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Zhilong He
wqchen@hotmail.com

Jiubing Shen

Wenqing Chen

Ziwen Xing

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Zhilong He , Jiubing Shen , Wenqing Chen* , Ziwen Xing

[1]School of Energy and Power Engineering, Xi'an Jiaotong Univercity,
Xi'an,710049, China
Phone: 86-29-82675258, Fax: 86-29-82663783, E-mail: wqchen@hotmail.com

* Corresponding Author

ABSTRACT

The heat pump system of mechanical vapor compression/recompression (MVC/MVR) combined with evaporation is a high efficiency, energy-saving solution for energy intensive processes. However, a suitable compressor with high pressure ratio and low discharge temperature is not available in engineering practice. In this paper a water-injected twin screw compressor recognized as a promising type for water vapor compression is presented by detailed descriptions of the rotor profile development and structure design. Then the calculation of water quantity and its influence on the steam flow rate are presented. Moreover, the effects of injected water on the working process and performance of the compressor are discussed. Finally, it is found that the volume flow rate increases a lot because of the water evaporation during the compressing process which is originally aims to guarantee saturate discharge temperature. And the temperature difference of the MVC system is a main parameter that affects the performance of the compressor.

1. INTRODUCTION

The heat pump concept of mechanical vapor compression/recompression(MVC/MVR) was firstly proposed in 1980s by Kawamura K, Banquet F etc. as a way for energy saving in industries like drying, concentration, evaporation and distillation where low pressure steam as a by-product was vented to the environment with its valuable latent heat content. As water is the working medium, the COP of the MVC/MVR heat pump systems can be very high, always greater than 5(Xiao Feng,1997). The working principle of the MVC/MVR systems is that a compressor is used to compressor the low pressure and temperature steam from industry processes after which the pressure, temperature and enthalpy of the steam are elevated to an appropriate level and return back to the system as a heat source. Although the MVC/MVR heat pump system has obvious advantages in energy saving, the technology and economic of the water vapor compressor, a key component of the system, are the limitation of its extension. As the specific volume of the steam at low temperature is high and high pressure ratio is needed for the compressor, the problems of high compressor outlet temperature and big volume flow demands have to be overcomed. The types of compressor used for steam compression include multistage centrifugal, multistage axial, twin screw, roots, liquid ring et al. According to the limitations of: low compression ratio, poor durability with mist, erosion, corrosion, etc, most of these compressors are not suitable in some application situations. A screw steam compression heat pump system (SSHP) was introduced by K. Kawamura. It's a MVC/MVR system using a screw compressor to compress the steam. Twin screw compressor used in the MVC/MVR has its special advantages as it can tolerate wet compression:
(1) High compression ratio (high temperature difference) with saturate discharge vapor temperature by water injection. Irreversibility caused by vapor superheating is prevented.
(2) High durability and reliability when mist or foreign particles appear in the system.
(3) Stability of performance for a wide operation range especially for the unloading capacity and can be easily sized to specific compression needs.
(4) Less expensive.

Twin screw compressor is thought to be most suitable for water vapor compression. However seldom literatures were reported about the water vapor twin screw compressor. Also the influence of the injected water to the performance of the steam compressor has not been theoretically and experimentally studied.
The profile and structure design of a twin screw water vapor compressor used in multiple-effect evaporation desalination systems is reported in this article. Also the effect of the water injection is discussed and the mass calculation of the injected water is analyzed.

2. Process Description and Technical Parameters of the Compressor

A schematic diagram of two effect evaporation MVC desalination system is shown in Figure 1. The system includes the evaporator/condenser, feed pre-heaters, vapor compressor. Feed pretreatment unit, vacuum system and pimping units are omitted for simpleness. In the system, vapor releasing from boiling seawater in the evaporator of the last effect is compressed by a mechanical compressor to raise its pressure and temperature. Then the compressed vapor is returned to the condensing side of the evaporator in the first effect to be used as a heating source for producing additional vapor which goes through the evaporator of the next effect for heating. The condensed distillate product and the brine stream exchange heat with the intake stream within the pre-heaters before collected. Normally, it's recommended to use multiple effects in the process which gives increased performance ratio when combined with MVC.

