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ORIGINAL ARTICLE

Exergy analysis of simple & cascade vapour compression refrigeration systems using HFO+HFC blends low temperature applications

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Abstract

Numerical computation was carried out for finding performance parameters using HFO+HFC blends as alternative refrigerants in the vapour compression refrigeration systems at evaporator temperature of -30º and condenser temperature of 50ºC at 80% of compressor efficiency and it was found that the first law efficiency (COP) of vapour compression refrigeration systems using eight HFC and HFO blends at dead state temperature of 313K(40ºC) the R515A gives highest first law efficiency , exergetic efficiency with lowest exergy destruction ratio. To improve thermodynamic performance (COPs, work done by compressors, exergy destruction ratio, mass flow rates, heat rejected by condensers, the cascade refrigeration systems have been suggested using HFO+HFC blends to achieve temperature up to -70°C to -90°C for the applications (i.e. in the cold storage and stores and in blood banks). The cascade refrigeration systems are the combination of two refrigeration cycle using HFO+HFC blends having low GWP and negligible ODP, harmless to environment, and do not violate the Kyoto protocol, the first law efficiency (COP) of cascade vapour compression refrigeration systems using R454B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency, exergetic efficiency with lowest exergy destruction ratio.

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. Condensing temperature is governed by temperature of cooling tower water which is about 35 ºC. Thus, system has to work for wide range of temperature. Single stage vapor compression system is not feasible for such application and its performance decreases below -35 ºC.

Cabello,et,al., [1], have analyzed the performance of a vapour compression refrigeration system using three different working fluids (R134a, R407c & R22). The operating variables are the evaporating pressure, condensing pressure and degree of superheating at the compressor inlet and analyzed that the power consumption decreases when compression ratio increases with R22 than using the other working fluids. Multistage or compound systems can be useful but no refrigerants available to work efficiently for high temperature lift. 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 maximise system performance. Synthetic refrigerants prominently used in till now due to their

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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 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. Amongst the natural refrigerants.

B.O. Bolaji et al [2] investigated experimentally the performances of three ozone friendly Hydrofluorocarbon (HFC) refrigerants R12, R152a and R134a. R152a refrigerant found as a drop in replacement for R134a in vapour compression system and discussed the process of selecting environmental-friendly refrigerants that have zero ozone depletion potential and low global warming potential. R23 and R32 from methane derivatives and R152a, R143a, R134a and R125 from ethane derivatives are the emerging refrigerants that are nontoxic, have low flammability and environmental-friendly. These refrigerants need theoretical and experimental analysis to investigate their performance in the system [3]

James M. Calm [4], has studied the emission and environmental impacts of R11, R123, R134a due to leakage from centrifugal chiller system. He also investigated the total impact(TEWI) and change in system efficiency or performance due to charge loss and summarized the methods to reduce the refrigerant losses by the system like design modifications, improvement in preventive maintenance techniques, use of purge system for refrigerant vapour recovery, servicing and lubricant changing in system

Leonardo Arrieta Mondragon, et.al [5] suggested the use of carbon dioxide (CO_2) and seems to be the most promising one especially as the natural refrigerant. The key advantages of CO_2 include the fact that is not explosive, non-toxic, easily available, environmental friendly and has excellent thermo-physical properties. On the other hand, researches in Norway in 1993 showed that the refrigerant leakages coming from the commercial sector were 30% of the annual total. In this research, the use of a cascade system using CO_2 in the low temperature stage and NH_3 in the high temperature stage turned out to be an excellent alternative for cooling applications at very low temperatures

It is well-known that cascade refrigeration system is usually adopted to meet the low-temperature cooling requirement in many commercial and industrial applications where single-stage or multistage systems are insufficient. There are two cycles in a cascade refrigeration system: the high-temperature cycle (HTC) is used to absorbed the energy released by the low temperature cycle (LTC) during the condensation process. In this way, cascade refrigeration system can satisfy the low-temperature cooling requirement range from -70°C to -90°C. As regards energy shortage problems, much attention has been devoted to the optimization of cascade refrigeration system performance. One of the research topics is the selection of refrigerant couples [6].

Application of a three-stage vapour compression system for evaporating temperature below −70°C is limited, because of difficulties with refrigerants reaching their freezing temperatures. The Montreal protocol and Kyoto underlined the need of substitution of CFC’s and HCFC’s regarding their bad impact on atmospheric ozone layer which protects earth from U.V rays. For many industrial and medical applications, very low temperatures are required. Thus the temperatures of the order of -80ºC are required to freeze and store blood and for precipitation hardening of special alloy steels, temperatures as low as -90ºC are required. To obtain such low temperature by conventional system as mentioned earlier becomes difficult because of extremely low evaporator pressures. R.S. Mishra [7] deals with thermodynamic analysis of three stages cascade vapour 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 - 50ºC to -100ºC) applications. It was observed that the best combination in terms of R1234ze-R134a-R404a gives better thermal performance than using R1234yf-R134a-R404a. Similarly, other combination in terms of R1234ze-R134a-R404a gives better thermal performance than using R1234ze-R1234yf-R404a. In this paper the exergy computation of simple and cascaded vapour compression refrigeration have been carried out by methods suggested by Mishra [7] using HFO+HFC blends and detailed thermodynamic performances have bbe investigated.

2. Results and discussion

The vapour compression refrigeration systems have been used using ecofriendly refrigerants having HFC+HFO blends. For which following environmental parameters are given in Table 1.

