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Thermodynamics of a Carbon Dioxide and Ammonia Cascade Refrigeration System

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ABSTRACT

A cascade refrigeration system's condensing temperature is estimated by analysing the thermodynamics of the system using R744-R717 and a few design parameters. This research examines the effects of ammonia (R717) in a high-temperature circuit and carbon dioxide cooling in a low-temperature circuit (R744). Analysis of the relationships between optimum COP and ideal condensing temperature was carried out using regression analysis. Refrigeration systems may benefit from a variety of optimization techniques.

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]. Using natural refrigerants and a two-stage or cascade refrigeration system might assist in fulfilling obligations under environmental treaties. Despite its many drawbacks, ammonia (R717) is often used as a natural refrigerant in low-temperature, two-stage refrigeration systems. 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. Therefore, a non-toxic and flammable gas with a high positive evaporation pressure should be utilized to successfully evaporate the 35°C liquid.

All of these needs may be satisfied by combining CO2 and NH3. Water evaporation below -35 degrees Celsius requires a thick, environmentally friendly refrigerant gas that won't ignite. It is possible to use CO2 and NH3 in a cascade refrigeration system to achieve this goal. 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.

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There are no harmful byproducts, such as vapors or odors, either. Cascade systems are more efficient than two-stage ammonia refrigeration systems [3,5,7] because they require much less ammonia at low temperatures. This has led to the increased use of CO2/NH3 cascade refrigeration systems. Different condensing methods may be required in CO2/NH3 systems due to the temperature difference between the high and low temperature circuits in cascade refrigeration systems and the evaporating and condensing temperatures. Some consumers are turned off by a 10% increase in the cost of cascade refrigeration. The refrigerant charge and environmental impact of single-stage systems are both higher than those of two-stage systems. Reducing the volume of superheated gas in a high-temperature circuit discharge improves cooling performance and lessens the load on the condenser (Ratts and Brown,2000).

The pressure ratio is considered while measuring the isentropic and volumetric efficiency of a compressor. 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

In Figure 1, we see a refrigeration cascade. Figure 2 (below) depicts a T-s and P-h diagram. This system's refrigeration components include both high- and low-temperature compressors (LTC). HTC's cooling system employs ammonia, whereas LTC opts for carbon dioxide. The cascade condenser acts as a thermal barrier between the circuits and operates as both an evaporator and a condenser. Figure 2 shows that CO2 has a substantially higher condensing and evaporating pressure than NH3. Therefore, the CO2 circuit is called the LTC, while the NH3 circuit is called the HTC.

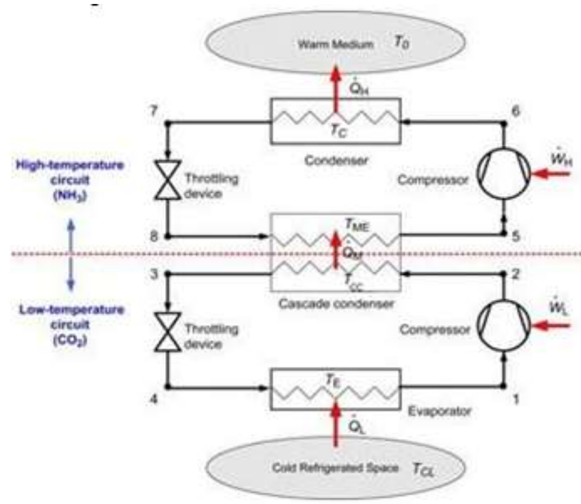
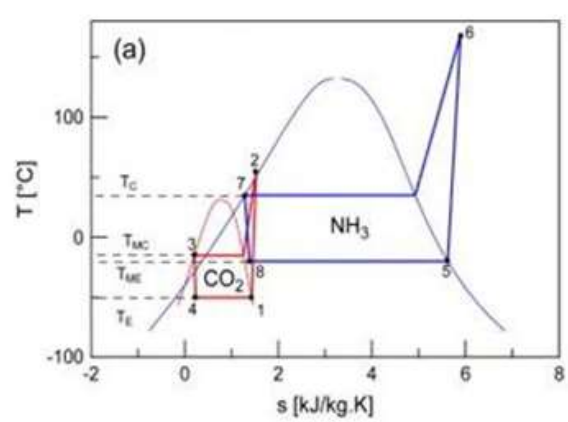


Fig.1.Schematic diagram of a CO_2/NH_3 cascaderefrigeration system



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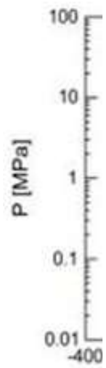

System diagrams for cooling using CO2 and NH3 may be shown in Figures 2 (a) and (b).

When QH reaches its condensing temperature of Tc, the condenser in a cascade refrigeration system rejects it to the coolant or environment at a temperature of To. The evaporator in a cascade system brings the chilled refrigerated load QL up to the evaporating temperature TE. If the LTC compressor is working, the same amount of thermal energy is absorbed by the LTC evaporator as by the HTC evaporator. The thermal conductivity of the cascade-condenser may be represented by TCC or TME. The difference between the temperatures at condensation and evaporation (TCC-TME) is reported. The operating temperatures of the CO2/NH3 cascade refrigeration system are specified by the evaporating, condensing, and dewpoint temperatures, respectively (TE, Tc, and Td).

