International Journal of Research in Engineering and Innovation
(IJREI)
**journal home page: http://www.ijrei.com**
**ISSN (Online): 2456-6934**

International Journal of Research in Engineering and Innovation
Vol-1, Issue-2

# Thermal modelling of three stage vapour compression cascade refrigeration system using entropy generation principle for reducing global warming and ozone depletion using ecofriendly refrigerants for semen preservation

R S Mishra

*Department of Mechanical, Production & Industrial and Automobiles Engineering*
*Delhi Technological University Delhi*
*E mail: rsmishra@dce.ac.in , rsmishra@dtu.ac.in*

## Abstract

This paper mainly deals with thermodynamic analysis of three stages cascade vapour compression refrigeration systems using ecofriendly refrigerants used for low temperature applications. The effect of thermal performance parameters (i.e. approaches, condenser temperature, and temperature variations in the evaporators) on the first law thermal performances $COP_{System}$ and also in terms of second law efficiency of the cascade system (exergetic efficiency) and System exergy destruction ratio (SEDR) have been optimized thermodynamically using entropy generation principle.

The utility of R1234ze and R1234yf and in the high temperature circuits and new ecofriendly 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. It was observed that 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.

*Keywords:* Three stages Cascade VCR, Energy-Exergy Analysis, and Thermodynamic Optimization

## 1. Introduction

Low-temperature refrigeration systems are typically required for low temperature range from –40°C to –100°C for applications chemical, food, pharmaceutical, and other industries. For low temperature applications, single-stage/Double stages systems with reciprocating compressors are not feasible due to higher pressure ratios. High pressure ratio means high discharge and oil temperatures with low volumetric Compressor efficiencies which results low first law efficiency in terms of COP values. Vapor compression cascade refrigeration systems be used to achieve low temperatures applications in such a manner , where series of single-stage units are used that are thermally coupled through evaporator/condenser cascading. Each circuit has a different ecofriendly refrigerant suitable for that temperature. The high-temperature circuit uses high boiling point refrigerants such as R-1234ze, and R1234yf, R 717 and R152a and Intermediate circuit's ecofriendly refrigerants such as R-1234yf, R134a, R407c R125, etc. are used. Similarly for the low-temperature cascade circuit low boiling refrigerants are used.

In a vapour compression cascade refrigeration system where low pressure vapour in the evaporator stage is compressed and then recycled for condensation in the evaporator of a previous stage, the improvement of passing the low pressure refrigerant's vapour from an evaporator stage through a heat exchanger to heated vapour to ambient temperature, compressing said heated vapour, removing the compressor work by passing said compressed vapour through a evaporator, then cooling is by compressed

*Corresponding Author: R.S. Mishra*
*Email Id: rsmishra@dce.ac.in*

vapour by passing it through heat exchanger in heat exchanger at a low pressure vapour, and condensing it in the evaporator of the next higher temperature cycle of the cascade system and recycling the liquid to the low pressure evaporator stage. Most of the investigators even did not found the effect of various approaches on the system first and second law performances on three stages cascade refrigeration systems and effect of ecofriendly refrigerants in the intermediate temperature circuit.

This paper mainly deals with thermal performances in terms of exergy destruction ratio by thermodynamically analyzing the use of R1234yf and R1234ze in the high temperature circuits and R134a/ R404a eco-friendly refrigerants in the low temperature circuit.