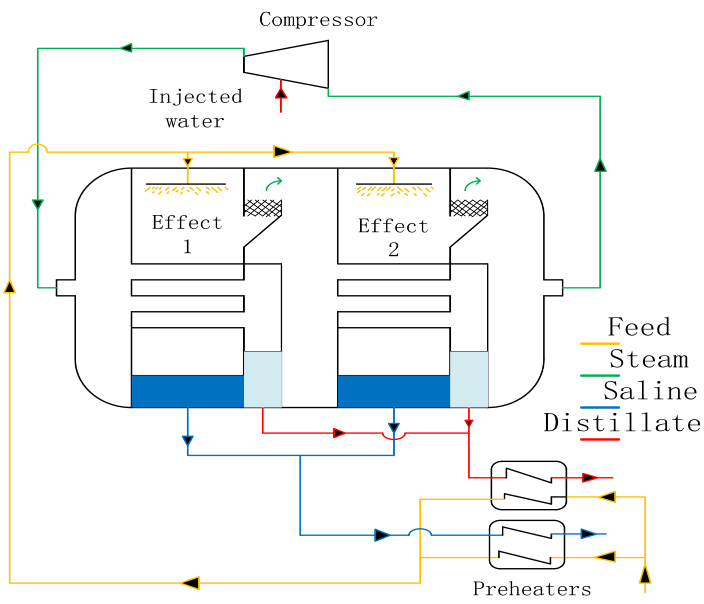

Figure 1: schematic diagram of two effect evaporation MVC desalination system

In this system, twin screw compressor with water injection is used to compress the water vapor. Compared with systems using centrifugal compressor, gas-liquid separator and desuperheater are not needed. Also as the pressure ratio of the screw compressor is higher, the temperature difference of the system can be higher and the number of effects of system can be increased. It should be noted that electricity is the only energy need by the operation of the system except its start-up or condition changing.
The design technical parameters of the water vapor compressor are shown in Table 1. The discharge temperature is saturation at the compressor's exhaust pressure. It should be addressed that the exhaust pressure of the compressor is positive which can prevent the inleakage of air and then reduce the oxidation.

Table 1: Technical parameters of the compressor

Suction steam temperature（℃）	73.0
Suction steam pressure（kPa）	35.42
Discharge steam temperature（℃）	105.0
Discharge steam pressure（kPa）	120.66
Pressure ratio	3.41
Inlet steam specific volume（m^3/kg）	4.49
Inlet volume flow rate（m^3/min）	100.42

3. Profile and Structure Design of the Twin-screw Compressor

3.1 Profile design

According to the given technical parameters of the compressor, a profile of the twin screw compressor rotors is designed as shown in Figure 2. This profile is bilateral dissymmetrical composed of the circular arc and its envelope, which can completely achieve “Surface-Surface” sealing between the rotors and reduce the leakage across the contact line. So the efficiency of the twin screw compressor is improved. Also, the profile has excellent workability and grinding method can be applied to machining the rotors. On the base of the designed sectional profile, the SCCAD software package is used to calculate and optimize the structure parameters and geometrical features of the rotors are.

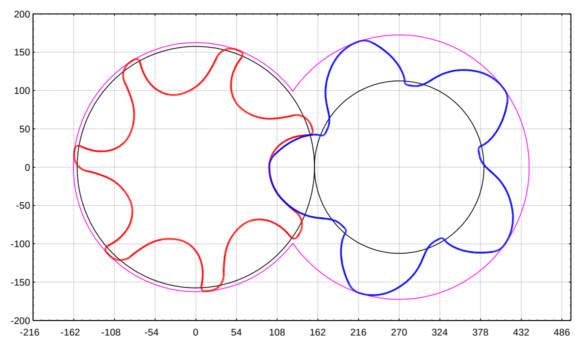

Figure 2: sectional profile of the screw rotors

3.2 Structure design

3.2.1 General layout

As the steam screw compressor is oil-free, direct contact between the rotors is forbidden. So the synchromesh gears are used for the drive of female. Considering the processability and assembly ability, the compressor is divided into five parts as shown in Fig.3.

