Redesign of energy recovery device to keep the production recovery constant

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ABSTRACT

One of the problems of producing fresh water by reverse osmosis is its sensitivity to process conditions. In this article, a method for redesigning the hydraulic turbocharger rotor as an energy Recovery device in desalination units has been discussed. For this purpose, firstly, the performance of a desalination unit in operation is investigated. Then, using turbomachinery similarity relations and CFD, two new rotors have been designed for two high- and low-pressure mode and replaced with the primary rotor. The validated results with test show that despite changing membrane inlet pressure, the amount of produced water was not changed, the total efficiency has increased by more than 4% and the energy recovery has increased by about 2% in the high-pressure mode, which shows that this method can be used in situations where the pressure change of the membranes is noticeably higher or lower than the initial design pressure.

KEYWORDS

Reverse osmosis, permeate water, Energy recovery, hydraulic turbocharger, CFD.

1. Introduction

The increase in the need for fresh water and the limitation of natural resources have led to the use of industrial water softeners, especially units that work with the reverse osmosis method, to produce drinking water all over the world. [1]. Usually, in the reverse osmosis method, the waste energy returned from the filtration membranes is used with the help of energy recovery devices. The hydraulic turbocharger is one of the centrifugal energy recovery equipment, which is widely used in reverse osmosis desalination units due to its simplicity of design, flexibility in operation and relatively low supply cost [2]. This equipment has a rotor including the impeller of the pump section, the impeller of the turbine section and the axis connected to them, as well as the outer shell in which the rotor is placed. In many cases, due to the change of working conditions with the initial design, it is necessary to adapt the hydraulic conditions of the entire circuit to their optimal working point [3]. One of the common ways to change the general conditions of desalination units is to use a variable frequency drive (VFD), a pressure relief valve and a turbocharger equipped with an electric motor. But the use of these methods generally requires a waste of energy and a high cost [4] . In the current research, a method has been adopted so that the flow rate of the produced water remains constant and the total efficiency does not change significantly (more than 10%) as mentioned in section 2. The main difference of this research is focused on the changes in the inlet pressure to the membrane and as a result the return water pressure from it at the inlet to the turbocharger, which is discussed in section 3.

2. Method description

In this article, a more affordable option has been discussed. To adjust the operating condition of the plant with raw water condition and membrane inlet pressure, the performance characteristic of the turbocharger has been modified by replacing new rotors. A. When site condition changes, the existing rotor can be replaced with a new one which is designed for that condition. To do this, two situations were considered: The high-pressure mode when the membrane required pressure is higher than the initial design pressure, and the low-pressure mode when the membrane required pressure is lower than the initial design pressure. The aim is to modify the design of the turbocharger rotor in such a way to achieve the required pressure without a significant change in the permeate recovery in each case. In fig. 1, the steps of the work are represented.

The steps of the work Firstly, the performance of an existing turbocharger was investigated. For this purpose, the flow field inside the existing turbocharger has been modeled in three dimensions and simulated using CFD analysis. The results have been compared and validated with the site data. Then, using fluid mechanics and similarity relations, two new rotors were designed and the new flow field inside them simulated for two pressure mode. Finally, the obtained data for new rotors were validated again with experimental test results. It has been shown that replacing new rotors can lead to a new situation where the amount of permeate water remains unchanged despite the changing membrane condition.

3. Analysis of the Existing plant conditions

To investigate the effect of the rotor design on working condition, a medium plant with the production capacity of 1260 m3/day (150 m3/h of raw water), has been studied. In this plant a high-pressure pump is used with a turbocharger. The hydraulic parameters of the plant and main geometric specifications of the original turbocharger is presented in table 1 and fig. 1.

