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Application of Ammonia and Carbon Dioxide Thermodynamics to a Cascade Refrigeration System

A Hari Krishna[1,] S Vijay Kumar [2] B Srihari [3], J Suresh Babu[4]

ABSTRACT

By analyzing the system's thermodynamics using R744-R717 and certain design factors, the condensing temperature of a cascade refrigeration system may be determined. The effects of carbon dioxide cooling in a low-temperature circuit (R744) and ammonia cooling in a high-temperature circuit (R717) are investigated. Using regression analysis, we looked at how different values of COP and TC may be related to one another. Several optimization strategies have the potential to improve refrigeration systems.

INTRODUCTION

For low temperature applications like quick freezing and storing frozen food, a single stage vapour compression refrigeration system cannot be used since the needed evaporation temperature varies from -40°C to -55°C. Two-stage or cascade refrigeration systems are often employed in cold climates. In contrast to the two-stage system, the high and low temperature circuits in a cascade refrigeration system each utilize their own refrigerant [1,2]. Natural refrigerants may be utilized in two-stage or cascade refrigeration systems to assist fulfill obligations under environmental treaties. Ammonia (R717) is a natural refrigerant often used in low-temperature, two-stage refrigeration systems despite its many drawbacks. The smoke produced by its combustion is very carcinogenic. One chemical that exemplifies this is ammonia.

When the evaporation temperature drops below -35 degrees Celsius, air seepage causes ammonia systems to be less effective in the short term and less reliable in the long run. Evaporating the 35°C liquid requires a non-toxic and flammable gas with a high positive evaporation pressure.

Using just CO2 and NH3, it is feasible to achieve all of these goals. It is advisable to utilize a thick, environmentally friendly refrigerant gas that won't burn while evaporating water at temperatures below -35°C. Cascade refrigeration might use CO2 and NH3 to do this. Both carbon dioxide and ammonia may be used as refrigerants in a CO2/NH3 cascade system. Using carbon dioxide (CO2) in industrial-scale refrigeration systems that function at very low temperatures has a number of benefits. It also doesn't give out any potentially dangerous fumes or odors. Cascade systems are more efficient than two-stage ammonia refrigeration systems [3,5,7] because they require much less ammonia at low temperatures. As a consequence, CO2/NH3 cascade refrigeration systems have grown increasingly widespread.

[1,2,3,4] Asst. Professor,

Department of ME, K. S. R. M College of Engineering(A), Kadapa

Evaporating and condensing temperatures in CO2/NH3 systems may need the use of alternative condensing methods due to the temperature difference between the high and low temperature circuits in cascade refrigeration systems.

Some potential buyers could be discouraged by a 10% price increase for cascade refrigeration systems. Both the refrigerant charge and the environmental impact are larger in single-stage systems. By decreasing the volume of superheated gas, cooling performance is enhanced while condenser capacity is decreased under high-temperature circuit discharge conditions (Ratts and Brown,2000).

A compressor's isentropic and volumetric efficiency are both measured by the pressure ratio. There are two correlations that may be used to determine the optimal condensing temperature and maximum COP for CO2/NH3 cascade refrigeration systems and accompanying machinery.

System description

Figure 1 depicts a cascade refrigeration system. T-s and P-h diagrams are shown in Figure 2 (see below). The refrigeration systems in this system are comprised of both high- and low-temperature systems (LTC). HTC uses ammonia as a refrigerant, while LTC uses carbon dioxide. The cascade condenser serves as both an evaporator and a condenser, providing a thermal interface between the circuits. When it comes to condensing and evaporating pressure, CO2 has a much greater figure in Figure 2 than NH3. As a result, the NH3 circuit is known as the HTC, whereas the CO2 circuit is known as the LTC.