Table 1: Environmental parameters used in the simple and cascaded vapour compression refrigeration systems

S. No.	New Refrigerants	%(HFC+HFO Blends)	GWP Non flammable	ODP	Safety Code
1	R513A	56%R1234yf,44% 134a	631 (573)	Non ozone depleting	A1
2	R515A	88%R1234ze,12% 227ea	387 (573)	Non ozone depleting	A1
3	R448A	26% R32,26%R125,20% R1234yf,7%R1234ze(E)	1273 to 1387	Non ozone depleting	A1
4	R449A	23.3% R32, 24.5%R125, 24.3% R1234yf, 25.5%R134a	1282 to 1387	Non ozone depleting	A1
5	R407H	32.5% R32, 15%R125, 52.5%R134a	1378 to 1495	Non ozone depleting	A1
6	R450A	58% R1234ze(E), 42% 134a	547 to 604	Non ozone depleting	A1
7	R454A	35% R32 , 65% R1234yf	238 -239	Non ozone depleting	A2L
8	R454B	21.5% R32, 78.5% R1234yf	1377 to 1494	Non ozone depleting	A2L
9	R454C	21.5% R32, 78.5% R1234yf	139 to 148	Non ozone depleting	A2L
10	R452A	11%R32, 59%R125, 30%R1234yf	676 to 698	Non ozone depleting	A1
11	R452B	12.5%R32, 61%R125, 26.5%R1234yf	676 to 698	Non ozone depleting	A1

In this study, an ideal vapour-compression system is used for the thermodynamic performance analysis of alternative new refrigerants using eight HFC+HFO blends as a substitute for replacing R134a in a vapour compression refrigeration system at varying evaporating temperature and condensing temperature have been investigated.

2.1 Effect of Evaporator temperature

on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R452b refrigerants (HFC+HFO blends) using ecofriendly HFC+HFO blends. Table-2(a) to table-2(d) show the effect of evaporator temperature on first law efficiency (COP) of vapour compression refrigeration systems using R515A refrigerant (HFC +HFO Blends) and it was found that by increasing the evaporator temperature, the first law efficiency (COP) and exergy destruction ratio(EDR) increased while and exergetic efficiency of vapour compression refrigeration systems is decreased. Similarly, compressor work in form of exergy of input and heat rejected by the condenser decreased. The exergy destruction in compressor and evaporator increased while exergy destruction in condenser and expansion (throttle) valve and mass flow rate decreased. Similarly, by increasing dead state temperature the second law efficiency and exergetic efficiency is increased and first law efficiency (COP) remains same (i.e. does not affect)

Table 2(a): Effect of evaporator temperature in VCRS on thermodynamic performances of VCRS using ecofriendly low GWP R452b refrigerants (HFC+HFO blends) using ecofriendly HFC+HFO blends ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-75ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%

Evaporator temperature in VCRS HFC +HFO Blends	-30	-25	-20	-15	-10	-5	0
First Law Efficiency $COP_{\_VCRS}$	1.465	1.636	1.831	2.058	2.323	2.637	3.014
Exergy Destruction Ratio	2.017	2.034	2.072	2.136	2.237	2.390	2.625
Exergetic Efficiency	0.331	0.3296	0.3255	0.3189	0.3090	0.3195	0.3219
Exergy of Fuel “kW”	2.40	2.15	1.92	1.709	1.514	1.334	1.167
Exergy of Product “kW”	0.795	0.7086	0.6251	0.5449	0.4677	0.3934	0.3215
Second Law Efficiency	0.482	0.4943	0.5064	0.5182	0.5296	0.5408	0.5517
Mass flow Rate (Kg/sec)	0.0218	0.0215	0.0212	0.0209	0.0206	0.0204	0.0201
$Q_{\_Cond\_HTC}$ “kW”	5.917	5.667	5.437	5.226	5.031	4.850	4.683
$Q_{\_Eva\_LTC}$ “kW”	3.516	3.5167	3.5167	3.5167	3.5167	3.5167	3.5167
Exergy Destruction in compressor(%)	15.37	15.61	15.83	16.05	16.26	16.46	16.66
Exergy Destruction in condenser(%)	26.74	27.6	28.69	30.05	31.72	33.80	36.40
Exergy Destruction in valve(%)	24.57	23.51	22.64	21.68	20.71	19.73	18.76
Exergy Destruction in evaporator	0.181	0.2276	0.2818	0.3445	0.4170	0.5006	0.5971

2.2 Effect of condenser temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R515A refrigerant (HFC+HFO blends) in higher temperature cycle

Table-3(a) to 3(c) show the effect of condenser temperature first law efficiency (COP) of vapour compression refrigeration systems using *R515A* refrigerants HFC +HFO Blends and it was found that by increasing the condenser temperature, the first law efficiency (COP) and exergetic efficiency decreases while exergy destruction ratio(EDR) of vapour compression refrigeration systems is increases. Similarly, compressor work in form of exergy of input and heat rejected by the condenser increased. The exergy destruction in compressor and evaporator decreased while exergy destruction in condenser and expansion (throttle) valve and mass flow rate increased. Similarly, by increasing dead state temperature the second law efficiency and exergetic efficiency is increased and first law efficiency (COP) remains same (i.e. does not affect).

