Design and optimization of a large flow rate booster pump in SWRO energy recovery system

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Abstract. Seawater reverse osmosis (SWRO) is a high energy-consumption industry, so energy efficiency is an important issue. Energy recovery systems, which contain a pressure exchanger and a booster pump, are widely used in SWRO plants. As a key part of energy recovery system, the difficulty of designing booster pumps lies in high inlet pressure, high medium causticity and large flow rate. High inlet pressure adds difficulties to seal design, and large flow rate and high efficiency requirement bring high demand for hydraulic design. In this paper, a 625 m$^3$/h booster pump is designed and optimized according to the CFD (Computational Fluid Dynamics) simulation results. The impeller and volute is well designed, a new type of high pressure mechanical seal is applied and axial force is well balanced. After optimization based on blade redesign, the efficiency of the pump was improved. The best efficiency reaches more than 85% at design point according to the CFD simulation result.

1. Introduction

Seawater desalination is a practical approach to settle water supply crisis. The Seawater Reverse Osmosis (SWRO) is the most widely used desalination method with a market share of more than 60%. The large energy consumption is the main bottleneck of SWRO, so most SWRO factories have applied energy recovery system to reduce energy consumption. The energy consumption of SWRO process reached 12kWh/m$^3$ in 1960s, it reduced to 3.4 kWh/m$^3$ after applied 6 PX energy recovery system at Yueqing Power Plant[1] and 2.56 kWh/m$^3$ in Liuheng SWRO Plant[2].

Figure.1 introduces SWRO system process[3]. After entering the process, some of seawater is pumped to entrance of reverse osmosis membrane with a pressure of 5.8~8.0MPa by a high pressure pump. Some turns to fresh water, the rest still reaches 5.5~6.0MPa in pressure and goes through a pressure exchanger, where pressure energy is exchanged to seawater from C. The pressure of seawater at D is not high enough to go to RO process directly, so a booster pump is needed[4]. The high inlet pressure, high medium causticity and large flow rate makes booster pump difficult to design. The typical booster pump is RPH-RO series designed by KSB. RPH-RO is a single stage pump made of duplex stainless steel or super duplex stainless steel, with double volute.
2. Technical parameters and hydraulic design

2.1. Design parameters
Design parameters of the booster pump are given as follows. Flow rate $Q=625$ m$^3$/h, head $H=50$m, rotational speed $n=2900$rpm and efficiency $\eta=80\%$. The specific speed $n_s=234.6$.

2.2. Hydraulic design
Hydraulic design is based on traditional velocity coefficient method. All hydraulic parameters is shown in table 1[5,6].

| Parameters                     | value        |
|--------------------------------|--------------|
| Impeller inlet diameter (mm)   | 140          |
| Blade inlet width(mm)          | 1.8 cm       |
| Impeller outside diameter(mm)  | 250          |
| Blade number                   | 6            |
| Blade wrapping angle(°)        | 100          |
| Blade outlet angle(°)          | 25           |
| Blade thickness(mm)            | 5            |
| Impeller outlet width(mm)      | 44           |
| Suction nozzle diameter(mm)    | 200          |
| Discharge nozzle diameter(mm)  | 150          |
| Volute base circle diameter(mm)| 270          |
| Volute inlet width(mm)         | 66           |
| Volute tongue angle(°)         | 15           |
| Volute tongue start angle(°)   | 40           |
| Diffuse angle(°)               | 12           |
According to the hydraulic parameters above, the drawings of impeller and volute are shown in figure 2 and figure 3. The blade outlet is designed to oblique to axis to enlarge flow rate.

![Figure 2. Wooden patterns of impeller.](image)

![Figure 3. Wooden patterns of volute.](image)

![Figure 4. Cross section of volute.](image)

3. Structure design

3.1. Basic design

Booster pump is designed as a single-stage single-suction bracket centrifugal pump. To avoid corrosion caused by highly corrosive seawater, the material of impeller and volute is chosen to be 022Cr22Ni5Mo3N duplex stainless steel. Duplex stainless steel is a half austenite half ferrite stainless steel with outstanding resistance to chloride corrosion. The diameter of the shaft is checked. The axial force is balanced by 6 balancing holes, and the radial force is balanced by two 7007C angular contact ball bearings[5]. The shaft power of the pump is 105.96kW according to calculations, so the motor type is chosen as Y2-315L1-2-160, considering a 30% allowance.

3.2. High pressure seal

The seal must be well designed since the inlet pressure reaches 5.5~6.0MPa. Bad wear and overheat may occur on traditional seal because of high face pressure[7]. This paper designed a hydrodynamic
mechanical seal to solve these problems. There are some shallow slots on the seal face of rotating ring as shown in figure 5. Small gap occurs between rotating ring and stationary ring due to hydrodynamic force when rotating ring rotates, the rotating ring and the stationary ring do not contact directly, thus this type of mechanical seal solves over-wear and overheat problems. The material of the rotating ring is chosen as WC-Ni hard alloys with high hardness and good abrasion resistance. The stationary ring is chosen as antimony filled carbon with good abrasion resistance and self-lubrication under high load and high temperature situations. The hardness of rotating ring and stationary ring is different for conveniently repairing and the cross sectional area of rotating ring and stationary ring are different to avoid hard ring inserting into the soft ring[8].

4. CFD simulation

4.1. Modeling, gridding and settings
To predict the pump performance, CFD simulation is applied using Fluent software. The model is built in UG, and gridding is done in Gambit. The grid type is unstructured meshes, total grid number is 3,406,251, as shown in figure 6. Water is assumed to be viscous, incompressible and isothermal. Boundary conditions are chosen to be velocity-inlet, pressure-outlet and no-slip wall.

4.2. results
According to the CFD results, the head is 52.76m and efficiency is 88.82% at design point 625 m$^3$/h, design requirements achieved. High efficiency (higher than 80%) range is 380~750 m$^3$/h, so it can suit a large operation range. The overall result is shown in figure 7. The shaft power decreases when flow rate exceed design point, this protects motor from overload. This phenomenon is called non-overload characteristics. It will increase reliability of the motor and save a lot of maintenance cost.
5. Conclusion
A large flow rate booster pump is designed and simulated in this paper. The impeller and the high pressure seal are specially designed. The slant outlet design on blade enlarges flow rate and hydrodynamic mechanical design overcomes wear and overheat problems. The CFD results show the booster pump achieved design requirements.

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