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ORIGINAL ARTICLE

Evaluation of thermodynamic performances using ecofriendly low GWP blends of HFC+HFO refrigerants in higher temperature cycle using another ecofriendly blends of HFC+HFO refrigerants in low temperature cycle of VCRS

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Abstract

The use of artificial refrigerants (CFC's, HCFC's and HFC's) caused environmental problems related to global warming and depletion of the ozone layer is knowledge over the last decades and the the use of natural substances for refrigeration purposes is also well defined since 19nineth century. It must be a better solution to use HFO refrigerants and their blends which are environmentally harmless substances as alternatives refrigerants in refrigeration systems.
Cascade refrigeration system is the combination of two refrigeration cycle for maximum refrigeration effect can be obtained. Cascade refrigeration system are achieving temperature up to -40 to -90°C for the applications like cold storage in malls and stores and in blood banks. These fluids are harmless to environment with low GWP and negligible ODP, which do not violate the Kyoto protocol. The thermodynamic energy-exergy analysis of cascaded vapor compression refrigeration systems has been carried out to predict cascade COP, work done by both compressors, and HTC condenser and LTC condenser heat rejected heat rejected. In the cascaded systems, the cooling produced in HTC cycle evaporator is used to cool the condenser of LTC cycle, which reduces the cooling capacity in condenser and enables to produce very low temperature for various cold storage applications. The effect of performance parameters on the thermodynamic performances of cascaded vapor compression refrigeration system using HFC+HFO blends in both cycles at ultra-low evaporator temperature (below -80ºC) have been presented in this papers.

1. Introduction

Many industrial applications require low temperature refrigeration such as quick freezing biomedical preservations, manufacturing of dry ice, liquefaction of petroleum vapors, pharmaceutical reactions etc. where evaporating temperature requires between -40ºC to- 80ºC. Single stage vapor compression system is not feasible for such application and its performance decreases below -40 ºC when condenser temperature around 40ºC. Therefore, multistage or compound vapor compression refrigeration systems (VCRS) can be useful up to temperature -65ºC but no refrigerants available to work efficiently for high temperature raise. Also, it will be difficult to balance the oil level in compressor because of large difference in suction pressures of low stage and higher stage compressors. Cascade refrigeration system has two different stages which permits appropriate selection refrigerants to maximize system performance. HFC refrigerants significantly used in till now due to their excellent thermodynamic properties but owing to higher ODP (Ozone Depletion Potential), GWP (Global worming Potential) they are contributor to ozone depletion and global warming. Cascade refrigeration system is the combination of two single stage vapor compression system together, condenser of LTC and

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evaporator of HTC is cascaded and forms the heat exchanger where evaporator cascade absorbs the heat from the condenser cascade which further leads to better refrigeration effect. [1-2].

2. Cascade Refrigeration System

The first low temperature refrigeration system was primarily developed for solidification of carbon dioxide and liquefaction & distillation of gases such as air, oxygen, nitrogen, hydrogen and helium Ultra low temperature refrigeration in industrial work has increased tremendously in the last few years Cascade system is just similar to the binary vapor cycle used for the power plants. In a binary vapor cycle, a condenser for mercury works as boiler for water. Similarly, in cascade system condenser of low temperature cycle works as evaporator for the high temperature cycle. In cascade system, a series of refrigerants with gradually lower freezing points are used in a series of single stage unit. The cascade condensing unit used two refrigerating systems or cycles and referred to as cycles (i.e. HTC and LTC cycles. The condenser of cycle HTC, called the “high stage”, is usually fan cooled or in some cases a water supply may be used to cool but air cooling is common. The Evaporator of cycle HTC is used to cool the condenser of cycle LTC called the “low stage”. The unit that consist of condenser of cycle HTC and evaporator of cycle HTC. is often referred to as the “Inter-stage condenser” or “cascade condenser”. Thus a cascade condenser serves as an evaporator “for high temperature cascade system (HTC cycle)”. The difference in low temperature cascade condenser temperature and high temperature cascade evaporator temperature is called temperature overlap and is necessary for heat transfer. Cascade system use two different refrigerants in each stage. The reason that two refrigeration systems are used because single stage system cannot economically achieve the high compression ratio necessary to obtain evaporating and condensing temperatures. The high temperature cascade system uses a refrigerant with low boiling temperature such as R404a. These low boiling temperature refrigerants have extremely high pressure which ensures a smaller compressor displacement in the low temperature cascade system and a higher COP. Another set of refrigerants commonly used for liquefaction of gases in a three stage cascade system is ammonia, ethylene and methane. The additional advantage of a cascade system over multi stage compression is that the lubricating oil from one compressor cannot wander to the other compressors. Cascade staging incorporates several individual refrigeration systems that use different refrigerants and have closed heat exchangers to achieve low operating temperatures and reasonable condensing pressure. For some industrial applications which require moderately low temp, single stage vapor compression refrigeration cycle and vapor absorption refrigeration cycle become impractical therefore cascade system are employed to obtain high temperature differentials between the heat source & heat sink. These systems are applied for temperature ranging from -70ºC to -100º C. In the system both Low Temperature Cycle (LTC) and High Temperature Cycle (HTC) work with different refrigerants and thermally connected to each other through a heat exchanger which acts as an HTC evaporator for the and LTC condenser. HTC operates with refrigerant having high boiling point and high critical temperature and LTC operates with refrigerant having low boiling point. Exergy analysis is a useful way for determining the real thermodynamic losses and optimising environmental and economic performance in the systems such as vapor compression refrigeration Systems. Alptunganbaba et.al.[3] carried out exergy analysis of a two evaporator vapor compression refrigeration system using R1234yf, R1234ze and R134a as refrigerants and computed the effect of evaporator and condenser temperatures on the exergy destruction and exergy efficiency of the system.

