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Suitability Evaluation of Seawater Source Heat Pump in a Seashore Refrigeration Station

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Abstract. In this paper, the suitability of using seawater source heat pump in a seaside refrigeration station in Qingdao was evaluated. A systematic evaluation was made on the conventional chiller with cooling tower system, the conventional chiller with titanium plate heat exchanger system and the seawater source heat pump system, including energy saving evaluation, economic evaluation (initial investment cost and operating cost) and environmental evaluation. The evaluation results showed that the initial investment cost was slightly increased, the operating cost was low, the cop value was high and the impact on the marine environment was small when the seawater source heat pump system was directly used.

1. Introduce

A refrigeration station was planned to be built in a large seaside building in Qingdao, which provides chilled water as the cold source of the building air conditioning system, with a cooling load of 6000 kW and a supply of 1200 t/h of refrigerant water. Qingdao, as a coastal city, has the potential of using seawater as cooling water, so the seawater source heat pump should be considered first when choosing the type of water chiller.^[1] However, to evaluate the suitability of seawater source heat pump needed systematic evaluation including energy efficiency, economy and environmental benefits. Energy efficiency reflected the energy consumption under the same load, economy was evaluated from the initial investment and running cost of the system, and environmental benefit was the evaluation of the impact of the system on the environment.

2. Energy-saving evaluation

The cooling capacity and power consumption of water chiller were closely related to the cooling water temperature of chiller and the demand cooling temperature of user side. [2] Appropriate operation control strategy could make the chiller running in the high efficiency area as far as possible, and improve the energy saving effect.

A high efficiency seawater source heat pump unit was selected, under the cooling condition in summer, the inlet water temperature (IWT) of evaporator was kept at 12 °C and the temperature difference between inlet and outlet water of condenser is kept at 5 °C, the outlet water temperature (OWT) of evaporator changes with the cooling load, and the inlet water temperature (IWT) of condenser changes with the seawater temperature.

According to the product sample data, the working conditions were fitted to obtain the relationship between the COP, the OWT of the evaporator and the IWT of condenser, as shown in Figure 1. When the cooling load was reduced, the OWT of the evaporator was correspondingly increased, and the COP was increased. At the same OWT of evaporator, the cop decreases with the increase of IWT of condenser.



The cold station was located at the seaside of Huangdao, Qingdao City. As shown in Figure 2, the seawater temperature in Qingdao coastal area was lower than 25 °C in the whole cooling season, and the highest temperature appeared at the end of August and the beginning of September. In June and July, the seawater temperature was 15~18 °C. According to the above analysis, the cop of seawater source heat pump using seawater as cooling water could be maintained above 5.8, which was better than that of conventional chillers (4.0 ~ 5.0).

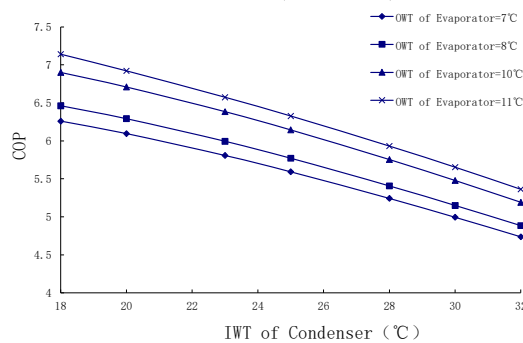


Figure1 Fitting Diagram of COP and Operating Conditions

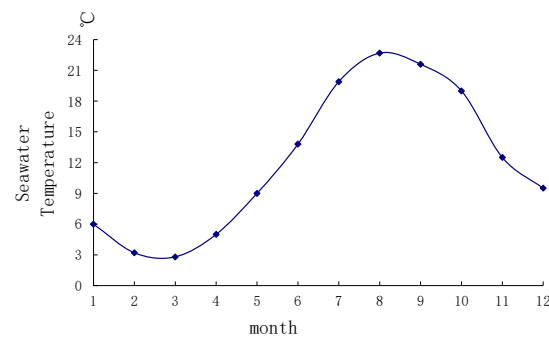


Figure2 Distribution of seawater temperature in Qingdao

3. Economic evaluation

The economy of the system was determined by the initial investment cost and operation cost. In order to compare the economy of the cooling system using seawater as cold source, three cooling modes were compared: Model A was a conventional water chiller plus cooling tower system, as shown in figure 3. Model B was an indirect seawater utilization system of a conventional water chiller plus a titanium plate heat exchanger, as shown in figure 4. Model C was a seawater source heat pump system using seawater directly, as figure 5.[3][4]

