Nature & Environment
Vol. 20 (1), 2015: 23-32
Website: www.natureandenvironment.com

ISSN (Print) : 2321-810X
ISSN (Online) : 2321-8738

RESEARCH ARTICLE

Use of ecofriendly in Low Temperature Circuit in Terms of First Law and Second Law Efficiency of Three Stages Cascade Refrigeration of Biomedical Applications

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Received: 17th October 2014, Revised: 15th December 2014, Accepted: 22nd December 2014

ABSTRACT

Biomedical preservation requires storing biological specimens like stem cells blood and organs, at a storage temperature below -95°C, Hence, the main aim of the current research is to conduct a thermodynamic energy and exergy analysis to determine the thermal performance of three stages cascade refrigeration systems in the high temperature condenser temperature using R1234ze and R1234yf in high temperature circuit of condenser temperature of 70°C and zero degree centrigade of first evaporator temperature in High temperature circuit, and evaporator temperature(-80°C) in intermediate circuit using R134a and R410a as ecofriendly refrigerants is investigated. For low temperature evaporator temperature (-135°C) using hydrocarbons (R290, R600 and R600a), R404aand other refrigerants in low temperature evaporator circuit on system performances (i.e. overall system coefficient of performance, (first law efficiency), exergetic efficiency (second law efficiency) and system exergy destruction ratio (EDR) is investigated in three stages /four stages cascade refrigeration systems are shown in this paper

***Keywords**: Three stages cascade refrigeration system, Energy–Exergy analysis, Low temperature cascade system, Irreversibility Prediction, Biomedical applications.*

INTRODUCTION

Biomedical preservation requires storing biological specimens like stem cells,sperm, blood and organs, at a storage temperature below -95°C. For long-term storage of biological materials, temperatures below -100°C are generally considered to safeguard against the effects of denitrification and Crystallization (ASHRAE Handbook, 2006). The use of a single-cycle vapour compression refrigeration system can only achieve effective cooling of about -40°C, and the efficiency begins to deteriorate under -35°C due to the vast difference between the evaporating and condensing temperatures. Thus, in order to reach a lower temperature, a cascade refrigeration system is utilized NIST (2007); Nasruddin and Syaka (2012). In cascade refrigeration systems consist of at least two refrigeration systems that work independently. The two or more than refrigeration systems are connected by a cascade heat exchanger, where heat is released in the condenser low-temperature circuit (LTC) and is absorbed from the evaporator high-temperature circuit (HTC).The hydrocarbon refrigerants have good thermo physical properties and are environmentally friendly can be used for low temperature applications below -80°C (COX N. 2007).

Hence, the main aim of the current research is to conduct a thermodynamic energy and exergy analysis to determine the thermal performance of three stages / four stages cascade refrigeration systems by varying the high temperature condenser temperature from 0°C to 70°C using R1234ze (GWP =6) and R1234yf (GWP=4) in high temperature circuit with zero degree centigrade evaporator temperature in High temperature circuit, and (-80°C) evaporator temperature in intermediate circuit using R134a and R410a as ecofriendly refrigerants is investigated. The effect of various ecofriendly refrigerants in the low temperature evaporator temperature (-135°C) using hydrocarbons (R290, R600 and R600a), R404a and other refrigerants in low temperature evaporator circuit is also investigated.

LITERATURE REVIEW

Several researchers such as Cox *et.al* (2007), Dopazo *et. al.* (2009), Kim *et. al.* (2008), Lee *et. al.* (2006), Nasruddin and Syaka (2012), Rahadiyan (2007) have evaluated the thermodynamic performance of the two-stage cascade refrigeration systems. Bhattacharyya et al. (2005) studied a carbon dioxide–propane (R744–R290) optimum cascade evaporating system to define an evaporating temperature of R744 for application in heating circuits. Getu and Bansal(2008) 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 give the system maximum COP in terms of sub-cooling, superheating, evaporating temperature, condensing temperature and temperature difference in the system's cascade condenser. The thermodynamic analysis of the carbon dioxide–ammonia (R744–R717) cascade system by Dopazo Alberto, *et al.* (2009) employed both exergy analysis and energy optimization, to determine the optimum condensing temperature of R744 in the low-temperature circuit. Lee et al. (2006) also analyzed a carbon dioxide–ammonia (R744–R717) cascade system thermodynamically to determine the optimum condensing temperature of R744 in the low-temperature circuit.

