REVIEW OF CASCADE REFRIGERATION SYSTEM WITH DIFFERENT REFRIGERANT PAIRS

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ABSTRACT

A Comparative assessment of a cascade refrigeration cycle with different refrigerant pair is presented in this paper. R744 is used in Low-temperature (LT) cycle whereas R134a, R290, R717 and R404A (R125(44%)/R143a(52%) /R134a(4%)) are used in the High-temperature (HT) cycle. The effects of the thermodynamic parameters on the cascade system are evaluated with an objective to find the best working fluid pair based on COP. R744-717 is selected based on thermodynamic and environmental performance. A parametric evaluation is also presented for R744-R717 working pair by varying parameters like sub cooling, superheating, evaporating, condensing temperature and temperature difference in the cascade condenser of the system.

INDEX TERMS - cascade refrigeration system, co-efficient of performance, R744, R134a, R290, R717 and R404A.

INTRODUCTION

Low temperature two stage cascade refrigeration systems are suitable for industrial applications, like manufacturing of dry ice, storage of frozen food etc. Ammonia, carbon dioxide, propane and other natural refrigerants have drawn increased attention as working fluids to protect the environment. An appropriate selection of refrigerants to operate the LT and HT cycles should be made in order to obtain high coefficient of performance (COP). The temperature level in LT and HT cycle is also an important parameter to decide best working fluids along with other important characteristics such as toxicity, flammability, ODP,GWP etc.

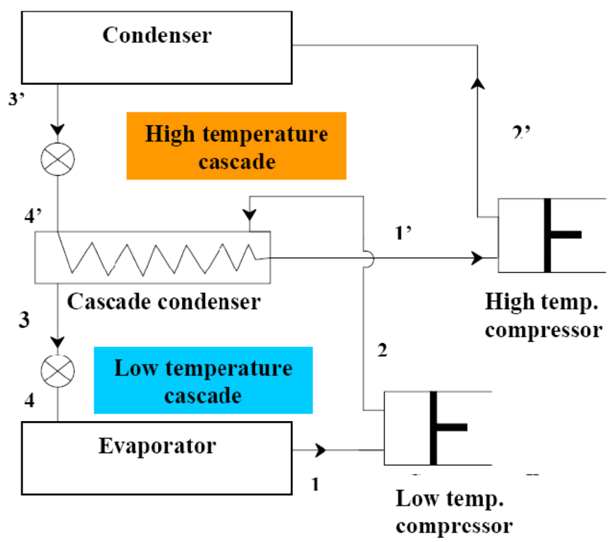
A. D. Parekh and P. R. Tailor [1] studied thermodynamic analysis of cascade refrigeration system using ozone friendly refrigerants pair R507A and R23. R507A is azeotropic mixture composed of HFC refrigerants R125/R143a (50%/50% wt.). R23 is a single component HFC refrigerant used as replacement to CFC refrigerant R13 in low temperature applications. These refrigerants have zero ozone depletion potential and are non-flammable and as R507A an azeotropic mixture there is no problem of temperature glide. This study thermodynamically analyzed R507A-R23 cascade refrigeration system to optimize the design and operating parameters of the system. The design and operating parameters include: Condensing, evaporating, sub cooling and superheating temperatures in the high temperature circuit, temperature difference in the cascade heat exchanger, Condensing, evaporating, subcooling and superheating temperatures in the low temperature circuit.

A direct expansion in low temperature refrigeration cycle (Getu and Bansal, 2006) [2] involves a large pressure lift between evaporating and condensing temperatures resulting in an increase in the compression ratio and reduction of volumetric efficiency of the compressors. Now a day's GWP and ODP of the refrigerant is also considering due to environmental safety. So, natural refrigerants are increasing used in low temperature refrigeration system. Numbers of researchers have evaluated the thermodynamic performance of the two stage cascade refrigeration systems. Parekh et al., (2012) analyzed that cascade system R507A-R23 are nonflammable and ozone friendly refrigeration pair [2]. Lee et al. (2006) analyzed a carbon dioxide–ammonia (R744-R717) cascade system thermodynamically to determine the optimum condensing temperature of CO_2 in LT cycle [3]. Ammonia is a naturally available refrigerant with disadvantage of toxicity and flammability (Christensen et al. A. Mr. Hiren A. Shah, B. Dr. Ragesh G. Kapadia [3] experimented cascade refrigeration cycle with different refrigerant pair is presented in this paper. R744 is used in Low-temperature (LT) cycle whereas R134a, R290, R717 and R404A (R125(44%)/R143a(52%) /R134a(4%)) are used in the High-temperature (HT) cycle. The effects of the thermodynamic parameters on the cascade system are evaluated with an objective to find the best working fluid pair based on COP. R744-717 is selected based on thermodynamic and environmental performance. A parametric evaluation is also presented for R744-R717 working pair by varying parameters like sub cooling, superheating, evaporating, condensing temperature and temperature difference in the cascade condenser of the system.

