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EFFECTS OF SUPERHEATING AND SUBCOOLING IN A VAPOR COMPRESSION REFRIGERATION SYSTEM WITH R507A REFRIGERANT

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ABSTRACT

Vapor compression cooling systems are the most used and most efficient cooling method in industrial and commercial applications. The reason of these systems are preferred is that they reduce environmental impacts, provide energy efficiency and have economic advantages. In this article, the effects of superheating and subcooling on the system performance in the vapor compression refrigeration cycle (VCRS) using R507A were theoretically examined. The thermodynamic data used the calculation were taken from the Coolpack program. The performance analysis of the VCRS were made for different operating conditions. In the analyses, the evaporator temperature was changed between -5 and -25 oC, the condenser temperature was changed between 25 and 45 oC, and the superheat and subcooling temperatures were changed as 0, 3, 5 and 7 oC. In the analysis made depending on the change in evaporator temperature, superheat and subcooling temperatures, the highest COP value of the cycle is 3.71. In the analysis made depending on the change in condenser temperature, superheat and subcooling temperatures, the highest COP value of the cycle was found to be 4.367.

1. INTRODUCTION

VCRSs work on the refrigeration cycle principle. A typical VCRS consists of a compressor, a condenser, an expansion valve and an evaporator. In cooling cycles, a working fluid is generally used, and heat transfer is achieved by the transition of this fluid from liquid to gas phase and back to liquid phase. This cycle provides the desired cooling effect by taking the surrounding heat from one environment and releasing it into another environment. Superheating refers to a condition in VCRSs where the vapor in the evaporator is at a higher temperature than normal. Superheating allows the refrigerant in vapor form to absorb more heat and, as a result, provide a greater cooling effect to the environment. Superheating helps cool the steam more effectively by the condenser, making the steam more suitable for the condensation process. However, excessive superheating can negatively affect the efficiency of the system. In the case of extreme superheating, the condensation temperature of the steam is higher than normal, which means the condenser must transfer more heat to the environment. This can reduce energy efficiency, reduce cooling capacity in the system and increase operating costs. Subcooling is the condition in VCRSs where the liquid fluid in the condenser is at a lower temperature than normal. Subcooling further lowers the temperature of the liquid fluid to complete the condensation process, allowing a cooler fluid to enter the evaporator. Therefore, it provides more heat transfer in the evaporator and thus increases the cooling capacity. However, excessive subcooling can negatively impact system performance. In case of extreme subcooling, the temperature of the liquid fluid may be lower than normal, reducing the heat transfer ability of the fluid entering the evaporator. This may affect system efficiency by reducing cooling capacity and may also increase energy consumption in case of excessive subcooling.

Arzu Şencan et al. made thermodynamic analysis of subcooling and superheating in vapor compression cooling system using alternative refrigerant. They found that subcooling and superheating temperatures which directly affect condenser and evaporator temperatures, thus affect system performance [1]. Feiza Memet examined the effects of evaporation temperature and subcooling temperature changes on VCRS. It was determined that only increasing the evaporation temperature increased the COP while decreasing the exergy efficiency. In addition, it was determined that subcooling increased both COP

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and exergy efficiency [2]. Önder Kızılkan et al. studied the thermal-economic effects of subcooling and superheating in VCRS. In the study, optimum conditions were determined for optimum heat exchanger area and optimum system efficiency [3]. R. Yıldırım and A. Şencan Şahin estimated the energy and exergy performance of subcooled and superheated VCRS with an adaptive network-based fuzzy inference system (ANFIS). The results showed that ANFIS was successful in predicting the thermodynamic performance in the cooling system [4]. Cingiz et al. conducted thermodynamic analysis of R22 alternative refrigerants (R417A, R438A, R422A and R422D) in VCRS. As a result, it was determined that R438A and R417A, among the 4 alternative fluids examined, would be a better alternative to R22 in terms of COP, exergy efficiency and exergy destruction [5].

Kadir Bakırcı and Derya Çolak investigated the effects of superheating and subcooling heat exchanger on the performance of the ground source heat pump system. They used their experimental results to determine the COP values of the heat pump system [6].

Schematic representation of the cycle, logarithmic pressure-enthalpy (lnP-h) diagram and temperature-entropy (T-s) diagram are shown in Figure 1.

