ijcrr
Vol 03 issue 08
Category: Review
Received on:19/07/11
Revised on:03/08/11
Accepted on:24/08/11

REFRIGERANTS PROGRESSION IN ANALYSIS OF TWO STAGE CASCADE REFRIGERATION SYSTEM -A REVIEW

Devanshu Pyasi[1], R.C. Gupta[1]

[1]Mechanical Engineering Department, Jabalpur Engineering College Jabalpur

E-mail of corresponding author: devanshumishra86@gmail.com

ABSTRACT

The objective of this paper is to provide a literature review on analysis of Cascade Refrigeration Systems using various working fluids (refrigerants) and to give useful guidelines regarding background and operating principles of Cascade System. The recent interest and development of two-circuit cascade systems are highlighted and principal aspects of the environmental pollution by working fluids in Cascade refrigeration systems are reported. Thus, paper discussed one of the crucial point of refrigerants selection which makes these systems more efficient from both economical and environmental point of view.

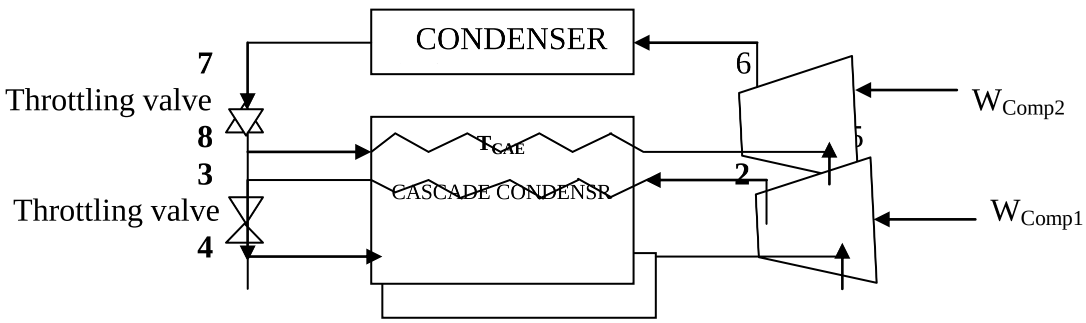
Key words: refrigeration; cascade system; working fluids;

1.INTRODUCTION

Cascade refrigeration system is a low temperature refrigeration system and is used for very low temperature range about (-40C to -130C).At such low temperature simple Vapor Compression Refrigeration Cycle (VCRS) is not efficient due to very high compression ratio that further leads to high discharge problem and low volumetric efficiencies. Whereas cascade refrigeration is much efficient for such conditions. Cascade refrigeration cycle is nothing but simply a combination of two (VCRS) cycles named as low and high temperature circuit that are combined together by a cascade condenser. This cascade condenser unit act as evaporator for low temperature circuit and condenser for high temperature circuit, the low temperature circuit uses low boiling refrigerants such as R23, R744 etc and high temperature uses high boiling point refrigerants such as R717, R290, R404A, R1270, R410A etc. Various refrigerants have been analyzed in cascade refrigeration system among which few are CO_2/Ammonia, Propane/CO_2, 507A/R23, 404a/CO_2 etc**.** Generally, two-circuit and rarely three-circuit cascade systems are used for low temperature refrigeration In the present study a critical review is discussed about analysis of two stage cascade refrigeration system with refrigerants progression in low and high temperature circuit.

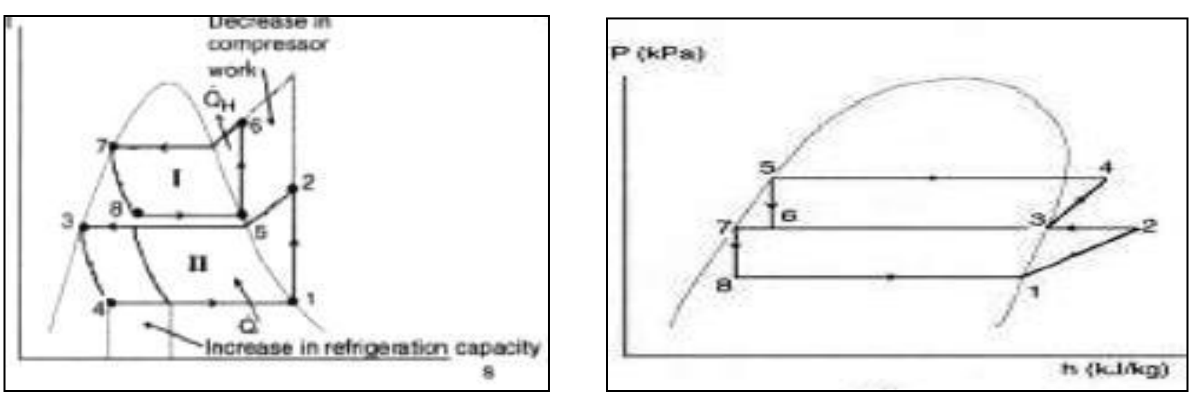
2. Background and Operation Principles Of Cascade System.