### *1.1 Literature Review*

B. Agnew, et.al [1] considered finite time analysis of a cascade refrigeration system using alternative refrigerants. Bansal P.K [2] used thermodynamic analysis of carbon dioxide–ammonia (R744–R717) cascade refrigeration system. Bhattacharyya et al [3] carried out thermal modelling of a cascade refrigeration–heat pump system by incorporating both internal and external irreversibility's. Cabell et al [4] developed steady-state modelling of a single stage vapours compression plant. James M. Calm, [5] considered the next generation of refrigerants in VCR. Ecir et al [6] used thermal modelling techniques for predicting thermo-physical properties of refrigerants. Kilicarslan [7] carried out experimental investigation of a different type of two-stage vapour compression cascade refrigeration system. Jain et al [8] showed that carbon dioxide is a potential low temperature refrigerant.. Pearson [9] traced the development of the old carbon dioxide systems Samant [10] design and development of two stage cascade refrigeration system using CO2 as LTC refrigerant and Propane as HTC refrigerant. Resat S. et al [11] exergy based thermo-economic optimization of subcooled and superheated vapour compression refrigeration cycle. Wang et al [12] potential benefits of compressor cooling. Tzong-Shinge et al [13] comprehensive investigation of numerical methods in simulating a steady-state vapor compression system. Mukhopadhyay, [14] used CO2–C3H8 cascade refrigeration–heat pump system: and carried out numerical verification of heat exchanger inventory optimization Mishra [15–16] examined the performance of a Four stage cascade refrigeration systems using hydrocarbon as refrigerants and evaluated thermal performance of four stages cascade vapour Compression System and theoretical study of a different type of two-stage vapour compression refrigeration system.

The above investigators did not studies the thermodynamic performances in terms of COP and exergetic efficiency and system exergy destruction ratio (SEDR) for very low temperature application using ecofriendly refrigerants in the low temperature circuits and R1234ze in higher temperature circuit, and R1234yf in intermediate temperature circuit and R134a in low temperature circuit.

## 2. Description of Three Stage Cascade Systems

The following assumptions have been taken for analyzing three stages cascade vapour compression system for low temperature applications. The cooling load is considered to be 70 [kW‖ Temperature of condenser is to be $50^0$C and temperature of low circuit evaporator to be $-100^0$C, The temperature of high temperature evaporator to be $-10^0$C, temperature of secondary intermediate cascade evaporator is to be $-50^0$C, The effect of temperature overlapping (approach means temperature difference between cascade condenser and cascade evaporator is $10^0$C in each stage is considered.

## 3. Results and Discussions

For Cascade vapor compression refrigeration System using ecofriendly refrigerants R-1234ze-R1234yf-R134a in high temperature circuit, intermediate temperature circuit and low temperature circuit, for reducing global warming and ozone depletion following Input values are taken for numerical computation of model developed by author

Compressor efficiency in each temperature circuit is 80%. Condenser temperature in High temperature circuit is $50^0$C, temperature of High temperature evaporator is $0^0$C. Temperature of intermediate temperature evaporator is $-50^0$C and Temperature of low temperature evaporator is $-100^0$.

Approach (i.e. Temperature Overlapping) means the temperature difference between cascade condenser (intermediate temperature circuit) minus high temperature evaporator circuit and another approach (i.e. temperature overlapping between low temperature cascade condenser temperature minus evaporator temperature in intermediate temperature circuit is ranging from $0^0$C to $10^0$C.

Table-1(a) to 1(b) showing the first law efficiency of the three stage cascade refrigeration system usingR1234ze in the high temperature circuit and R1234yf in the secondary cascade intermediate temperature circuit and R134a in a lower temperature circuit. It was observed that the use of R1234ze in higher temperature circuit gives better thermodynamic performance than using R1234yf in high temperature circuit up to temperature range of $-100^0$C.

However for low temperature applications The best combination of three stage cascade is system is to be R1234ze-R134a-R404a .The other refrigerants such as R123 and hydrocarbons containing chlorine and R152, R600 and R290 are also flammable in nature can be considered by adopting safety measures while R717 in toxic in nature. Therefore R1234ze-R1234yf-R134a is most suitable for practical applications.

*Table-1(a) Variation of system thermal performance of three stages cascade vapour compression refrigeration systems with ecofriendly refrigerant in high temperature circuit*

| Ecofriendly Refrigerant in Low Temperature Circuit | System First Law Efficiency (COP) | Exergy Destruction Ratio EDRSystem | Exergetic Efficiency/ Second Law efficiency/ EFFSecond |
|---|---|---|---|
| R1234ze | 0.5074 | 1.728 | 0.3666 |
| R1234yf | 0.4963 | 1.789 | 0.3586 |
| R717 | 0.5249 | 1.637 | 0.3792 |
| R152a | 0.5201 | 1.661 | 0.3758 |