RESEARCH GAPS IDENTIFIED

Although lot of research work available on the two stages cascade refrigeration systems for lower temperature of circuit up to minimum temperature up to (-70°C) but using ecofriendly new refrigerants such as R1234ze (of GWP six and zero ODP) and R1234yf (of GWP four and zero ODP) in three stages cascade refrigeration systems maintaining temperature below -95 °C for biomedical applications etc is not reported in literature so far. Thepresent investigation mainly deals with energy –exergy analysis of three stage cascase vapour compression refrigeration system using 70°C condenser temperature and zero degree centigrade evaporator temperature and -80°C of second evaporator and -135°C of low temperature evaporator circuit was investigated. Similarly the effect of temperature overlapping in the cascade systems is also known as approach1 (Cascade condenser1-evaporator temperature1) and approach 2 (cascade condenser temperature-evaporator temperature2) and approach 3 (cascade condenser temperature3-evaporator temperature3) on system performances (i.e. overall system coefficient of performance, (first law efficiency), exergetic efficiency (second law efficiency) and system exergy destruction ratio (EDR) is also investigated in three stages cascade refrigeration systems. The results of present investigated systems are shown in this paper

SYSTEM DESCRIPTION

The systems chosen for present investigation is three stages cascade vapour compression refrigeration system, which consist of R1234ze /R1234yf in high temperature evaporator circuit (HTC) using condenser temperature of 70°C while R134a/R410a in the intermediate temperature cascade evaporator circuit (ICT) and hydro-carbons and other ecofriendly refrigerants in the low temperature (-135°C) evaporator circuit (LTC). The performance equations using energy exergy analysis for finding irreversibilities in the system as well as components the three stages cascade vapour compression refrigeration system have been formulated and performance equations have been analysed by using EES and results for above system have been shown in Table-1 to 6 respectively.

RESULTS AND DISCUSSIONS

The performance of three stages cascade refrigeration system using R1234ze in hot temperature evaporator circuit and R1234a in intermediate temperature circuit and six ecofriendly refrigerants in low temperature evaporator circuit are shown in presented Table-1(a) to Table 1(d) respectively. It was observed that using R1234ze in high temperature circuit gives better performance than using ecofriendly R1234yf refrigerant. It was also observed that using R134a in the intermediate temperature circuit gives better thermal performance in terms of overall system COP and exergetic efficiency (in terms of second law efficiency)than using R410a in the intermediate temperature circuit. The exergy destruction ratio is larger by using R1234yf in high temperature circuit while using R410a in the intermediate temperature circuit is also higher than using R134a in the intermediate temperature circuit.

Table 1(a): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond} = 70°C, $T_{cascade\_eva1}$ = 0°C, $T_{cascade\_eva2}$ = -80°C, T_{eva3} = -135°C, Temperature overlapping (Approach1) = Approach2 = 10(°C) and $Compressor_{Efficiency1}$ = 0.80, $Compressor_{Efficiency2}$ = 0.80, $Compressor_{Efficiency3}$ = 80%.

Ecofriendly Refrigerant in LTC	System COP	System EDR	Exergetic Efficiency
R404a	0.2230	2.867	0.2586
Ethylene	0.2179	2.958	0.2526
Ethane	0.2241	2.848	0.2599
R290	0.2266	2.806	0.2627
R600a	0.2306	2.741	0.2673
R600	0.2299	2.752	0.2665

Table 1(b): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature Temperature -overlapping (Approach1) =Approach2 = 10 (°C) and $Compressor_{Efficiency1}$ = 0.80, $Compressor_{Efficiency2}$ = 0.80 $Compressor_{Efficiency3}$= 0.80

Refrigerant in LTC	System COP	System EDR	Exergetic Efficiency
R404a	0.2081	3.145	0.2413
Ethylene	0.2034	3.241	0.2358
Ethane	0.2091	3.125	0.2424
R290	0.2114	3.080	0.2451
R600a	0.2150	3.011	0.2493
R600	0.2144	3.023	0.2486

