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Thermodynamic Performance Comparison using HFO-1234yf and HFO-1234ze in the High Temperature Cascade Refrigeration Systems and Ecofriendly Refrigerants in Low Temperature Applications

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ABSTRACT

The present paper relates to a cascade refrigeration system which circulates a HFO refrigerant in the high temperature circuit and HFC-134a in the low temperature (173K) circuit for cryogen applications .The thermodynamic analysis using entropy generation for finding exergy destruction ratio indicating that R1234ze (GWP=6) gives better performance than R-1234yf (GWP=4) in the high temperature circuit. The numerical computation has been carried out for 173 K evaporator temperature for ten ecofriendly refrigerants in the low temperature circuit and HFO-1234yf, HFO-1234ze, R152a and R717 in the high temperature circuit. The effect of condenser temperature from temperature (303K to 333K), cascade evaporator range (253K to 293K) and evaporator temperature range 173K to 223K and temperature overlapping (Approach) rages from zero to 10 on thermodynamic performance have been investigated. It was observed that R1234ze in high temperature circuit and R 134a in lower temperature circuit is a best alternative than R1234yf in high temperature circuit and R 134a in lower temperature circuit.

Keywords: *HFO-1234ze/HFO-1234yf; Cascade Refrigeration System; Ecofriendly Refrigerants; Alternative Refrigerants.*

1.0 Introduction

Low global warming potential refrigerants R1234ze and R1234yf are anticipated to be the refrigerants of choice for high-temperature refrigeration systems and heat pump in the industrial applications. HFO-1234ze is a global warming potential (GWP) rating one 225th and HFO-1234yf is the first in a global warming potential (GWP) rating one 335th that of R-134a [1] Cascade refrigeration systems for Low-Temperature are typically uses a refrigerant such as 1,1,1,2-tetrafluoroethane (R134a) or blends thereof with HFC-125 and HFC-143a (i.e., R404A) and carbon dioxide (C02) in the low temperature loop in the low temperature loop to provide cooling at 173K for crygen applications. HFC-134a and HFO-1234yf & HFO1234ze being the most widely used now a day , have zero ozone depletion potential and thus are not affected by the current regulatory phase out as a result of the Montreal Protocol.

This paper mainly deals with HFO refrigerants used in HTC and HFC-134a include pure hydrocarbons such as butane or propane, in the low temperature refrigerants for maintaining 173"K" for crygen applications. These replacements are found, new uses of such alternative refrigerants are being sought in order to take advantage of their low or zero ozone depletion potential and lower global warming potential.

2.0 Literature Review

The cascade refrigeration system has at least two refrigeration loops, each circulating a ecofriendly refrigerant there comprising: a first expansion device for reducing the pressure and temperature of a HFO refrigerant and evaporator having an inlet and an outlet, wherein the first refrigerant liquid from the first expansion device enters the evaporator through the evaporator inlet and is evaporated in the evaporator to form a HFO refrigerant vapor, thereby producing cooling, and circulates to the outlet;

The first compressor having an inlet and an outlet, wherein the first refrigerant vapor from the evaporator circulates to the inlet of the first

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compressor and is compressed, thereby increasing the pressure and the temperature of the first refrigerant vapour, and the compressed first refrigerant vapour circulates to the outlet of the first compressor. The cascade heat exchanger system having:(i) a first inlet and a first outlet, wherein the first refrigerant vapour circulates from the first inlet to the first outlet and is condensed in the heat exchanger system to form a first refrigerant liquid, thereby rejecting heat, and (ii) a second inlet and a second outlet, wherein a second refrigerant liquid circulates from the second inlet to the second outlet and absorbs the heat rejected by the first refrigerant and forms a second refrigerant vapour; and second compressor having an inlet and an outlet, wherein the second refrigerant vapour from the cascade heat exchanger system is drawn into the compressor and is compressed, thereby increasing the pressure and temperature of the second refrigerant vapour; The condenser having an inlet and an outlet for circulating the second refrigerant vapour there through and for condensing the second refrigerant vapour from the compressor to form a second refrigerant liquid, wherein the second refrigerant liquid exits the condenser through the condenser outlet; and (g) a second expansion device which reduces the pressure and temperature of the second refrigerant liquid exiting the condenser and entering the second inlet of the cascade heat exchanger system. The cascade heat exchanger system may include a first and a second cascade heat exchanger, and a secondary heat transfer loop which extends between the first and the second cascade heat exchanger. In this system, the second refrigerant liquid indirectly absorbs the heat rejected by the first refrigerant vapour through a heat transfer fluid which circulates between the first cascade heat exchanger and the second cascade heat exchanger through the secondary heat transfer loop. The first cascade heat exchanger has a first inlet and a first outlet, and a second inlet and a second outlet, wherein the first refrigerant vapour circulates from the first inlet to the first outlet and rejects heat and is condensed, and a secondary heat transfer fluid circulates from the second inlet to the second outlet and absorbs the heat rejected from the first refrigerant vapour and circulates to the second cascade heat exchanger. The second cascade heat exchanger has a first inlet and a first outlet, and a second inlet and a second outlet, wherein the heat transfer fluid circulates from the second outlet of the first cascade heat exchanger to the first inlet of the second cascade heat exchanger and to the first outlet of the second cascade heat exchanger and rejects the heat absorbed from the first refrigerant. The second refrigerant liquid circulates from the second inlet to the second outlet of the second cascade heat exchanger and absorbs the heat rejected by the heat transfer fluid and forms a second refrigerant vapour. In accordance there is provided a method of exchanging heat between at least two refrigeration loops, comprising:

(a) absorbing heat from a body to be cooled in a first refrigeration loop and rejecting this heat to a second refrigeration loop; and (b) absorbing the heat from the first refrigeration loop in the second refrigeration loop and rejecting heat to ambient, as discussed in literature[2-3]

3.0 System Description

The object of the present study is to provide cascade refrigeration systems which use HFO-1234yf and HFO-1234ze refrigerant in the high temperature circuit which have unique characteristics to meet the demands of low or zero ozone depletion potential and lower global warming potential as compared to R11, R12 and R22 refrigerants.

In addition to lower global warming potential advantages, using R-1234yf and R1234ze in the high temperature circuit and R134a in the low temperature cascade refrigeration circuit the present investigation may have several advantages than currently used cascade refrigeration systems.

4.0 Results and Discussions

Table-1a and Table-2a showing the effect of ecofriendly refrigerants on first law efficiency (i.e. Overall system COP) and exergetic efficiency of cascade refrigeration system using R1234yf (of GWP 6) in the high temperature circuit and it was found that both thermal efficiencyies (i.e. overall first law efficiency and also second law efficiency) have highest values in case , when R123 is used in the low temperature circuit and R407c is used in the low temperature circuit. Similarly system exergy destruction ratio (EDR) is lowest when R600 hydrocarbon is used in the low temperature circuit. The low temperature circuit first law performance is lowest when R407c is used in the low temperature circuit. However high temperature circuit frist law performance does not affect. The temperature variation of high temperature circuit condenser with thermodynamic performances of cascade refrigeration system is also shown in Table-1(b) and Table-2(b) respectively and it is found that by increasing condenser's temperature in the high temperature circuit, the first law thermodynamic efficiency (overall system COP) second law efficiency (exergetic efficiency) is decreases Similarly system exergy destruction ratio is increases.

The temperature overlapping (Difference of temperature between cascade condenser and cascade evaporator) is known as approach is greatly influencing the thermodynamic performances of cascade refrigeration system using R1234ze/R1234yf in the high temperature circuit and R134a in the low temperature circuit as shown in Table-1(c) and Table-2(c) respectively. The best performance of the cascade refrigeration system is achieved without temperature overlapping.

As increasing approach, the first and second law efficiency have ben decreasing and system exergy destruction ratio is increasing.

The temperature variation of low temperature circuit evaporator with thermodynamic performances of cascade refrigeration system is also shown in Table-1(d) and Table-2(d) respectively and it is found that by increasing evaporator's temperature in the low temperature circuit, the first law thermodynamic efficiency (overall system COP) second law efficiency (exergetic efficiency) is increases Similarly system exergy destruction ratio is decreases. Effect of variation in temperature of cascade evaporator on thermal performance of cascade Refrigeration system using R-1234yf/R1234ze in HighTemperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit is shown in Table-1(e) & Table-2(e) respectively and it was observed that by increasing cascade evaporator temperature, the first law efficiency (overall system COP) increases and reached to a optimum (maximum) value at 268K temperature and then decreases significantly and it strongly affecting circuit first law efficiency as high temperature circuit first law efficiency (COP_{HTC}) increases while low temperature circuit first law efficiency (COP_{LTC}) decreases.