2003) [4] A carbon dioxide-propane (R744-R290) cascade system was analyzed by Bhattacharyya et al. (2005) [4], where an optimum cascade evaporating temperature of CO_2 in HT cycle was determined for heating application. Main disadvantage of propane is its highly flammability. R134a was chosen since in recent years; R404A is listed as a zoetrope of near-azeotropic proportions. But due to high GWP of R134a and R404A they should be totally phased out by 2020 in developing countries as per Montreal Protocol and its amendments from the United Nations Environment

CASCADE REFRIGERATION SYSTEM

Two stage cascade refrigeration system is represented by a line diagram, P-h and T-s diagram in Fig.3.1, 3.2 and 3.3 respectively. In the system both Low Temperature Cycle (LTC) and High Temperature Cycle (HTC) work with different refrigerants and thermally connected to each other through a heat exchanger which acts as an evaporator for the HTC and a condenser for the LTC. HTC operates with refrigerant having high boiling point and high critical temperature and LTC operates with refrigerant having low boiling point. Properties of refrigerants are given in Table I. Fig.1 shows that the condenser rejects heat Q_{HT} from the condenser at condensing temperature of Tc to its condensing medium or environment. The useful refrigerating effect is produce in evaporator of LTC by absorbing the cooling load Q_{LT} from the cooling space at the evaporating temperature Te. Heat absorbed by LTC evaporator and work input to LTC compressor equals the heat absorbed by HTC evaporator that is cascade condenser. Tc,cas and Te,cas represent the condensing and evaporating temperatures respectively. The temperature difference between them, ΔT= Tc,cas – Te,cas is called temperature overlap which is necessary for heat transfer.



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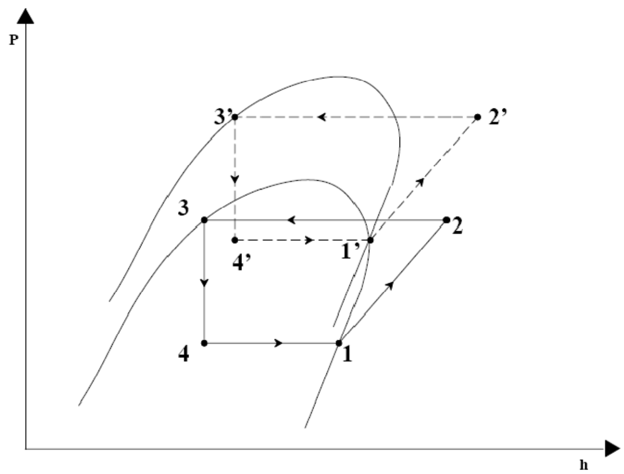

THERMODYNAMIC ANALYSIS

Following assumptions are considered for the thermodynamic analysis of two stage cascade refrigeration system.

i. Adiabatic and irreversible compression with an isentropic efficiency of 0.8 for both high- and low- temperature compressors.

ii. Negligible pressure and heat drop in the piping or system components.

iii. Isenthalpic expansion of refrigerants in expansion valves.

iv. Heat transfer process in heat exchanger is isobaric.

v. Changes in kinetic and potential energy are negligible.

The thermo physical and environment properties of the refrigerants used in this paper are given inTable1

	N_2O	R23	R507A	R717	R290
Boiling Point (°C)	-88.5	-82.1	-46.7	-33.3	-42.1
Critical Temp(°C)	36.4	25.6	70.9	132.3	96.8
Critical Pressure (MPa)	7.25	4.86	3.79	1.33	4.97
Molecular Mass (kg/Kmol)	44.01	70.01	98.86	77.65	44.1
ODP	0	0	0	0	0.0

					5
GWP	280	1480 0	3985	0	3

RESULTS AND DISCUSSION

Effect of particular parameter on the performance of system is investigated by varying only that parameter keeping rest of parameters constant. Variable parameters considered as evaporating, condensing temperature, temperature difference in cascade condenser that is temperature overlap and isentropic efficiency of compressors. It varied in the ranges given below:

Low temperature cycle evaporator temperature varied from -80°c to -55°c.