Nikolaidis et.al [4] carried out analytically the effect of change in evaporator and condenser temperatures using R22 in the two stage vapor compression refrigeration plant and found considerable effect on plant irreversibility and suggested that there is need for optimizing the conditions imposed upon the condenser and evaporator.

J. Alberto Dopazo [5] carried out the experimental evaluation on prototype of cascade refrigeration system using R717 (i.e.NH_3) in the high temperature circuit and R744 (i.e.CO_2) and compared the experimental results with single stage refrigeration system using NH3 as refrigerant.

Bansal P.K [6] carried out thermodynamic analysis of carbon dioxide–ammonia (R744–R717) cascade refrigeration system.

Lee et al. [7] analyzed a carbon dioxide–ammonia (R744–R717) cascade system thermodynamically to determine the optimum condensing temperature of R744 in the low-temperature circuit

Bhattacharyya et al. [8] studied a carbon dioxide–propane (R744–R290) optimum cascade evaporating system to define an evaporating temperature of R744 for application in heating circuits.

Brain Agnew and S.M. Ameli [9] examined with a view to determine the best combination of modern environmental friendly refrigerants to produce the minimum power consumption for a given refrigeration rate and computed the thermodynamic performance of a three stage cascade refrigeration systems using two different environmental friendly refrigerants and found the significant effect of overlap temperature on the thermodynamic performances

Bolaji et al. [10] had done experimentally comparative analysis of R32, R152a and R134a refrigerants in vapor compression refrigerator and concluded that R32 shows lowest performance whereas R134a and R152a showing nearly same performance but best performance was obtained of system using R152a

Mishra [11] described thermodynamic analysis of cascade refrigeration system with huge refrigerant sinking CFC, HCFC, HFC, HFC an HFO refrigerants etc and optimizations conducted for such refrigerants. Huge number of refrigerants has been examined in cascade system for determining the appropriate combination of refrigerants in high temperature and low temperature cycle both circuits of refrigerants however the trends shows that the HFO refrigerants a natural refrigerants are gaining more importance due to environmental conditions few natural refrigerants.

R.S. Mishra [12-14] deals with thermodynamic analysis of three stages cascade vapor compression refrigeration systems using eco-friendly refrigerants used for low temperature applications. The effect of thermal performance parameters on the first law thermal performances COP system and also in terms of second law efficiency of the cascade system and System exergy destruction ratio have been optimized thermodynamically using entropy generation principle. 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 - 50°C to -100°C) 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

Leonardo A.M., et.al.[15] studied on combined refrigeration system consisting of two vapor compression refrigeration cycles coupled by a heat exchanger, which 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

Yilmaz & Selbas [16] had carried out a comparative thermodynamic performance analysis of cascade system for cooling and heating applications is presented and compared for different refrigerant couples. The cascade VCRS consists of the low temperature cycle (LTC) and high-temperature cycle (HTC). The CO2 was used as working fluid in LTC, whereas the HFE 7000, R134a, R152a, R32, R1234yf, and R365mfc refrigerants were used in HTC. The heating and cooling coefficients of performance ($COP_{\_heating}$, and $COP_{\_cooling}$) and exergy efficiency of cascaded refrigeration system are investigated parametrically according to various factors such as the evaporator, condenser, and reference temperatures.

Adrián Mota-Babiloni [17] studied the feasibility of R454C and R455A, refrigerants, in vapor compression refrigeration systems as alternatives to R404A and found that the R454C and R455A will be the most viable low GWP options to perform a direct replacement of R404A The environmental parameters of HFC+HFO Blends are given in Table-1.

Table-1: Environmental parameters of HFC+HFO Blends

New Refrigerants	% (HFC+HFO Blends)	GWP Non flammable	ODP	Safety Code
R513A	56%R1234yf, 44% 134a	631 (573)	Non ozone depleting	A1
R515A	88%R1234ze, 12% 227ea	387 (573)	Non ozone depleting	A1
R448A	26% R32, 26%R125, 20% R1234yf, 7%R1234ze(E)	1273 to 1387	Non ozone depleting	A1
R449A	23.3% R32, 24.5%R125, 24.3% R1234yf, 25.5%R134a	1282 to 1387	Non ozone depleting	A1
R407H	32.5% R32, 15%R125, 52.5%R134a	1378 to 1495	Non ozone depleting	A1
R450A	58% R1234ze(E), 42% 134a	547 to 604	Non ozone depleting	A1
R454A	35% R32, 65% R1234yf	238 -239	Non ozone depleting	A2L
R454B	21.5% R32, 78.5% R1234yf	1377 to 1494	Non ozone depleting	A2L
R454C	21.5% R32, 78.5% R1234yf	139 to 148	Non ozone depleting	A2L
R452A	11%R32, 59%R125, 30%R1234yf	676 to 698	Non ozone depleting	A1
R452B	12.5%R32, 61%R125, 26.5%R1234yf	676 to 698	Non ozone depleting	A1

This paper mainly deals with the static and dynamic thermodynamic energy& exergy performances of nine optimal cascade vapor compression using HFO+HFC blends in the high temperature cycle and another HFO+HFC blends in the high temperature cycle.