The performance of cascade refrigeration system using various ecofriendly refrigerants in the high temperature circuit and R134a in the also shown in Table-3 respectively and it was observed that First law efficiency in terms of overall system COP and second law efficiency (i.e. exergetic efficiency) is highest with lowest exergy destruction ratio using R717 which is toxic in nature and performance of R-152a is nearly approaching the same value which is also flammable in nature.

Therefore the next alternative is R1234ze a (of GWP=4) and R1234yf (of GWP=6) for high temperature circuit gives better options after 2030 in terms of environmental aspects and it was found that R1234ze gives better thermodynamic performance than using R1234yf in the high temperature circuit.

Table 1.a (i): Effect of ecofriendly refrigerants on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants in Lower Temp. Circuit	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
R-134a	0.3894	2.554	0.2814
R-290	0.3928	2.523	0.2838
R-600a	0.3917	2.533	0.2830
R-600	0.4004	2.456	0.2893
R-404a	0.3695	2.746	0.2670
R-125	0.3628	2.814	0.2622
R-123	0.4004	2.546	0.2894
R-407c	0.3365	3.113	0.2431
R-410a	0.3873	2.579	0.2799

Table 1.a: (ii). Effect of ecofriendly refrigerants on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T_{eva2}=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants in Lower Temp. Circuit	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
R-134a	1.258	1.020
R-290	1.258	1.025
R-600a	1.258	1.021
R-600	1.258	1.054
R-404a	1.258	0.9390
R-125	1.258	0.9152
R-123	1.258	1.054
R-407c	1.258	0.8244
R-410a	1.258	1.004

Table: 1.b. (i). Effect of High temperature condenser on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T_{eva2}=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Variation of condenser temperature of cascade system in High Temp. Circuit (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
333	0.3893	2.555	0.2813
328	0.4281	2.233	0.3093
323	0.4654	1.974	0.3363
318	0.5017	1.758	0.3625
313	0.5373	1.576	0.3382

Table 1.b(ii): Effect of High temperature condenser on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T_{eva2}=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping= 10

Variation of condenser temperature of cascade system in High Temp. Circuit (K)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
333	1.258	1.012
328	1.476	1.012
323	1.714	1.012
318	1.979	1.012
313	2.279	1.012

Table: 1c(i). Effect of Temperature overlapping on thermal performance in cascade temperature-evaporator on Thermal Performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T_{eva2}=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of Approach (Effect of temperature overlapping)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
0	0.4389	2.154	0.3171
2	0.4286	2.229	0.3096
4	0.4184 `	2.307	0.3023
6	0.4085	2.388	0.2952
8	0.3988	2.470	0.2882
10	0.4201	2.294	0.3036

Table: 1c(ii). Effect of Temperature overlapping on thermal performance in cascade temperature-evaporator on Thermal Performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of Approach (Effect of temperature overlapping)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
0	1.258	1.210
2	1.258	1.167
4	1.258	1.125
6	1.258	1.086
8	1.258	1.048
10	1.258	1.012

Table: 1.d(i). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping= 10

Effect of low temperature evaporator (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
173	0.3893	2.555	0.2813
178	0.4219	2.516	0.2844
183	0.4562	2.488	0.2867
188	0.492	2.474	0.2879
193	0.5292	2.472	0.2880
198	0.5686	2.482	0.2872
203	0.6095	2.506	0.2852
208	0.6522	2.544	0.2822
213	0.6967	2.597	0.2780
218	0.7431	2.667	0.2727
223	0.7915	2.756	0.2662

Table: 1. d(ii). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234yf in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of low temperature evaporator (K)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
173	1.258	1.012
178	1.258	1.14
183	1.258	1.285
188	1.258	1.45
193	1.258	1.641
198	1.258	1.862
203	1.258	2.122
208	1.258	2.431
213	1.258	2.803
218	1.258	3.259
223	1.258	3.832

Table: 1.e(i). Effect of variation in temperature of cascadeevaporator on thermal performance of cascadeRefrigeration system using R-1234yf in HighTemperatureCircuit and R134a ecofriendly refrigerant in the LowTemperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, $T_{cascade-evaporator}$=253K, $Compressor_{Efficiency-2}$=0.80, Approach=temperature overlapping=10

Effect of cascade evaporator temperature (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
253	0.3894	2.554	0.2814
258	0.3967	2.489	0.2866
263	0.4009	2.452	0.2897
268	0.4020	2.443	0.2905
273	0.3998	2.462	0.2889
278	0.3943	2.510	0.2849
283	0.3855	2.590	0.2785
288	0.3734	2.706	0.2698
293	0.3582	2.864	0.2588