Table 2(b): Effect of Evaporator temperature in VCRS *on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R452b refrigerants (HFC+HFO blends) using ecofriendly HFC+HFO blends (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva_HTC}$=-30ºC , T_$_{Eva_LTC}$=-75ºC, Temperature overlapping=10, Compressor efficiency_$_{HTC}$=80%, Compressor efficiency_$_{LTC}$=80%*

Evaporator temperature in VCRS HFC +HFO Blends	-5	0	5	15	15
First Law Efficiency COP_ $_{VCRS}$	2.637	3.014	3.475	4.052	4.792
Exergy Destruction Ratio	2.390	2.625	3.002	3.659	5.014
Exergetic Efficiency	0.2950	0.2619	0.2499	0.2146	0.1663
Exergy of Fuel “kW”	1.334	1.167	1.012	0.8679	0.7339
Exergy of Product “kW”	0.3934	0.3215	0.2529	0.1863	0.1220
Second Law Efficiency	0.5408	0.5517	0.5623	0.5724	0.5820
Mass flow Rate (Kg/sec)	0.0204	0.02019	0.02001	0.01986	0.01974
Q_$_{Cond_HTC}$ “kW”	4.850	4.683	5.437	5.226	5.031
Q_$_{Eva_LTC}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167
Exergy Destruction in compressor(%)	16.46	16.66	16.85	17.04	17.22
Exergy Destruction in condenser(%)	33.80	36.40	39.66	43.84	49.31
Exergy Destruction in valve(%)	19.73	18.76	17.79	16.82	15.84
Exergy Destruction in evaporator	0.5006	0.5971	0.7088	0.8385	0.9907

Table 2(c): Effect of Evaporator temperature in VCRS *on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R515 refrigerants (HFC+HFO blends) using ecofriendly HFC+HFO blends (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva_HTC}$=-30ºC , T_$_{Eva_LTC}$=-75ºC, Temperature overlapping=10, Compressor efficiency_$_{HTC}$=80%, Compressor efficiency_$_{LTC}$=80%*

Evaporator temperature in VCRS HFC +HFO Blends	-30	-25	-20	-15	-10	-5	0
First Law Efficiency COP_ $_{VCRS}$	1.452	1.643	1.864	2.12	2.422	2.78	3.212
Exergy Destruction Ratio	2.045	2.020	2.018	2.044	2.105	2.216	2.018
Exergetic Efficiency	0.3285	0.3311	0.3313	0.3285	0.3221	0.311	0.3313
Exergy of Fuel “kW”	2.420	2.14	1.887	1.653	1.452	1.265	1.095
Exergy of Product “kW”	0.7955	0.7085	0.6251	0.5449	0.4677	0.3934	0.3628
Second Law Efficiency	0.4778	0.4967	0.5154	0.5339	0.5521	0.5701	0.5879
Mass flow Rate (Kg/sec)	0.0388	0.03733	0.03597	0.03471	0.03355	0.03248	0.03248
Q_$_{Cond_HTC}$ “kW”	5.939	5.657	5.403	5.175	4.969	4.7822	4.672
Q_$_{Eva_LTC}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167	3.5167	3.5167

Table 2(d): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R513B refrigerants in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in low temperature cycle (Q_Eva_$_{LTC}$=35.167 kW, T_$_{cond}$=50ºC, T_ambient=40ºC, T_$_{Eva_HTC}$=-30ºC , T_$_{Eva_LTC}$=-75ºC, Temperature overlapping=10, Compressor efficiency_$_{HTC}$=80%, Compressor efficiency_$_{LTC}$=80%,

Effect of evaporator temperature using HFC +HFO Blends in VCRS	-30	-25	-20	-15	-10	-5	0
First Law Efficiency COP_ $_{VCRS}$	1.452	1.652	1.864	2.12	2.422	2.78	3.212
VCRS Exergetic Efficiency	0.418	0.4305	0.4418	0.4517	0.4601	0.4665	0.4703
Exergy of Fuel “kW”	2.422	2.14	1.887	1.659	1.452	1.265	1.095
Exergy of Product “kW”	1.012	1.012	1.012	1.012	1.012	1.012	1.012
Second Law Efficiency	0.4778	0.4967	0.5154	0.5339	0.5521	0.5701	0.5879
Mass flow Rate (Kg/sec)	0.0388	0.03733	0.03597	0.03471	0.03255	0.03248	0.03148
Q_$_{Cond}$ “kW”	5.939	5.657	5.403	5.175	4.969	4.7822	4.672
Q_$_{Eva}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167	3.5167	3.5167

2.3 Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends (R515B) in low GWP in VCRS cycle

Table-4(a) and table-4(b) shows the comparison of first law efficiency (COP_$_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO Blends at dead state temperature of 313K (40ºC) and it was found that vapour compression refrigeration systems using R515A gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio.

Table 3(a): Effect of condenser temperature in VCRS using *on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R515A refrigerant (HFC+HFO blends) in higher temperature cycle(Q_Eva_$_{LTC}$=3.5167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva}$=-30ºC Compressor efficiency=80%,*

Condenser temperature in VCRS using HFC +HFO Blends	60	55	50	45	40
First Law Efficiency COP_ $_{VCRS}$	1.138	1.296	1.465	1.649	1.853
Exergy Destruction Ratio	2.886	2.411	2.017	1.681	1.386
Exergetic Efficiency	0.2574	0.2932	0.3314	0.3730	0.4191
Exergy of Fuel “kW”	3.091	2.713	2.40	2.133	1.898
Exergy of Product “kW”	0.7955	0.7955	0.7955	0.7955	0.7955
Second Law Efficiency	0.4211	0.4531	0.4820	0.5087	0.5334
Mass flow Rate (Kg/sec)	0.02545	0.02347	0.0188	0.02055	0.01943
Q_$_{Cond_HTC}$ “kW”	6.608	6.230	5.917	5.649	5.415
Q_$_{Eva_LTC}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167
Exergy Destruction in compressor(%)	14.73	15.04	15.37	15.71	16.07
Exergy Destruction in condenser(%)	30.60	28.90	26.74	24.09	20.86
Exergy Destruction in valve(%)	28.79	26.58	24.57	22.70	20.93
Exergy Destruction in evaporator	0.1405	0.1601	0.1810	0.2037	0.2288

