

A Study of the Cooling and Heating Performance of a Two-Stage Screw Heat Pump Using Treated sewage Water

**Ji-Young Kim¹, Young-Jin Baik², Young-Soo Lee³, Ki-Chang Chang⁴
and Ho-Sang Ra⁵**

¹Korea Institute of Energy Research, Daejeon, Korea, bigkjy@kier.re.kr

² Korea Institute of Energy Research, Daejeon, Korea, twinjin@kier.re.kr

³Korea Institute of Energy Research, Daejeon, Korea, yslee @kier.re.kr

⁴Korea Institute of Energy Research, Daejeon, Korea, kcchang@kier.re.kr

⁵Korea Institute of Energy Research, Daejeon, Korea, hsra@kier.re.kr

ABSTRACT: The treated sewage water temperature is about 5°C lower in summer and 5~10°C higher in winter than ambient air. It can be used as a high-performance heat pump heat source. In this study, a 100RT two-stage compression heat pump was developed using a treated sewage water heat source and system applicable to sewage disposal plants. Although a heat pump performs better than general heat pump, the large temperature difference between its load and source degrades its performance. To solve this problem, two-stage screw compression is considered. The experiment focused on the system's operating performance variations over the water supply and the temperature of the treated sewage water in the field. The results showed that the system's cooling and heating performance is higher than that of general heat pumps and is enough to supply 70°C water.

Keywords: Treated sewage water, 2-stage compression, Heat pump, COP

1. INTRODUCTION

In recent years, considerable attention has been given to the issue of skyrocketing oil prices with the depletion of energy due to industrialization. In this situation, the effective use of energy, such as the efficient use of various types of waste heat and renewable energy should be promoted to reduce dependence on fossil fuels.

Treated sewage water is common near urban areas and is a form of unutilized energy. A survey reported that sewage water

has an energy potential of up to 36,000 Tcal/year, which comprised 2.1% of the total domestic energy consumption and 9.7% of the energy usage in the household and business sectors in 2006. The temperature of sewage water differs across sites, but has been observed in the range of 20~25°C in summer and 8~13°C in winter. Since the temperature range of sewage water has a better seasonal distribution of about 5~10°C compared to ambient air, it is a high-performance heat source for heat pumps (heat sinks for summer or heat sources for

winter). Sewage water is also a high-quality heat source due to its abundant quantity and uniform temperature. Considering that the ambient temperature of Korea is very low in winter, a heat pump system that uses sewage water can prevent capacity deficiency and frost formation.

Therefore, the temperature difference between condensation and evaporation is not significant. The temperature of hot water for heating was 50~55°C, however, when the sewage water temperature was 5~10°C in winter. Thus, the heating cycle must consider the system's efficiency, because the temperature difference between the heat source and the hot water temperature supplied for heating is significant. To solve this problem, two-stage screw compression is considered.

The objectives of this study are the recycling of unutilized energy such as treated sewage water for heating, cooling, and hot water for residential and commercial buildings. Consequently, in this study, to develop treated sewage as a water heat source, a 100RT-class two-stage screw vapor compression heat pump system was designed for heating and cooling of offices. The system is used at the sewage disposal plants at the Daegu Metropolitan City Environment Installations Corporation.

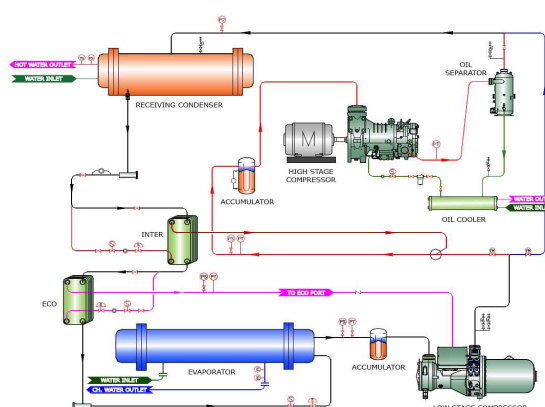


Figure 1: Schematic diagram of 2-Stage Screw Heat Pump

2. HEAT PUMP COMPONENTS AND SITE APPLICATION

2.1 Screw 2-stage vapor compression heat pump components

Fig. 1 shows the schematic diagram of the components of two-stage vapor compression. The system consists of a single-stage and a two-stage screw compressor, a shell and tube type evaporator and condenser, an accumulator, an oil separator, an oil cooler, an inter-heat exchanger(plate-type), an economizer- heat exchanger(plate-type), an EEV (electronic expansion valve), etc.