Table 1(c): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C ,T_{eva3}= - 135 °C, Temperature overlapping (Approach1)=Approach2= 10(°C) and $Compressor_{Efficiency1}$=0.80 $Compressor_{Efficiency2}$= 0.80, $Compressor_{Efficiency3}$= 80%

Ecofriendly Refrigerant in LTC	System COP	System EDR	Exergetic Efficiency
R404a	0.2228	2.871	0.2583
Ethylene	0.2177	2.962	0.2524
Ethane	0.2239	2.852	0.2596
R290	0.2264	2.810	0.2625
R600a	0.2303	2.745	0.2670
R600	0.2297	2.756	0.2663

Table 1(d): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^oC, $T_{cascade\_eva1}$= 0 ^oC, $T_{cascade\_eva2}$= - 80 ^oC , T_{eva3}= - 135 ^oC, Temperature -overlapping (Approach1) =Approach2= 10 (^oC) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Refrigerant in LTC	System COP	System EDR	Exergetic Efficiency
R404a	0.2079	3.149	0.2410
Ethylene	0.2032	3.245	0.2355
Ethane	0.2089	3.129	0.2422
R290	0.2114	3.084	0.2448
R600a	0.2148	3.015	0.2491
R600	0.2142	3.027	0.2483

Similarly the circuit first law efficiency COP of low temperature circuit) is significantly affecting using different ecofriendly refrigerants in the low temperature evaporator circuit used for biomedical applications. The Circuit COP using R600a is better than using other ecofriendly refrigerants. Therefore by using safety measures one can use R600a in the three stages cascade refrigeration system due to better first law and second law performances.

Table 2(a): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^oC, $T_{cascade\_eva1}$= 0 ^oC, $T_{cascade\_eva2}$= - 80 ^oC , T_{eva3}= - 135 ^oC, Temperature -overlapping (Approach1) =Approach2= 10 (^oC) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Refrigerant in LTC	COP_{HTC}	COP_{ITC}	COP_{LTC}
R404a	1.797	1.118	1.163
Ethylene	1.797	1.118	1.117
Ethane	1.797	1.118	1.173
R290	1.797	1.118	1.196
R600a	1.797	1.118	1.234
R600	1.797	1.118	1.228

Table 2(b): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^oC, $T_{cascade\_eva1}$= 0 ^oC, $T_{cascade\_eva2}$= - 80 ^oC , T_{eva3}= - 135 ^oC, Temperature-overlapping (Approach1) =Approach2= 10 (^oC) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Refrigerant in LTC	COP_{HTC}	COP_{ITC}	COP_{LTC}
R404a	1.544	1.118	1.163
Ethylene	1.544	1.118	1.117
Ethane	1.544	1.118	1.173
R290	1.544	1.118	1.196
R600a	1.544	1.118	1.234
R600	1.544	1.118	1.228

Table 2(c): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Refrigerant in LTC	COP_{HTC}	COP_{ITC}	COP_{LTC}
R404a	1.797	1.116	1.163
Ethylene	1.797	1.116	1.117
Ethane	1.797	1.116	1.173
R290	1.797	1.116	1.196
R600a	1.797	1.116	1.234
R600	1.797	1.116	1.228

Table 2(d): First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature-overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Refrigerant in LTC	COP_{HTC}	COP_{ITC}	COP_{LTC}
R404a	1.544	1.116	1.163
Ethylene	1.544	1.116	1.117
Ethane	1.544	1.116	1.173
R290	1.544	1.116	1.196
R600a	1.544	1.116	1.234
R600	1.544	1.116	1.228

As approach-1 (temperature overlapping between low temperature condenser and intermediate evaporator circuit) decreases, the first law efficiency (overall system COP) increases and also second law efficiency in terms of exergetic efficiency increases.