Table 3(b): Effect of Condenser temperature in VCRS using *on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R515A refrigerants (HFC+HFO blends) in higher temperature cycle (Q_Eva_$_{LTC}$=3.5167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva}$=-30ºC Compressor efficiency=80%,*

Condenser temperature in VCRS using HFC +HFO Blends	60	55	50	45	40
First Law Efficiency COP_ $_{VCRS}$	1.121	1.279	1.452	1.642	1.854
Exergy Destruction Ratio	2.943	2.455	2.045	1.692	1.384
Exergetic Efficiency	0.2536	0.2894	0.3285	0.3715	0.4194
Exergy of Fuel “kW”	3.167	2.749	2.422	2.141	1.896
Exergy of Product “kW”	0.7955	0.7955	0.7955	0.7955	0.7955
Second Law Efficiency	0.4150	0.4473	0.4778	0.5066	0.5338
Mass flow Rate (Kg/sec)	0.04617	0.04214	0.03881	0.03601	0.03363
Q_$_{Cond_HTC}$ “kW”	6.654	6.265	5.939	5.658	5.413
Q_$_{Eva_LTC}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167

Table 3(c): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends (R515B) in low GWP in VCRS cycle (Q_Eva_$_{LTC}$=3.5167 kW, T_$_{cond}$=50ºC, T_ambient=40ºC, T_$_{Eva}$=-30ºC Compressor efficiency=80%

Variation of condenser temperature using HFC +HFO Blends in VCRS	40	45	50	55	60
First Law Efficiency COP_ $_{VCRS}$	1.854	1.642	1.452	1.279	1.121
VCRS Exergetic Efficiency	0.5338	0.4728	0.4180	0.3683	0.3227
Exergy of Fuel “kW”	1.896	2.141	2.422	2.749	3.137
Exergy of Product “kW”	1.012	1.012	1.012	1.012	1.012
Second Law Efficiency	0.5338	0.5066	0.4778	0.4473	0.4150
Mass flow Rate (Kg/sec)	0.05338	0.03601	0.03881	0.04214	0.04617
Q_$_{Cond}$ “kW”	5.413	5.658	5.939	6.265	6.654
Q_$_{Eva}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167

Table 4(a): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends (R515B) in low GWP in VCRS cycle (Q_Eva_$_{LTC}$=3.5167 kW, T_$_{cond}$=50ºC, T_ambient=25ºC, T_$_{Eva}$=-30ºC Compressor efficiency=80%

Effect of HFC +HFO Blends in VCRS	R515A	R450A	R513A	R454B	R454C
First Law Efficiency COP_ $_{VCRS}$	1.452	1.417	1.381	1.434	1.235
Exergy Destruction Ratio	2.045	2.119	2.202	2.083	2.581
VCRS Exergetic Efficiency	0.3285	0.3206	0.3123	0.3243	0.2793
Exergy of Fuel “kW”	2.422	2.481	2.547	2.453	2.848
Exergy of Product “kW”	0.7955	0.7955	0.7955	0.7955	0.7955
Second Law Efficiency	0.4778	0.4664	0.4543	0.4717	0.4062
Mass flow Rate (Kg/sec)	0.03881	0.03682	0.04084	0.02206	0.03619
Q_$_{Cond}$ “kW”	5.939	5.998	6.063	5.969	6.365
Q_$_{Eva_}$ “kW”	3.5167	3.5167	3.5167	3.5167	3.5167

Table 4(b): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends in VCRS cycle (Q_Eva_{LTC}=3.5167 kW, T_{cond}=50°C, T_ambient=40°C, T_{Eva}=-30°C Compressor efficiency=80%

Effect of HFC +HFO Blends in VCRS	R515A	R450A	R513A	R454B	R454C
First Law Efficiency $COP\__{VCRS}$	1.452	1.417	1.381	1.434	1.235
VCRS Exergetic Efficiency	0.4180	0.4081	0.3975	0.4128	0.3555
Exergy of Fuel "kW"	2.422	2.481	2.547	2.453	2.848
Exergy of Product "kW"	1.012	1.012	1.012	1.012	1.012
Second Law Efficiency	0.4778	0.4081	0.4543	0.4128	0.4062
Mass flow Rate (Kg/sec)	0.03881	0.03682	0.04084	0.02206	0.03619
Q_{Cond} "kW"	5.939	5.998	6.063	5.969	6.365
$Q\_{Eva\_}$ "kW"	3.5167	3.5167	3.5167	3.5167	3.5167

2.4 Thermodynamic performances of cascaded VCRS using HFO +HFC blends.

Similarly, table-4(c) and table-4(d) show the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO blends at dead state temperature of 298K (25°C) and it was found that cascaded vapour compression refrigeration systems using R452B gives highest first law efficiency and exergetic efficiency lowest exergy destruction ratio in vapour compression refrigeration systems with lowest exergy destruction ratio.