3. Results and Discussion

In this paper, two types of thermodynamic energy and exergy performances for different optimal combination of cascaded vapor compression refrigeration systems have been computed. The numerical computation was carried out for optimal conditions explained in details. However dynamic thermodynamic performances have been computed with varying HTC evaporator temperature from -0°C to -30°C), the HTC condenser temperature variation from 40°C to 60°C, LTC evaporator temperature from -50°C to -70°C and temperature overlapiping from 0 °C to 15 °C.

3.1 Static thermodynamic performances

For finding static thermodynamic (energy and exergetic) performances of cascaded vapor compression refrigeration systems the following eight optimal cascaded vapor compression refrigeration systems have been considered for numerical computations.

System-1: Cascaded vapor compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50°C, T_ambient=25°C, $T_{\_Eva\_HTC}$=-30°C, $T_{\_Eva\_LTC}$=-90°C, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System- 2: Cascaded thermodynamic performances of vapor compression refrigeration system using ecofriendly low GWP

R450A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System- 3: Cascaded thermodynamic performances of vapor compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System-4: Cascaded thermodynamics performances of vapor compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System-5: Cascaded hermodynamic performances of vapor compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R452b low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System-6: Cascaded thermodynamics performances of vapor compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R515A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

Table-2 shows the comparison of static thermodynamic performances of cascaded vapor compression refrigeration systems using eight different combinations of HFC +HFO Blends in high temperature cycle at -30ºC in HTC evaporator and two different HFC +HFO Blends (R513a and R R452a) in low temperature cycle and it was found that optimal cascaded vapor compression refrigeration system-2 using R454B in high temperature cycle and R513A in low temperature cycle gives highest first law efficiency and exergetic efficiency with lower power consumption in the both compressors along with lowest system exergy destruction ratio. Similar trends was observed in the thermodynamic system first law (energy) performance ($COP_{\_cascade}$) and exergetic performance at HTC evaporator temperature of -30ºC and LTC evaporator temperature of -90ºC as shown in table-2 respectively.

Table-2 Thermodynamic performances of optimum combinations of cascaded vapor compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC , $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

Cascaded VCRS	System: 1	System: 2	System: 3	System: 4	System: 5	System: 6
HFC +HFO Blends in HTC	*R450A*	*R450A*	*R450A*	*R450A*	*R450A*	*R450A*
HFC +HFO Blends in LTC	R513a	R454B	*R454C*	*R449A*	*R452B*	*R515A*
First Law Cascaded Efficiency $COP_{\_Cascade}$	0.5524	0.4520	0.5053	0.5051	0.5441	0.5492
Exergy Destruction Ratio($EDR_{\_Cascade}$)	1.883	1.994	2.152	2.153	1.927	1.90
Cascaded Exergetic Efficiency	0.3468	0.334	0.3173	0.3172	0.3416	0.3448
Exergy of Fuel "kW"	63.66	66.10	69.60	69.62	64.63	64.3
Exergy of Product "kW"	22.8	22.8	22.83	22.8	22.8	22.08
HTC Mass flow Rate (Kg/sec)	0.6067	0.6217	0.6431	0.6432	0.6126	0.6089
LTC Mass flow Rate (Kg/sec)	0.2440	0.1413	0.2183	0.2021	0.1434	0.2541
$W_{\_comp\ \_HTC}$"kW"	40.88	41.89	43.24	43.35	41.28	41.03
$W_{\_comp\_LTC}$ "kW"	22.78	24.21	26.26	26.27	23.35	23.0
$Q_{\_Cond\_HTC}$ "kW"	98.83	101.30	104.80	104.80	99.80	99.2
$Q_{\_Cond\_LTC}$ "kW"	57.95	59.38	61.43	61.44	58.52	58.16
$Q_{\_Eva\_HTC}$ "kW"	57.95	59.38	61.43	61.44	58.52	58.16
$Q_{\_Eva\_LTC}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.452	1.339	1.338	1.506	1.529
First Law HTC Efficiency $COP_{\_HTC}$	1.417	1.417	1.417	1.417	1.417	1.417
HTC Exergy Destruction Ratio($EDR_{\_HTC}$)	2.119	2.113	2.119	2.119	2.119	2.119
HTC Exergetic Efficiency	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206
HTC Exergy of Fuel "kW"	40.88	41.89	43.24	43.35	41.28	41.03
HTC Exergy of Product "kW"	13.11	13.43	13.90	13.90	13.24	13.16

3.2 Dynamic thermodynamic(energy) and exergetic performances cascaded VCRS using ecofriendly low GWP R513a refrigerant in HTC in higher temperature cycle using ecofriendly low GWP R450A refrigerant in low temperature cycle(system-2)

Thermodynamic performances of cascaded vapor compression refrigeration system using ecofriendly low GWP R513A refrigerant in HTC in higher temperature cycle and ecofriendly low GWP R452A refrigerant in low temperature cycle and R513a refrigerant in low temperature cycle for varying evaporator temperature from 0ºC to -30ºC and it was found that when evaporator temperature is increasing the system first law (energy) performance ($COP\_{cascade}$) and exergetic performance is increasing as shown in Table-3(a) respectively.