Table 1. The geometric specification and hydraulic parameters of the plant

Geometric dimensions	Values	hydraulic parameters	Values	Geometric dimensions
Dto	86 mm	Q_P (Inlet Flow)	150 (m^3/h)	Dto
Dti	41 mm	Pin_p	40 (bar)	Dti
bt	17.5 mm	$Pout\_P$	65 (bar)	bt
Dpo	86 mm	Pin_T	63 (bar)	Dpo
Dpi	48.8 mm	$Pout\_T$	1 (bar)	Dpi
bp	18 mm	Q_R (Reject Flow)	100 (m^3/h)	bp
Nb (blade number)	8	Number of membranes	103	Nb (blade number)
SL (horizontal clearance))	0.6 mm	η (Total Efficiency, Eq.2)	60.4%	SL (horizontal clearance))
SR (vertical clearance)	3.5 mm			SR (vertical clearance)
L (clearance length)	54 mm			L (clearance length)

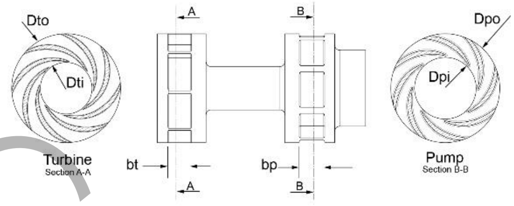

Figure 1. The main effective dimensions in the hydraulic characteristics of the turbocharger rotor

Using CFD Analysis, the working condition for the existing turbocharger has been obtained about 16570 rpm and the shaft power of 127 kW (Fig. 10). The result has been validated with test results.

4. Flow field analysis in new rotors

Using new hydraulic condition for low- and high-pressure mode, the new rotos were preliminary designed using turbomachinery affinity law and the flow field at the pump and turbine section has been simulated. Two pressure mode parameters is presented in table 2.

Table 2: Hydraulic conditions for the main rotor and two new rotors

Hydraulic Parameters	Existing rotor	High pressure rotor (1)	Low pressure rotor (2)
(Pout_P)	65 bar	68 bar	60 bar
(Pin_T)	63 bar	66 bar	58 bar
(Pout_P - Pin_P)	25 bar	28 bar	20 bar
(Pin_T - Pout_T)	62 bar	65 bar	57 bar
(Qp)	150 m3/h	150 m3/h	150 m3/h
(Qr)	100 m3/h	100 m3/h	100 m3/h

Fig. 2 shows the contour of the static pressure in the pump and turbine section for new working condition in a section parallel to the impeller plane.

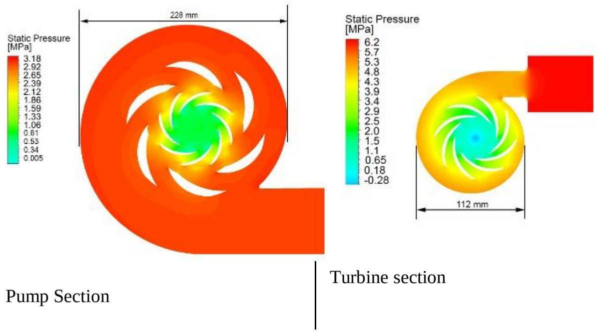

Figure 2. Static pressure contour in pump and turbine section for new working condition

5. Results

In the test process, to adjust the flow rate of feed and produced water, in accordance with the values used in the hydraulic analysis, the speed of the high-pressure pump and the outlet valve of the waste water was been adjusted. To compare the design parameters of new rotors, the data obtained from the test and the results obtained from the simulation is shown in table 3.

Table 3. The results of the test data for three rotors, original, high-pressure and low-pressure rotor

Rotor	Eff (%)	HPIP (kW)	W_{Turbo} (kW)	ER (%)
Original	60.04	205.5	102.2	30.2
Rotor1	64.6	205.5	114.4	32.3
Rotor1	58.8	205.5	81.7	26.3

HPIP is the input power of the HP pump, Wturbo is the power generated by the turbocharger, and ER is the energy recovery percent.

6. Conclusion

The obtained results show that the design parameters obtained from the similarity methods agree with both the flow field simulation results and the experimental test data with an acceptable difference, and in cases where computer optimization or experimental testing is not possible, it can be a reliable method. According to the results, it can be concluded that in order to keep produced water constant, replacing a new redesigned rotor with the existing one makes sense and is effective economically and hydraulically. In some cases (when high pressure is needed), this method even could lead to higher efficiency and cause a longer life of the turbocharger (due to the use of two or three rotors during the year).

7. References

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