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Analysis of Cascade Vapour Refrigeration System with Various Refrigerants

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Abstract

In this paper report the performance analysis of different refrigerants couples in cascade refrigeration system. Refrigerants such as R134a/R23, R410A/R23 and R404A/R170 have been successfully analyzed in the superheating and sub cooling range of 10 °C and 5 °C respectively. The variation in condenser temperature was from 30 to 50 °C in high temperature circuit while evaporator temperature in low temperature circuit varied in the range of -70°C to -50 °C. The compressor efficiency was assumed to be 0.7 throughout the experiment. It has been revealed that there is enhancement in coefficient of performance and flow rate with rise in compressor work and evaporator temperature. From the present study we conclude that the refrigerant pair R134a/R170 was found to have greater coefficient of performance and lower mass flow rate and the pair R404A/R508B was found to have smaller coefficient of performance and greater mass flow rate.

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Keywords: Coefficient of performance, Evaporator, Condenser, Heat Exchanger, Cascade Refrigeration system.

1. Introduction

In the present world, refrigeration plays a key role to maintain very low temperature for various purposes. Temperature ranges of -10°C to -30 °C, is used for the vapour compression refrigerants. Low temperature refrigeration system requires temperatures between –30 °C to –100 °C which are common in food, chemical, pharmaceutical and various other industries which involve processes at low temperatures. As the operating temperatures get lowered, the single-stage vapour compression systems are no longer useful because of their higher pressure ratio. It has been shown that the increase in pressure ratio usually results in greater discharges and decrease in volumetric efficiency. Low temperatures of –40 °C to –50 °C in single stage systems have been achieved with the compressors with a flat volumetric efficiency.

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Nomenclature

LTC	Lower Temperature Circuit
COP	Coefficient of Performance
HTC	Higher Temperature Circuit

The Cascade refrigeration system are applicable to low temperature systems, with a series of single stage units which are thermally insulated in evaporator / condenser cascades. There are several refrigerant which are appropriate for a wide range of temperatures. The system may employ multiple cascades such as two-circuit and three-circuit and the required temperature can be achieved by single-stage system with a better efficiency when compared to the cascade system because of several losses and irreversible nature.

2. Analysis of Cascade Refrigeration System based on thermodynamic perspective

The cascade vapour refrigeration system with high side and low side vapour refrigeration systems is given as namely A and B and is attached to one another via a heat exchanger. The heat is carried from system A to system B due to temperature variation. The rate of flow of refrigerants is not uniform in the two systems and in certain cases the same refrigerant can be employed in both system A and B. On the basis of irreversibility and comparison of energy in the two stage cascade vapour refrigeration system the results have been obtained. The equation (1) and (2), are the continuity and energy equations for a control volume (CV).

$$Q_{c.v} + \sum m_i \left(h_i \frac{v_i}{2} + gz_i \right) = \frac{dE_{c.v}}{dt} + \sum m_o \left(h_o + \frac{v_o}{2} + gz_o \right) + Wc.v \quad (1)$$

$$\frac{dE_{c.v}}{dt} + \sum m_o - \sum m_i = 0 \quad (2)$$

Here, Q_{cv}, W_{cv} and E_{cv} are the rate of heat transfer to the control volume (CV) and the actual power carried by the CV and energy within the boundary condition of the CV such as gZ, $V^2/2$, m, h are the potential energy, specific kinetic energy, flow rate and specific enthalpy of the fluid at the inlet and outlet settings.

3. Methodology and laboratory setup

The experimental setup included a cascade vapour refrigeration system with two single stage systems followed by a heat exchanger. Among the two refrigerants one acted as working medium and was used in LTS and other was used in HTS. Gives the Schematic circuit diagram of a Cascade refrigeration experimental setup is shown in Fig. 1.