Similarly, by increasing LTC evaporator temperature from -50ºC to -70ºC, the first law (energy) performance ($COP\_{cascade}$) is increasing and exergetic performance is is decreasing as shown in Table-3(b) respectively.

By increasing HTC condenser temperature from 40ºC to 60ºC, the first law (energy) performance ($COP\_{cascade}$) and exergetic performance is decreasing as shown in Table-3(c) respectively.

Similarly by increasing temperature overlapping , the first law (energy) performance ($COP\_{cascade}$) and exergetic performance is decreasing as shown in Table-3(d) to table-3(g) respectively

Table-3(a) Thermodynamic performances of optimum combinations of cascaded VCRS using ecofriendly low GWP R450A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5524	0.5964	0.6427	0.6914	0.7425
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.883	1.868	1.862	1.866	1.88
Cascaded Exergetic Efficiency	0.3468	0.3487	0.3494	0.3489	0.3472
Exergy of Fuel “kW”	63.66	58.96	54.71	50.86	47.36
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6066	0.5778	0.5517	0.5281	0.5066
LTC Mass flow Rate (Kg/sec)	0.244	0.2389	0.2339	0.2291	0.2245
W_{comp_HTC}“kW”	40.88	38.94	37.18	35.59	34.14
W_{comp_LTC} “kW”	22.78	20.02	17.53	15.28	13.22
Q_{Cond_HTC} “kW”	98.83	89.88	89.88	86.03	82.53
Q_{Cond_LTC} “kW”	57.95	55.19	52.70	50.44	48.30
Q_{Eva_HTC} “kW”	57.95	55.19	52.70	50.44	48.30
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_{HTC}	1.417	1.417	1.417	1.417	1.417
HTC Exergy Destruction Ratio(EDR_{HTC})	2.119	2.119	2.119	2.119	2.119
HTC Exergetic Efficiency	0.3206	0.3206	0.3206	0.3206	0.3206
HTC Exergy of Fuel “kW”	40.88	38.94	37.18	35.59	34.14

Table-3(b) Thermodynamic performances of optimum combinations of cascaded VCRS using ecofriendly low GWP R454B refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_ambient=25ºC, T_{Eva_HTC}=-30ºC , T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5652	0.6106	0.6585	0.7089	0.7619
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.818	1.801	1.794	1.795	1.807
Cascaded Exergetic Efficiency	0.3549	0.3570	0.3580	0.3577	0.3563
Exergy of Fuel “kW”	62.23	57.59	53.4	49.61	46.16
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.3557	0.3388	0.3235	0.3096	0.2970
LTC Mass flow Rate (Kg/sec)	0.244	0.2389	0.2339	0.2291	0.2245
W_{comp_HTC}“kW”	39.94	37.57	35.87	34.33	32.94
W_{comp_LTC} “kW”	22.78	20.02	17.53	15.28	13.22
Q_{Cond_HTC} “kW”	97.39	92.76	88.57	84.74	81.33
Q_{Cond_LTC} “kW”	57.95	55.19	52.70	50.44	48.39
Q_{Eva_HTC} “kW”	57.95	55.19	52.70	50.44	48.30
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_{HTC}	1.469	1.469	1.469	1.469	1.469
HTC Exergy Destruction Ratio(EDR_{HTC})	2.009	2.009	2.009	2.009	2.009
HTC Exergetic Efficiency	0.3323	0.3323	0.3323	0.3323	0.3323
HTC Exergy of Fuel “kW”	39.94	37.57	35.87	34.33	32.94

Table-3(c) Thermodynamic performances of optimum combinations of cascaded VCRS using ecofriendly low GWP R454C refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513A *refrigerant in low temperature cycle (Q_Eva_LTC=35.167 kW, T_cond=50ºC, T_ambient=25ºC, T_Eva_HTC=-30ºC, T_Eva_LTC=-70ºC, Compressor efficiency_HTC=80%, Compressor efficiency_LTC=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency COP_ Cascade	0.4981	0.5363	0.5763	0.6180	0.6616
Exergy Destruction Ratio(EDR_Cascade)	2.197	2.189	2.192	2.206	2.232
Cascaded Exergetic Efficiency	0.3128	0.3136	0.3113	0.3119	0.3094
Exergy of Fuel "kW"	70.6	65.57	61.02	56.9	53.16
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6163	0.5841	0.5578	0.5339	0.5122
LTC Mass flow Rate (Kg/sec)	0.244	0.2389	0.2339	0.2291	0.2245
W_comp _HTC"kW"	47.82	45.55	43.49	41.63	39.93
W_comp_LTC "kW"	22.78	20.02	17.53	15.28	13.22
Q_Cond_HTC "kW"	105.8	100.7	96.19	92.07	88.32
Q_Cond_LTC "kW"	57.95	55.19	52.70	50.44	48.39
Q_Eva_HTC "kW"	57.95	55.19	52.70	50.44	48.30
Q_Eva_LTC "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_ HTC	1.212	1.212	1.212	1.212	1.212
HTC Exergy Destruction Ratio(EDR_HTC)	2.648	2.648	2.648	2.648	2.648
HTC Exergetic Efficiency	0.2741	0.2741	0.2741	0.2741	0.2741
HTC Exergy of Fuel "kW"	47.82	45.55	43.49	41.63	39.93
HTC Exergy of Product "kW"	13.11	12.48	11.92	11.41	10.95