3.2.2 Bearing selection

Considering the working conditions, forces acted on the rotors are calculated and consequently the bearings are chosen. QJ bearings are installed at the discharge side to bear the axial forces for both male and female. To support the radial forces, NU bearings are used on both sides of the compressor. As the bearings are lubricated by oil, shaft seals are used between the working cylinder and the bearing chamber.

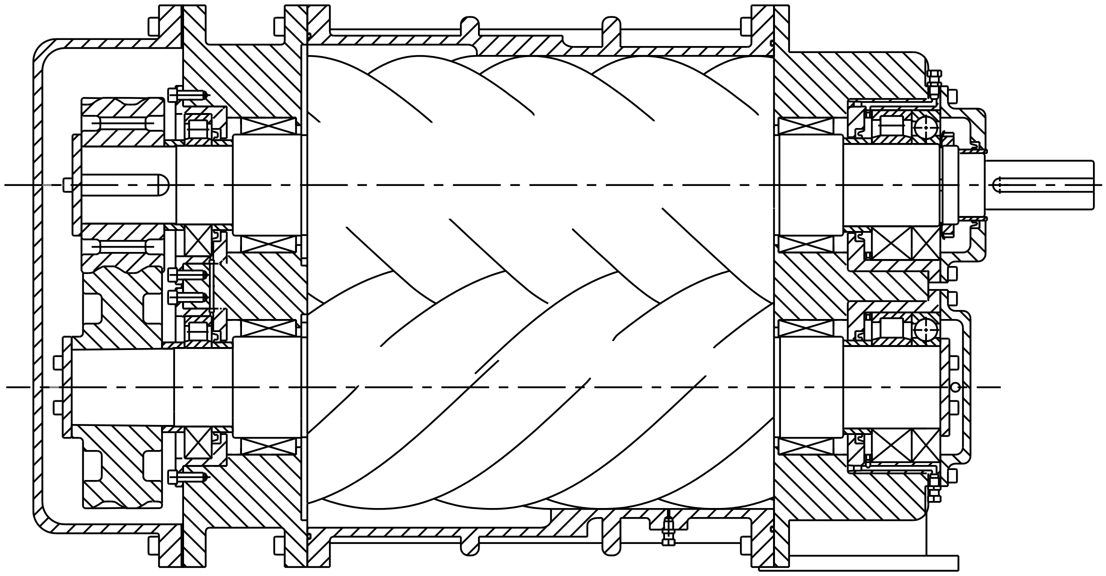

Figure 3: General layout of the twin-screw compressor

4. Water Quantity Calculation and Performance Evaluation of the compressor

4.1 Quantity calculation of injected water

Energy conservation equation is used the mass calculation of injected water. For the compressing system, the equation can be written as follows:

$$M\,h_1 + M_w h_w + N_s = (M + M_w)h_3 \tag{1}$$

In the equation, M and M_w represent the mass flow of the suction vapor and the injected water respectively; h_1 and h_3 are enthalpy of the saturated vapor at suction and discharge pressure; h_w is the enthalpy of the injected water and N_s is the shaft power of the compressor. According to the working condition of the designed compressor and assumed that the injected water is saturate with the temperature of 50℃, the mass of the injected water is calculated which is 2.268kg/min. During the calculation, N_s is calculated with the assumption that η_{ad} is 0.75. The values of M and N_s is 22.4kg/min and 113kW respectively. It can be noted that the mass of injected water is a tenth of that of the suction vapor, which means the volume flow can be increased to 1.1 times of the suction volume flow rate by water injection.