High temperature cycle condensing temperature varied from 30°c to 40°c.

Temperature overlap, ΔT is varied from 3 °c to 15°c.

Isentropic efficiency of both stage compressors varied as, ηisen = 0.7 to 0.9.

Mass flow rate of refrigerant for LT cycle is assumed 0.2 kg/min[2]. The parameters have been varied for the computation results are mentioned below:

The low temperature cycle evaporator temperature is varied from TE,LT = -55º C to -30º C

The high temperature cycle condenser temperature is
varied from TC,HT = 30º C to 45º C

The cascade condenser temperature difference Tcc =1
The low temperature cycle condenser temperature is varied from $T_{C,LT}$ = -30º C to 10º C

Degree of subcooling $(T)_{sub}$ and Degree of superheating (T)sup is varied from 0º C to 6º C

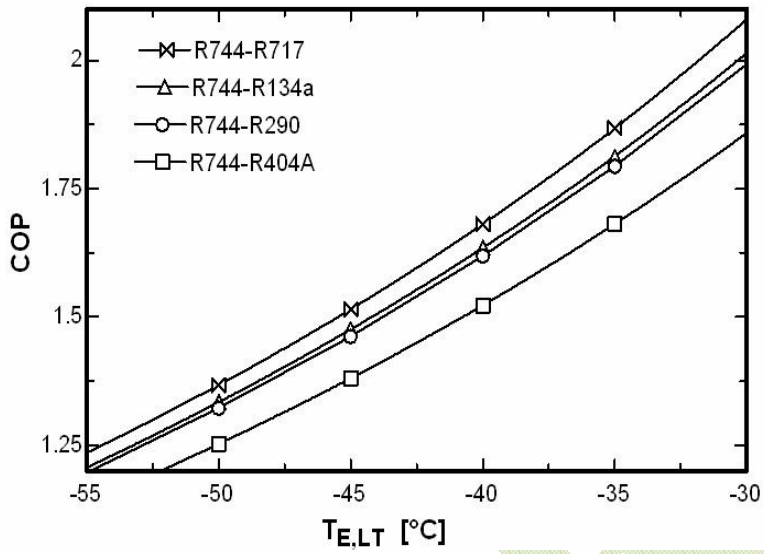

Fig. Effect Of LT Stage Evaporating Temperature on COP of Different Refrigerant Pairs.

From Fig it is clear that the cascade refrigerant pair R744-R717 has higher COP as compared to other refrigerant pairs R744-R134a, R744-R290 and R744-R404A for the same thermodynamics parameters. When the temperature of the condenser ($T_{C,HT}$) increases from 30^{o} C to 45^{o} C (HT cycle) and evaporator ($T_{E,LT}$) increases from -55^{o} C to -30^{o} C (LT cycle); the COP of cascade refrigeration system with a refrigerant pair R744-R717 remains on higher side as compared to R744-R134a, R744-R290 and R744-R404A while keeping other parameters constant.

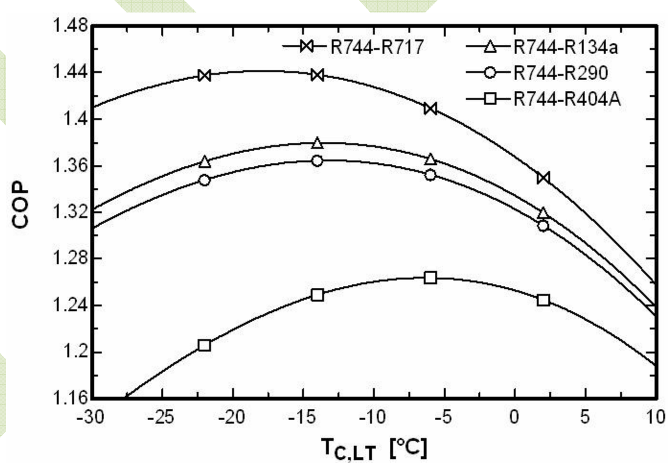

Fig. Effect of LT stage condensing temperature on COP of different refrigerant pairs.

GWP of the refrigerants R134a and R404A is higher as compared to other refrigerants. Therefore, from the environmental point of view, they are not suitable for the system. R290 is highly flammable.