Table-3(d) Thermodynamic performances of optimum combinations of cascaded VCRS using ecofriendly low GWP R448A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_LTC=35.167 kW, T_cond=50ºC, T_ambient=25ºC, T_Eva_HTC=-30ºC , T_Eva_LTC=-70ºC, Compressor efficiency_HTC=80%, Compressor efficiency_LTC=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency COP_ Cascade	0.5342	0.5763	0.6205	0.6668	0.7153
Exergy Destruction Ratio(EDR_Cascade)	1.981	1.968	1.654	1.972	1.990
Cascaded Exergetic Efficiency	0.3351	0.3369	0.3351	0.3365	0.3345
Exergy of Fuel "kW"	65.83	61.02	56.68	52.74	49.17
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.5174	0.4927	0.4705	0.4303	0.4320
LTC Mass flow Rate (Kg/sec)	0.2440	0.2389	0.2339	0.2291	0.2245
W_comp _HTC"kW"	43.04	41.0	39.14	37.47	35.94
W_comp_LTC "kW"	22.78	20.02	17.53	15.28	13.22
Q_Cond_HTC "kW"	101.0	96.19	91.85	87.91	84.33
Q_Cond_LTC "kW"	57.95	55.19	52.70	50.44	48.39
Q_Eva_HTC "kW"	57.95	55.19	52.70	50.44	48.30
Q_Eva_LTC "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_ HTC	1.346	1.346	1.346	1.346	1.346
HTC Exergy Destruction Ratio(EDR_HTC)	2.284	2.284	2.284	2.284	2.284
HTC Exergetic Efficiency	0.3045	0.3045	0.3045	0.3045	0.3045
HTC Exergy of Fuel "kW"	43.04	41.0	39.14	37.47	35.94
HTC Exergy of Product "kW"	13.11	12.48	11.92	11.41	10.95

3.3 Dynamic thermodynamic(energy) and exergetic performances cascaded VCRS using ecofriendly low GWP R515A refrigerant in HTC in higher temperature cycle using ecofriendly low GWP R454B refrigerant in low temperature cycle

R515A (also known as Honeywell Solstice R515A) is an azeotropic mixture and non-flammable refrigerant consisting of 88 weight% R1234ze and 12% R227ea is used to be a alternative to R134a in the cascade vapor compression refrigeration system. The thermodynamic performances of cascaded vapor compression refrigeration system using ecofriendly low GWP R515A refrigerant in HTC in higher temperature cycle using ecofriendly low GWP R454B refrigerant in low temperature cycle for varying evaporator temperature from 0oC to -30oC and it was found that when evaporator temperature is increasing the system first law (energy) performance (COP_cascade) and exergetic performance is is increasing as shown in Table-4(a). Similarly, by increasing LTC evaporator temperature from -50oC to -70oC, the first law (energy) performance (COP_cascade) is increasing and exergetic performance is is decreasing as shown in Table-4(b) respectively. By increasing HTC condenser temperature from 40ºC to 60ºC, the first law (energy) performance (COP_cascade) and exergetic performance is decreasing as shown in Table-4(c) respectively. Similarly, by increasing temperature overlapping, the first law (energy) performance (COP_cascade) and exergetic performance is decreasing as shown in Table-4(d) respectively.

Table-3(e) Thermodynamic performances of optimum combinations of cascaded vapor compression refrigeration system using ecofriendly low GWP R449A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC , T_{Eva_LTC}=-70ºC, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5219	0.5627	0.6054	0.6501	0.6969
Exergy Destruction Ratio($EDR\_{Cascade}$)	2.052	2.040	2.039	2.024	2.069
Cascaded Exergetic Efficiency	0.3277	0.3290	0.3291	0.3281	0.3259
Exergy of Fuel “kW”	67.38	62.90	58.09	54.01	50.46
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.5478	0.5218	0.4982	0.4769	0.4575
LTC Mass flow Rate (Kg/sec)	0.2440	0.2389	0.2339	0.2291	0.2245
W_{comp_HTC}“kW”	44.6	42.48	40.56	38.82	37.24
W_{comp_LTC} “kW”	22.78	20.02	17.53	15.28	13.22
Q_{Cond_HTC} “kW”	102.5	97.67	93.26	89.26	85.63
Q_{Cond_LTC} “kW”	57.95	55.19	52.70	50.44	48.39
Q_{Eva_HTC} “kW”	57.95	55.19	52.70	50.44	48.30
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_{HTC}	1.299	1.299	1.299	1.299	1.299
HTC Exergy Destruction Ratio(EDR_{HTC})	2.402	2.402	2.402	2.402	2.402
HTC Exergetic Efficiency	0.2939	0.3045	0.3045	0.3045	0.3045
HTC Exergy of Fuel “kW”	44.6	42.48	40.56	38.82	37.24
HTC Exergy of Product “kW”	13.11	12.48	11.92	11.41	10.95