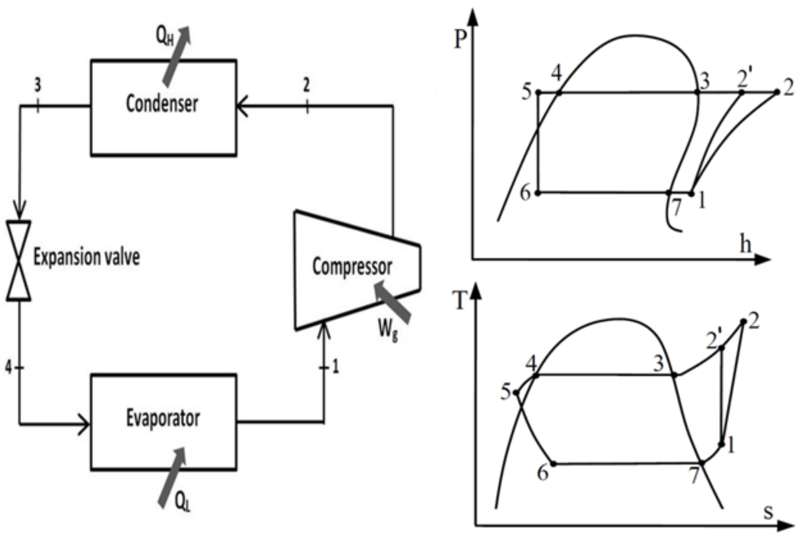

Fig. 1. Schematic refrigeration cycle, lnP-h and T-s diagram of the cycle [3]

R507A is a mixed refrigerant that does not contain CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon). This fluid is frequently used in commercial and industrial refrigeration applications. R507A is especially preferred in cooling systems operating in low and medium temperature ranges. R507A consists mainly of the components R125 (50%) and R143a (50%). This mixture has a suitable operating pressure and temperature range for low temperature applications. Additionally, its ODP (Ozone Depletion Potential) value is zero, meaning it has no damaging effect on the ozone layer. However, R507A is high in global warming potential (GWP), meaning it may contribute to greenhouse gas emissions. Thermophysical properties of R507A are shown in Table 1.

Table 1. General properties of R507A [7]

Refrigerant	R507A
Composition	C_2HF_5 (50%) + $C_2H_3F_3$ (50%)
Boiling point at 1 atm, (°C)	-46.7
Critical temperature, (°C)	70.9
Critical pressure, (Bar)	37.9
Ozone depletion potential (ODP)	0
Global warming potential (GWP)	3985

2. MATERIAL AND METHOD

The following assumptions were made in the calculations for the performance analysis of the refrigeration cycle;

- All components work in steady state.
- Changes in kinetic and potential energies in the elements forming the cycle are neglected.
- The system's cooling capacity is Q_E = 1 kW and is fixed.
- The isentropic efficiency of the compressor is η_{comp}=0.7.

In the refrigeration cycle given in Fig. 1, evaporator capacity can be determined as follows [8]:

$$\dot{Q}_E = \dot{m}\ (h_1 - h_4) \tag{1}$$

Compressor work is [9];

$$\dot{W}_{Comp} = \dot{m}\ (h_2 - h_1) \tag{2}$$

Conderser capacity is [10];

$$\dot{Q}_C = \dot{m}\ (h_3 - h_2) \tag{3}$$

COP of the refrigeration cycle can be determined as follows [11];

$$COP = \frac{\dot{Q}_E}{\dot{W}_{Comp}} \tag{4}$$

3. RESULTS

The VCRS was analyzed for different evaporator, condenser, superheat and subcooling temperatures. The results obtained from the analysis are given graphically below. In the analysis results given in Figure 2, the condenser temperature of the cycle was kept constant at 35 °C. Evaporator temperature was changed between -5 and -25 °C, and superheat and subcooling temperatures were changed to 0, 3, 5 and 7 °C. In the analysis made depending on the change in evaporator temperature, superheat and subcooling temperatures, the highest COP value of the cycle is 3.71. This value was obtained for -5 °C evaporator temperature, 35 °C condenser temperature, 7 °C superheat and subcooling temperatures. The lowest COP value is 1.848. This value was obtained under operating conditions of -25 °C evaporator temperature, 35 °C condenser temperature, 0 °C superheat and subcooling temperatures. When Figure 2 is examined, it was seen that COP values decrease as the evaporator temperature and also the superheat and subcooling temperatures decrease. Increasing the subcooling temperature reduces the temperature of the liquid refrigerant entering the evaporator. Increasing the superheat temperature allowed the vapor refrigerant to absorb more heat and, as a result, to increase the COP value.