This system applies to a screw compressor. A screw compressor is a positive displacement machine that uses a pair of intermeshing rotors instead of a piston to produce compression. It has many advantages such as high efficiency, low vibration, low mechanical trouble, and quiet operation. The single-stage compressor was the Germany Bitzer Company's semi-hermetic twin rotor screw compressor with infinite or four-step slider capacity control and an economizer operation function. Slider system allows for infinite or 4-setp capacity control without compressor modification. There was no need for compressor modification. The two-stage compressor was also the open-type screw compressor available for capacity control and economizer operation. The different operating modes can be achieved by adapting the control sequence of the solenoid valves. The economizer was disposed in a refrigerant liquid passage to subcool the refrigerant liquid using the refrigerant with reduced pressure. A refrigerant gas injection line, through which the refrigerant gas was generated in the said economizer, was injected into the compression chamber of the screw compressor in the compression phase that comprised the refrigerant gas injection system.

Part of the high-temperature refrigerant that came out of the condenser expanded in the inter-heat exchanger and increased the degree of subcooling of the condenser. After the application of the high temperature, it was mixed with the pressure from the single-stage refrigerant gas , after which it was

sucked into the two-stage compressor as the EEV, which was established in the inter-heat exchanger, was controlled according to the degree of superheat of the two-stage compressor's entrance. The EEV opening allowed the compressor inlet temperature and pressure to be controlled, as with the condensers with the parallel liquid reservoir function.

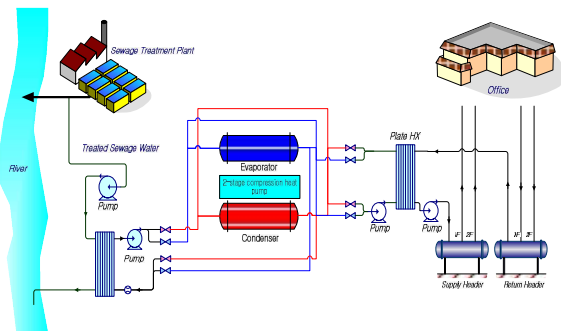


Fig. 2 Schematic diagram of system site application

2.2 System configuration and site application

Fig. 2 shows the schematic diagram of the system site application at Daegu Metropolitan City. The sewage treatment water used the plate-type heat exchanger and acquired it as it came, as a heat source in the indirect method and as the secondary fluid to be supplied by the heat pump.



Fig. 3 Photograph of system in site

The valve outside the heat pump controlled the cooling and heating mode change. The heat pump produced cold and hot water through the plate-type heat

exchanger supply-to-supply heater, which was installed in the existing equipment and which used the fan coil at the office for air conditioning.

Fig. 3 shows the photograph of the system that was established in the site.

3. OPERATION PERFORMANCE RESULT OF SYSTEM

The results of the operation efficiency test of the system are shown in Table 1. For the single-stage operation, the experiment followed the supply temperature, compressor capacity ratio, and on/off of economizer operation. The single-stage operation experiment established the supply temperature.

Table 1: Test condition

	Mode	Supply temp. °C	Comp. capacity[%]	ECO
single-stage	cooling	4, 7, 10, 13		on/off
	heating	47, 50, 53, 56	50, 70, 100	on/off
two-stage	heating	50, 60, 70		off

Fig. 4 shows the cooling capacity with respect to the supply temperature. The supply temperature increased when the cooling capacity increased rapidly. It operated according to the increase in the economizer's cooling capacity.

Fig. 5 shows the variations in the heating capacity with the supply temperature. As the supply temperature increased, the heating capacity slightly decreased. When the compressor capacity increased, the economizer's cooling capacity increased rapidly. Compared with the cooling and heating tests, which set the sewage temperature at 22°C and 20°C, respectively, when the economizer was operated, its heating capacity increased even though the condition of the heat source was poor. Also the case compressor capacity is 100%, does not operate economizer due to high consumption power.