Two stage cascade refrigeration system is a combination of two vapor compression cycles which utilizes two different refrigerants. These systems employ two circuits namely a high temperature circuit (HTC) and a low temperature circuit (LTC). The primary refrigerant flows from low temperature circuit evaporator to compressor and condensed in cascade condenser which also acts as evaporator for high temperature circuit. The heat rejected from condenser of low temperature circuit is extracted by evaporator of high temperature circuit containing secondary refrigerant then this refrigerant get compressed in high stage compressor and finally condensed to atmosphere. The desired refrigerating effect is occurred from evaporator of low temperature circuit. The heat absorbed by the evaporator of the (LTC) plus the work input to the (LTC) compressor equals the heat absorbed by the evaporator of the (HTC). The temperature difference in cascade condenser is an important design parameter that decides the COP of the entire system.



(Fig 1) Two stage cascade refrigeration system

For Cascade system lower temperature limit of (HT) side is termed as intermediate temp. (IT) Three important parameters are used to analyze the performance of an cascade system are (1) Evaporator temperature (2) Condensing temperature and (3) Temperature difference in the cascade condenser. Several researchers have evaluated the thermodynamic performance of the two-stage cascade refrigeration systems with these three parameters. In some cases Degree of Sub cooling and Superheat is also taken in consideration for optimization .Therefore, almost all current studies have been focused on the analysis including effect of these parameters on cascade system analysis. (Fig:2) represents the (T-S) diagram showing decrease in compressor work and increase in refrigeration capacity for cascade refrigeration system.



(Fig 2) :T-s and P-h diagram of 2-stage cascade Refrigeration System

3. Working fluids:

In this section, the criteria for working fluid (refrigerant) selection for the Cascade refrigeration systems are provided. The choice of the appropriate working fluid (refrigerant) is one of the most important parts in the design of the Cascade refrigeration system. A commonly used refrigerant pair in the past has been R12 and R13 for the high pressure and low-pressure stages respectively in cascade system. But these refrigerants are now banned due to presence of chlorine in it which is ozone depleting. So eco-friendly refrigerants are most suitable for industrial applications related to food preservation, such as in supermarkets, cold storages, blast freezing etc. According to he rules and regulations developed by Kyoto protocol only those refrigerants are now permitted in refrigeration industry which are environmental friendly and have low global warming potential and ozone depleting potential. Natural refrigerants such as two-stage ammonia, carbon dioxide and various Hfc blends are mostly used to cater these rules and regulations. (Fig 3) lists some commonly used working fluids for analyzing in cascade refrigeration system. The following requirements should be met by the fluid:

1) The fluid should have a large latent heat of vaporization in order to minimize circulation rate per unit of cooling capacity.

2) The fluid pressure at the generator temperature should not be too high in order to minimize the power required by compressor.

3) The fluid should be chemically stable, non-toxic, non-explosive, non-corrosive, environmental friendly and low cost.

4. Environmental Effect: Ozone Depletion Potential (ODP), Global Warming Potential(GWP):

The effects of refrigerants on the environment are well documented. Industrial refrigeration contributes both directly and indirectly to global warming. leakage of HFC refrigerants causes green house gas emission that destructs environmental stability These refrigerants have very high global warming potential with GWP's in excess of 1000. Many working fluids suggested in previous work for cascade refrigeration systems are now forbidden due to their environmental effect, such as R12, R13, or R23. New refrigerants are now studied, for example, R404a, R744, R290, R1270 and R717 etc. [Table 1] shows properties of few refrigerants that are being used in cascade system currently.