*Table-1(b).Variation of system thermal performance along with circuit thermal performance of three stages cascade vapour compression refrigeration systems with ecofriendly refrigerant in high temperature circuit*

| Ecofriendly Refrigerant in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPITC | COPLTC |
|---|---|---|---|---|
| R1234ze | 0.5074 | 3.215 | 2.204 | 1.79 |
| R1234yf | 0.4963 | 3.027 | 2.204 | 1.79 |
| R717 | 0.5249 | 3.546 | 2.204 | 1.79 |
| R152a | 0.5201 | 3.451 | 2.204 | 1.79 |

*Table-2(a).Variation of thermal performance of three stages cascade vapour compression refrigeration systems with ecofriendly refrigerant in intermediate temperature circuit*

| Ecofriendly Refrigerant in Intermediate Temperature Circuit | System First Law Efficiency (COP) | Exergy Destruction Ratio EDRSystem | Efficiency Second |
|---|---|---|---|
| R1234yf | 0.5074 | 1.728 | 0.3666 |
| R134a | 0.5169 | 1.677 | 0.3735 |
| R407c | 0.4795 | 1.887 | 0.3464 |
| R410a | 0.5152 | 1.682 | 0.3723 |
| R404a | 0.4966 | 1.787 | 0.3588 |

*Table-2(b).Variation of thermal performance of three stages cascade vapour compression refrigeration systems with ecofriendly refrigerant in intermediate temperature circuit*

| Ecofriendly Refrigerant in Intermediate Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPITC | COPLTC |
|---|---|---|---|---|
| R1234yf | 0.5074 | 3.215 | 1.79 | 2.204 |
| R134a | 0.5169 | 3.215 | 1.79 | 2.294 |
| R407c | 0.4795 | 3.215 | 1.79 | 1.961 |
| R410a | 0.5152 | 3.215 | 1.79 | 2.278 |
| R404a | 0.4966 | 3.215 | 1.79 | 2.107 |

*Table-3(a).Thermal performance of three stages cascade vapor compression refrigeration systems with ecofriendly refrigerant in low temperature circuit*

| Ecofriendly Refrigerant in Low Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| R134a | 0.5074 | 1.728 | 0.3666 |
| R404a | 0.4971 | 1.784 | 0.3592 |
| R600a | 0.5123 | 1.701 | 0.3702 |
| R290 | 0.510 | 1.714 | 0.3685 |
| R600 | 0.5148 | 1.688 | 0.3720 |
| Ethylene | 0.4781 | 1.895 | 0.3454 |
| Ethane | 0.4951 | 1.795 | 0.3578 |

*Table-3(b).Variation of thermal performance of three stages cascade vapour compression refrigeration systems with ecofriendly refrigerant in low temperature circuit*

| Ecofriendly Refrigerant in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| R134a | 0.5074 | 3.215 | 2.204 | 1.79 |
| R404a | 0.4971 | 3.215 | 2.204 | 1.724 |
| R600a | 0.5123 | 3.215 | 2.204 | 1.822 |
| R290 | 0.510 | 3.215 | 2.204 | 1.807 |
| R600 | 0.5148 | 3.215 | 2.204 | 1.839 |
| Ethylene | 0.4781 | 3.215 | 2.204 | 1.607 |
| Ethane | 0.4951 | 3.215 | 2.204 | 1.711 |

*Table-4(a) Variation of thermal performance of three stages cascade vapor compression refrigeration systems*

| Effect of Approach in Low Temperature Circuit | System First Law Efficiency (COP) | EDR System | Efficiency Second |
|---|---|---|---|
| 0 | 0.570 | 1.428 | 0.4119 |
| 2.5 | 0.5535 | 1.50 | 0.3999 |
| 5.0 | 0.5376 | 1.574 | 0.3884 |
| 7.5 | 0.5222 | 1.650 | 0.3773 |
| 10.0 | 0.5074 | 1.728 | 0.3666 |

