Desalination 398 (2016) 189–197

Contents lists available at ScienceDirect

Desalination

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

Theoretical investigations on rotor speed of the self-driven rotary energy recovery device through CFD simulation

Enle Xu [a,b,c], Yue Wang [a,b,c,*], Jie Zhou [a,b,c], Shichang Xu [a,b], Shichang Wang [a,b]

[a] *Chemical Engineering Research Center, School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, PR China*
[b] *Tianjin Key Laboratory of Membrane Science and Desalination Technology, Tianjin 300072, PR China*
[c] *Collaborative Innovation Center of Chemical Science and Engineering (Tianjin), Tianjin 300072, PR China*

HIGHLIGHTS

- A simple way to calculate the rotor speed of self-driven RERD was presented.
- Impulse torque was studied at different flow rates and oblique ramp angles.
- A theoretical formula for calculating the rotor speed was built for the self-driven RERD.
- Experimental rotor speed is in agreement with that of the CFD and theoretical results.

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 23 July 2016
Accepted 25 July 2016
Available online xxxx

Keywords:
Computational fluid dynamics
Rotor speed
Impulse torque
Rotary energy recovery device

ABSTRACT

The theory about how to calculate the rotor speed for a self-driven rotary energy recovery device has been investigated by methods of computational fluid dynamics simulation and validating experiments in this paper. Rotor speed can be obtained according to impulse torque of the rotor and its frictional resistance. Impulse torque was simulated at different flow rates and oblique ramp angles, and the frictional resistance can be calculated according to the Newton's law of viscosity. Simulative rotor speed was in agreement with the experimental rotor speed, indicating that the simulation model was reasonable. Based on the simulation results, a theoretical formula was established between rotor speed and key dimensions of the self-driven device, which provides a simple way to calculate and predict the rotor speed in the designing of an eligible device.

1. Introduction

As an important water desalination technology, sea water reverse osmosis (SWRO) technology is now a well-established water desalination way to alleviate the water crisis globally [1–4]. The rotary energy recovery device (RERD) can effectively recover the pressure energy from the rejected high pressure brine on the principle of positive displacement [5,6] and is well known and widely used in the SWRO desalination, where energy costs account for saving approximate 40% of the operating cost [7–9].

The schematic representation of the RERD is provided in Fig. 1. The core components of the RERD are the seawater endcover, the rotor, and the brine endcover. The seawater endcover contains a port for incoming low pressure seawater (LP-IN), and a port for outgoing high pressure seawater (HP-OUT). The brine endcover likewise embodies two ports (HP-IN and LP-OUT) [10]. The rotor containing axial ducts arranged in a circle is fit into a rotor sleeve between the seawater endcover and the brine endcover. The RERD transfers the hydraulic energy from the rejected high pressure brine to the low pressure seawater by putting the streams in a direct, momentary contact in the rotor ducts [5,11,12]. At any time, half of the rotor ducts are exposed to low pressure stream and the other ducts to the high pressure stream [13]. As the rotor turns, the ducts pass a sealed area that separates high and low pressure areas [14].

The rotor is the only rotating part of the device, which is driven either by a motor or by the streams into the rotor channels. Usually, the RERD with the later driven mode was defined as the self-driven device such as the PX device [10] which has been widely used in many SWRO plants due to the advantages of not needing a motor and easy operation. The rotor speed is a key parameter to determine the mixing of the device, which is one of the main parameters that qualify the performance of the device [11]. However it is difficult to measure and adjust the rotor speed on the basis of the flow rate timely in order to limit the mixing to a certain level for self-driven RERD. A suitable rotor speed needs to be obtained based on the flow rate of the device during its design phase.

---

[*] Corresponding author at: Chemical Engineering Research Center, School of Chemical Engineering and Technology, Tianjin University, Tianjin 300072, PR China.
E-mail address: tdwy75@tju.edu.cn (Y. Wang).