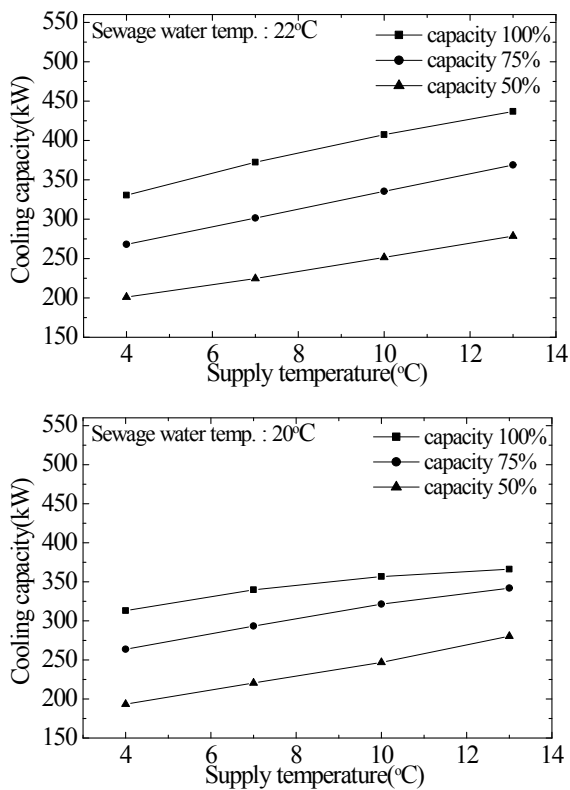


Fig. 4 Cooling capacity with respect to supply temp. (ECO 1st : ON, 2nd : OFF)

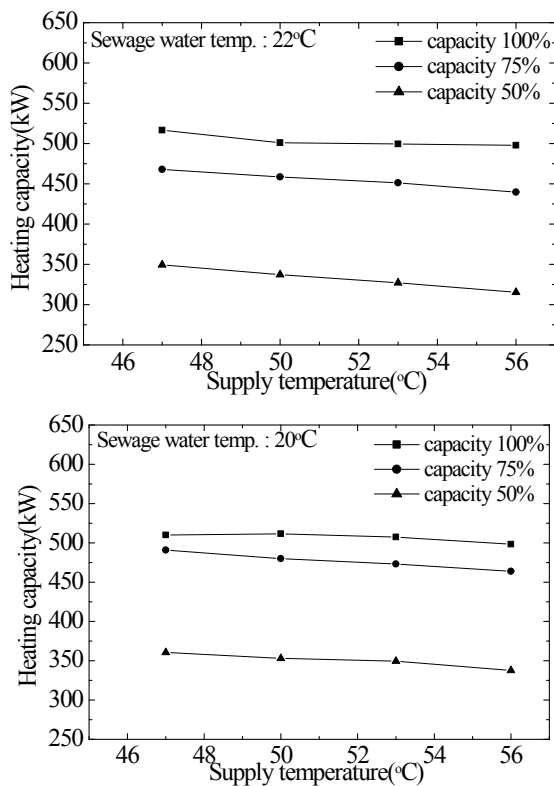


Fig. 5 heating capacity with respect to supply temp. (ECO 1st : OFF, 2nd : ON, capacity 100% : off)

Fig. 6 shows the variations in the COP with respect to the supply temperature. Fig. 6 shows the variations in the COP with respect to the supply temperature.

The cooling COP increased linearly with a rise in the supply temperature. The overall COP was 4.5~5.3.

Fig. 7 shows the heating COP with respect to the supply temperature. The heating COP decreased linearly with a rise in the supply temperature. The overall COP was 4.5~5.3.

Fig. 8, 9 shows the two-stage operation, the heating capacity and the COP with respect to the supply temperature. We know that it is possible for the COP to remain at 3.11 when the temperature is 60°C. The general heat pump is possibly the most difficult means of 70°C hot water production, which makes this system possibly stable.

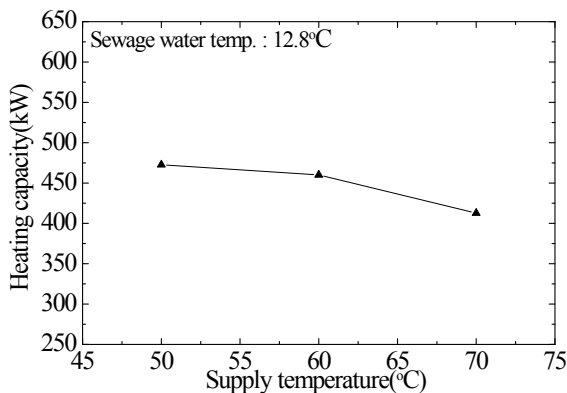


Fig. 8 heating capacity with respect to supply temp.