*Table-4(b) Variation of thermal performance of three stages cascade vapor compression refrigeration systems*

| Effect of Approach in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| 0 | 0.570 | 3.215 | 2.204 | 2.247 |
| 2.5 | 0.5535 | 3.215 | 2.204 | 2.116 |
| 5.0 | 0.5376 | 3.215 | 2.204 | 1.998 |
| 7.5 | 0.5222 | 3.215 | 2.204 | 1.889 |
| 10.0 | 0.5074 | 3.215 | 2.204 | 1.79 |

*Table-5(a) Variation of thermal performance of three stages cascade vapour compression refrigeration systems*

| Effect of Approach in Low Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 0 | 0.5675 | 1.439 | 0.410 |
| 2.5 | 0.5522 | 1.507 | 0.399 |
| 5.0 | 0.5371 | 1.577 | 0.388 |
| 7.5 | 0.5221 | 1.651 | 0.3773 |
| 10.0 | 0.5074 | 1.728 | 0.3666 |

*Table-5(b) Variation of thermal performance of three stages cascade vapour compression refrigeration systems*

| Effect of Approach in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPITC | COPLTC |
|---|---|---|---|---|
| 0 | 0.5675 | 3.215 | 2.844 | 1.79 |
| 2.5 | 0.5522 | 1.507 | 2.633 | 1.79 |
| 5.0 | 0.5371 | 1.577 | 2.497 | 1.79 |
| 7.5 | 0.5221 | 1.651 | 2.345 | 1.79 |
| 10.0 | 0.5074 | 1.728 | 2.204 | 1.79 |

*Table-6(a) Variation of condenser temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Condenser temperature in High Temperature (R1234ze) Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 60 | 0.4530 | 2.055 | 0.3273 |
| 55 | 0.4804 | 1.881 | 0.3471 |
| 50 | 0.5074 | 1.728 | 0.3666 |
| 45 | 0.5340 | 1.592 | 0.3859 |
| 40 | 0.5606 | 1.469 | 0.4051 |
| 35 | 0.5873 | 1.356 | 0.4244 |
| 30 | 0.6143 | 1.253 | 0.4438 |
| 25 | 0.6416 | 1.157 | 0.4636 |

*Table-6(b) Variation of condenser temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Condenser temperature in High Temperature (R1234ze) Circuit | System First Law Efficiency (COP) | COPHTC | COPITC | COPLTC |
|---|---|---|---|---|
| 60 | 0.4530 | 2.407 | 2.204 | 1..79 |
| 55 | 0.4804 | 2.779 | 2.204 | 1..79 |
| 50 | 0.5074 | 3.215 | 2.204 | 1..79 |
| 45 | 0.5340 | 3.737 | 2.204 | 1..79 |
| 40 | 0.5606 | 4.379 | 2.204 | 1..79 |
| 35 | 0.5873 | 5.192 | 2.204 | 1..79 |
| 30 | 0.6143 | 6.264 | 2.204 | 1..79 |
| 25 | 0.6416 | 7.750 | 2.204 | 1..79 |

*Table-7(a) Variation of evaporator temperature on thermal performance of three stages cascade vapor compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 20 | 0.4698 | 1.946 | 0.3395 |
| 15 | 0.4847 | 1.855 | 0.3502 |
| 10 | 0.4958 | 1.791 | 0.3583 |
| 5 | 0.5033 | 1.75 | 0.3637 |
| 0 | 0.5074 | 1.728 | 0.3666 |
| -5 | 0.5081 | 1.724 | 0.3671 |
| -10 | 0.5057 | 1.737 | 0.3654 |
| -15 | 0.5003 | 1.766 | 0.3615 |
| -20 | 0.4923 | 1.811 | 0.3557 |

*Table-7(b) Variation of evaporator temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| 20 | 0.4698 | 6.446 | 1.356 | 1.79 |
| 15 | 0.4847 | 5.287 | 1.533 | 1.79 |
| 10 | 0.4958 | 4.421 | 1.729 | 1.79 |
| 5 | 0.5033 | 3.75 | 1.951 | 1.79 |
| 0 | 0.5074 | 3.225 | 2.204 | 1.79 |
| -5 | 0.5081 | 2.78 | 2.497 | 1.79 |
| -10 | 0.5057 | 2.42 | 2.844 | 1.79 |
| -15 | 0.5003 | 2.117 | 3.261 | 1.79 |
| -20 | 0.4923 | 1.86 | 3.777 | 1.79 |