So, overall comparison of the different refrigerant pairs based on thermodynamic performance and environment criterion; the best working fluid pair is R744-R717.
Henceforth, parametric analysis of R744-R717 using: sub cooling, superheating, evaporating, condensing temperatures and temperature difference in the cascade condenser of the system is presented.

CONCLUSION

From the comparative assessment of different cascade refrigeration pairs; the R744-R717 pair has the maximum COP. Thermodynamics analysis of cascade refrigeration pair R744-R717 presents the following interpretation.

1. The cascade refrigerant pair R744-R717 has higher COP as compared to other refrigerants pairs R744-R134a, R744-R290 and R744-R404A for the same $T_{C,HT}$, $T_{E,LT}$ and $T_{C,LT}$; other parameters remain constant.

2. The COP of the R744-R717 system increased from 1.236 to 2.08 at LT cycle evaporator temperature

   ($T_{E,LT}$) is varied from -55º C to -30º C; other parameters remain constant.

3. The COP of the system R744-R717 decreased from 1.554 to 1.285 at HT cycle condenser temperature ($T_{C,HT}$) is varied from 30º C to 45º C; other parameters remain constant.

4. The COP of HT cycle increased whereas the COP of LT cycle decreased when ($T_{C,LT}$) is varied from -30º C to 10º C for R744-R717 system. Therefore the optimal value of ($T_{C,LT}$) where COP found maximum is -14º C and corresponding maximum value of the COP is 1.310 found.
5. The COP of R744-R717 system reduced by about 15.37 % when temperature difference in cascade condenser (T_{CC}) was increased from 1º C to 13º
6. Maximum COP of the system R744-R717 increased significantly with an increase in degree of superheat while increased slightly with increase in sub cooling.

7. The mass flow ratio decreased with rise in for different degree of superheating and sub cooling for R744-R717 system. Ration of mass flow is reduced more in case of sub cooling as compared to superheating.

8. Maximum COP of the R744-R717 system goes Upward proportionally with an increase in Isentropic efficiency (η_{isen}) of the compressors.

9. It can be stated that by substituting R507A-R23 having GWP about 3985 and 14,800 respectively by R717-N_2O having 240 GWP for N_2O,higher energetic performances can be achieved.

10. However, R717 is toxic, R290 is flammable in nature and safety properties of N_2O are yet to study thoroughly hence these refrigerants must be used considering all safety precautions and suitability for

particular applications.

REFERENCES

A. D. Parekh and P. R. Tailor "Thermodynamic Analysis of R507A-R23 Cascade .Refrigeration System" World Academy of Science, Engineering and Technology Vol:5 2011-09-28

1. Getu, H.M., Bansal, P.K., 2006. "*Simulation model of a low-temperature supermarket refrigeration system." Int. J. HVAC&R Res. 12 (4), 1117–1139.*

2. Lee, T.S., Liu, C.H., Chen, T.W., 2006. "*Thermodynamic analysis of optimal condensing temperature of cascade-condenser in CO2/NH3 cascade refrigeration systems." Int. J. Refrigeration 29, 1100–1108.*

3. Christensen, K.G., Bertilsen, P., 2003. "*Refrigeration systems in supermarkets with propane and CO2-energy*

4. consumption and economy." *In: 21st International Congress of Refrigeration, Washington, DC, pp. 1–10*

5. Bhattacharyya, S., Mukhopadhyay, S., Kumar, A., Khurana, R.K., Sarkar, J., 2005. " *Optimization of a CO2–C3H8 cascade system for refrigeration and heating." Int. J.Refrigeration 28, 1284–1292.*

6. *Montreal protocol on substances that deplete the ozone layer. United Nations Environment programme (UNEP), 1987. .*

7. *UNEP Assessment report of the technology and economic assessment panel, UNEP Ozone Secretariat,* Nairobi, Kenya.,2007

8. Bansal P.K., Getu H.M., "*Thermodynamic analysis of an R744-R717 cascade refrigeration system." In: Internation Juornal of Refrigeration 3I (2008) 45-54.*

9. Bansal, P.K., Jain, S., 2007. "*Cascade systems: past, present, and future." ASHRAE Trans. 113 (1), 245–252 (DA-07-027).*

10. Dopazo, J.A., et al., 2009. "*Theoretical analysis of a CO2- NH3 cascade refrigeration system for cooling applications at low temperatures." Applied Thermal Engineering, 29, 15771583.*

11. EES: Engineering Equation Solver 2006