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Optimal Design of Low Temperature (Cascade) Refrigeration System

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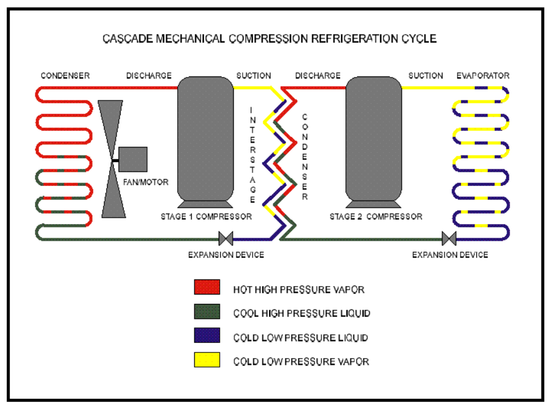
***Abstract* - Ammonia/CO2 mixture is presently considered to be the best for cascade refrigeration up to 216.58ºK. However to approach temperatures lower than 216.58ºK the mixture of CO2 with other refrigerants are required. The aim of present work was to study the possibility of using carbon dioxide mixtures in those applications where temperatures below triple point (216.58 K) are needed. The blends considered for analysis purpose are R744/R125, R744/R41, R744/R32, and R744/R23. The analysis of cascade refrigeration cycle has been carried out with the help of a computer program developed using Engineering Equation Solver (EES). The composition of CO2 is varied from a mole fraction of 0.1 to 0.8 along with R23, R32, R41 and R125. The mixtures properties of the investigated blends (R744/R125, R744/R41, R744/R32, and R744/R23) were calculated by Ref Prop 7.0 and used in EES program.**

INTRODUCTION

Refrigeration is defined as ―the transfer of heat from a lower temperature region to a higher temperature one. Refrigeration devices that produce refrigeration are heat pumps, refrigerators, automotive air-conditioners, and residential/commercial air-conditioners. All of these devices have one thing is common, to reduce the temperature of an enclosed environment. Vapour compression cycle can be used in temperature range -10 to -30°C easily. And low-temperature refrigeration systems are typically required in the temperature range from –30°C to –100°C for applications in food, pharmaceutical, chemical, and other industries, e.g., blast freezing, cold storages, liquefaction of gases such as natural gas, etc. At such low temperatures, single-stage compression systems with reciprocating compressors are generally not feasible due to high pressure ratios. A high pressure ratio implies high discharge and oil temperatures and low volumetric efficiencies and, hence, low COP values. Screw and scroll compressors have relatively flat volumetric efficiency curves and have been reported to achieve temperatures as low as –40°C to –50°C in single-stage systems. Further, the use of a single refrigerant over such a wide range of temperature results in either extremely low pressures in the evaporator and large suction volumes or extremely high pressures in the condenser. The conventional two-stage ammonia systems that were mostly used to cater to these applications are coming under.



Two stage cascade refrigeration cycle

REVIEW PROCESSES

Parthiban Kasi and M Cheralathan [2] have analysed of carbon dioxide–ammonia(R744–R717) cascade refrigeration system to optimize the design and operating parameters of the system. A multi linear regression analysis was employed in terms of subcooling, superheating, evaporating, condensing, and cascade heat exchanger temperature difference in order to develop mathematical expressions for maximum COP, an optimum evaporating temperature of R717 and an optimum mass flow ratio of R717 to that of R744 in the cascade system. Wilson and

Maier have analysed that cascade refrigeration systems is the initial installation cost being 10% higher than the traditional direct expansion systems. But this cost can be negated with less refrigerant charge requirements and the environmental advantage of the cascade system due to less direct emissions as compared to single-stage system.