*Table-8(a) Variation of evaporator temperature on thermal performance of three stages cascade vapor compression refrigeration systems*

| S.No | Evaporator temperature in Low Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|---|
| 1 | -80 | 0.6759 | 1.72 | 0.3677 |
| 2 | -85 | 0.6312 | 1.708 | 0.3693 |
| 3 | -90 | 0.5882 | 1.705 | 0.3697 |
| 4 | -95 | 0.5470 | 1.712 | 0.3687 |
| 5 | -100 | 0.5074 | 1.728 | 0.3666 |

*Table-8(b) Variation of evaporator temperature on thermal performance of three stages cascade vapor compression refrigeration systems*

| Evaporator temperature in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| -80 | 0.6759 | 3.215 | 2.204 | 3.323 |
| -85 | 0.6312 | 3.215 | 2.204 | 2.810 |
| -90 | 0.5882 | 3.215 | 2.204 | 2.40 |
| -95 | 0.5470 | 3.215 | 2.204 | 2.067 |
| -100 | 0.5074 | 3.215 | 2.204 | 1.79 |

*Table-9(a) Variation of condenser temperature on thermal performance of three stages cascade vapor compression refrigeration systems*

| Condenser temperature in High Temperature (R1234ze) Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 60 | 0.4530 | 2.055 | 0.3273 |
| 55 | 0.4804 | 1.881 | 0.3471 |
| 50 | 0.5074 | 1.728 | 0.3666 |
| 45 | 0.5340 | 1.592 | 0.3859 |
| 40 | 0.5606 | 1.469 | 0.4051 |
| 35 | 0.5873 | 1.356 | 0.4244 |
| 30 | 0.6143 | 1.253 | 0.4438 |
| 25 | 0.6416 | 1.157 | 0.4636 |

*Table-9(b) Variation of evaporator temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| -50 | 0.5074 | 3.215 | 2.204 | 1.79 |
| -45 | 0.5092 | 3.215 | 2.529 | 1.613 |
| -40 | 0.5090 | 3.215 | 2.921 | 1.461 |
| -35 | 0.5067 | 3.215 | 3.404 | 1.328 |
| -30 | 0.5023 | 3.215 | 4.011 | 1.211 |

*Table-10(a) Variation of condenser temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 20 | 0.4698 | 1.946 | 0.3395 |
| 15 | 0.4847 | 1.855 | 0.3502 |
| 10 | 0.4958 | 1.791 | 0.3583 |
| 5 | 0.5033 | 1.75 | 0.3637 |
| 0 | 0.5074 | 1.728 | 0.3666 |
| -5 | 0.5081 | 1.724 | 0.3671 |
| -10 | 0.5057 | 1.737 | 0.3654 |
| -15 | 0.5003 | 1.766 | 0.3615 |
| -20 | 0.4923 | 1.811 | 0.3557 |

*Table-10(b) Variation of condenser temperature on thermal performance of three stages cascade vapour compression refrigeration systems*

| Condenser temperature in High Temperature (R1234ze) Circuit | System First Law Efficiency (COP) | COPHTC | COPITC | COPLTC |
|---|---|---|---|---|
| 60 | 0.4530 | 2.407 | 2.204 | 1..79 |
| 55 | 0.4804 | 2.779 | 2.204 | 1..79 |
| 50 | 0.5074 | 3.215 | 2.204 | 1..79 |
| 45 | 0.5340 | 3.737 | 2.204 | 1..79 |
| 40 | 0.5606 | 4.379 | 2.204 | 1..79 |
| 35 | 0.5873 | 5.192 | 2.204 | 1..79 |
| 30 | 0.6143 | 6.264 | 2.204 | 1..79 |
| 25 | 0.6416 | 7.750 | 2.204 | 1..79 |