Table 4(c): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends (R515B) in low GWP in VCRS cycle (Q_Eva_{LTC}=3.5167 kW, T_{cond}=50°C, T_ambient=25°C, T_{Eva}=-30°C Compressor efficiency=80%

HFC +HFO Blends in VCRS	R515A	R448A	R449A	R452A	R452B
First Law Efficiency $COP\__{VCRS}$	1.452	1.346	1.299	1.131	1.465
Exergy Destruction Ratio	2.045	2.284	2.402	2.909	2.017
Cascaded Exergetic Efficiency	0.3285	0.3045	0.2939	0.2558	0.3314
Exergy of Fuel "kW"	2.422	2.612	2.707	3.110	2.40
Exergy of Product "kW"	0.7955	0.7955	0.7955	0.7955	0.7955
Second Law Efficiency	0.4778	0.4430	0.4275	0.3721	0.4820
Mass flow Rate (Kg/sec)	0.03881	0.03140	0.03325	0.05028	0.02188
Q_{Cond_HTC} "kW"	5.939	6.129	6.223	6.626	5.917
Q_{Eva_LTC} "kW"	3.5167	3.5167	3.5167	3.5167	3.5167

Table 4(d): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP refrigerant of HFC+HFO blends (R515B) in low GWP in VCRS cycle (Q_Eva_{LTC}=3.5167 kW, T_{cond}=50°C, T_ambient=40°C, T_{Eva}=-30°C Compressor efficiency=80%

Effect of HFC +HFO Blends in VCRS	R515A	R448A	R449A	R452A	R452B
First Law Efficiency $COP\__{VCRS}$	1.452	1.452	1.417	1.381	1.434
VCRS Exergetic Efficiency	0.4180	0.3876	0.3741	0.3256	0.4216
Exergy of Fuel "kW"	2.422	2.612	2.707	3.110	2.40
Exergy of Product "kW"	1.012	1.012	1.012	1.012	1.012
Second Law Efficiency	0.4778	0.4430	0.4295	0.3721	0.4820
Mass flow Rate (Kg/sec)	0.03881	0.03881	0.03682	0.04084	0.02206
Q_{Cond} "kW"	5.939	2.612	2.707	3.110	2.40
$Q\_{Eva\_}$ "kW"	3.5167	3.5167	3.5167	3.5167	3.5167

2.5 Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO refrigerants in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in low temperature

Table-5 (a) and Table-5(b) show the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO Blends in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R515A in low temperature cycle gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R454C in low temperature cycle gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table 5(a): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO refrigerants in higher temperature cycle using ecofriendly HFC+HFO blends in 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}=-75ºC, Temperature overlapping=10, Compressor efficiency_HTC=80%, Compressor efficiency_LTC=80%

Cascaded VCRS	*System1*	*System2*	*System3*	*System4*	*System5*	*System6*
HFC +HFO Blends in HTC	R513A	R454B	R450 A	*R454C*	*R454C*	*R454C*
HFC +HFO Blends in LTC	R454C	R454C	R454C	R513A	R454B	R452A
First Law Cascaded Efficiency $COP\_{Cascade}$	0.6214	0.5401	0.6325	0.6265	0.6093	0.5855
Cascade Exergy Destruction Ratio($EDR\_{Cascade}$)	2.189	2.669	2.133	2.163	2.252	2.385
Cascaded Exergetic Efficiency	0.3136	0.2726	0.3192	0.3162	0.3075	0.2955
Exergy of Fuel "kW"	56.60	65.11	55.60	56.13	57.72	60.07
Exergy of Product "kW"	17.75	17.75	17.75	17.75	17.75	17.75
HTC Mass flow Rate (Kg/sec)	0.6181	0.7610	0.6572	0.5191	0.5281	0.5414
LTC Mass flow Rate (Kg/sec)	0.2061	0.2061	0.2061	0.2291	0.1381	0.2516
Q_{Cond_HTC} "kW"	91.76	100.3	90.77	91.30	92.88	95.24
Q_{Cond_LTC} "kW"	53.22	53.22	53.22	50.44	51.32	52.62
Q_{Eva_HTC} "kW"	53.22	53.22	53.22	50.44	51.32	52.62
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.948	1.948	1.948	2.302	2.177	2.015
First Law HTC Efficiency COP_{HTC}	1.381	1.131	1.417	1.235	1.236	1.236
HTCExergy Destruction Ratio(EDR_{HTC})	2.202	2.909	2.119	2.581	2.581	2.581
HTC Exergetic Efficiency	0.3123	0.2558	0.3206	0.2793	0.2793	0.2793
HTC Exergy of Fuel "kW"	38.54	47.06	37.55	40.85	41.57	42.62
HTC Exergy of Product "kW"	12.04	11.90	12.04	11.41	11.61	11.90
W_{comp_HTc}"kW"	38.54	47.06	37.55	40.85	41.57	42.62
W_{comp_LTC} "kW"	18.05	18.05	18.05	16.15	16.15	17.45

Table 5(b): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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}=-75ºC, Temperature overlapping=10, Compressor efficiency_HTC=80%, Compressor efficiency_LTC=80%

Effect of HFC +HFO Blends in VCRS	System-7	System8	System9	System10	System11	System12
HFC +HFO Blends in HTC	R452A	R452A	R513A	R513A	R454B	R452a
HFC +HFO Blends in LTC	R513A	R454B	R452A	R454B	R513a	R454B
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5873	0.5715	0.6330	0.6596	0.6970	0.6494
Exergy Destruction Ratio($EDR\_{Cascade}$)	2.374	2.467	2.130	2.004	1.843	2.051
Cascaded Exergetic Efficiency	0.2964	0.2884	0.3194	0.3329	0.3510	0.3277
Exergy of Fuel "kW"	59.88	61.53	55.56	53.32	50.45	54.15
Exergy of Product "kW"	17.75	17.75	17.75	17.75	17.75	17.75
HTC Mass flow Rate (Kg/sec)	0.7213	0.7338	0.6111	0.5960	0.3164	0.330
LTC Mass flow Rate (Kg/sec)	0.2291	0.1368	0.2516	0.1368	0.2291	0.2516
Q_{Cond_HTC} "kW"	95.05	96.7	90.72	88.49	85.62	89.32
Q_{Cond_LTC} "kW"	50.44	51.32	52.62	51.32	50.44	52.62
Q_{Eva_HTC} "kW"	50.44	51.32	52.62	51.32	50.44	52.62
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.302	2.177	2.015	2.177	2.302	2.015
First Law HTC Efficiency COP_{HTC}	1.131	1.131	1.381	1.381	1.434	1.434
HTCExergy Destruction Ratio(EDR_{HTC})	2.909	2.909	2.202	2.202	2.083	2.083
HTC Exergetic Efficiency	0.2558	0.2558	0.3123	0.3123	0.3243	0.3243
HTC Exergy of Fuel "kW"	44.6	45.38	38.11	37.17	35.18	36.7
HTC Exergy of Product "kW"	11.41	11.61	11.90	11.61	11.41	11.90
W_{comp_HTC}"kW"	44.6	45.38	38.11	37.17	35.18	36.7
W_{comp_LTC} "kW"	15.28	16.15	17.45	16.15	15.28	17.45