Properties	R-717	R-744	R404A	R290	R12
Chemical formula	NH_3	CO_2	$CHF_2CF_3/CH_3CF_3/CH_2FCF_3$	C_3H_8	CCL_2F_2
Molecular wt.(kg/kmo)	17.0	44.01	97.6	44.0	120.9
B.P at 1.013 bar	33.3	56.5	-46.6	-42.0	- 29.75
Critical temperature	135	30.	72.1	96.6	111.9
Ozone Depleting Potential	1	0	0		1
Global Warming Potential	<1	1	3260	<20	8500

(Table 1) :Properties of refrigerants used in cascade refrigeration system

Another advantage of the cascade refrigeration system is the possibility of using a wide range of refrigerants with the system. In experimental and theoretical studies on an cascade refrigeration system, various refrigerants such as CO_2, ammonia, R12, R23,R13, R290 etc were selected as working fluid . High-temperature circuit of a cascade refrigeration system can normally be charged with ammonia (R717), propane (R290), propylene (R1270), ethanol or R404A, whereas carbon dioxide (R744) may be used in the low-temperature circuit of the refrigeration system. Ammonia is a naturally available refrigerant with few application constraints such as toxicity and flammability the disadvantage of propylene, propane and ethanol is their high flammability. Refrigerants in cascade cycles such as R12, R13, R404a, R134a, is a low-pressure refrigerant having high molecular weight; producing a high mass ratio, good cascade efficiency and high compressibility factor which is relatively close to an ideal gas.

5. Literature Review:

A large number of experimental and analytical studies regarding development of Cascade refrigeration systems occurred with the two stage system type. Several test rigs have been built and tested. Initially CFC refrigerants were used but due to environmental consideration these refrigerants were banned, then HCFC refrigerants were used for few more time and were also restricted. Subsequently, more environmentally friendly refrigerants were suggested, e.g. natural refrigerants, hydrocarbon refrigerant as well as HFC refrigerants.

Bhattacharya et al [1]. Analyzed the theoretical performance of cascade refrigeration system. Further the system has also been numerically optimized to obtain the maximum coefficient of performance of the system. Two refrigerants (R744 and R290) were taken in two circuits of system. For the theoretical analysis Temperature approached (AT),Overlap Temperature, isentropic efficiency of compressor were taken as parameters and it was found that R744 in (HT) side and R290 in (LT) side can offer a much larger temperature lift. The overall performance of the cascaded system remains invariant with the effectiveness of the propane cycle and increases when effectiveness of the HT cycle is increased. These refrigerants R744 in high temperature circuit and R290 in low temperature circuit used for simultaneous heating and cooling applications.

Shing Lee et al [2] analyzed a cascade refrigeration system using R717/R744 as refrigerants to determine the optimal condensing temperature of cascade condenser, to maximize the COP and minimize the Exergy destruction of the system. The parameters considered in this study are evaporator temperature, condensing temperature and temperature difference in cascade condenser. Analysis shows that optimal condensing temperature of cascade condenser increases with condenser temperature (T_C), evaporator temperature (T_E) & temperature difference in cascade condenser (D_T). Also the maximum COP increases with (Te) ,but decreases as (Tc) & (DT) increases.

Getu and Bansal [3] Analyzed a carbon dioxide–ammonia (R744–R717) cascade system thermodynamically to determine the optimum condensing temperature of R744 in the low-temperature circuit and mass flow ratio, to find out the system maximum COP in terms of sub cooling, superheating, evaporating temperature, condensing temperature and temperature difference in the system's cascade condenser. Result conclude an increase of superheat increased mass flow rate but reduces COP of system also an increase in sub cooling increased both COP and mass flow ratio.

A. D. Parekh et al [4] I reported the analysis of cascade refrigeration system has been carried out using ozone friendly refrigerants pair R507A and R23. Here R507a is a blend of HFC refrigerant composing different refrigerant mixtures. A thermodynamic analysis of cascade system has been carried to optimize the design and operating parameters of the system. Results concluded that COP of the system increased from 0.7851 to 1.232 as low temperature circuit evaporator temperature (TE, LT) is varied from -80 C to -50 C.

A. D. Parekh et al [5] In this work the thermal design of condenser (HTS), cascade condenser and evaporator (LTS) of cascade refrigeration system has been carried out using two HFC refrigerant pairs R404A-R508B and R410A-R23. Results shows that the required heat-transfer area of condenser and cascade condenser for R410A-R23 cascade system is lower than the R404A-R508B cascade system but heat transfer area of evaporator is similar for both the system.