*Table-11(a) Variation of condenser temperature on thermal performance of three stages cascade vapor compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| 20 | 0.4698 | 1.946 | 0.3395 |
| 15 | 0.4847 | 1.855 | 0.3502 |
| 10 | 0.4958 | 1.791 | 0.3583 |
| 5 | 0.5033 | 1.75 | 0.3637 |
| 0 | 0.5074 | 1.728 | 0.3666 |
| -5 | 0.5081 | 1.724 | 0.3671 |
| -10 | 0.5057 | 1.737 | 0.3654 |
| -15 | 0.5003 | 1.766 | 0.3615 |
| -20 | 0.4923 | 1.811 | 0.3557 |

*Table-11(b) Thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| 20 | 0.4698 | 6.446 | 1.356 | 1.79 |
| 15 | 0.4847 | 5.287 | 1.533 | 1.79 |
| 10 | 0.4958 | 4.421 | 1.729 | 1.79 |
| 5 | 0.5033 | 3.75 | 1.951 | 1.79 |
| 0 | 0.5074 | 3.225 | 2.204 | 1.79 |
| -5 | 0.5081 | 2.78 | 2.497 | 1.79 |
| -10 | 0.5057 | 2.42 | 2.844 | 1.79 |
| -15 | 0.5003 | 2.117 | 3.261 | 1.79 |
| -20 | 0.4923 | 1.86 | 3.777 | 1.79 |

*Table- 12 (a) Thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator Temperature nt in Low Temperature Circuit | System First Law Efficiency (COP) | EDR System | EFF Second |
|---|---|---|---|
| -80 | 0.6759 | 1.72 | 0.3677 |
| -85 | 0.6312 | 1.708 | 0.3693 |
| -90 | 0.5882 | 1.705 | 0.3697 |
| -95 | 0.5470 | 1.712 | 0.3687 |
| -100 | 0.5074 | 1.728 | 0.3666 |

*Table- 12 (b) Thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator Temperature in Low Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| -80 | 0.6759 | 3.215 | 2.204 | 3.323 |
| -85 | 0.6312 | 3.215 | 2.204 | 2.810 |
| -90 | 0.5882 | 3.215 | 2.204 | 2.40 |
| -95 | 0.5470 | 3.215 | 2.204 | 2.067 |
| -100 | 0.5074 | 3.215 | 2.204 | 1.79 |

*Table- 13 (a) Thermal performance of three stages cascade vapour compression refrigeration systems*

| Evaporator temperature in intermediate Temperature Circuit | System First Law Efficiency (COP) | COPHTC | COPLTC | COPLTC |
|---|---|---|---|---|
| -50 | 0.5074 | 3.215 | 2.204 | 1.79 |
| -45 | 0.5092 | 3.215 | 2.529 | 1.613 |
| -40 | 0.5090 | 3.215 | 2.921 | 1.461 |
| -35 | 0.5067 | 3.215 | 3.404 | 1.328 |
| -30 | 0.5023 | 3.215 | 4.011 | 1.211 |

From Tables-3: it was observed that as condenser temperature decreases with increasing First law efficiency of cascade system in terms of overall system COP. Similarly the System EDR is decreases and also second law efficiency/exergetic efficiency increases with decreasing condenser temperature. Regarding First law efficiency in terms of circuit COP of hot fluid circuit is increases. There will not be effect on other circuit first law efficiencies (COP). The exergetic efficiency and Overall COP of system using R1234ze is higher than using R1234yf in the high temperature circuit while system EDR is increases. As decreasing High temperature evaporator temperature, the first law efficiency (i.e. overall COP of system) and second law efficiency (i.e. exergetic efficiency of whole system) is increasing up to maximum value at the evaporator temperature of 25oC and then decreases rapidly.

As decreasing High temperature evaporator temperature the system EDR first decreasing up to decreasing evaporator temperature and then further constant and then increasing and optimum becomes at evaporator temperature at 25oC in both cases using R1234yf and R1234ze in the high temperature circuit. However first law efficiency (COP) of hot fluid circuit is decreases and COP of primary intermediate fluid circuit is increases.. As evaporator temperature decreases, the first law efficiency ( overall COP) and second law efficiency (exergetic efficiency) of the system is increases and maximum efficiency is obtained at evaporator temperature of -10 oC and also cop of primary intermediate temperature circuit is decreases and secondary intermediate temperature circuit COP is increases.