2.6 Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using low GWP ecofriendly HFC+HFO refrigerants in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in ultra-low temperature

Table-6 (a) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO Blends in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using *R513A* in high temperature cycle and R515A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R515A in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table 6(a): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R513A (HFC+HFO blends) in higher temperature cycle using following ecofriendly HFC+HFO blends in 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%

Effect of HFC +HFO Blends in VCRS	System1	System2	System3	System4
HFC +HFO Blends in HTC	R513A	R513A	R513A	R513A
HFC +HFO Blends in LTC	R515A	R449A	R454B	R454C
First Law Cascaded Efficiency $COP\_{Cascade}$	0.540	0.4969	0.5232	0.4971
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.949	2.205	2.044	2.204
Cascaded Exergetic Efficiency	0.3391	0.3120	0.3285	0.3121
Exergy of Fuel "kW"	65.12	70.77	67.21	70.75
Exergy of Product "kW"	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/s)	0.6755	0.7135	0.6896	0.7134
LTC Mass flow Rate (Kg/s)	0.2541	0.2021	0.1413	0.2183
Q_{Cond_HTC} "kW"	100.30	105.90	102.40	105.9
Q_{Cond_LTC} "kW"	58.16	61.44	59.38	61.43
Q_{Eva_HTC} "kW"	58.16	61.44	59.38	61.43
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_{LTC}	1.529	1.338	1.452	1.339
First Law HTC Efficiency COP_{HTC}	1.381	1.381	1.381	1.381
HTCExergy Destruction Ratio(EDR_{HTC})	2.202	2.202	2.202	2.202
HTC Exergetic Efficiency	0.3123	0.3123	0.3123	0.3123
HTC Exergy of Fuel "kW"	42.12	44.50	43.0	44.49
HTC Exergy of Product "kW"	13.16	13.90	13.43	13.90
W_{comp_HTC}"kW"	42.12	44.50	43.0	44.49
W_{comp_LTC} "kW"	23.0	26.27	24.21	26.26

Table-6 (b) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO Blends in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R454C in low temperature cycle gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table 6(b): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R454B *(HFC+HFO blends) in higher temperature cycle using ecofriendly HFC+HFO blends in 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%*

Effect of HFC +HFO Blends in VCRS	System-5	System-6	System-7	System-8
HFC +HFO Blends in HTC	R454B	R454B	R454B	R454B
HFC +HFO Blends in LTC	R515A	R513A	R449A	R454C
First Law Cascaded Efficiency ($COP_{Cascade}$)	0.5619	0.5652	0.5168	0.5164
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.834	1.818	2.082	2.084
Cascaded Exergetic Efficiency	0.3528	0.3549	0.3285	0.3528
Exergy of Fuel "kW"	62.59	62.23	68.05	68.09
Exergy of Product "kW"	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.3570	0.3557	0.3770	0.3772
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.2184	0.2021
Q_{Cond_HTC} "kW"	97.75	97.39	103.20	103.30
Q_{Cond_LTC} "kW"	58.16	57.95	61.42	61.44
Q_{Eva_HTC} "kW"	58.16	57.95	61.42	61.44
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.340	1.338

First Law HTC Efficiency $COP\__{HTC}$	1.469	1.469	1.469	1.469
HTCExergy Destruction Ratio($EDR\__{HTC}$)	2.009	2.009	2.009	2.009
HTC Exergetic Efficiency	0.3323	0.3323	0.3323	0.3323
HTC Exergy of Fuel "kW"	39.59	39.44	41.80	41.82
HTC Exergy of Product "kW"	13.16	13.11	13.89	13.90
$W\__{comp\ \_HTC}$"kW"	39.59	39.44	41.80	41.82
$W\__{comp\_LTC}$ "kW"	23.0	22.78	26.25	26.27

Table-6 (c) shows the comparison of first law efficiency ($COP\__{Cascade}$) of cascaded vapour compression refrigeration systems using R449A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R449A in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R449A in high temperature cycle and R454C in low temperature cycle gives lower first law efficiency ($COP\__{Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table 6(c): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R449A (HFC+HFO blends) in higher temperature cycle using ecofriendly HFC+HFO blends in 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%

