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Functionality test of an innovative single-cylinder energy recovery device for SWRO desalination system

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HIGHLIGHTS

- An innovative single-cylinder energy recovery device is introduced and developed.
- Two new plates greatly improve power consumption and flow continuity of the device.
- Functionality and reliability of the SC-ERD are well verified through experiments.

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ABSTRACT

Energy recovery devices (ERDs) are widely used in seawater reverse osmosis (SWRO) desalination systems, and have become a vital facility of the system due to their great contribution for significant reductions of the power consumption. The innovative single-cylinder ERD (SC-ERD) technology is an improved pressure exchanger concept which follows the principle of positive displacement, and provides more advantages than the current devices, including the simple installation, flexible operation and stable performance. This paper focuses on verifying the functionality of the SC-ERD and evaluating its operating performance based on the industrial conditions. Experiments are carried out by using two sets of SC-ERD working in parallel and the performance of the devices are evaluated by employing an inhouse emulational SWRO system with the flow rate of 30 m^3/h and the operating pressure of 6.5 MPa. The experimental results show that two SC-ERDs in parallel have reached the basic function of the double-cylinders ERD (DC-ERD). The pressure fluctuation of the SC-ERD has been reduced about 80% compared with the DC-ERD under the same operating conditions and the energy recovery efficiency could still be remained as high as 98%.

1. Introduction

The application and continuous improvement of seawater reverse osmosis (SWRO) desalination technology have reduced the power consumption of the system significantly, and make it possible to produce affordable potable water at a minimum cost [1–3]. Energy recovery device, as an indispensable component of the SWRO system, is of striking importance for significant reduction of the energy consumption by means of transferring the pressure energy in the reject stream to the seawater feed. The isobaric and the centrifugal energy recovery device (ERD) are two typical categories of the ERD. The former one transfers the pressure energy in a direct way and owns a higher efficiency than that of the later one and has become the research focus of the field [4–6].

At present, Flowserve's Duplex Work Exchanger Energy Recovery (DWEER) and KSB's SalTec DT are two typical commercial products of the isobaric ERDs [7–9]. Both of them consists of three subassemblies that are the actuated switcher (also called LinX valve or rotating valve), the hydraulic cylinders and the passive check valve nest. The role of the actuated switcher is to direct the high pressure (HP) brine and low pressure (LP) brine to flow into and out of the hydraulic cylinders periodically on the brine side. The hydraulic cylinders provide the main location for pressure exchanging. The passive check valve nest is used to direct the LP seawater and HP seawater flow into and out of the cylinders respectively on the feed side. The continuity of the pressure exchanging and recycling can be insured by the sequential alternation of pressurization and depressurization strokes occurring in hydraulic cylinders through the switcher.

The common features of the products lie in two aspects, the necessary configuration of the switcher with two parallel cylinders, a relative separate pressurization or depressurization stroke in each cylinder [10]. Based on the common features mentioned above, the products

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were also called double-cylinder ERD (DC-ERD) for easy distinction from the innovative ERD introduced in this paper.

Since the DC-ERDs have been commercially used in SWRO plants for many years, their limitations and inadequacies existing in practical applications begin to be recognized in recent years. On the one hand, the installation precision between the switcher and the hydraulic cylinders is rigorous, which increases the installation difficulty of the DC-ERD. On the other hand, in order to meet the needs of the large or mega SWRO system, multiple units of the DC-ERD are usually arranged in parallel. Thus, the DC-ERD has some difficulties in contenting a capacity variety of SWRO desalination plants by using minimum ERD units and in a flexible way, since the capacity of each DC-ERD unit is generally designed extremely large.

According to the configurative characteristics of DC-ERD, though two hydraulic cylinders are configured with one switcher, they implement the stroke independently under the help of same check valve configuration pattern, which provides the basis for the realization of an innovative single-cylinder ERD (SC-ERD). The SC-ERD attempts to release the installation precision requirement as well as enlarge capacity gradually by arranging multiple SC-ERDs in parallel to satisfy different level capacity needs of SWRO desalination plants.

The SC-ERD concept was first introduced and used in product design by KSB AG. In 2011, a new product named SalTec N system was shown in IDA World Congress by the company [11]. The traditional DC-ERD unit SalTec DT is replaced by the SC-ERD unit SalTec N. Each switch is connected with one hydraulic cylinder to form an independent operating unit. Multiple units in parallel can achieve continuous operation of the energy recovery system.

In our previous works, a DC-ERD called reciprocating-switcher energy recovery device (RS-ERD) was designed and investigated [12]. On the basic of RS-ERD, an improved SC-ERD with a nominal capacity of 30 m^3/h was designed and structurally analyzed in this paper. The functionality and basic performances of SC-ERD are experimentally evaluated in an emulational SWRO system by employing two sets of SC-ERDs working in parallel under the flow rate of 30 m^3/h and operating pressure of 6.5 MPa. As a result, the outcomes of the related performance including the curves of flow and pressure, internal leakage and energy recovery efficiency are assessed and compared with our previous studies.