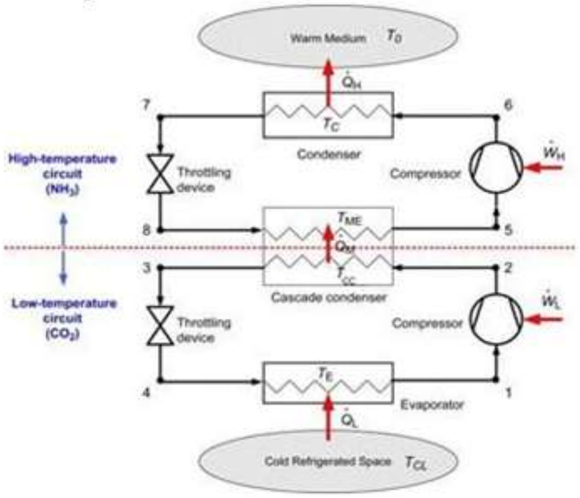
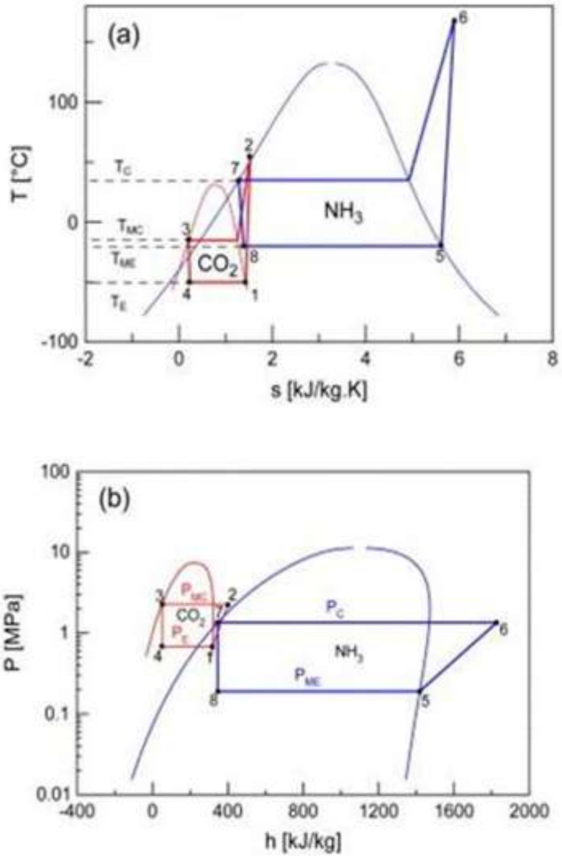


Fig.1.Schematic diagram of a CO_2/NH_3 cascaderefrigeration system



System diagrams for cooling using CO2 and NH3 may be shown in Figures 2 (a) and (b).

The condenser in the cascade refrigeration system rejects QH to the coolant or environment at temperature To when QH is at its condensing temperature of Tc. The cold refrigerated load QL is transported to the evaporating temperature TE via the cascade system's evaporator. The LTC evaporator and HTC evaporator both absorb the same amount of thermal energy if the LTC compressor is functioning. TCC and TME may be used to represent the thermal conductivity of the cascade-condenser. Condensing and evaporating temperatures are given as a temperature differential (TCC-TME). TE, Tc, and Td are the design parameters for the CO2/NH3 cascade refrigeration system, which includes the evaporating and condensing temperatures.

Thermodynamic analysis

A parametric study using a constant cooling capacity, varied condensing temperatures, evaporating temperatures, and temperature variations in the cascade-condenser identified the ideal condensing temperature. Cascade refrigeration system's low-temperature condenser At 35°C, 40°C, and 45°C condensing temperatures were used in the parametric study. As you can see, the evaporation temperatures range from 45 to -50 degrees Celsius. The temperature of the cascade-condenser varies by 3°C, 4°C, and 5°C. Control volume may be employed for each component of the cascade refrigeration system seen in fig.1.

Assumptions

- It is the goal of these hypotheses to make understanding thermodynamics a little bit simpler.
- Everything in this model assumes a stable state.
- Across components, the potential and kinetic energy of the working fluids don't change considerably.
- The pressure ratio may be used to express the isentropic efficiency of the high- and low-temperature circuit compressors.
- It is anticipated that each compressor would have a total efficiency of 93% in terms of motor and mechanical components.
- There is a minimal heat loss and pressure drop in the pipe that connects the components.
- Throttling devices must be isenthalpic in order to work.
- The evaporator output temperature ranges from subcooled to superheated, while the condenser and cascade condenser temperatures stay at subcooled levels.
- Calculation of the heat transfer rates of the condenser, cascade condenser, and evaporator for each cycle is done using the balanced equation.

Mass balance

$$\sum_{in} m = \sum_{out} m \tag{1}$$

Energy balance

$$Q - W + \sum_{in} mh - \sum_{out} mh = 0 \tag{2}$$

Table-1. Mass and energy balance equations of different components.