4.2 Performance evaluation of the twin-screw compressor

When the water-injected twin-screw compressor is used in a 4 effects MVC desalination system with a mass flow rate of 10.4kg/min, its performances including shaft power N_s and volume flow rate V_t under different working conditions are evaluated. Changing the evaporating temperature from 65 ℃ to 110 ℃， condensing temperature from 70℃ to 115℃, the calculation results of N_s and V_t are shown in Figure 4 and Figure 5. It could be found that the shaft power increases greatly as the temperature difference between the evaporating and condensing temperature grows. However, the shaft power N_s decreases slightly if the condensing temperature increases at a given temperature difference. As shown in Figure 5, the volume flow rate changes little with the condensing temperature at the fixed evaporating temperature. But the volume flow rate increases rapidly with the increase of temperature difference. This is mainly because of the increase the specific volume at the suction of the compressor.

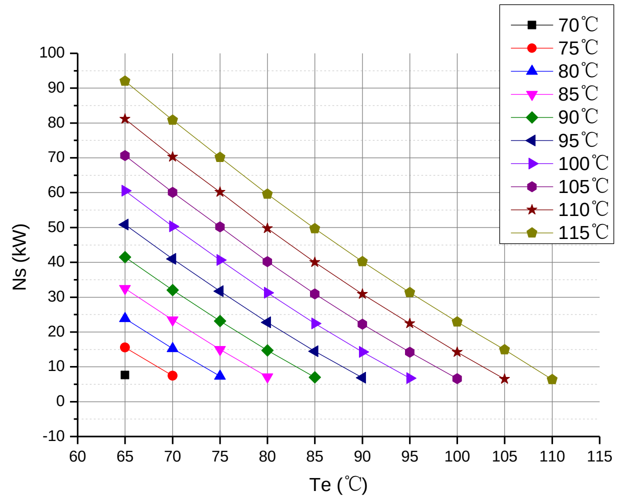

Figure 4: changes of shaft power at different working conditions

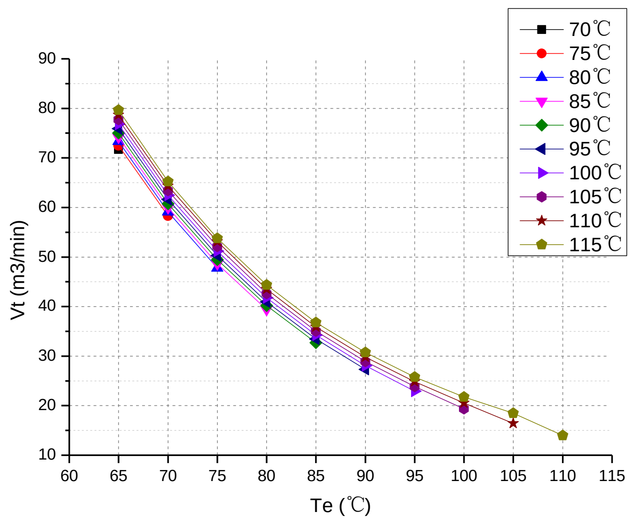

Figure 5: changes of volume flow rate at different working conditions

5. Conclusion

Application of MVC/MVR heat pump as an effective way of energy saving is limited by the compressor technology. As twin screw compressor can tolerate wet compression, it can satisfy the demands of high pressure ratio and low discharge temperature for water vapor compressor by injecting water to the working chamber. Profile and structure design of a twin screw water vapor compressor are introduced in the article. The designed compressor is used in a MVC desalination system, which demands a pressure ratio of 3.41 with saturated discharge vapor temperature. As the compressed vapor and the water are the same medium, performance evaluation of this compressor is different from that of ordinary air or refrigeration twin screw compressor. The effects of the water injected and its quantity calculation are analyzed. It is found that the volume flow of the compressor increases about a tenth of the suction volume flow by water injection. What's more, the performance evaluation of the compressor under different working conditions is presented. Results of the performance calculation show that the performance changes greatly with the temperature difference of the MVC system.

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