Table-3(f) Thermodynamic performances of optimum combinations of cascaded vapor compression refrigeration system using ecofriendly low GWP R452A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC , T_{Eva_LTC}=-70ºC, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency $COP\_{Cascade}$	0.4751	0.5110	0.5483	0.5873	0.6279
Exergy Destruction Ratio($EDR\_{Cascade}$)	2.362	2.348	2.355	2.374	2.406
Cascaded Exergetic Efficiency	0.2983	0.2987	0.2981	0.2964	0.2936
Exergy of Fuel “kW”	74.02	68.83	64.13	59.88	56.45
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.8286	0.7892	0.7535	0.7213	0.6919
LTC Mass flow Rate (Kg/sec)	0.244	0.2389	0.2339	0.2291	0.2245
W_{comp_HTC}“kW”	51.24	48.80	46.60	44.60	42.79
W_{comp_LTC} “kW”	22.78	20.02	17.53	15.28	13.22
Q_{Cond_HTC} “kW”	109.2	104.0	99.3	95.05	91.18
Q_{Cond_LTC} “kW”	57.95	55.19	52.70	50.44	48.39
Q_{Eva_HTC} “kW”	57.95	55.19	52.70	50.44	48.30
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.756	2.006	2.302	2.66
First Law HTC Efficiency COP_{HTC}	1.131	1.131	1.131	1.131	1.131
HTC Exergy Destruction Ratio(EDR_{HTC})	2.909	2.909	2.909	2.909	2.909
HTC Exergetic Efficiency	0.2558	0.2558	0.2558	0.2558	0.2558
HTC Exergy of Fuel “kW”	51.24	48.80	46.60	44.60	42.79
HTC Exergy of Product “kW”	13.11	12.48	11.92	11.41	10.95

Table-3(g) Thermodynamic performances of optimum combinations of cascaded VCRS using ecofriendly low GWP R452A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R513a *refrigerant in low temperature cycle (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva_HTC}$=-30ºC , T_$_{Eva_LTC}$=-70ºC, Compressor efficiency_$_{HTC}$=80%, Compressor efficiency_$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-100	-95	-90	-85	-80	-75	-70
First Law Cascaded Efficiency COP_ Cascade	0.4663	0.5067	0.5492	0.5938	0.6407	0.6898	0.7414
Exergy Destruction Ratio(EDR_Cascade)	1.971	1.93	1.90	1.88	1.871	1.873	1.884
Cascaded Exergetic Efficiency	0.3366	0.3419	0.3448	0.3472	0.3483	0.3481	0.3467
Exergy of Fuel "kW"	75.42	69.4	64.3	59.22	54.89	50.98	47.44
Exergy of Product "kW"	25.39	23.69	22.08	20.56	19.2	17.75	16.45
HTC Mass flow Rate (Kg/sec)	0.6788	0.6419	0.6089	0.5794	0.5528	0.5288	0.6919
LTC Mass flow Rate (Kg/sec)	0.2679	0.2608	0.2541	0.2477	0.2477	0.2357	0.2301
W_comp _HTC "kW"	45.74	43.26	41.03	39.04	37.25	35.64	34.17
W_comp_LTC "kW"	29.67	26.15	23.0	20.18	17.64	15.34	13.27
Q_Cond_HTC "kW"	110.6	104.6	99.2	94.39	90.06	86.15	82.60
Q_Cond_LTC "kW"	64.84	61.31	58.16	55.34	52.81	50.51	48.43
Q_Eva_HTC "kW"	64.84	61.31	58.16	55.34	52.81	50.51	48.43
Q_Eva_LTC "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.185	1.345	1.529	1.743	1.994	2.292	2.651
First Law HTC Efficiency COP_ HTC	1.417	1.417	1.417	1.417	1.417	1.417	1.417
HTC Exergy Destruction Ratio(EDR_HTC)	2.119	2.119	2.119	2.119	2.119	2.119	2.119
HTC Exergetic Efficiency	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206
HTC Exergy of Fuel "kW"	45.74	43.26	41.03	39.04	37.25	35.64	34.17
HTC Exergy of Product "kW"	14.67	13.87	13.16	12.52	11.94	11.43	10.96

Table-4(a) Effect of HTC evaporator temperature on the thermodynamic performances of cascaded vapor compression refrigeration system using ecofriendly low GWP R515A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R454B *refrigerant in low temperature cycle (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva_HTC}$=-30ºC , Approach (temperature overlapping)=10ºC, Compressor efficiency_$_{HTC}$=80%, Compressor efficiency_$_{LTC}$=80%,*