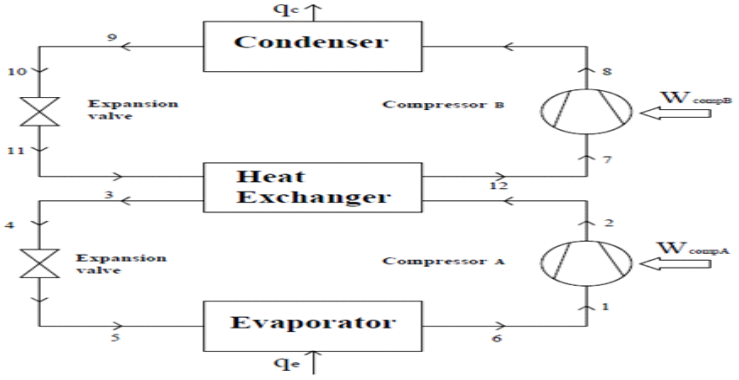

Fig.1 Schematic circuit diagram of a Cascade refrigeration

4. Results and Discussion

The coefficient of performance, rate of flow and compressor work were taken into account and based on these parameters the best refrigerant is selected. The enhancement in work done in the compressors was due to combined effect of both refrigerants. The temperature range in condenser R23/ R404A was found to have higher work done, while R23/ R134a achieved lower value. The work potential of the refrigerant couples were observed to be intermediate as R23/ R290, R23/ R410A and R23/ R407C boosted parallel in alignment to each other.

4.1. Effect of Evaporator Temperature on COPs

In the present study, the coefficient of performance of cascade Vapour Refrigeration system with condenser and evaporator temperatures of about -20 °C and 40 °C, -20 °C respectively and compressor I efficiency of 0.7 have been considered. Here, the temperature of condenser, compressor efficiency and intermediate temperature were kept constant. The results revealed that the coefficient of performance of cascade system boosted. This further indicates that R23/ R134A has the greater COP, while R23/R404A has the lesser value. The coefficient of performance of the refrigerant couples R23/ R290, R23/ R410A and R23/ R407C are in the intermediate range and were observed to augment parallel to each other as shown in below Fig 2 and Fig 3.

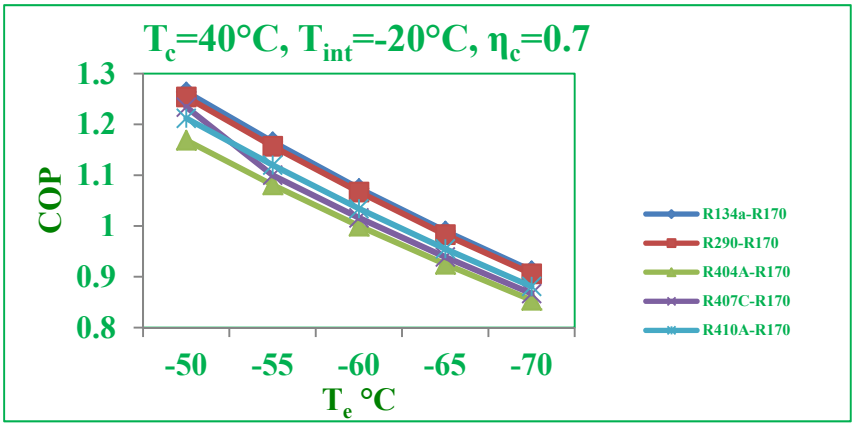

Fig.2 Changes in coefficient of performance values with evaporator temperature

The coefficient of performance of cascade Vapour Refrigeration system with condenser and evaporator temperatures of about -20 °C and 40 °C, -20 °C respectively and compressor I efficiency of 0.7 have been considered.