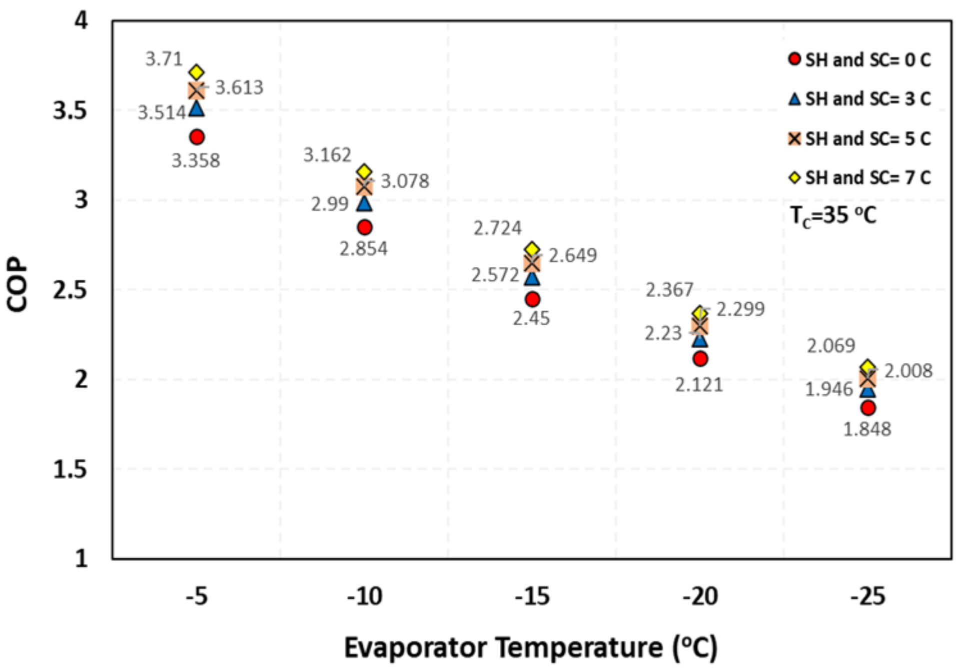

Fig. 2. Variation of COP with evaporator, subheat and subcooling temperature

In the analysis results given in Figure 3, the evaporator temperature of the cycle was kept constant at -10 °C. The condenser temperature was changed between 25 and 45 °C, and the superheat and subcooling temperatures were changed to 0, 3, 5 and 7 °C. In the analysis made depending on the change in condenser temperature, superheat and subcooling temperatures, the highest COP value of the cycle is 4.367. This value was obtained for -10 °C evaporator temperature, 25 °C condenser temperature, 7 °C superheat and subcooling temperatures. The lowest COP value is 2.054. This value was obtained under operating conditions of -10 °C evaporator temperature, 45 °C condenser temperature, 0 °C superheat and subcooling temperatures. Figure 3 shows that COP values decrease as the condenser temperature increases and at the same time the superheat and subcooling temperatures decrease. Not increasing the condenser temperatures too much and not decreasing the superheat and subcooling temperatures too much will ensure that the COP value remains high.