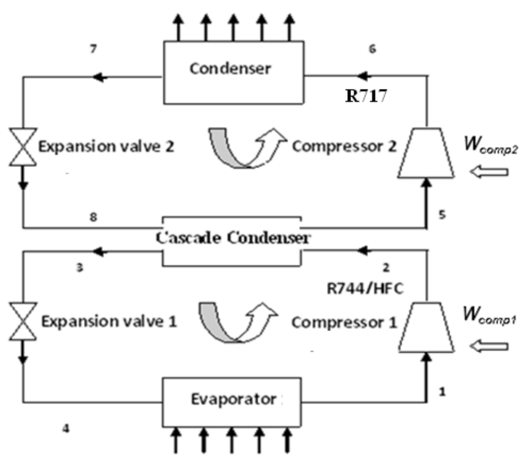
Problem formulation

In the present study, analysis of cascade refrigeration system has been carried out by taking R717 in low temperature circuit and R-744 mixture with HFCs (R23, R32, R41 and R125) to achieve low temperatures down to 200°K.

It is proposed to examine the effect of following parameters of the performance of cascade refrigeration system and evaluation of optimum cascade condenser temperature in the present work.

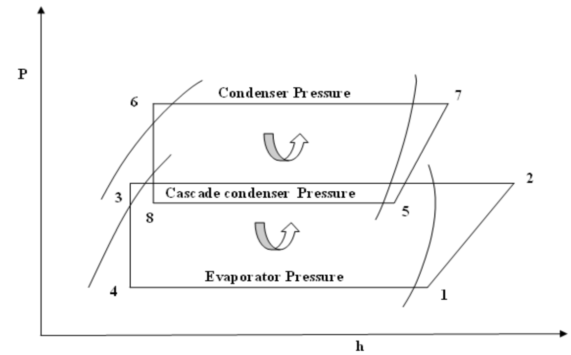
- Effect of approach
- Analysis with and without superheating and subcooling
- Effect of varying the condenser temperature
- Varying the mole fraction of R-744
- Effect of using LVHE in low temperature circuit

SYSTEM DESCRIPTION



Schematic representation of two stage cascade refrigeration cycle

This refrigeration system comprises two separate refrigeration circuits- the high-temperature circuit (HTC) and the low- temperature circuit (LTC). Ammonia is the refrigerant in HTC, whereas carbon dioxide blend with HFCs (R-23, R-32, R-41 and R-125) are the refrigerants in LTC.

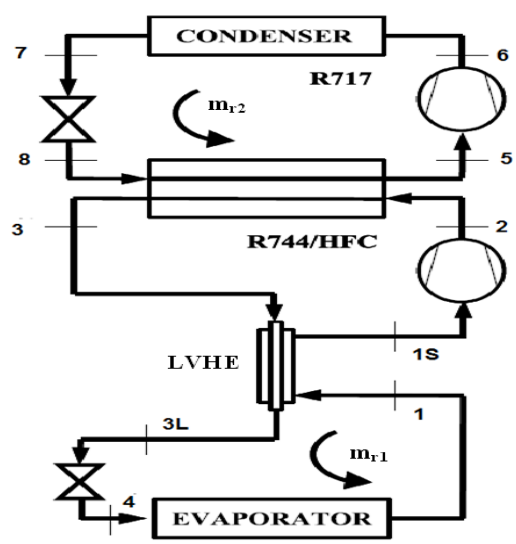


P-h diagram of cascade refrigeration system

The condenser in this cascade refrigeration system rejects a heat of QC from the condenser at condensing temperature of TC, to its warm coolant or environment at temperature of T0. The evaporator of this cascade system absorbs a refrigerated load QE from the cold refrigerated space at evaporating temperature TE. The heat rejected by condenser of LTC equals the heat absorbed by evaporator of HTC. TMC and TME represent condensing and evaporating temperatures of the cascade condenser, respectively.

THERMODYNAMIC ANALYSIS

In the present work, a parametric study with fixed mass flow rate in LTC, and various condensing temperature, evaporating temperature and approach in the cascade-condenser have been conducted to determine the optimum condensing temperature of the cascade- condenser.



Schematic representation of cascade refrigeration cycle with liquid vapour heat exchanger

Formulation of problem

Analysis of the cascade Refrigeration System shown in fig.3 and fig. has been carried out in this work.