2. Description of the SC-ERD

2.1. Structural design of the SC-ERD

A schematic representation of the structural components of SC-ERD is provided in Fig. 1. The SC-ERD mainly consists of three subassemblies that are the single-cylinder-switcher (SC-switcher), the sole hydraulic cylinder and the passive check valve pair. The SC-switcher is the core component of the SC-ERD, whose role is to guide the HP brine and the depressurized brine to flow in and out of the hydraulic cylinders periodically, and also to keep the continuity and stability of pressure exchanging in the cylinder. The check valve pair comprised of two parallel check valves directs the raw seawater and pressurized seawater to flow in and out of the cylinders, respectively. A free piston in the cylinder is used to prevent the salinity mixing between the brine and the seawater streams.

Due to the unique configuration of the SC-ERD, only one stroke (either the pressurization stroke or the depressurization stroke) could be carried out at a time, thus a minimum of two SC-ERD units which operate out of phase all the times is needed to ensure the continuity of pressure exchanging process. Also, by operating two SC-ERD units in parallel, the basic function of RS-ERD should be realized.

As the core and executive component of the SC-ERD, the SC-switcher mainly comprises two parts, the hydraulic actuator and the switching valve. The internal structure of the SC-switcher is shown in Fig. 2. In order to minimize the operational costs of the ERD itself, water hydraulic actuator is applied, which uses HP brine from the desalting system as the medium to drive the switcher [13]. The SC-switcher valve contains two flow channels which are associated with three related port, including the HP brine inlet, the LP brine outlet and the hydraulic cylinder connecting port. In order to better satisfy the forcing needs of the water hydraulic actuator, a pre-pressurization plate and a pre-depressurization plate are typically incorporated in the SC-switcher except the basic HP sealing plate and the LP sealing plate.

When the SC-switcher lies in its backward stroke as shown in Fig. 2, the pre-depressurization plate and the LP plate will be firstly closed, then the pre-pressurization plate and the HP plate could be opened sequentially under the drive of the water hydraulic actuator. On this condition, the HP inlet port and the hydraulic connecting port get communicated and the HP channel of the SC-switcher is established. Contrarily, when the SC-switcher lies in the forward stroke as shown in Fig. 3, the pre-pressurization plate and the HP plate will be firstly closed, then the pre-pressurization plate and the LP plate could be opened sequently. On this condition, the LP outlet port and the hydraulic connecting port get communicated and the LP channel of the SC-switcher is established. In the paper, in order to overlap the pressurization processes in two parallel SC-ERDs, the HP plate pair in 1# ERD unit should be opened before another HP plate pair of 2# ERD was closed during the position switch of the hydraulic actuators.

The unique structures of the SC-ERD make it have many advantages. First of all, the section area of the pre-pressurization plate and pre-depressurization plate is significantly reduced comparing to that of HP plate and LP plate. The reduction is favorable for minimizing the driving force of the hydraulic actuator and thus the operating cost of the SC-ERD itself. Besides, the pre-pressurization plate or pre-depressurization plate will be opened first and permits only a small part of the fluid flow through, which is useful for avoiding the occurrence of cavitation phenomenon in SC-ERD. In addition, both the LP plate pair and the HP plate pair of the SC-ERD can achieve good sealing adaption since the seal greatly relies on the internal flow pressure differential between HP brine and LP brine. Finally, the flow cross-sectional area needed inside SC-switcher can be formed through a relative short-distance movement of each plate, which contributes to reducing the running distance and switching time of the actuator.

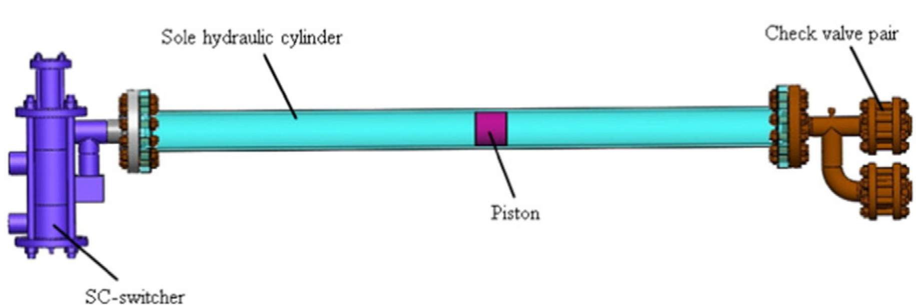

Fig. 1. Structural components of the SC-ERD.