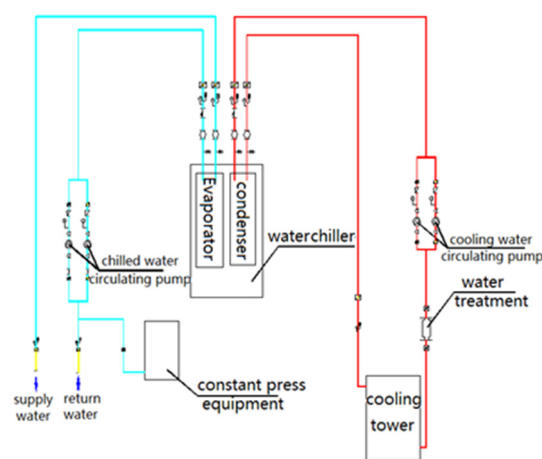


Figure 3 Model A system

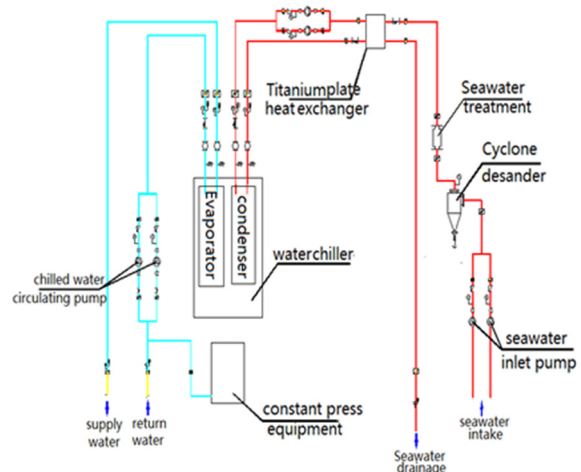


Figure 4 Model B system

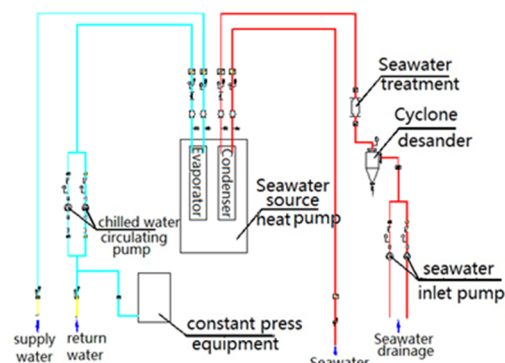


Figure 5 Model C system

3.1. Initial Investment Comparison

The initial investment cost of the system included the cost of the chiller and its accessory equipment, power distribution system and pipeline installation in the engine room. In model A, four chillers and matching cold water pumps, cooling water pumps, cooling tower water and other equipment were used, while the initial investment cost of the system was about 5.6 million; In model B, seawater was used indirectly where the cooling water from condenser was cooled by seawater through titanium plate heat exchanger, so it needed to add seawater intake and treatment system, titanium plate heat exchange and intermediate circulation system, and the initial investment cost was obviously increased to about 9 million; In model C, the seawater directly entered a condenser to absorb heat, so seawater heat pump with an anticorrosive condenser was adopted, and a zinc block was added at the inlet and the outlet of heat exchanger materials to slow down the corrosion rate; and the initial investment cost of the system was slightly increased to about 5.9 million.

3.2. Operating cost comparison

Operating cost of chiller = rated power of equipment × number of equipment × daily operation time × days × annual average load factor × electricity price. In the three models, the temperatures and flow of the chilled water provided by chillers was basically equal and the operation mode and cost of the chilled water circulation system were basically the same. Therefore, the operation cost of this part was not compared.

The operating cost comparison results were shown in Table 1.

