthermore, when processing capacity was kept 13 m^3/h constant and the efficiency was required to exceed 94%, under the existing operating conditions, the maximal leakage of the device was needed no more than 0.43 m^3/h.

1. Introduction

With the rapid development of membrane technology recently, seawater reverse osmosis (SWRO) has become the most promising seawater desalination technology, which can offer affordable yet effective solutions to produce suitable and sustainable supplies of freshwater for local populations, agriculture and industry [1,2]. Energy recovery device (ERD), as one of the core components of the SWRO system, has a great significance on reducing the cost of seawater desalination [3,4]. From past to present, there are many ERDs developed to recovery pressure energy from the concentrate reject stream [3,5,6]. These ERDs are divided into two categories: one is centrifugal energy recovery devices and the other is the isobaric energy recovery devices [7,8]. Nowadays, there are two general patterns of isobaric ERDs that employ positive displacement mechanisms, including piston-type work exchangers like the DWEER and the rotary energy recovery devices (RERDs) like the PX [9,10]. The RERDs offer the additional benefits of operational flexibility, installation convenience, ease of control, in addition to energy savings, which has attracted more and more public attention [11,12].

It is critical to improve the energy recovery efficiency of ERDs which directly determines whether engineering applications of ERDs can be realized and this has been also the focus of the research field. In recent years, improvement of energy recovery efficiency of ERDs has been investigated intensely by some experts or authors. R.L. Stover [13] studied the efficiency losses of the RERD and estimated that about 4% pressure transfer efficiency was lost to the internal leakage or lubrication. Later, R.L. Stover made a comparison between the DWEER and PX device. From his research we could know that the efficiency of the PX device was higher because the high and low pressure differentials through the PX device were lower than DWEER though the lubrication flow required by the two types of the devices was almost identical [13]. Wang [14] made investigations on characteristics and efficiency of a positive displacement energy recovery device. The result depicted that pressure of high pressure brine had a positive effect on energy recovery efficiency of the device and speculated a higher efficiency could be reached when this kind of ERD was used in brackish water or SWRO processes. Qi [15] focused on the theoretical investigation of internal leakage and its effect on the efficiency of a newly developed pilot-scale fluid switcher-energy recovery device (FS-ERD) for SWRO system. The results of his work implied that low internal leakage and high retentate brine pressure brought benefits to achieve high FS-ERD efficiency. The

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leakage can not only reduce permeate flow for a given high pressure pump flow rate, but also decrease the energy recovery efficiency of the ERDs, therefore, a lot of efforts have been made to improve the energy recovery efficiency of the ERDs. Li [16] designed a special structure to reduce the leakage and abrasion. The experimental result proved that the novel fully-rotary valve energy recovery device (FRV-ERD) had low pressure loss and excellent energy recovery efficiency. Xu [17] introduced a hydrostatic bearing structure employed in the RERD in order to establish a fluid film lubrication environment for the rotation of the rotor, which can improve the frictional state of the rotor and improve the energy recovery efficiency. In order to reduce the effect of leakage across seals, hard mating materials and tight clearances have to be adopted in the RERD. For instance, Wu [18] employed groove-textured surfaces of two end covers to improve dynamical seal performance in membrane desalination system. The experimental results showed that the energy recovery efficiency of the device with groove-textured surface was 7.6% higher than that of the untextured. However, few attempts have been made so far to study the optimization of energy recovery efficiency of the RERD by theoretical analysis and some auxiliary experiment.

In the present study, a new RERD was designed specifically and the layout of the whole reverse osmosis system was also established. The energy recovery efficiency of the device varied with the change of the operating variables include the processing capacity, leakage, and even pressure losses of high pressure and low pressure fluids which is easily overlooked. Therefore, the objective of this paper is from a new perspective to analyze how to improve the energy recovery efficiency for a specific RERD and an established SWRO desalination system. According to the theoretical analysis and some auxiliary experiment, the optimal processing capacity was determined and the maximal leakage was specified for the designed RERD operated in the established SWRO system.