LTC Evaporator temperature (ºC)	-30	-25	-20	-15	-10	-5	0
First Law Cascaded Efficiency COP_ Cascade	0.5403	0.5493	0.5556	0.5590	0.5595	0.6211	0.6111
Exergy Destruction Ratio(EDR_Cascade)	1.948	1.899	1.867	1.849	1.846	1.564	1.606
Cascaded Exergetic Efficiency	0.3392	0.3449	0.3488	0.3510	0.3513	0.390	0.3837
Exergy of Fuel "kW"	65.09	64.02	63.30	62.91	62.85		
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6552	0.6546	0.6554	0.6578	0.6618	0.6552	0.6552
LTC Mass flow Rate (Kg/sec)	0.1413	0.1456	0.1499	0.1548	0.1602	0.5913	0.6002
W_comp _HTC "kW"	40.89	37.52	34.38	31.43	28.65	0.1660	0.1725
W_comp_LTC "kW"	24.30	26.50	28.92	31.48	34.20	19.51	17.29
Q_Cond_HTC "kW"	100.3	99.19	98.47	98.08	98.02	37.12	40.26
Q_Cond_LTC "kW"	59.37	61.67	64.08	66.64	69.37	91.79	92.72
Q_Eva_HTC "kW"	59.37	61.67	64.08	66.64	69.37	72.28	75.42
Q_Eva_LTC "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.453	1.327	1.216	1.117	1.028	0.9475	0.8736
First Law HTC Efficiency COP_ HTC	1.452	1.643	1.864	2.12	2.422	3.705	4.362
HTC Exergy Destruction Ratio(EDR_HTC)	2.045	2.020	2.018	2.044	2.105	1.412	1.505
HTC Exergetic Efficiency	0.3285	0.3311	0.3313	0.3285	0.3221	0.4146	0.3992
HTC Exergy of Fuel "kW"	40.89	37.52	34.38	31.43	28.65	19.51	17.29
HTC Exergy of Product "kW"	13.43	12.43	11.39	10.33	9.226	8.087	6.903

Table-4(b) Effect of LTC evaporator temperature on the thermodynamic performances of cascaded VCRS using ecofriendly low GWP R515A refrigerant in HTC *in higher temperature cycle using ecofriendly low GWP* R454B *refrigerant in low temperature cycle (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva_HTC}$=-30ºC , Approach (temperature overlapping)=10ºC, Compressor efficiency_$_{HTC}$=80%*

LTC Evaporator temperature (ºC)	-90	-85	-80	-75	-70
First Law Cascaded Efficiency COP_ Cascade	0.5403	0.5857	0.6332	0.6831	0.7355
Exergy Destruction Ratio(EDR_Cascade)	1.948	1.921	1.905	1.901	1.908
Cascaded Exergetic Efficiency	0.3392	0.3424	0.3442	0.3448	0.3439
Exergy of Fuel "kW"	65.90	60.05	55.55	51.48	47.81
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6550	0.6222	0.5928	0.5662	0.5423

LTC Mass flow Rate (Kg/sec)	0.1413	0.1397	0.1382	0.1368	0.1353
W_{comp_HTC} "kW"	40.89	38.83	36.99	35.34	33.84
W_{comp_LTC} "kW"	24.20	21.22	18.55	16.14	13.97
Q_{Cond_HTC} "kW"	100.3	95.21	90.7	86.65	82.98
Q_{Cond_LTC} "kW"	59.37	56.38	53.71	51.31	49.14
Q_{Eva_HTC} "kW"	59.37	56.38	53.71	51.31	49.14
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.453	1.657	1.896	2.178	2.517
First Law HTC Efficiency COP_{HTC}	1.452	1.452	1.452	1.452	1.452
HTC Exergy Destruction Ratio(EDR_{HTC})	2.909	2.909	2.909	2.909	2.909
HTC Exergetic Efficiency	0.3285	0.3285	0.3285	0.3285	0.3285
HTC Exergy of Fuel "kW"	40.89	38.83	36.99	35.34	33.84
HTC Exergy of Product "kW"	13.43	12.75	12.15	11.61	10.75

Table-4(c) Effect of HTC condenser temperature on the thermodynamic performances of cascaded VCRS using low GWP R515A refrigerant in HTC *in higher temperature cycle using low GWP* R454B *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50°C, T_ambient=25°C, T_{Eva_HTC}=-30°C , Approach (temperature overlapping)=10°C, Compressor efficiency$_{HTC}$=80%*