Table 3(a): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	System COP	System EDR	Exergetic Efficiency
15	0.2110	3.087	0.2447
10	0.2230	2.867	0.2586
5	0.2352	2.667	0.2727
0	0.2477	2.483	0.2871

Table 3(b): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^{o}C, $T_{cascade\_eva1}$= 0 ^{o}C, $T_{cascade\_eva2}$= - 80 ^{o}C , T_{eva3}= - 135 ^{o}C, Temperature-overlapping (Approach1) =Approach2= 10 (^{o}C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	System COP	System EDR	Exergetic Efficiency
15	0.1970	3.378	0.2284
10	0.2081	3.145	0.2413
5	0.2193	2.932	0.2543
0	0.2303	2.738	0.2675

Table 3(c): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^{o}C, $T_{cascade\_eva1}$= 0 ^{o}C, $T_{cascade\_eva2}$= - 80 ^{o}C , T_{eva3}= - 135 ^{o}C, Temperature -overlapping (Approach1) =Approach2= 10 (^{o}C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-2	System COP	System EDR	Exergetic Efficiency
15	0.2109	3.090	0.2445
10	0.2228	2.871	0.2583
5	0.2339	2.672	0.2723
0	0.2472	2.489	0.2866

Table 3(d): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^{o}C, $T_{cascade\_eva1}$= 0 ^{o}C, $T_{cascade\_eva2}$= - 80 ^{o}C , T_{eva3}= - 135 ^{o}C, Temperature-overlapping (Approach1) =Approach2= 10 (^{o}C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	System COP	System EDR	Exergetic Efficiency
15	0.1969	3.381	0.2283
10	0.2079	3.149	0.2410
5	0.2190	2.938	0.2539
0	0.2304	2.744	0.2671

As approach-2 (temperature overlapping between low temperature condenser and intermediate evaporator circuit) decreases, the first law efficiency (overall system COP) increases and also second law efficiency in terms of exergetic efficiency increases.

Table 4(a): Effect of Approach2 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 ^{o}C,

$T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80 $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Effect of Approach-2	System COP	System EDR	Exergetic Efficiency
15	0.2108	3.092	0.2444
10	0.2230	2.867	0.2586
5	0.2360	2.654	0.2737
0	0.2499	2.451	0.2898

Table 4(b): Table-4(b) Effect of Approach2 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature-overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Effect of Approach-2	System COP	System EDR	Exergetic Efficiency
15	0.1968	3.383	0.2282
10	0.2081	3.145	0.2413
5	0.2201	2.919	0.2552
0	0.2328	2.704	0.270

4(c): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature-overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Effect of Approach-1	System COP	System EDR	Exergetic Efficiency
15	0.2106	3.092	0.2441
10	0.2228	2.871	0.2583
5	0.2358	2.658	0.2734
0	0.2497	2.455	0.2895

Table 4(d): Effect of Approach1 on First law performance (overall system) Exergetic Efficiency (second law efficiency) and system exergy Destruction Ratio (EDR) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3=}$ 0.80

Effect of Approach-1	System COP	System EDR	Exergetic Efficiency
15	0.1966	3.387	0.2279
10	0.2079	3.149	0.2410
5	0.2198	2.923	0.2549
0	0.2326	2.708	0.2697

Table 5(a): Effect of Approach1 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80, $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.797	1.018	1.163
10	1.797	1.118	1.163
5	1.797	1.228	1.163
0	1.797	1.351	1.163

Table 5(b): Effect of Approach1 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80 $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.544	1.018	1.163
10	1.544	1.118	1.163
5	1.544	1.228	1.163
0	1.544	1.351	1.163

Table 5(c): Effect of Approach1 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.797	1.017	1.163
10	1.797	1.116	1.163
5	1.797	1.225	1.163
0	1.797	1.346	1.163

Table 5(d): Effect of Approach1 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80 $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-1	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.544	1.017	1.163
10	1.544	1.116	1.163
5	1.544	1.225	1.163
0	1.544	1.346	1.163

Table6(a): Effect of approach2 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80 $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-2	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.797	1.118	1.055
10	1.797	1.118	1.163
5	1.797	1.118	1.289
0	1.797	1.118	1.436

Table 6(b): Effect of approach2 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R134a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature-overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80, $Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-2	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.544	1.118	1.055
10	1.544	1.118	1.163
5	1.544	1.118	1.289
0	1.544	1.118	1.436