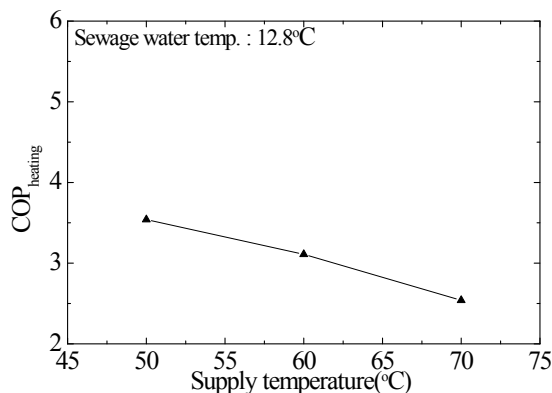


Fig. 9 COP with respect to supply temp.

4. CONCLUSION

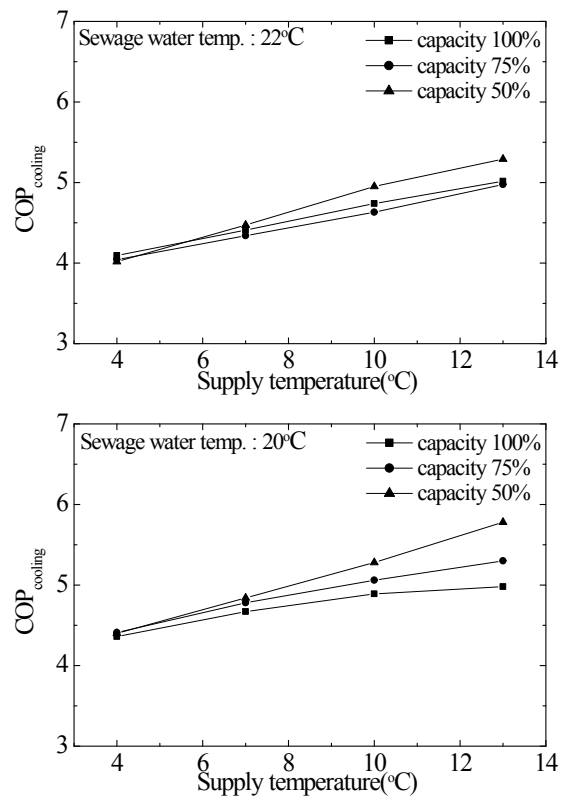


Fig. 6 COP with respect to supply temp. (ECO 1st : ON, 2nd : OFF)

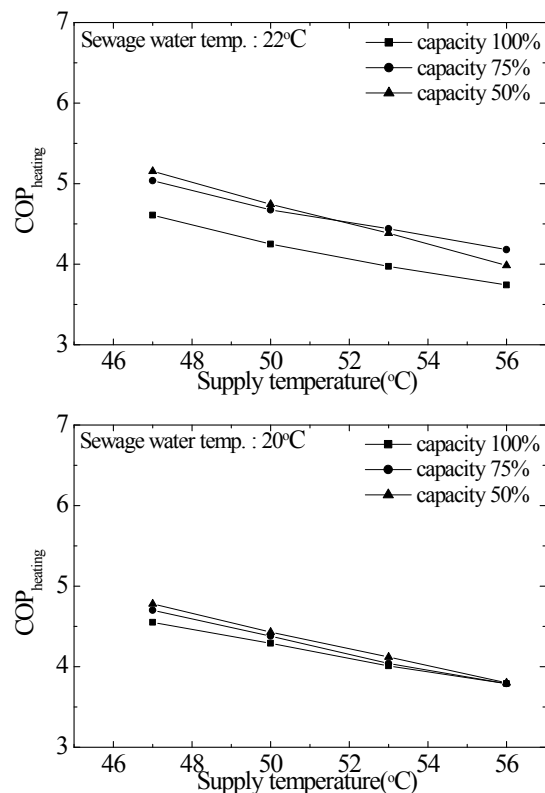


Fig. 7 COP with respect to supply temp. (ECO 1st : OFF, 2nd : ON, capacity 100% : off)

The objectives of this study were to use unutilized energy such as treated sewage to reduce the consumption of fossil fuels so as to reduce greenhouse gases.

In this study, a two-stage screw heat pump system was developed to produce 70°C hot water. According to the application site, the operating characteristics in various driving conditions were monitored to ensure reliability and to observe the designed components.

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