Russmann and Kruse [6] (2006) have performed analysis of cascade refrigerating systems using N_2O as refrigerant for the low temperature cascade stage and various natural refrigerants like ammonia, propane, propylene, carbon dioxide and nitrous oxide itself for the high temperature stage the basis of the comparison was a conventional R23/R134a-cascade refrigerating system. This N_2O system has nearly equal COP as a conventional R23/R134a-cascade refrigerating system

Dopazo et al [7]. They theoretically employed both exergy analysis and energy optimization, to determine the optimum condensing temperature of (R744) in the low-temperature circuit The analysis show that the COP increases 70% when the evaporator temperature ($T_{\mathbf{evap}}$) CO_2 varies from (55 C to 30 C). As T_{evap} CO_2 increases, the effect of other parameters on the COP also increases. COP diminishes 45% when the $T_{\mathbf{Cond}}$ NH3 increases from (25C to 50 C) the exergetic efficiency decreases around 45% and 9% with the increases in condenser temperature ($T_{\mathbf{cond}}$ **)** of NH_3 and DT, respectively. Thus the CO2 evaporating temperature has to be as high as possible in order to obtain the highest COP and the NH3 condensing temperature has to be as low as possible to increase the COP to the maximum also for temperature differences in the cascade exchanger, and (DT) always show that for a lower (DT) a higher COP is obtained.

Dopazo et al [8] An Experimental evaluation of prototype of a cascade refrigeration system with CO2 and NH3 is done. Tests were performed fixing four CO2 evaporating temperatures (50, 45, 40 and 35 C). At each evaporating temperatures,(CO_2) condensing temperature was varied from 17.5 to 7.5 C and an experimental optimum value of CO_2

condensing temperature was determined. (Table 2) shows the validation results of experimental data with various theoretical analyses done by researchers.

Experimental		Lee et al. (2006)		Getu and Bansal (2008)		Dopazo et al. (2009)	
Te,CO2 (C)	Tc,CO2 (K)	Tc,CO2 (K)	Diff. (%)	Tc,CO2 (K)	Diff. (%)	Tc,CO2 (K)	Diff. (%)
-35	257.2	254.4	-1.0	253.4	-1.5	263.4	2.4
-40	259.7	256.7	-1.2	255.7	-1.5	265.4	2.2
-45	262.7	258.7	-1.5	258.0	-1.8	267.4	1.8
-50	263.7	260.7	-1.1	260.3	-1.1	269.3	2.2

(Table 2) :Experimental and theoretical data's of analysis

A. D. Parekh et al [9] In present work the thermal design of condenser, cascade condenser and evaporator of R404A-R508B and R410A-R23 cascade refrigeration system is carried out. The comparison is made for heat transfer area of condenser (HTS), cascade condenser and evaporator (LTS) for both the systems. The effect of condenser and evaporator temperature on heat transfer area of condenser (HTS), cascade condenser and evaporator (LTS) are studied for both the systems

G.Nicola et al [10] A comparison analysis was done between results obtained in different temperature and pressure conditions, firstly the system was operated using R23 in the low-temperature circuit, then replacing this fluid with the refrigerant binary system R744-R744A. Results conclude that, it is possible to use the binary system R744-R744A to solve problems of the pure R744. Cascade cycle stability with blends of R744 would seem an attractive option for future tests.

Souvik Bhattacharyya, S. Bose, et al. [11] In this analysis two-stage cascade cycle has been performed and optimum intermediate temperature for maximum exergy have been found analytically. Results showed that at low values of T_h simulation follows the theoretical plots, but at higher temperatures large deviation occurs and unexpectedly high exergy rate is obtained due to drastic variation in supercritical CO2 properties.

Alhamid et al [12] The thermodynamic energy and exergy analysis was conducted by taking propane as high circuit refrigerant and a mixture of CO_2+N_2O also known as ethane mixture were taken as low circuit refrigerant. a multi liner regression analysis was conducted to optimize various performance parameters such as COP, Optimum evaporating and condensing temperatures.

6. CONCLUSION

This paper describes a basic background and development on analysis of cascade refrigeration system with various refrigerants and optimizations conducted for such refrigerants. Large number of refrigerants has been analyzed in cascade system for determining the appropriate combination of refrigerants in both circuits of refrigerants however the trends shows natural refrigerants are gaining more importance due to environmental conditions few natural refrigerants such as ammonia, co2 are analyzed but there is still shortcomings in analysis of eco friendly refrigerants. Refrigerants including blends of natural refrigerants, Hfc refrigerants can be more widely adopted to fill this gap also the analysis process can involve more design and operating parameters such as effect of sub cooling and superheating should also be taken in account.

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