"A REVIEW ON THERMODYNAMIC PERFORMANCE OF THE CASCADE VAPOUR REFRIGERATION SYSTEM OPERATED BY DIFFERENT REFRIGERANT PAIRS"

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ABSTRACT

With the increase of people awareness of the global warming and ozone depleting effect, research on alternative refrigerants has attracted more attention in recent years. Many research institutions have made lot of achievements in the replacement of refrigerants, searching for the refrigerant alternative in LTC and HTC of cascade refrigeration system with zero ozone depletion potential [ODP] value and low global warming potential [GWP] value. That's why I review on thermodynamic performance of the cascade vapour refrigeration system operated by different refrigerant pairs in my research work. On the basis of my review, I will choose refrigerants in my research work with zero ODP and low GWP value for cascade vapour refrigeration system. In this paper, several research options such as various designs of Cascade Vapour Refrigeration System, studies on refrigerants, optimization works on the systems, Various experimental and analytical studies has been carried out by using different combination of refrigerant to improve overall Coefficient of Performance are discussed. Moreover, the influence of parameters on system performance is defined, followed by conclusions and suggestions for future studies.

Keywords: Cascade vapour refrigeration systems, refrigerant pairs, GWP, ODP.

1. INTRODUCTION

Refrigeration technology plays an important role in human production and life; it is widely used in daily lives, commerce, and industrial production. Refrigeration means a continued extraction of heat from a body whose temperature is already below the temperature of its surroundings. For many industrial and medical applications, very low temperatures are required. Thus the temperatures of the order of -80ºC are required to freeze and store blood and for precipitation hardening of special alloy steels, temperatures as low as -90ºC are required. To obtain such low temperature by conventional systems such Vapour Compression Refrigeration System and Vapour Absorption Refrigeration System are not sufficient. Temperature ranges of -10°C to -30 °C, is used for the vapour compression refrigeration system. Ammonia absorption refrigeration system wide operates between ranges of 5^0C to -55^0C. Therefore, it has no alternative except cascading which consists of using two different vapour compression plants operating with different refrigerants and coupled together so that the condensing of low temperature stage vapour is achieved by evaporation of high temperature stage liquid.

2. NEED OF CASCADE VAPOUR REFRIGERATION SYSTEM

Cascade Vapour Refrigeration System has been proposed to achieve lower refrigeration temperatures. It is an important system that can achieve an evaporating temperature as low as -170 ^{0}C and broadens the refrigeration temperature range of conventional systems .When the vapour compression system is to be used for the production of low temperature; the common alternative to stage compression is the cascade system. In this system, a series of refrigerants with progressively lower boiling temperatures are used in a series of single stage units.

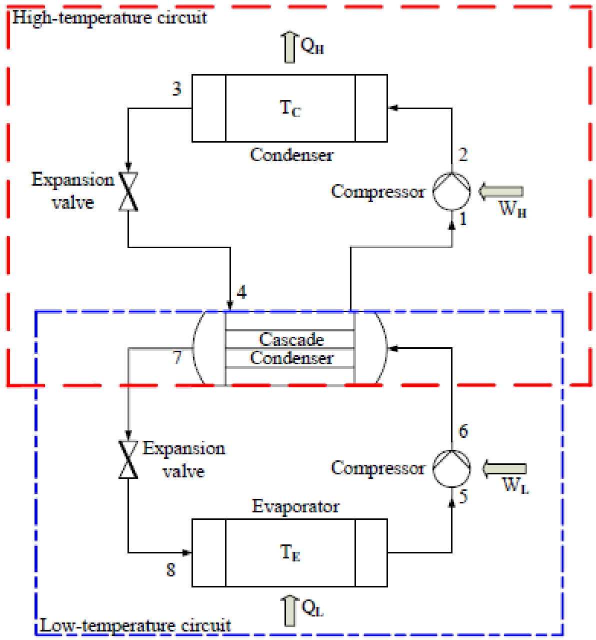

Fig.1 Schematic diagram of two stage cascade vapour refrigeration system

For LTC, in the evaporator the R_{LTC} at the evaporating temp, absorbs the cooling duty $Q_{evap}R_{LTC}$ from the cooling space (at T_E temp), then is compressed in the LTC compressor and condensed in the cascade heat exchanger at a condensing temp, of $T_{cond}R_{LTC}$ and then sent to the from which evaporator is applied.

