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Thermodynamic Analysis of Refrigerants Pairs in Two Stages Cascade Vapor Compression Refrigeration Cycle for Cooling of Telecommunications Equipment with Volume Decreasing Approach

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ABSTRACT: In this research, a two-stage cascade refrigeration cycle with different refrigerants is analyzed thermodynamically and then every component of the cycle with the approach to decrease the volume is studied. Functional variables are including evaporation temperature, pressure ratio and the amount of input work in both high and low-temperature cycle and cooling capacity as stated in issue is considered. With the change of refrigerants in high and low-temperature circuits, variation the volume of the components and change the coefficient of performance of the system is investigated. The results show that the lowest volume of the system achieves in the high-temperature cycle with the use of refrigerant R-134a use and in the low-temperature cycle with the use of R-508B and R- 23 and the total volume of the system is reduced. It is observed that at low evaporation temperatures, the compressor volume is highly dependent on the amount of cooling capacity. As for the evaporation temperature 173K, with increasing cooling capacity from 100 W to 200 W, the compressor volume increases 3.2 times from 9100 cm3. It is also seen with increasing the evaporation temperature, the volume of air-cooled condenser reduces and in the evaporation temperature 173K, with increasing of cooling capacity from 100 W to 200 W, the volume of air-cooled condenser system in two-stage cascade increases from 4500 cm^3 to 13000 cm^3.

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1. INTRODUCTION

During the past decade, the structure of the server computers to shrink the decreasing size of Complementary Metal–Oxide–Semiconductor (CMOS) has much progress but despite the reduction of the volume, heat production per unit volume has increased. International Technology Roadmap for Semiconductors (ITRS) estimates that the maximum amount of energy that the microprocessor without the use of cooling equipment is equal to 198 W [1]. Also it is known that the performance of the microprocessor with decreasing of working environment temperature increases. Recently it has been shown that at low temperature (100 ℃), the performance of the chip CMOS increases equal to 3.4 times compared with 85 ℃ [2]. Indlee et al. [3] investigated the determination of the optimal condensation temperature in the condenser cascade that reduces the volume and increases the coefficient of performance. Also, they studied the maximum coefficient of performance and minimum exergy destruction of the system with a variation of the evaporation temperature in the low-temperature cycle, the condensation temperature in the high-temperature cycle and temperature difference in the cascade condenser. In another research, Dubai and Kumar [4] carried out the analysis of a two-stage cascade refrigeration system with the carbon dioxide-propylene refrigerants. Propylene considered as a low-temperature cycle refrigerant and carbon dioxide as a high-temperature cycle refrigerant. In this research, the variation of three important design parameters including, the condenser temperature, evaporator temperature and temperature difference in the cascade condenser to achieve a maximum coefficient of performance has been investigated. Keshtkar and Talebizadeh in 2017 [5] investigated the optimization of a cold water production cycle in the second refinery, unit 132 South Pars, from thermodynamic, economic and environmental viewpoints. In another investigation, Keshtkar and Zahiri in 2018 [6] carried out a thermodynamic simulation of a refrigeration system with variable flow. In this work, the thermodynamic response to different conditions, such as changing the temperature of evaporation and condensation was investigated. Review of the studies in the field of refrigeration systems analysis shows the analysis of the cascade refrigeration with decreasing volume approach has not carried out. Therefore, in the present study, a two-stage cascade refrigeration system with specific conditions simulated thermodynamically with the purpose of the application in electronic and telecommunication equipment and then using the governing equations for every component of the cycle by changing the refrigerants of every cycle, the minimum volume of the components is investigated.

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2. THEORY

Fig. 1 shows a two-stage cascade refrigeration cycle with the pressure-enthalpy diagram. This system consists of two separate refrigeration circuit means a High-Temperature Circuit (HTC) and a Low-Temperature Circuit (LTC). These two circuits have been coupled by a heat exchanger called cascade condense. The condenser heat Q_h removes from condensation temperature T_C to ambient temperature T_0. Refrigeration capacity $\dot{Q}_c$ produces in the evaporator at the evaporation temperature T_E from the cold temperatures T_{CL}, $T_{cas,E}$ and $T_{cas,C}$ which are the evaporation temperature in the low-temperature cycle and the condensation temperature in the high-temperature cycle, respectively. $\Delta T_{cas} = T_{cas,C} - T_{cas,E}$