Component	mass balance	Energy balance
HTC compressor	$\dot{m}_5 = \dot{m}_6 = \dot{m}_H$	$\dot{W}_H = \frac{\dot{m}_H (h_{6s} - h_5)}{\eta_s \eta_m \eta_e} = \frac{\dot{m}_H (h_6 - h_5)}{\eta_m \eta_e}$
Condenser	$\dot{m}_6 = \dot{m}_7 = \dot{m}_H$	$\dot{Q}_H = \dot{m}_H (h_6 - h_7)$
HTC throttling Device	$\dot{m}_7 = \dot{m}_8 = \dot{m}_H$	$h_7 = h_8$

$$\dot{m}_2 = \dot{m}_3 = \dot{m}_L$$

Cascade condenser

$$\dot{m}_8 = \dot{m}_5 = \dot{m}_H$$

$$\dot{Q}_M = \dot{m}_H(h_5 - h_8) = \dot{m}_L(h_2 - h_3)$$

LTC compressor

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_L$$

$$\dot{W}_L = \frac{\dot{m}_L(h_{2s} - h_1)}{\eta_s \eta_m \eta_e} = \frac{\dot{m}_L(h_2 - h_1)}{\eta_m \eta_e}$$

LTC throttling device

$$\dot{m}_3 = \dot{m}_4 = \dot{m}_L$$

$$h_3 = h_4$$

Evaporator

$$\dot{m}_4 = \dot{m}_1 = \dot{m}_L$$

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

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

Energy Efficient. It's possible to compare the isentropic and volumetric efficiency of ammonia and carbon dioxide compressor compressors. How many times the volume is compressed in a unit of measurement.

NH_3 Compressor [20] $\eta_s = -0.00097 R_p^2 - 0.01026 R_p + 0.83955$ (3)

$$\eta_V = -0.00076 R_p^2 - 0.05080 R_p + 1.03231 \quad (4)$$

CO2 Compressor [21]

$$\eta_s = -0.00476 R_p^2 - 0.0923 R_p + 0.89810 \quad (5)$$

$$\eta_V = -0.00816 R_p^2 - 0.15293 R_p + 1.13413 \quad (6)$$

Performances of the system

The cascade refrigeration system's total coefficient of performance, or first law efficiency, is given by

$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}_H + \dot{W}_L} = \frac{(COP_{LTC})(COP_{HTC})}{1 + COP_{LTC} + COP_{HTC}} \quad (7)$$

where

$$COP_{LTC} = \frac{\dot{Q}_L}{\dot{W}_L} \quad (8)$$

$$COP_{HTC} = \frac{\dot{Q}_M}{\dot{W}_H} \quad (9)$$

The refrigeration capacity $\dot{Q}_L$, the heat transfer rate in the cascade condenser $\dot{Q}_M$, the work in put to the HTC compressor $\dot{W}_H$ and the work input to the LTC compressor $\dot{W}_L$ can all be determined using the relationship given in the table.

Conclusions and Findings

Ammonia and carbon dioxide, as well as their thermodynamic characteristics, are calculated using the EES programme.

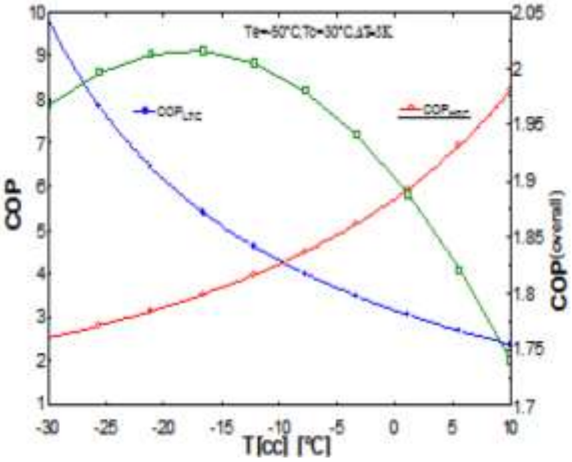


Fig-3 Effect of TCC on the COP of HTC and LTC

As shown in Fig. 3, TC and TCC curves are shown for TC = 30°C, as well as for TE=-50°C and 3K T. In this table, HTC and LTC's COP is calculated using formulas (8) and (9) (9). (9). There is an increase in HTC, but a drop in LTC's COP with a rise in TCC, No matter whether system is used, both systems have the same optimal TCC and maximum COP, regardless of which refrigerant is used. In this temperature range, the COP is 2.01 and Tcc is -17°C.