2. Rotary energy recovery device (RERD)

2.1. Description of working principle of the RERD

The working principle of the rotary energy recovery device utilizes the Pascal principle [19]. Fig. 1 provides the schematic representation of the RERD. As seen in Fig. 1, the core components of the RERD are composed of the feed water end cover, the rotor, the rotor sleeve and the concentrate end cover. The feed water end cover contains a port for incoming low pressure feed water, and a port for outgoing pressurized seawater. The concentrate end cover likewise embodies two ports consisting of a high pressure brine inlet and a depressurized brine outlet. The rotor containing axial ducts arranged in a circle is fit into a rotor sleeve between the feed water end cover and the concentrate end cover. In addition, the rotor is only rotating part of the device.

In the operation process of the device, the high pressure brine directly pressurizes the low pressure seawater and drives the pressurized seawater to be discharged from the pressurized seawater outlet, this is called "pressurization process". As the rotor continues to rotate, the rotor ducts enter the sealing area which prevents the ducts from streaming each other and at this time the fluid is sealed and the pressure remains constant. The rotor continues to rotate, the low pressure seawater enters the low pressure side and drives the depressurized brine discharged from the depressurized brine outlet, which is called "depressurization process". Through the continuous rotation of the rotor, the rotor ducts alternate from the high pressure side-sealing area-low pressure side, to achieve continuous fluid pressure exchange process.

2.2. Theoretical calculation of rotor inflow height (L)

In order to make some required auxiliary experiment done smoothly, a new RERD was designed by referring to the relevant *mechanical design manual*. Fig. 2 illustrates through a picture of the overall outline of the device.

In the designing process, rotor inflow height (L) needs to be taken into account. If the rotor inflow height is too small, the device will not be able to carry out effectively pressure exchange. Likewise, if the height is too large, the volumetric efficiency of the device will be reduced. Fig. 3 displays the coverage diagram of the rotor duct and the end plate sumps. The theoretical calculation of rotor inflow height was performed here.

Herein the rated processing capacity of the device is Q (m^3/h), the period of rotation of the rotor is T (s) and the rotation speed of the rotor is n (r/min). Then the calculated value of period is $T = 60/n$.

It is assumed that the time from the beginning of one duct of the rotor into the end plate sump to the ending of completely transferring out the sump is t (s). The following formula will be held.

$$t = \frac{\alpha + \beta}{360^\circ} T = \frac{\alpha + \beta}{360^\circ} \frac{60}{n} \tag{2-1}$$

α the angle of the end plate sump occupied in the center;
β the angle of the rotor duct occupied in the center;

Let the average velocity of the fluid into a single duct be v (m/s), then:

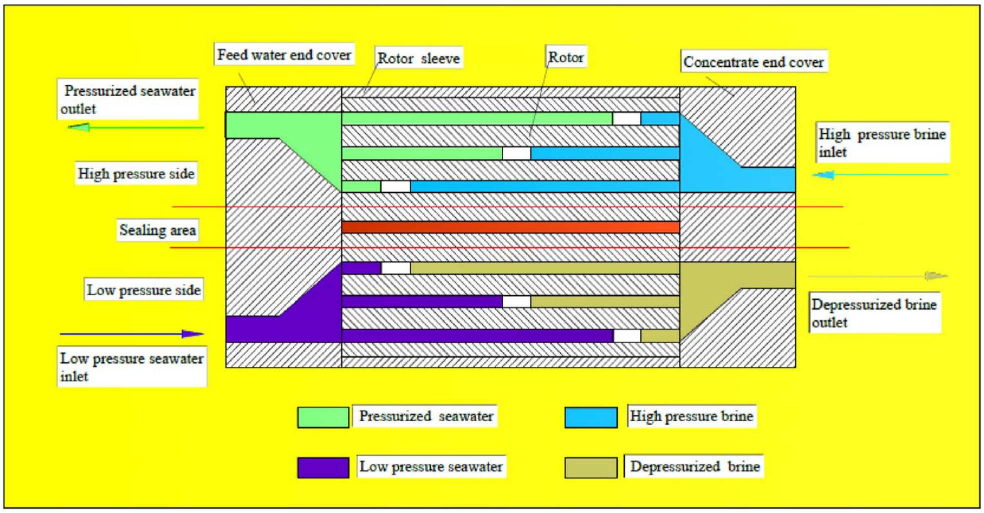

Fig. 1. The schematic representation of the RERD.