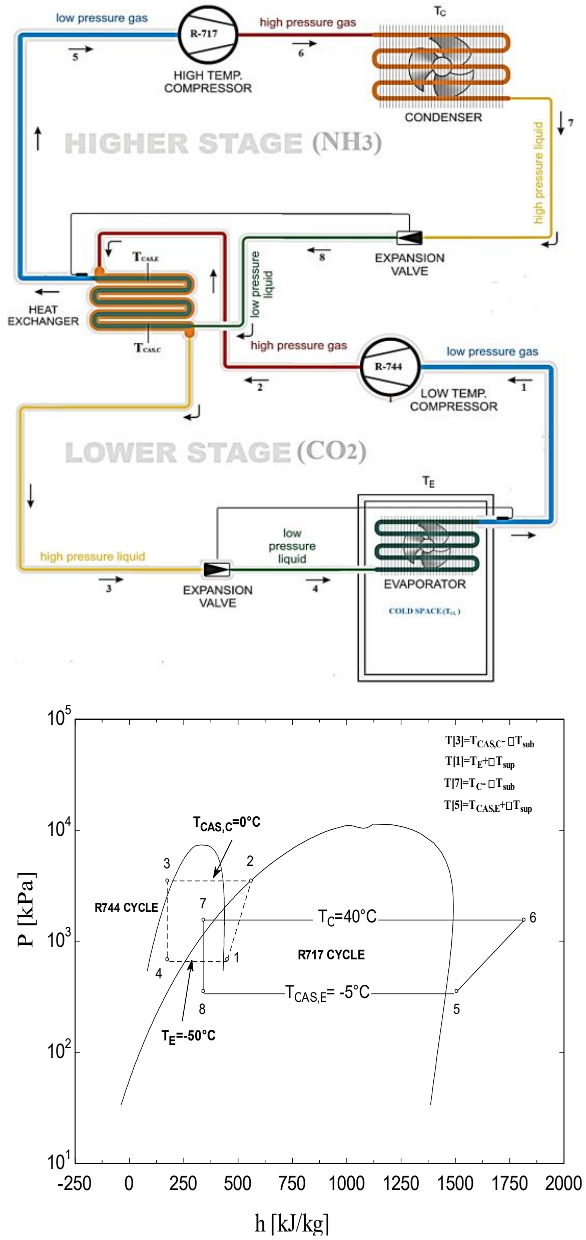

Fig. 1: Schematic of a two-stage cascade refrigeration cycle and the corresponding pressure-enthalpy diagram

is the temperature difference in the cascade condenser. In the present work, thermodynamic analysis of refrigeration system is carried out based on the following assumptions [7].

The governing equations in accordance with Fig. 1 for energy analysis are as follows [7]:

Cooling capacity:

$$\dot{Q}_L = \dot{m}_L (h_1 - h_4) \quad (1)$$

High temperature circuit compressor power consumption:

$$\dot{W}_{comp,HTC} = \frac{\dot{m}_H (h_{6S} - h_5)}{\eta_s \eta_m \eta_e} = \frac{\dot{m}_H (h_6 - h_5)}{\eta_m \eta_e} \quad (2)$$

Low temperature circuit compressor power consumption:

$$\dot{W}_{comp,LTC} = \frac{\dot{m}_L (h_{2S} - h_1)}{\eta_s \eta_m \eta_e} = \frac{\dot{m}_L (h_2 - h_1)}{\eta_m \eta_e} \quad (3)$$

In the above equations η_m and η_e considered equal to 0.93, are the mechanical and electrical efficiency of the compressor motor. The coefficient performance is equal to:

$$COP = \frac{\dot{Q}_L}{\dot{W}_{HTC} + \dot{W}_{LTC}} \quad (4)$$

3. RESULTS AND DISCUSSION

In this section by using the refrigerant R-134a for a high-temperature circuit and the use of R-508B for a low-temperature circuit, the volume of every single component and then the overall system volume can be calculated. In Figs. 2 and 3, the effect of evaporation temperature on the volume of the compressor and condenser for two refrigeration capacities have been shown, respectively. As well as the total volume of the system includes the volume of the electric motor, compressor, evaporator, condenser and cascade condenser for two different refrigeration capacities has been shown in Fig. 4.