http://dx.doi.org/10.1016/j.desal.2016.07.038

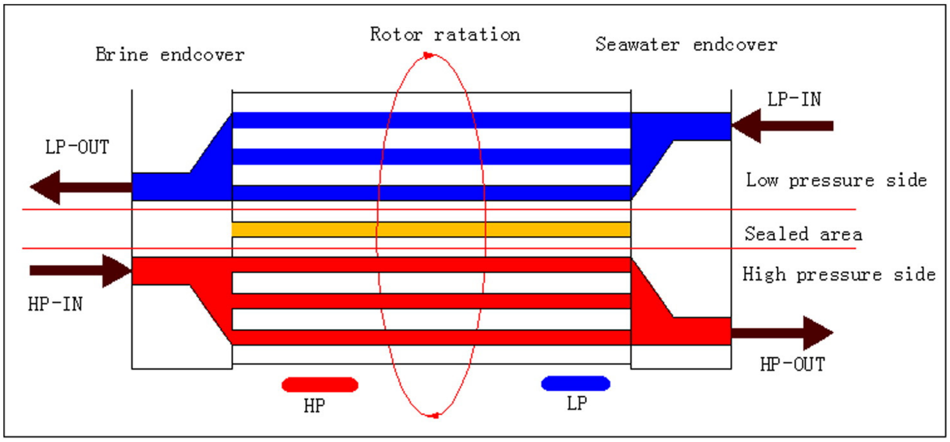

Fig. 1. The schematic representation of the RERD.

So it is significant to build the relation between the rotor speed and the flow rate in order to design an elegant self-driven device.

Leif Hauge [15] illustrated the impulse momentum principle for self-driven device and indicated that the rotor speed has a relation with the oblique ramp, the stream velocity and frictional resistance of the rotor. Gonzalo G. Pigue [16] discovered that the oblique ramp angle in HP-IN port cause directional flow of high pressure fluid into the rotor ducts to force the rotor to revolve in a first angular direction, while reverse oblique ramp in LP-IN port cause directional flow of low pressure fluid into of the rotor ducts to provide an additive impetus to boost the rotor to revolve in the first angular direction. The oblique ramp at an appropriate angle within the range of about 12° and 65° was also given. In conclusion, previous research have revealed that the oblique ramp and the stream velocity are the main factor affecting the rotor speed, but the specific relationship or function was not given among the oblique ramp, the flow rate, frictional resistance of the rotor and the rotor speed.

The paper aims to find a proper way to calculate the rotor speed according to the frictional resistance of the rotor and its impulse torque, to reveal how the oblique ramp angel and the flow rate influence the rotor speed, and to establish a theoretical formula about the rotor speed.

2. Experiments

The experiments to measure the rotor speed were carried out with a self-driven RERD in our laboratory. For this device, the rotor speed was determined by the flow rate and its oblique ramp angel. Fig. 2 provides the two-dimensional central cylindrical diagram of the endcover. The angle α in this figure was defined as the oblique ramp angle which is about 20° for the device.

Fig. 3 shows the picture of the experimental device. As the rotor was laid in a confined space, the laser velocimeter which is a typical non-contact method of measuring speed was chosen to measure the rotor speed. The laser from the laser velocimeter can pass through the glass window showed in Fig. 3, and is reflected by four reflective sheeting symmetrically glued on the rotor, and returns to the laser velocimeter through the glass window. The velocimeter can calculate the rotor speed according to the interval between the reflections with a testing range of about 0 to 9999 rpm and a precision of about ±12 rpm.

The experimental flow diagram is given in Fig. 4. Fresh water was used in the experiment instead of the seawater and brine, because the density of the three fluids is similar and its corresponding influence on the rotor speed is not significant. The fresh seawater pump provided the low pressure fluid to the device, the booster pump was used to circulate the high pressure fluid within the system, and the high pressure pump was adopted to maintain a high pressure environment in this system. The pressure of the high pressure fluid was adjusted by a bypass valve V1. The flow rate of the high pressure fluid and the low pressure fluid were adjusted by valve V2 and V3, respectively. A data-acquisition system was designed and incorporated in the experiment. The pressure and the flow rate of the streams in and out the RERD were measured through the corresponding transducers with a precision of ±0.5%.

During the experiment, the pressure of HP-IN was 6.0 MPa which is referenced according to the working pressure of the SWRO. The experimental flow rate ranged from 7.0 m^3/h to 11.0 m^3/h, and the flow rate of HP-IN was always maintained equal to that of the LOW-IN.

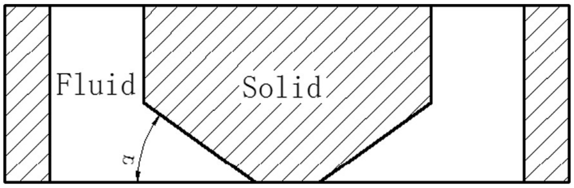

Fig. 2. Two-dimensional central cylindrical diagram of the endcover.

Fig. 3. Picture of the experimental device.