The computer program has been developed in EES. The mixtures properties of the investigated blends (R744/R125, R744/R41, R744/R32, and R744/R23) were calculated by Ref Prop 7.0 (Huber et al. 2002) and used in EES program to calculate the performance parameters for a cascade refrigeration cycle.

RESULTS AND DISCUSSION

In the present results computed from the compute program have been discussed.

MASS FLOW RATE IN HIGH TEMPERATURE CIRCUIT

The variation of mass flow rate in high temp circuit for cascade refrigeration cycle with varying intermediate temperature for carbon dioxide blend with HFCs (R-23, R-32, R-41 and R-125) for different mole fraction. These figures show that the mass flow rate decreases with increase in intermediate temperature at a particular evaporator and condenser temperature for R-125 and R-23 due to decrease in load on cascade condenser.

Effect of superheating (10°C) and subcooling (5°C)

The effect of superheating of refrigerant inlet to compressor and subcooling of refrigerant outlet to condenser. By the comparison of figures with superheating and without superheating

Effect of mole fraction of carbon dioxide

The variation of mole fraction of carbon dioxide in mixture with HFCs. Figure shows that by increasing mole fraction of carbon dioxide mass flow rate decreases for R-125 and R-23 and increases for R-41 and R-32.

Effect of liquid vapour heat exchanger

By using liquid vapour heat exchanger in low temperature circuit, mass flow rate in high temperature circuit increases by around 3%.

TOTAL COMPRESSOR WORK

This happens because for a given condenser and evaporator temperature, as the intermediate temperature increases, the low temperature circuit compressor's work done(WCOMP1) increases but the high temperature circuit compressor's work done (WCOMP2) decreases, and the combined effect of these is to decrease work done

COEFFICIENT OF PERFORMANCE

This happens because for a given condenser and evaporator temperature, as the intermediate temperature increases, the refrigerating effect and the work done by the compressor both decreases, and combined effect of these is to increase COP up to optimum temperature but after optimum temperature COP decreases.

CONCLUSION

In the present study, thermodynamic analysis have been carried out for cascade refrigeration cycle using CO2/HFC blends as the low-temperature fluid and ammonia as the high- temperature fluid with a view to extending the applicability of carbon dioxide in such systems below its triple point (216.58 K).

The results obtained permit the following remarks:

1. Mass flow rate in high temperature circuit decreases with increase in intermediate temperature for R-125 and R-23.
2. Mass flow rate in high temperature circuit increases slightly with increase in intermediate temperature for R-41 and R-32.
3. The total compressor work decreases with increase in intermediate temperature.
4. The total compressor work for R-41 mixture is highest among all mixtures followed by R-32, R-23 and R-125 respectively.
5. COP increases with increase in intermediate temperature up to a temperature (optimum temperature) after this COP decreases with increase in intermediate temperature.

R744 blends can be considered an attractive option for the low-temperature-circuit in cascade refrigeration cycle operating at temperatures approaching 200 ºK due to its low cost, easy availability and favorable properties

SCOPE FOR FUTURE WORK

1. Further investigating should be carried out for use of different hydrocarbons (HFCs)with carbon dioxide.

2. Exergy analysis should be carried out for this cascade refrigeration system using carbon dioxide blend with HFCs in low temperature circuit.
3. Exergo economic analysis should be carried out for this cascade refrigeration system using carbon dioxide blend with HFCs in low temperature circuit.