Table 6(c): Effect of approach2 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234ze refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature -overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-2	COP_{HTC}	COP_{ITC}	COP_{LTC}
15	1.797	1.116	1.055
10	1.797	1.116	1.163
5	1.797	1.116	1.289
0	1.797	1.116	1.436

Table 6(d): Effect of approach2 on First law performance various circuit COPs) of Four stages cascade refrigeration system using ecofriendly R1234yf refrigerant in the high temperature evaporator circuit and ecofriendly R410a in intermediate cascade evaporator temperature circuit and six ecofriendly Refrigerants used in low temp evaporator circuit for T_{cond}= 70 °C, $T_{cascade\_eva1}$= 0 °C, $T_{cascade\_eva2}$= - 80 °C , T_{eva3}= - 135 °C, Temperature-overlapping (Approach1) =Approach2= 10 (°C) and $Compressor_{Efficiency1}$= 0.80,,$Compressor_{Efficiency2}$= 0.80 $Compressor_{Efficiency3}$= 0.80

Effect of Approach-2	COP_{HTC}	COP $_{ITC}$	COP $_{LTC}$
15	1.544	1.116	1.055
10	1.544	1.116	1.163
5	1.544	1.116	1.289
0	1.544	1.116	1.436

CONCLUSION

The following conclusions have been drawn from present investigations-

i.The use of R1234ze refrigerant has GWP =6) gives better thermal performance than using R1234yf (GWP=4) in the high temperature circuit although both refrigerants have zero ozone depletion potential.

ii. By using R410a in the intermediate temperature circuit the thermal performance decreases and system exergy destruction (EDR) is increases as compared with using R134a in the intermediate temperature circuit.

iii.By using safety measures, the use of R600a hydrocarbon gives better thermal performances than other hydrocarbons such as R290 and R600 and other ecofriendly refrigerants (R404a, ethane and ethylene etc).

REFERENCES

1. ASHRAE (2006): Handbook Refrigeration System and Applications, American Society of Heating, Refrigerating, and Air-Conditioning Engineer, Inc., Atlanta, Georgia.
2. Bhattacharyya S, Mukhopadhyay S, Kumar A, Khurana RK and Sarkar J. (2005): Optimization of a CO2–C3H8 cascade system for refrigeration and heating. International Journal of Refrigeration; Vol-28: 1284–1292.
3. Cox N. (2007): Working towards more environmentally friendly Refrigerant Blends. 12th European Conference, Milano, Italy, June 8 – 9.
4. Dopazo JA, Fernandez-Seara J, Sieres J and Uhi FJ. (2009): Theoretical Analysis of a CO2-NH3 Cascade Refrigeration System for Cooling Applications at Low Temperatures, Applied thermal engineering; Vol-29: 1577-1583.
5. Gettu HM and Bansal PK. (2008): Thermodynamic Analysis of an R744-R717 Cascade Refrigeration system. International Journal of Refrigeration; 31: 45-54.
6. Kim JH, Cho JM and Kim MS. (2008): Cooling performance of several CO2/propane mixtures and glide matching with secondary heat transfer fluid. International Journal of Refrigeration; Vol-31: 800-806.
7. Lee TS, Liu CH and Chen TW. (2006): Thermodynamic Analysis of Optimal Condensing Temperature of Cascade-Condenser In CO2/NH3 Cascade Refrigeration Systems. International Journal Of Refrigeration; Vol-29 :1100-1108
8. Nasruddin and Syaka DRB (2013): Thermodynamics Analysis of Refrigerant Selection in Cascade Refrigeration System, International Conference of Saving Energy in Refrigeration and Air-Conditioning. Departemen Teknik Mesin Fakultas Teknik-Universitas Indonesia,
9. Niu, Boulian and Zhang, Yufeng. (2007): Experimental Study of the Refrigeration Cycle Performance for R744/R290 Mixtures. International Journal of Refrigeration; Vol-30:pp.37-42.
10. Rahadiyan L. (2007): Study of Propane and Ethane Characteristics in Cascade Refrigeration System, Thesis, Department of Mechanical and Precision Engineering. The Graduate School of Gyeongsang National University, Gyeongsang.