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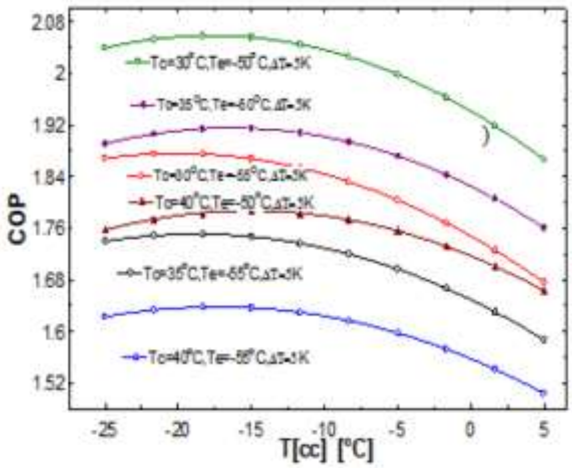

Fig. 4. plots the curves of overall COP versus Tcc at different design parameters

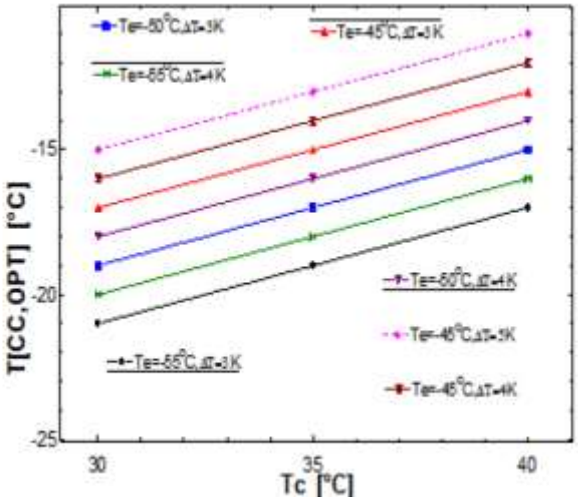

Fig. 5 The influence of Tc on the Tcc,opt of a CO_2/NH_3 cascade refrigeration system.

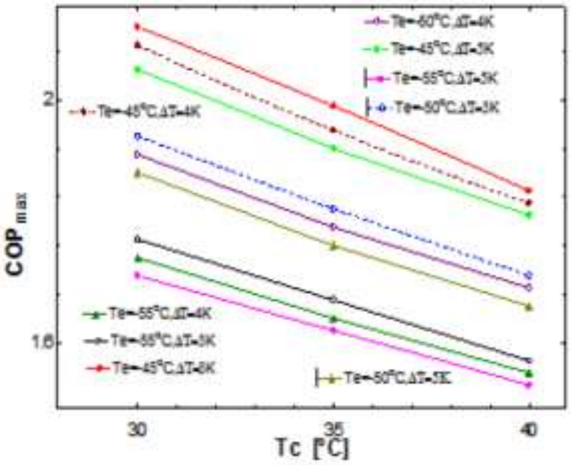

Fig-6 The influence of Tc on the COP_{max} of a CO_2/NH_3 cascade refrigeration system.

TCC,OPT, and COPmax are affected by changes in evaporation temperatures. Temperature fluctuations in the cascade condenser may be seen in Figures 6 and 7. (T). Increases in the TC seem to increase TCCOPT and decrease COPmax, according to the graphs.

According to Figure 6, TCCOPT is directly proportional to each of the three independent variables: TC, TE, and T. As seen in Figure 7, all of these variables exhibit linear connections to COPmax (Fig-6). A few regression equations have been developed using the aforementioned data:

$$T_{CC,OPT} = 41.48 + 0.4T_C + 0.4T_E + 0.78\Delta T \tag{10}$$

$$COP_{MAX} = 2.083 - 0.0231T_C + 0.0312T_E - 0.03167\Delta T \tag{11}$$

The unit used in Equations (10) and (11) is Kelvin (K).

CONCLUSION

In this publication (CC), the authors address the condensation temperature (OPT T) and its connection to the condensation temperature. The optimal performance coefficient for a CO2/NH3 cascade refrigeration system will be discussed in the next section. When the pressure and temperature of a liquid are equal, the evaporation temperature will have an effect on the condensation temperature. The condensers in the cascade are separated by a certain temperature difference (T) at each stage. liquid-to-gas condensation transition The thermal condenser temperature (Tc) rises in a cascade condenser. Nevertheless, when Tc or T rises, the maximum COP only rises by a little amount, whereas TE falls. By integrating the outcomes of these two correlations, the best possible correlation coefficient was calculated. The condensation point and the maximum performance coefficient are both temperature-dependent. parameters, seen from three distinct angles.

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