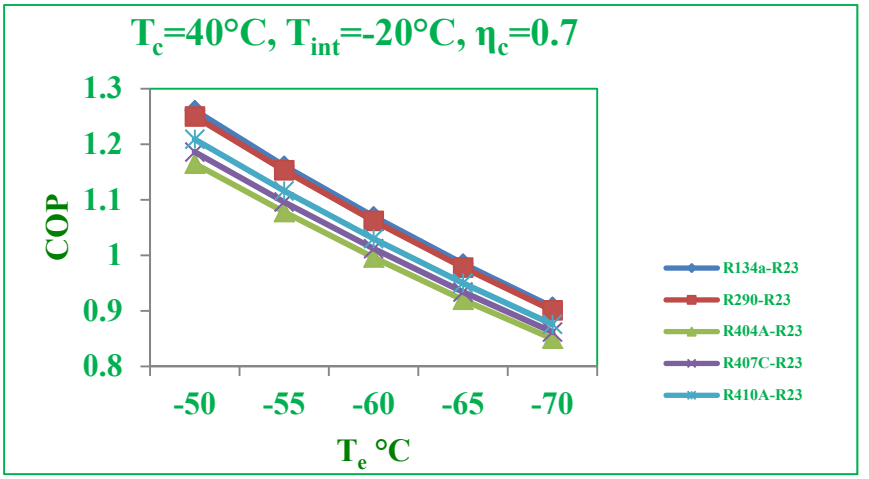

Fig.3 Changes in coefficient of performance values with evaporator temperature

The temperature of condenser, compressor efficiency and intermediate temperature were kept constant throughout the experiment. The results revealed that the cascade vapour refrigeration system showed an enhancement and specific work of compression lowered with increase in the evaporator temperature. It was observed that the coefficient of performance of cascade system boosted. The refrigerant couples R170/ R134a has the higher COP, while R170/ R404A has the lower one. The COPs of R170/ R290, R410A–R170 and R170/R407C were found to have intermediate values and their values increased parallel to one another as shown in below Fig 4.

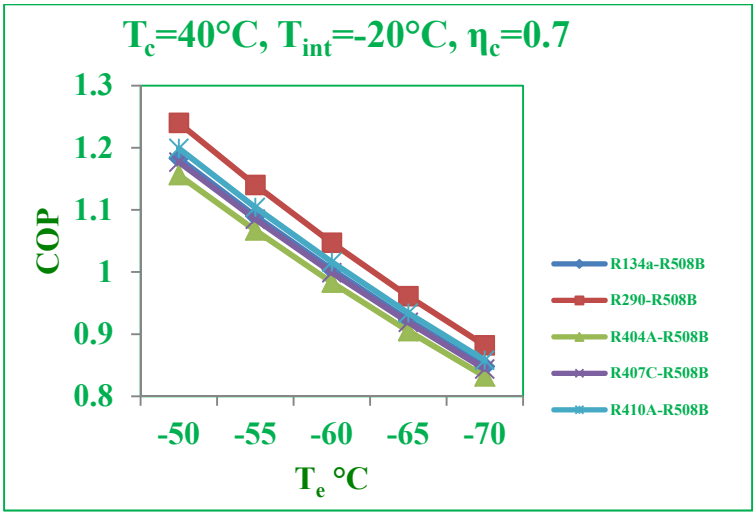

Fig.4 Variations in CoP with evaporation temperature

Considering the effect of evaporator temperature on COP with a constant condenser temperature, compressor efficiency and intermediate temperature the following observations have been made:

- The effect of cascade system was found to increase and specific work of compression lowered on rising the temperature of evaporator.
- The observation indicated that R508B/ R290 has the higher COP, while R508B/ R404A has the lower value. The COP of R508B/ R134a, R410A–R508B and R508B/ R407C were in the intermediate range and found to enhance paralleling each other.

5. Conclusion

The present investigation reveals the following results.

- The Coefficient of performance decreased with rise in temperature for different refrigerants.
- The refrigerant couple R134a/R170 was found to have highest COP and least flow of mass rate among all the refrigerant couples studied.
- There is good agreement between the results obtained from our newly designed experimental setup conditions and those from manufacturer's data.

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