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

$$\sum_{in} m = \sum_{out} m \quad (1)$$

Energy balance

$$Q - W + \sum_{in} mh - \sum_{out} mh = 0 \quad (2)$$

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

Component	mass balance	Energy balance

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HTC c

$\dot{W}_H =$

Conde

$\dot{Q}_H =$

HTC tl

$h_7 = h$

Device

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

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

Cascade condenser

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

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

LTC compressor

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

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

LTC throttling device

$$h_3 = h_4$$

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

Evaporator

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

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

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] η_s = -0.00097 R_p^2 -0.01026 R_p +0.83955 (3)

η_V = -0.00076 R_p^2 -0.05080 R_p +1.03231 (4)

CO2 Compressor [21]

η_s = -0.00476 R_p^2 -0.0923 R_p +0.89810 (5)

η_V = -0.00816 R_p^2 -0.15293 R_p +1.13413 (6)

Performances of the system

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

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

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.

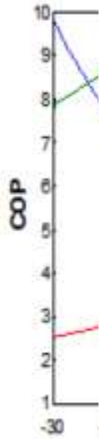

Fig-3 Effect of TCC on the COP of HTC and LTC

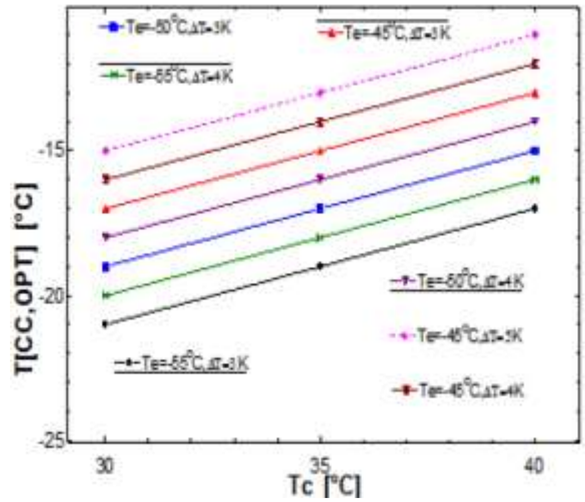

Fig. 5 The influence of Tc on the Tcc,opt of a CO_2/NH_3 cascade refrigeration system.

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.

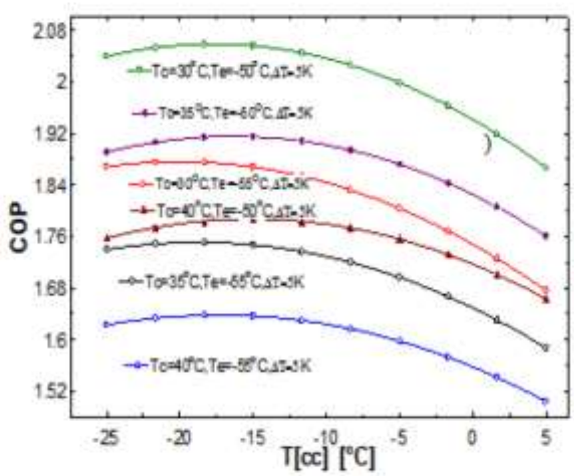

Fig. 4. plots the curves of overall COP versus Tcc at different design parameters

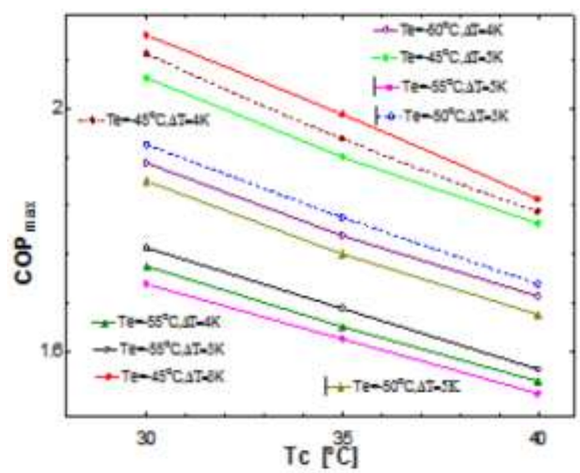

Fig-6 The influence of Tc on the COP_{max} of a CO_2/NH_3 cascade refrigeration system.

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:

$T_{cc,oi}$

COP_{MA}

The un
(K).

CONCLUSION

This work (CC) examines the link between the condensing temperature (OPT T) and other relevant factors. 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. There is a temperature difference (T) between the condensers at each stage of the cascade. liquid-to-gas condensation transition Cascade condensers raise the thermal condenser temperature (Tc). However, although the maximum COP does improve somewhat, TE falls with increasing Tc or T. By integrating the outcomes of these two correlations, the best possible correlation coefficient was calculated. There is a thermal cascade related with the condensation point and the highest performance coefficient that is practically achievable. parameters, seen from three distinct angles.

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