For HTC, in the condenser the heat flow $Q_{cond}R_{HTC}$ is removed from the R_{HTC} at condensing temp of $T_{cond}R_{HTC}$ to condensing medium (at T_C temp). The R_{HTC} is expanded, and then evaporated at an evaporating temp. of $T_{evap}R_{HTC}$ in the cascade heat exchanger and then compressed in HTC compressor and discharged into the condenser.

2.2 THREE STAGE CASCADE VAPOUR REFRIGERATION SYSTEM

The minimum temperature which can be attained by two stage Cascade Vapour Refrigeration System is -80^{0}C. If there is need of evaporation temperature lower than -80^{0}C, three stage cascade vapour refrigeration system or multistage cascade vapour refrigeration system can be used [11].The additional advantage of a cascade vapour refrigeration system over the multistage system is that the lubricating oil from one compressor cannot wander to other compressors.

2.3 SELECTION OF WORKING REFRIGERANTS IN CASCADE VAPOUR REFRIGERATION SYSTEM

The selection of working refrigerants has a great influence on the cascade vapour refrigeration system performance. In the selection of working refrigerants, besides thermodynamic properties, physical and chemical properties of working refrigerants should also be considered, such as toxicity, combustibility, explosively, interaction with metal materials, interaction with lubricants, low boiling temperature, and atmospheric environmental friendliness.

Desirable properties of working refrigerants in cascade vapour refrigeration system:
1. The critical temperature of refrigerant should be higher and the condensation temperature should be lower. The critical temperature determines whether the refrigerant can liquefy in the range of ordinary low temperature.
2. The boiling point should be as low as possible to produce a lower temperature. Moreover, the evaporation pressure of the refrigerant should be close to or slightly higher than the atmospheric pressure to increase the chance of air mixing into the system.
3. There is an urgent need of replacement of refrigerants by searching for the refrigerant alternative in LTC and HTC of cascade vapour refrigeration system with zero ozone depletion potential [ODP] value and low global warming potential [GWP] value.
4. The freezing point should be as low as possible.
5. The Working refrigerants should be higher COP.
6. Low cost, easily and regularly availability is also main factors in selection of working refrigerants.
7. Non corrosive to metal, non toxic, non flammable and non explosive are also some consideration in selection of working refrigerants.

Table1. Standard values for different working refrigerants in cascade vapour Refrigeration system

Refrigerant	ODP	GWP	Tb (°C)	Tcrit (°C)	Pcrit (bar)	Flammability
R744	0	1	−78.46	31.5	73.77	non-flammability
R717	0	0	−33.33	132.4	113.33	flammability
R600	0	20	−0.49	151.9	37.96	flammability
R1270	0	20	−47.62	92.4	45.55	flammability
R161	0	12	−37.5	102	51	flammability
R170	0	20	−88.58	32.3	48.72	flammability
R290	0	20	−42.11	96.9	42.512	flammability
R404a	0	3850	−46.1	72.4	36.9	non-flammability
R152a	0	124	−25	113.26	45.2	flammability
R23	0	5.7	−84	25.7	48.4	non-flammability
R41	0	107	−78.31	44.13	58.97	flammability
R1234yf	0	4	−29.45	94.7	33.82	flammability
R1234ze (E)	0	6	−18.95	109	36.32	non-flammability
R1233zd (E)	0	7	18.26	166.5	36.24	non-flammability

3. LITERATURE REVIEW

***REVIEW OF PAST STUDIES*:**

Barış Yilmaz Et al. (2020) study contributes to the theoretical evaluation of the feasible natural refrigerant alternatives for ULT applications and the comparison of these refrigerants with synthetic ones in terms of performance and the environmental aspects. It is found that the natural refrigerant R1270/R170 pair results in about 5% better COP and almost half less CO_2 emissions compared to synthetic refrigerant R404A/R508B pair. In this study, a theoretical model is established using Engineering Equation Solver (EES) software in order to investigate the effects of different design and operation parameters on the performance of the cascade systems for Ultra Low Temperature (ULT) between -50^{o}C and -100^{o}C.