Effect of HFC +HFO Blends in VCRS	System-9	System-10	System-11	System-12
HFC +HFO Blends in HTC	R449A	R449A	R449A	R449A
HFC +HFO Blends in LTC	R515A	R513A	R454B	R454C
First Law Cascaded Efficiency ($COP_{Cascade}$)	0.5190	5219	0.5031	0.4783
Exergy Destruction Ratio($EDR\__{Cascade}$)	2.069	2.052	2.165	2.329
Cascaded Exergetic Efficiency	0.3259	0.3277	0.3159	0.3004
Exergy of Fuel "kW"	67.76	67.38	69.90	73.52
Exergy of Product "kW"	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/s)	0.5499	0.5478	0.5613	0.5806
LTC Mass flow Rate (Kg/s)	0.2541	0.2440	0.1413	0.2184
$Q\__{Cond\_HTC}$ "kW"	102.9	102.5	105.1	108.7
$Q\__{Cond\_LTC}$ "kW"	58.16	57.95	59.37	61.42
$Q\__{Eva\_HTC}$ "kW"	58.16	57.95	59.37	61.42
$Q\__{Eva\_LTC}$ "kW"	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.453	1.340
First Law HTC Efficiency $COP\__{HTC}$	1.299	1.299	1.299	1.299
HTCExergy Destruction Ratio($EDR\__{HTC}$)	2.402	2.402	2.402	2.402
HTC Exergetic Efficiency	0.2939	0.2939	0.2939	0.2939
HTC Exergy of Fuel "kW"	44.77	44.60	45.69	47.27
HTC Exergy of Product "kW"	13.16	13.11	13.43	13.89
$W\__{comp\ \_HTC}$"kW"	44.77	44.60	45.69	47.27
$W\__{comp\_LTC}$ "kW"	23.0	22.78	24.20	26.25

Table-6 (d) shows the comparison of first law efficiency ($COP\__{Cascade}$) of cascaded vapour compression refrigeration systems using R449A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R454C in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R454C in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP\__{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-6 (e) shows the comparison of first law efficiency ($COP\__{Cascade}$) of cascaded vapour compression refrigeration systems using R515A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R515A in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R515A in high temperature cycle and R454C in low temperature cycle gives lower first law efficiency ($COP\__{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table 6(d): Effect of HFC+HFO blends on thermodynamic performances of VCRS using low GWP R454C (HFC+HFO blends) in higher temperature cycle using HFC+HFO blends in 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%

Effect of HFC +HFO Blends in VCRS	System13	System14	System15	System16
HFC +HFO Blends in HTC	R454C	R454C	R454C	R454C
HFC +HFO Blends in LTC	R515A	R513A	R454B	R449A
First Law Cascaded Efficiency $COP\_{Cascade}$	0.4953	0.4981	0.4804	0.4569
Exergy Destruction Ratio($EDR\_{Cascade}$)	2.215	2.197	2.315	2.486
Cascaded Exergetic Efficiency	0.3110	0.3128	0.3017	0.2869
Exergy of Fuel “kW”	71.0	70.60	73.20	76.98
Exergy of Product “kW”	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/s)	0.6156	0.6133	0.6284	0.6503
LTC Mass flow Rate (Kg/s)	0.2541	0.2440	0.1413	0.2021
Q_{Cond_HTC} “kW”	106.2	105.8	108.4	112.1
Q_{Cond_LTC} “kW”	58.16	57.95	59.37	61.44
Q_{Eva_HTC} “kW”	58.16	57.95	59.37	61.44
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_{LTC}	1.529	1.544	1.543	1.338
First Law HTC Efficiency COP_{HTC}	1.212	1.212	1.212	1.212
HTCExergy Destruction Ratio(EDR_{HTC})	2.648	2.648	2.648	2.648
HTC Exergetic Efficiency	0.2741	0.2741	0.2741	0.2741
HTC Exergy of Fuel “kW”	48.0	47.82	48.99	50.70
HTC Exergy of Product “kW”	13.16	13.11	13.43	13.90
W_{comp_HTC}“kW”	48.0	47.82	48.99	50.70
W_{comp_LTC} “kW”	23.0	22.78	24.20	26.27

Table 6(e): Effect of HFC+HFO blends on thermodynamic performances of VCRS using ecofriendly low GWP R515A (HFC+HFO blends) in higher temperature cycle using ecofriendly HFC+HFO blends in 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%

Effect of HFC +HFO Blends in VCRS	System-17	System- 18	System- 19	System- 20
HFC +HFO Blends in HTC	R515A	R515A	R515A	R515A
HFC +HFO Blends in LTC	R513A	R449A	R454B	R454C
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5610	0.5403	0.5130	0.5127
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.839	1.948	2.104	2.106
Cascaded Exergetic Efficiency	0.3522	0.3392	0.3221	0.3219
Exergy of Fuel “kW”	62.69	65.09	68.55	68.59
Exergy of Product “kW”	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6395	0.6552	0.6778	0.6780
LTC Mass flow Rate (Kg/sec)	0.2440	0.1413	0.2184	0.2021
Q_{Cond_HTC} “kW”	97.86	100.3	103.7	103.8
Q_{Cond_LTC} “kW”	57.95	59.37	61.42	61.44
Q_{Eva_HTC} “kW”	57.95	59.37	61.42	61.44
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.453	1.340	1.338
First Law HTC Efficiency COP_{HTC}	1.452	1.452	1.452	1.452
HTCExergy Destruction Ratio (EDR_{HTC})	2.045	2.045	2.045	2.045
HTC Exergetic Efficiency	0.3285	0.3285	0.3285	0.3285
HTC Exergy of Fuel “kW”	39.39	40.89	42.30	42.31
HTC Exergy of Product “kW”	13.11	13.43	13.89	13.90
W_{comp_HTC}“kW”	39.39	40.89	42.30	42.31
W_{comp_LTC} “kW”	22.78	24.20	26.25	26.27

Table-6(f) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded vapour compression refrigeration systems using R448A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R448A in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R448A in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table-6 (g) shows the comparison of first law efficiency