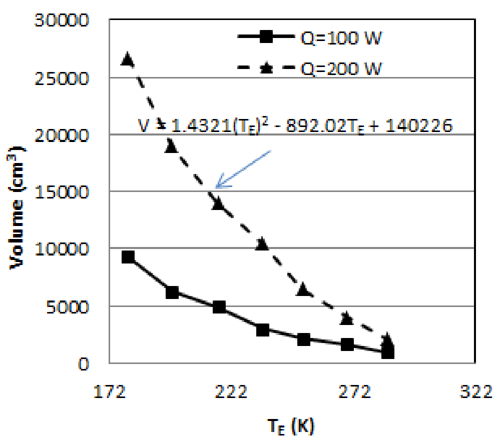

Fig. 2. Variation of the compressor volume with evaporation temperatures for two cooling capacities.

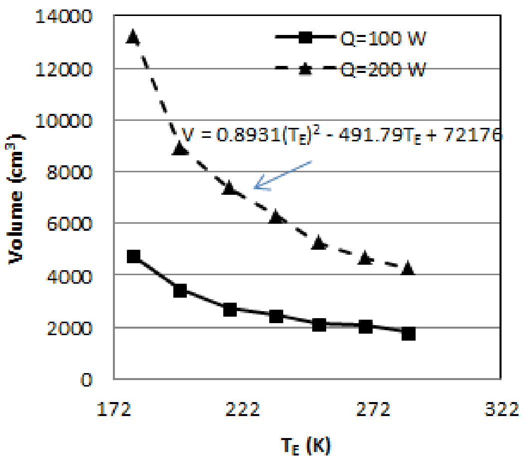

Fig. 3: Variation of the condenser volume with evaporation temperatures for two cooling capacities.

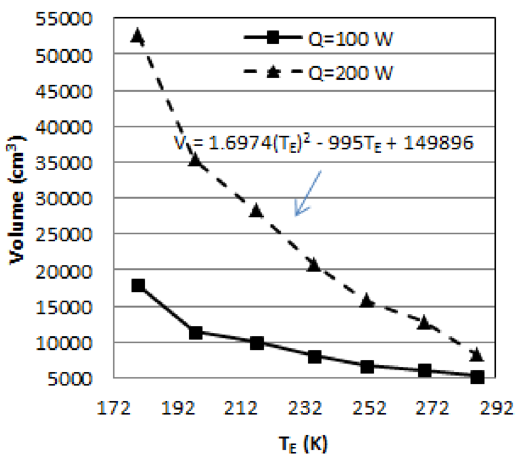

Fig. 4: Variation of the system volume with evaporation temperatures for two cooling capacities.

4. CONCLUSION

Due to the increasing use of computers in electronic and telecommunications systems, the refrigeration systems with low volume and high performance attract considerable attention. One of the high-performance refrigeration systems is a cascade refrigeration system. In this research, at the first step, cascade system modeling by thermodynamic analysis and energy carried out. After solving the cycle and change various parameters the following results were obtained. By reducing the temperature of the working environment of the system, the coefficient of performance of the system increases and its volume will be smaller. Results show that in the evaporation temperature $T_E = 183\,K$ by increasing the ambient temperature from 300 to 320 K, the coefficient of performance reduces from 2.16 to 1.8. The maximum coefficient of performance is obtained with the use of R-22 in the high-temperature circuit and R-600a in the low-temperature cycle, but both of these refrigerants due to their high global warming potential are not used. Results show that by increasing the evaporation temperature from 173K to 183K the coefficient of performance of the system with refrigerant R-22 increases from 2.28 to 2.45. Also, it is seen that the lowest volume of the system is obtained with utilizing refrigerant R-134a in the high-temperature cycle and refrigerants R-23 and R- 508 B in the low-temperature cycle. It was observed that by reducing the evaporation temperature from 290K to 173K for cooling capacity 200W, compressor volume increases from 2200 cm^3 to 27000 cm^3. The results also showed that by reducing the evaporation temperature from 290K to 173K for cooling capacity 200W, the volume of the condenser increases from 4000 cm^3 to 13000 cm^3. Moreover, the evaporation temperature at 173K, with double cooling capacity from 100 W to 200W the air condenser volume, increases from 4500 cm^3 to 13000 cm^3.

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