Yijian He Et al. (2020) study, a novel cascade refrigeration system was developed to utilize 45-60 ^{0}C heat. It is composed of a novel two-stage vapor absorption refrigeration (VAR) subsystem with LiBr/H2O working pairs and a conventional vapor compression refrigeration (VCR) subsystem. The VCR subsystem employs potential R1234yf and R1234ze (E) refrigerants. The novel VAR subsystem operates by utilizing ultra-low-grade heat of renewable energy and recycling condensing heat of the VCR subsystem. Based on thermodynamic models of the novel system, its operating mechanism was theoretically investigated and discussed.

Mingzhang Pan Et al. (2020) This paper provides a literature review of the cascade refrigeration system (CRS). It is an important system that can achieve an evaporating temperature as low as -170 ^{0}C and broadens the refrigeration temperature range of conventional systems.

Shyam Agarwal Et al. (2020) In this work, an absorption-compression cascade refrigeration system (ACCRS) has been analyzed theoretically for low temperature cooling applications. It comprises of a triple effect H2O-LiBr series flow vapor absorption refrigeration system in higher temperature section associated with vapor compression refrigeration (VCR) system using R1234yf refrigerant in lower temperature section. An EES software based computational model has been formulated for the computation of performance parameters. The results illustrate that
the electricity savings of triple effect cascade system are 45.84% in comparison to conventional VCR cycle.

Yousuf Alhendal Et al. (2020) In this paper, the energy and exergy of low-global warming potential (GWP) refrigerants were investigated experimentally and theoretically. Refrigerants with a modest GWP100 of $\leq$ 150 can be sufficient for bringing down emissions which were concerned for the automotive air-conditioning system. Three types of low-GWP refrigerants, R152a, R1234yf, and R1234ze(E), were examined with particular reference to the current high-GWP of R134a.The refrigerant R1234ze(E) has the highest energetic and exergetic performance compared with the other investigated refrigerants.

K.Logesh Et al. (2019) In this paper report the performance analysis of different refrigerants couples in cascade refrigeration system. Refrigerants such as R134a/R23, R410A/R23 and R404A/R170 have been successfully analyzed in the superheating and sub cooling range of 10°C and 5 °C respectively. The variation in condenser temperature was from 30 to 50 °C in high temperature circuit while evaporator temperature in low temperature circuit varied in the range of -70°C to -50 °C. From the present study we conclude that the refrigerant pair R134a/R170 was found to have greater coefficient of performance and lower mass flow rate and the pair R404A/R508B was found to have smaller coefficient of performance and greater mass flow rate.

Fatih Yilmaz Et al. (2019) In this study, a comparative thermodynamic performance analysis of cascade system (CCS) for cooling and heating applications is presented and compared for different refrigerant couples. The CO_2 was used as working fluid in LTC, whereas the HFE 7000, R134a, R152a, R32, R1234yf, and R365mfc refrigerants were used in HTC. After thermodynamic analyses are completed, the COP_{cl} of CCS is obtained as 1.802, 1.806, 1.826, 1.769, 1.777, and 1.835 for CO_2-HFE7000, CO_2-R134a, CO_2-R152a, CO_2-R32, CO_2-R1234yf and CO_2-365mfc refrigerant couples, respectively.

Luiz Henrique Et al. (2019) This work evaluates the thermodynamic performance of three different mixed refrigerants: R744/R1270, R744/R717 and R744/RE170 in a cascade refrigeration system composed of two vapor compression cycles. After optimization, COP increased from 18% to 32% when compared to the values obtained for pure refrigerants. R744/RE170 mixture showed the best results with a COP of 2.34, increasing exergetic efficiency up to 30% and reducing refrigerant mass flow rate in the range from 6% to 34%, compressor power between 20% to 23% and exergy destruction rate was decreased around 31% to 36%.

Ebru Mançuhan Et al. (2019) study is to propose a theoretical model to analyze the energy efficient and environment friendly cascade system for various refrigerant pairs. Natural refrigerant CO2 is selected instead of R404A which has high Global Warming Potential (GWP) value for the low temperature cycle (LTC). On the other hand, synthetic refrigerants (R134a, R152a) and a natural refrigerant (NH3) are chosen for the high temperature cycle (HTC). The COPmax and total equivalent warming impact (TEWI) values of the system's refrigerant pairs are evaluated and compared for various operating conditions.