Table 1: e(ii). Effect of variation in temperature of cascade evaporator on thermal performance of cascade Refrigeration system using R-1234yf in HighTemperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, $T_{cascade-evaporator}$=253K, $Compressor_{Efficiency-2}$=0.80, Approach=temperature overlapping=10

Effect of cascade evaporator temperature (K)	Effect of cascade evaporator temperature (K)	Overall System First law Performance $COP_{Overall}$
253	253	0.3894
258	258	0.3967
263	263	0.4009
268	268	0.4020
273	273	0.3998
278	278	0.3943
283	283	0.3855
288	288	0.3734
293	293	0.3582

Table 2:a(ii). Effect of ecofriendly refrigerants on thermal performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants in Lower Temp. Circuit	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
R-134a	1.428	1.012
R-290	1.428	1.025
R-600a	1.428	1.021
R-600	1.428	1.054
R-404a	1.428	0.939
R-125	1.428	0.9152
R-123	1.428	1.054
R-407c	1.428	0.8244
R-410a	1.428	1.004
R5.07a	1.428	0.959

Table: 2.a(i). Effect of ecofriendly refrigerants on thermal performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants in Lower Temp. Circuit	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
R-134a	0.4221	2.294	0.3036
R-290	0.4239	2.265	0.3063
R-600a	0.4227	2.274	0.3054
R-600	0.4323	2.202	0.3123
R-404a	0.3982	2.476	0.2877
R-125	0.3908	2.541	0.2814
R-123	0.4323	2.201	0.3124
R-407c	0.3619	2.824	0.2615
R-410a	0.4178	2.312	0.3019
R5.07a	0.4043	2.424	0.2921

Table: 2.b(i). Effect of High temperature condenser on thermal performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Variation of condenser temperature of cascade system in High Temp. Circuit (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
333	0.4201	2.294	0.3036
328	0.4534	2.052	0.3276
323	0.4863	1.846	0.3514
318	0.5189	1.687	0.3749
313	0.5514	1.510	0.3984
308	0.5841	1.369	0.4221
303	0.6172	1.242	0.4460

Table: 2.b(ii). Effect of High temperature condenser on thermal performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Variation of condenser temperature of cascade system in High Temp. Circuit (K)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
333	1.428	1.012
328	1.633	1.012
323	1.86	1.012
318	2.116	1.012
313	2.407	1.012
308	2.745	1.012
303	3.143	1.012

Table: 2c(i). Effect of Temperature overlapping on thermal performance in cascade temperature-evaporator on Thermal Performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of Approach (Effect of temperature overlapping)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
0	0.475	1.914	0.3432
2	0.4636	1.985	0.3350
4	0.4524	2.059	0.3269
6	0.4414	2.135	0.3190
8	0.4307	2.214	0.3112
10	0.4201	2.294	0.3036

Table: 2c(ii). Effect of Temperature overlapping on thermal performance in cascade temperature-evaporator on Thermal Performance of cascade Refrigeration system using R-1234ze in High Temperature Circuit and R134a ecofriendly refrigerant in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of Approach (Effect of temperature overlapping)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
0	1.428	1.211
2	1.428	1.167
4	1.428	1.126
6	1.428	1.087
8	1.428	1.049
10	1.428	1.012

Table: 2d(i). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234ze in HighTemperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of low temperature evaporator (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
173	0.4201	2.294	0.3036
178	0.4562	2.252	0.3075
183	0.4941	2.22	0.3105
188	0.5340	2.201	0.3124
193	0.5759	2.192	0.3133
198	0.6198	2.194	0.3130
203	0.6659	2.209	0.3117
208	0.7143	2.235	0.3091
213	0.7650	2.275	0.3053

218	0.8182	2.330	0.3003
223	0.874	2.402	0.2939
228	0.9324	2.493	0.2863
233	0.9936	2.608	0.2772
238	1.058	2.75	0.2667
243	1.125	2.927	0.2546

Table: 2d(ii). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234ze in HighTemperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T$_{eva2}$=173K, T$_{cond}$=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of low temperature evaporator (K)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
173	1.428	1.012
178	1.428	1.14
183	1.428	1.285
188	1.428	1.451
193	1.428	1.641
198	1.428	1.863
203	1.428	2.123
208	1.428	2.431
213	1.428	2.803
218	1.428	3.260
223	1.428	3.832
228	1.428	4.571
233	1.428	5.558
238	1.428	6.943
243	1.428	9.025