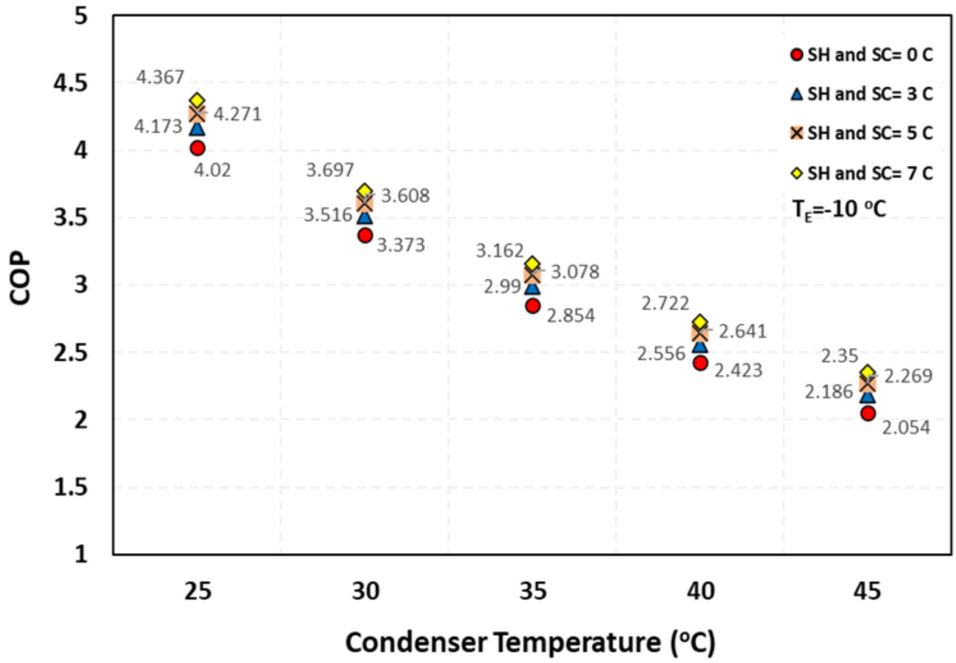

Fig. 3. Variation of COP with condenser, superheat and subcooling temperature

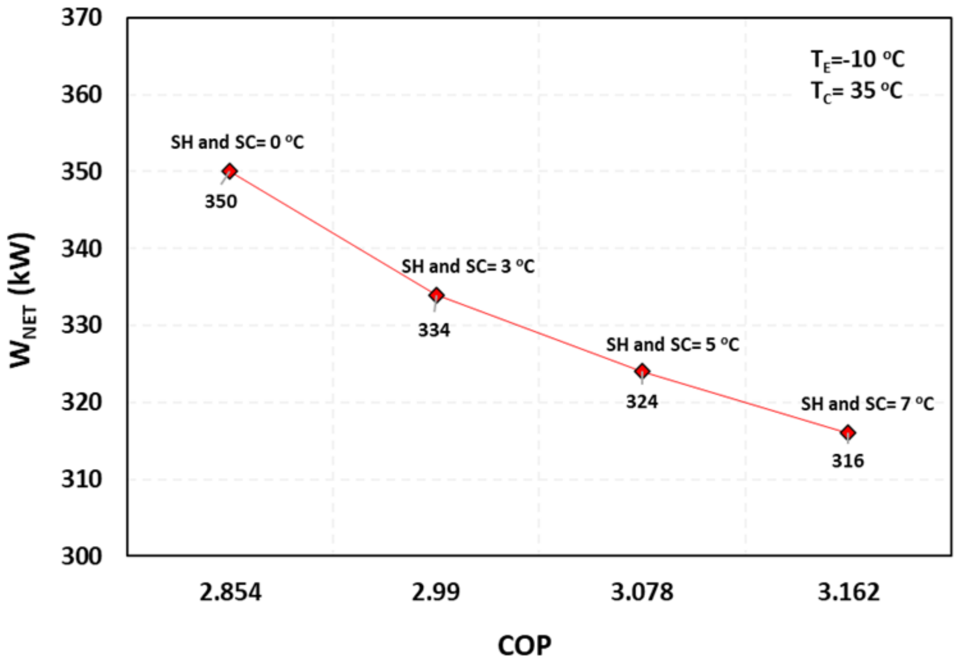

Fig. 4. Variation of COP and W_{net} with superheat and subcooling at constant evaporator and condenser

In VCRS, the evaporator temperature was kept constant at -10 °C, the condenser temperature was kept constant at 35 °C, and the SH and SC temperatures were changed to 0, 3, 5, 7 °C. COP and W_{net} changes were calculated for the specified operating conditions. The results obtained are given in Figure 4. In the analysis, it is seen that as SH and SC temperatures increase, COP values also increase. At the same time, it is seen that W_{net} values decrease accordingly. Therefore, increasing SH and SC temperatures both provides effective cooling performance and reduces energy consumption. For the operating conditions given in Figure 4, the highest COP value is 3.162 and the lowest W_{net} value is 316 kW. These values were obtained when SH and SC temperatures were 7 °C.

4. CONCLUSIONS

In this study, the effects of superheating and subcooling on the performance of the vapor compression refrigeration system using R507A, one of the alternative refrigerants, were examined. Superheating provides greater cooling effect in the evaporator, but excessive superheating can reduce energy efficiency. However, subcooling increases cooling capacity, while too much subcooling can increase energy consumption. Therefore, superheat and subcooling levels must be controlled during the design and operation of vapor compression refrigeration systems. It is important to determine appropriate superheat and subcooling levels to achieve better performance and energy efficiency.

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