As increasing evaporator temperature overall cop is increases while System EDR first decreases while second law efficiency is increases. The maximum efficiency was obtained at -50 oC and then decreases as increasing evaporator temperature. Secondary intermediate circuit COP is increases while low temperature circuit COP is decreases. Table-6(b): Performance variation with cascade evaporator temperature in the secondary intermediate temperature circuit temperature of four stage cascade vapour compression refrigeration system using R1234yf in High temperature circuit and R404a in the low temperature circuit Table-7(a) to 7(d) are showing the effect of low temperature evaporator on the system first and second law performances and system exergy destruction ratio and various circuit first law performances. As low temperature evaporator temperature is decreasing, the first law and second law efficiencies are increasing and exergy destruction ratio is decreasing and high temperature circuit first law performances in increasing.

## 4. Conclusion

The following conclusions were drawn while analysing three stages cascade refrigeration systems.

(i) The use of R1234ze has Global warming potential (GWP) = 6 gives better thermal performance than R1234yf of 4GWP in the higher temperature circuit of three stages cascade refrigeration system.

(ii) There is significant performance improvements using R134a as compared with R1234yf in the intermediate temperature circuit with R134a in lower temperature circuit.

(iii) The second law efficiency using R134a in the low temperature evaporator circuit gives better performance as compared with R410a in intermediate temperature circuit.

## 5. References

[1] B. Agnew, et.a.,[ 2004], A finite time analysis of a cascade refrigeration system using alternative refrigerants, Applied Thermal Engineering, 24, , 2557–2565.

[2] P. K. Bansal,[ 2008], Thermodynamic analysis of an R744–R717 cascade refrigeration system, international journal of refrigeration 31, , 45-54.

[3] Souvik Bhattacharyya, [2007], Exergy maximization of cascade refrigeration cycles and its numerical verification for a trans critical CO2-C3H8 system, International Journal of Refrigeration, 30, , 624-632.

[4] R. Cabello,[ 2005], Simplified steady-state modelling of a single stage vapour compression plant. Model development and validation, Applied Thermal Engineering, 25, 1740–1752.

[5] James M. Calm, [2008],The next generation of refrigerants – Historical review, considerations, and outlook, International Journal of Refrigeration, 31, 1123-1133.

[6] Ecir Ugˇur Küçüksille, [2008], Data mining techniques for thermophysical properties of refrigerants, Energy Conversion and Management.

[7] A. Kilicarslan, An experimental investigation of a different type vapor compression cascade refrigeration system, Applied Thermal Engineering, 24, 2004 2611–2626.

[8] P. K. Jain,[ 2007] Cascade Systems: Past, Present, and Future, ASHRAE Trans. 113(1), 245-252(DA-07-027).

[9] D. Peter,[ 2008] Refrigeration of the Future for Air Conditioning, Air conditioning and Refrigeration Journal, 8, , 20-27.

[10] Samant Maji, [2006]Design and Development of two stage cascade refrigeration system, Mechanical Engineering Department, IIT Delhi.

[11] Reşat Selbaş, Önder Kızılkan, Arzu Şencan,[ 2006,] Thermo economic optimization of subcooled and superheated vapor compression refrigeration cycle, Energy, 31, 2108–2128.

[12] Xudong Wang, Yunho Hwang, Reinhard Radermacher,[ 2008]Investigation of potential benefits of compressor cooling, Applied Thermal Engineering, 28, , 1791–1797.

[13] Tzong-Shinge.al, [2006], Thermodynamic analysis of optimal condensing temperature of cascade-condenser in CO2/NH3 cascade refrigeration systems, International Journal of Refrigeration, 29, , 1100-1108.

[14] S. M. Zubair, [1999] Performance evaluation of Vapour Compression System, International Journal of Refrigeration, 22, 235-243.

[15] Mukhopadhyay, [2008], CO2–C3H8 cascade refrigeration–heat pump system: Heat exchanger inventory optimization and its numerical verification, international journal of refrigeration, 31, , 1207-1213