Table 1 Operating cost comparison of the three models

Model	Equipment	Number	Power rating	Annual consumption	Annual operating cost	Total cost
A	Conventional chiller	4	311.7	808445	485067	565937
	Cooling pump	4	37	95903	57542	
	Cooling tower	4	15	38880	23328	
B	Centrifugal chiller	4	287.6	745458	447275	551473
	Inter-pump	4	37	95903	57542	
	Seawater pump	4	30	77760	46656	
C	Seawater heat pump	4	287.6	745458	447275	470603
	Seawater pump	2	30	38880	23328	

Note: (1) Cooling season was calculated as 90 days, and running time was 12 hours per day;

(2) The annual average load coefficient was 0.6;

(3) The electricity charge was calculated as 0.6 yuan/kwh (Qingdao Class II electricity charge, the specific electricity charge standard was adjustable).

3.3. Comprehensive economic comparison

Table2 Comprehensive Economic Analysis and Comparison of Three Cooling System Modes

Model	A		B		C	
Initial investment	562.7 WY		900.0WY		595.4 WY	
Operating cost	56.59 WY		55.15 WY		47.06 WY	
Machine room area	240m ²		330 m ²		260 m ²	
Electric power (single set)	Conventional chiller	311.9KW	Centrifugal chiller	287.6KW	Seawater heat pump	258.7KW
	Cooling pump	37KW	Seawater pump and Intermediate pump	67KW	Seawater pump	30KW
	Cooling power	15kW				
Water consumption	1300 m ³ /h		1200 m ³ /h		700 m ³ /h	
Cooling Water	30-35℃		28-35℃		26-34℃	
COP	5.09		5.47		5.9	
Cooling water form	Open system		Close system		Close system	
Advantages	①simple maintenance ②operation stable ③system simple		condenser has no danger of seawater corrosion		① highest system efficiency ②lowest operation cost	
disadvantages	①The open system easy to produce scaling, dirt and bacteria ② The cooling tower wasted water resources		① Secondary Heat Exchange and Inter-pump reduce the system efficiency ② highest initial investment		Seawater siphon and seawater source heat pump technology was relatively new	

The COP of the seawater source heat pump directly using seawater as cooling water could reach 5.9; The COP of the conventional chiller with cooling power was about 5.09; The COP of the chiller system indirectly using seawater could reach a higher level of 5.47.

Model C ,directly using seawater which had larger temperature difference, saved the number of submersible pumps and the corresponding operation cost, therefore, the operation cost was the lowest among the three systems' costs, and saved about 16.8% than traditional model A. Model B ,indirectly using seawater, increased the power consumption of the intermediate pump, and there was a loss of intermediate temperature difference, therefore, the operation cost saves only 3% than traditional model A.

4. Environmental Assessment

Seawater pump system had many advantages in terms of energy utilization and environmental protection [5] [6], as follows:

(1) Compared with conventional units, the seawater source heat pump saved objective operation power consumption which was generated by coal-fired, so the corresponding coal consumption was saved and the adverse impact of coal combustion on the environment was reduced. For every kwh of electrical consumed, it was equal to 341g standard coal. According to this calculation, the Seawater

pump system could save about 158890kWh per year, which saved about 54 tons of standard coal per year, and reduce 0.72 tons of dust, 0.97 tons of SO₂, 0.36 tons of nitrides and 145.59 tons of CO₂ per year.

(2) Because the heat of condenser was taken away by seawater, the open heat source—cooling tower was cancelled which could reduce the heat dissipation from the system to the air, save the fresh water supplement resources, reduce the running noise pollution to the city and the Legionella infection crisis peculiar to the cooling tower.

5. Summary

From the above evaluation, it could be seen that seawater cooling can reduce the operating cost while improving the environment, while it would increase the initial investment cost. The operating cost of the plate-exchange system indirectly using seawater cooling decreased less (by about 3%), but the initial investment cost increased more, while the energy-saving effect was not significant. The initial investment cost of the seawater source heat pump system directly using seawater cooling increased less. While the operating cost was significantly reduced (reduced by 16.8%), and the energy saving effect was significant. At present, the domestic seawater heat pump unit had been proved to be reliable in anticorrosion technology through long-term use. Therefore, the seawater heat pump unit directly using seawater was recommended in this refrigeration station.

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