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REFERENCES

[1] Parthiban Kasi and M Cheralathan (2021): Review of cascade refrigeration systems for vaccine storage J. Phys.: Conf. Ser. 2054 012041

[2] Akash Shakya, Nadeem Faisal, Trilok Chauhan (2019): PERFORMANCE ANALYSIS OF VAPOUR COMPRESSION CASCADE REFRIGERATION SYSTEM USING REFRIGERANTS R404A AND R134a

[3] Marcus Vinicius Almeida Queiroz (2016): Experimental comparison of a cascade refrigeration system operating with R744/R134a and R744/ R404a. University Federal of Uberlandia, Brazil

[4] Morosuk, T.; Tsatsaronis, T.; Schult, M. (2013): Conventional and advanced exergetic analyses: theory and application. Arab. J. Sci. Eng.38

[5] Parekh A.D., Tailor P.R. (2011): Thermodynamic analysis of R507A-R23 cascade refrigeration system. World Acad. Sci. Eng. Technol. 57, 992–996

[6] Kilicarslan A., Hosoz M. (2010): Energy and irreversibility analysis of a cascade refrigeration system for various refrigerant couples. Energy Convers. Manag. 51, 2947–2954

[7] Sawalha, S. (2008) ―Theoretical evaluation of trans-critical CO2 systems in supermarket refrigeration. Part II: System modifications and comparisons of different solutions‖, International Journal of Refrigeration, 31, pp. 525-534.

[8] Getu, H.M., Bansal, P.K. (2008), ―Thermodynamic analysis of an R744–R717 cascade refrigeration system‖ International Journal of Refrigeration 31, pp. 45–54.

[9] Bansal, P.K., Jain, S. (2006) ―cascade systems: past, present, and future, ASHRAE Journal in press.

[10] Wilson, I., Maier, D. (2006), ―Carbon dioxide for use as a refrigerant‖, The University of Auckland, pp. 305–311.

[11] Lee, T.S., Liu, C.H., Chen, T.W. (2006), ―Thermodynamic analysis of optima lcondensing temperature of cascade-condenser in CO2/NH3 cascade refrigeration systems‖, International Journal of Refrigeration 29, pp. 1100-1108.

[12] Russmann, H., Kruse, H. (2006), ‖The natural fluid nitrousoxide—an option as substitute for low temperature synthetic refrigerants‖, International Journal of Refrigeration 29, pp.799–806.

[13] Sawalha, S. (2005) ―Using CO2 in supermarket refrigeration‖, ASHRAE Journal 47(8), pp. 26–30.

[14] Klein,S.A., Alvarado, F. (2005), ―Engineering Equation Solver, Version 7.441‖, FChart Software, Middleton, WI.

[15] Nicola, G.D., Giuliani, G., Polonara, F., and Stryjek, R. (2005), ―Blends of carbon dioxide and HFCs as working fluids for the low temperature circuit in cascade refrigerating systems‖, International Journal of Refrigeration, 28, pp. 130– 40.

[16] Bhattacharyya, S., Mukhopadhyay, S., Kumar, A., Khurana, R.K., Sarkar, J. (2005),Optimization of a CO2–C3H8 cascade system for refrigeration and heating‖, International Journal of Refrigeration, 28, pp. 1284-1292

[17] Agnew, B., Ameli, S.M. (2004), ―A finite time analysis of a cascade refrigeration system using alternative refrigerants‖, Applied Thermal Engineering 24, pp. 2557–2565.

[18] Pearson, A., Cable, P.J. (2003), ―A distribution warehouse with CO2 as refrigerant‖ Proceedings of the 21st International Congress of Refrigeration, Washington, DC, paper ICR0624

[19] Huber, M., Gallagher, J., McLinden, M., Morrison, G.(2002), ―Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Database (REFPROP) Version7.0‖, National Institute of Standards and Technology, Thermo physics Division.
[20] Arora, C.P. (2002), ―Refrigeration and Air Conditioning‖, 2nd edition, Tata McGrawHill, New Delhi.
[21] Taylor, R. (2001), ―Carbon dioxide-based refrigerant systems‖, ASHRAE Journal,pp. 22–27.
[22] Ratts, E.B., Brown, J.S. (2000), ―A generalized analysis for cascading single fluid vapor compression refrigeration cycles using an entropy generation minimization method‖, International Journal of Refrigeration 23, pp. 353–365.
[23] Klein, S.A., Reindl, D.T, Brownell, K. (2000), ―Refrigeration system performance Using liquid–suction heat exchangers International Journal of Refrigeration, 23, pp.588–596.s