HTC condenser temperature (°C)	60	55	50	45	40
First Law Cascaded Efficiency $COP_{Cascade}$	0.4557	0.4980	0.5402	0.5825	0.6254
Exergy Destruction Ratio($EDR_{Cascade}$)	2.495	2.198	1.948	1.734	1.547
Cascaded Exergetic Efficiency	0.2861	0.3127	0.3392	0.3658	0.3927
Exergy of Fuel "kW"	77.18	70.62	65.11	60.37	56.23
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.7795	0.7115	0.6553	0.6081	0.5678
LTC Mass flow Rate (Kg/sec)	0.1413	0.1413	0.1413	0.1413	0.1413
W_{comp_HTC} "kW"	52.97	46.41	40.89	36.16	32.02
W_{comp_LTC} "kW"	24.21	24.21	24.21	24.21	24.21
Q_{Cond_HTC} "kW"	112.3	105.8	100.3	95.54	91.40
Q_{Cond_LTC} "kW"	59.38	59.38	59.38	59.38	59.38
Q_{Eva_HTC} "kW"	59.38	59.38	59.38	59.38	59.38
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.452	59.38	59.38	59.38	59.38
First Law HTC Efficiency COP_{HTC}	1.121	1.279	1.452	1.642	1.854
HTC Exergy Destruction Ratio(EDR_{HTC})	2.943	2.455	2.045	1.692	1.384
HTC Exergetic Efficiency	0.2536	0.2894	0.3285	0.3658	0.4194
HTC Exergy of Fuel "kW"	52.97	46.41	40.89	36.16	32.02

Table-4(d) Effect of temperature overlapping on the thermodynamic performances of cascaded VCRS using low GWP R515A refrigerant in HTC *in higher temperature cycle using low GWP* R454B *refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50°C, T_ambient=25°C, T_{Eva_HTC}=-30°C, Approach (temperature overlapping) =10°C, Compressor efficiency$_{HTC}$=80*

Temperature overlapping (°C)	0	3	4	5	6	8	9	10	12	15
$COP_{Cascade}$	0.6077	0.5864	0.5795	0.5728	0.5661	0.5530	0.5466	0.5403	0.5279	0.5099
($EDR_{Cascade}$)	1.621	1.716	1.748	1.781	1.813	1.88	1.914	1.948	2.017	2.123
Cascaded Exergetic Efficiency	0.3816	0.3682	0.3639	0.3596	0.3554	0.3472	0.3432	0.3392	0.3315	0.3202
Exergy of Fuel "kW"	57.87	59.97	60.68	61.40	62.12	63.59	64.34	65.90	66.62	68.97
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6080	0.6217	0.6264	0.6311	0.6358	0.6454	0.6503	0.6550	0.6652	0.6805
LTC Mass flow Rate (Kg/sec)	0.1339	0.1360	0.1367	0.1374	0.1382	0.1397	0.1405	0.1413	0.1429	0.1454
W_{comp_HTC} "kW"	37.94	38.80	39.09	39.38	39.68	40.28	40.58	40.89	41.51	42.47
W_{comp_LTC} "kW"	19.93	21.17	21.59	22.02	22.45	23.32	23.76	24.20	25.11	26.05
Q_{Cond_HTC} "kW"	93.04	95.14	95.85	96.57	97.29	98.76	99.51	100.3	101.8	104.10
Q_{Cond_LTC} "kW"	55.10	56.34	56.76	57.19	57.61	58.48	58.93	59.37	61.67	61.67
Q_{Eva_HTC} "kW"	55.10	56.34	56.76	57.19	57.61	58.48	58.93	59.37	61.67	61.67
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
COP_{LTC}	1.742	1.661	1.629	1.597	1.567	1.508	1.480	1.453	1.401	1.327
COP_{HTC}	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452	1.452
(EDR_{HTC})	2.045	2.045	2.045	2.045	2.045	2.045	2.045	2.045	2.045	2.045
HTC Exergetic Efficiency	0.3285	0.3285	0.3285	0.3285	0.3285	0.3285	0.3285	0.3285	0.3285	0.3285
HTC Exergy of Fuel "kW"	37.94	38.8	39.09	39.38	39.68	40.28	40.58	40.89	41.51	42.47

4. Conclusions

Following conclusions were made using HFC+HFO blends for Replacing R404a, R410a and R12, R22, R502, R507a

- Static thermodynamic performances of cascaded VCRS using eight different combinations of HFC+HFO Blends in high temperature cycle at -30ºC in HTC evaporator and two different HFC +HFO Blends (R513a and R R452a) in low temperature cycle and it was found that optimal cascaded vapor compression refrigeration system-2 using R454B in high temperature cycle and R513A in low temperature cycle gives highest first law efficiency and exergetic efficiency with lower power consumption in the both compressors along with lowest system exergy destruction ratio. The lowest thermodynamic performances were observed by using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle in the Cascaded thermodynamic performances of vapor compression refrigeration
- Cascaded vapor compression refrigeration system using R454B in high temperature cycle and R513A in low temperature cycle at -90ºC gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio
- Dynamic Thermodynamic performances of cascaded vapor compression refrigeration system using ecofriendly low GWP R450A refrigerant in HTC in higher temperature cycle using ecofriendly low GWP R513a refrigerant in low temperature cycle for varying evaporator temperature from 0ºC to -30ºC and it was found that when evaporator temperature is increasing the system first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is is increasing.
- By increasing LTC evaporator temperature from -50ºC to -70ºC in the all eight cascaded optimal vapor compression refrigeration systems, the first law (energy) performance ($COP_{\_cascade}$) is increasing and exergetic performance is is decreasing
- By increasing HTC condenser temperature from 40ºC to 60ºC, in the all eight cascaded optimal vapor compression refrigeration systems, the first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is decreasing.
- By increasing temperature overlapping, in the all eight cascaded optimal vapor compression refrigeration systems, the first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is decreasing respectively

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