Table 2:e(i). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234ze in HighTemperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T$_{eva2}$=173K, T$_{cond}$=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of cascade evaporator temperature (K)	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
253	0.4201	2.294	0.3036
258	0.4235	2.268	0.3060
263	0.4240	2.264	0.3064
268	0.4216	2.283	0.3046
273	0.4161	2.326	0.3007
278	0.4076	2.395	0.2945
283	0.3961	2.494	0.2862
288	0.3817	2.625	0.2758
293	0.3645	2.797	0.2645
298	0.3446	3.016	0.2490
303	0.3221	3.297	0.2327
308	0.2971	3.658	0.2147
313	0.2694	4.13	0.1949
318	0.2403	4.761	0.1736
323	0.2086	5.634	0.1507

Table: 2.e(ii). Effect of low temperature evaporator on thermal performance of cascade Refrigeration system using R-1234ze in HighTemperature Circuit and following ecofriendly refrigerants in the Low Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T$_{eva2}$=173K, T$_{cond}$=333K, Tcascade-evaporator=253K, CompressorEfficiency-2=0.80, Approach=temperature overlapping=10

Effect of cascade evaporator temperature (K)	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
253	1.428	1.012
258	1.621	0.9273
263	1.843	0.8496
268	2.102	0.7781
273	2.407	0.7120
278	2.77	0.6504
283	3.209	0.5928
288	3.747	0.5385
293	4.424	0.4871
298	5.298	0.4381
303	6.467	0.3914
308	8.109	0.3461
313	10.58	0.303
318	14.71	0.2609
323	22.97	0.2197

Table: 3. Effect of ecofriendly refrigerants in High temperature circuit on thermal performance of cascade refrigeration system using R-134a in LowTemperature Circuit and following ecofriendly refrigerants in the High Temperature Circuit (Compressor$_{Efficiency-1}$=0.80,T$_{eva2}$=173K, T$_{cond}$=333K, T$_{cascade-evaporator}$=253K, Compressor$_{Efficiency-2}$=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants	Overall System First law Performance $COP_{Overall}$	Overall Exergy Destruction Ratio of system EDR_{System}	Cascade System Exergetic Efficiency
R-717	0.4764	1.905	0.3442
R-1234yf	0.3898	2.554	0.2814
R-152a	0.4615	1.999	0.3334
R-1234ze	0.4201	2.294	0.3036

Table: 3. Effect of ecofriendly refrigerants in High temperature circuit on thermal performance of cascade refrigeration system using R-134a in LowTemperature Circuit and following ecofriendly refrigerants in the High Temperature Circuit ($Compressor_{Efficiency-1}$=0.80,$T_{eva2}$=173K, T_{cond}=333K, $T_{cascade-evaporator}$=253K, $Compressor_{Efficiency-2}$=0.80, Approach=temperature overlapping=10

Ecofriendly Refrigerants	High Temperature Circuit First law Performance COP_{HTC}	Low Temperature Circuit First law Performance COP_{LTC}
R-717	1.789	1.012
R-1234yf	1.258	1.012
R-152a	1.686	1.012
R-1234ze	1.428	1.012

5.0 Conclusions

The following conclusions have been drawn from present investigations;

(i) The use of HFO in the high temperature circuit is promising feature in the cascade refrigeration systems

(ii) The ecofriendly HFO-1234ze gives better first and second law performance than HFO-1234yf in high temperature circuit applications

(iii) The use of HFC-134a gives better performance in the low temperature circuit of cascade refrigeration systems

(iv) R-1234ze in high temperature circuit and R 134a in lower temperature circuit is a best alternative than R1234yf in high temperature circuit and R 134a in lower temperature circuit.

(v) The use of pure hydrocarbons (R-290(propane) , R600 (Butane) and R600a (isobutene) and R152a is limited use due to flammable nature.

References

[1] Honeywell Novel Low-Global-Warming, Honeywell press, 2008

[2] M. Kanoglu, Exergy analysis of the multistage cascade refrigeration cycle used for natural gas liquefaction, Int J Energy Res, 2002

[3] C. Nikolaidis, D. Probert, Exergy method analysis of a two stage vapour compression refrigeration-plants performance, Applied energy, 60, 1998, 241-256