Ranendra Roy Et al.(2019) In this study ,A numerical investigation of energetic, exergetic, economic and environmental performances of a 50-kW cooling capacity cascade refrigeration system using four different refrigerant pairs, namely R41–R404A, R170–R404A, R41–R161 and R170–R161, has been carried out. Effects of evaporator temperature, condenser temperature, LTC condenser temperature and cascade condenser temperature difference have been studied parametrically. The COP and exergetic efficiency of the system are found to be maximum with R41–R161 refrigerant pair followed by R170–R161 for the same operating conditions.

In **Canan Cimsit (2018)** study, the absorption part has been designed to improve the performance of absorption–vapour compression cascade cycle as serial flow double effect. The detailed thermodynamic analysis has been made of double effect absorption –vapour compression cascade refrigeration cycle. For the novel cycle working fluid used R-134a for vapour compression section & LiBr-H2O for absorption section. This cycle has been compared with single effect absorption – vapour compression cascade cycle & one stage vapour compression refrigeration cycle.

Leonardo Arrieta Mondragon Et al. (2018) document presents a combined refrigeration system consisting of two vapour compression refrigeration cycles linked by a heat exchanger that not only reduces the work of the compressor but also increases the amount of heat absorbed by the refrigerated space as a result of the cascade stages & improves the COP of a refrigeration system.

Jinkun Zhou Et al. (2018) study shows that the auto-cascade absorption refrigeration system could obtain a lower temperature than that of the traditional absorption refrigeration system since the non-azeotropic mixed refrigerants with large temperature glides were used. In this article, the performance of an auto-cascade absorption refrigeration system using R23/R134a/DMF (dimethyl formamide) solutions as the working substance was analyzed. Optimization analysis results showed that, to some extent, the coefficient of performance (COP) could be increased when the low pressure of the system decreased or the high pressure increased.

R.S. Mishra (2017) This paper gives the thermodynamic analysis of three stages cascade vapour compression refrigeration systems using eco-friendly refrigerants used for low temperature applications.. The utility of R1234ze and R1234yf and in the high temperature circuits and new eco-friendly refrigerants in the intermediates circuits and R134a or R404a in the low temperature cascade circuit have been optimized. It was observed that in the low temperature (between -50ºC to -100ºC) applications, the best combination in terms of R1234ze-R134a-R404a gives better thermal performance than using R1234yf-R134a-R404a. Similarly other combination in terms of R1234ze-R134a-R404a gives better thermal performance than using R1234ze-R1234yf-R404a.

Zhili Sun (2016) This study presents a comparative analysis of thermodynamic performance of cascade refrigeration systems (CRSs) for refrigerant couples R41/R404A and R23/R404A to discover whether R41 is a suitable substitute for R23. The results indicate that an optimum condenser temperature exists for LTC (T4opt) at which COP acquires maximum value. Under the same operation condition, the input power of R41/R404A CRS is lower than that of R23/R404A CRS, and COPopt is higher than that of R23/R404A CRS. The maximum exergy efficiency of R41/R404A and R23/R404A CRSs are 44.38% and 42.98% respectively. The theoretical analysis indicates that R41/R404A is a more potential refrigerant couple than R23/R404A in CRS.

4. CONCLUSIONS

This paper reviews on thermodynamic performance of the cascade vapour refrigeration system operated by different refrigerant pairs. Review based on different refrigerant pairs, various designs of cascade vapour refrigeration system, research on optimization, related experimental and analytical studies, performance analysis and environmental impact issues. Some conclusions and suggestions for further studies are as follows:

1. This review helps me to find out best feasible solution for refrigerant pairs in cascade vapour refrigeration system.
2. This review helps me to find out research methodology for my proposed work.
3. It helps me to improve the design of cascade vapour refrigeration system for increasing overall COP.
4. After study and analysis of above review, I find out the R41-R290 and R41-R600 refrigerant pairs with zero ODP and low GWP value for proposed thermodynamic analysis of cascade vapour refrigeration system.

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