($COP_{\_Cascade}$) of cascaded vapour compression refrigeration systems using R450A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R450A in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R450A in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP_{\_Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table-6 (h) shows the comparison of first law efficiency ($COP_{\_Cascade}$) of cascaded vapour compression refrigeration systems using R452A (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R452A in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R452A in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP_{\_Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table-6 (i) shows the comparison of first law efficiency ($COP_{\_Cascade}$) of cascaded vapour compression refrigeration systems using R452B (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R452B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R452B in high temperature cycle and R449A in low temperature cycle gives lower first law efficiency ($COP_{\_Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table 6(f): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R448A (HFC+HFO blends) in higher temperature cycle using ecofriendly following HFC+HFO blends in 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%,

Effect of HFC +HFO Blends in VCRS	System21	System-22	System23	System24	System25
HFC +HFO Blends in HTC	R448A	R448A	R448A	R448A	R448A
HFC +HFO Blends in LTC	R515A	R513A	R454B	R454C	R449A
First Law Cascaded Efficiency $COP_{\_Cascade}$	0.5312	0.5342	0.5148	0.4892	0.4890
Exergy Destruction Ratio($EDR_{\_Cascade}$)	1.998	1.981	2.094	2.256	2.257
Cascaded Exergetic Efficiency	0.3335	0.3355	0.3232	0.3071	0.3070
Exergy of Fuel “kW”	66.20	65.85	68.32	71.89	71.91
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.5193	0.5174	0.5301	0.5484	0.5485
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.1413	0.2183	0.2021
$Q_{\_Cond\_HTC}$ “kW”	101.4	101.0	103.50	107.10	107.10
$Q_{\_Cond\_LTC}$ “kW”	58.16	57.95	59.38	61.43	61.44
$Q_{\_Eva\_HTC}$ “kW”	58.16	57.95	59.38	61.43	61.44
$Q_{\_Eva\_LTC}$ “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.452	1.339	1.338
First Law HTC Efficiency $COP_{\_HTC}$	1.346	1.346	1.346	1.346	1.346
HTCExergy 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”	43.20	43.04	44.14	45.63	45.64
HTC Exergy of Product “kW”	13.16	13.11	13.43	13.90	13.90
$W_{\_comp\_HTC}$“kW”	43.20	43.04	44.14	45.63	45.64
$W_{\_comp\_LTC}$ “kW”	23.0	22.78	24.21	26.26	26.27

Table 6(g): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A (HFC+HFO blends) in higher temperature cycle using ecofriendly following HFC+HFO blends in 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%,

Effect of HFC +HFO Blends in VCRS	System-26	System27	System28	System29	System30
HFC +HFO Blends in HTC	R450A	R450A	R450A	R450A	R450A
HFC +HFO Blends in LTC	R515A	R513A	R454B	R454C	R449A
First Law Cascaded Efficiency $COP_{\_Cascade}$	0.5492	0.5524	0.5321	0.5054	0.5051
Exergy Destruction Ratio($EDR_{\_Cascade}$)	1.90	1.883	1.993	2.151	2.153
Cascaded Exergetic Efficiency	0.3448	0.3468	0.3341	0.3174	0.3172
Exergy of Fuel “kW”	64.03	63.66	66.09	69.58	69.62

Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6089	0.6067	0.6216	0.6430	0.6432
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.1413	0.2184	0.2021
$Q_{\_Cond\_HTC}$ "kW"	99.2	98.83	101.3	104.7	104.7
$Q_{\_Cond\_LTC}$ "kW"	58.16	57.95	59.37	61.42	61.44
$Q_{\_Eva\_HTC}$ "kW"	58.16	57.95	59.37	61.42	61.44
$Q_{\_Eva\_LTC}$ "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.453	1.340	1.338
First Law HTC Efficiency $COP_{\_HTC}$	1.417	1.417	1.417	1.417	1.417
HTCExergy 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"	41.03	40.88	41.89	43.33	43.35
HTC Exergy of Product "kW"	13.16	13.11	13.43	13.89	13.90
$W_{\_comp\_HTC}$ "kW"	41.03	40.88	41.89	43.33	43.35
$W_{\_comp\_LTC}$ "kW"	23.0	22.78	24.20	26.25	26.27

Table 6(h): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R452A (HFC+HFO blends) in higher temperature cycle using following ecofriendly HFC+HFO blends in 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%,

Effect of HFC +HFO Blends in VCRS	System-31	System32	System33	System34	System35
HFC +HFO Blends in HTC	R452A	R452A	R452A	R452A	R452A
HFC +HFO Blends in LTC	R515A	R513A	R454B	R454C	R449A
First Law Cascaded Efficiency $COP_{\_Cascade}$	0.4725	0.4751	0.4585	0.4366	0.4363
Exergy Destruction Ratio($EDR_{\_Cascade}$)	2.371	2.352	2.474	2.648	2.650
Cascaded Exergetic Efficiency	0.2967	0.2943	0.2879	0.2741	0.2740
Exergy of Fuel "kW"	74.43	74.02	76.70	80.56	80.60
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.8317	0.8286	0.8489	0.8782	0.8785
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.1413	0.2183	0.2021
$Q_{\_Cond\_HTC}$ "kW"	109.6	109.2	111.9	115.7	115.80
$Q_{\_Cond\_LTC}$ "kW"	58.16	57.95	59.38	61.43	61.44
$Q_{\_Eva\_HTC}$ "kW"	58.16	57.95	59.38	61.43	61.44
$Q_{\_Eva\_LTC}$ "kW"	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.453	1.340	1.338
First Law HTC Efficiency $COP_{\_HTC}$	1.131	1.131	1.131	1.131	1.131
HTCExergy 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"	51.43	51.24	52.50	54.31	54.33
HTC Exergy of Product "kW"	13.16	13.11	13.43	13.89	13.90
$W_{\_comp\_HTC}$ "kW"	51.43	51.24	52.50	54.31	54.33
$W_{\_comp\_LTC}$ "kW"	23.0	22.78	24.20	26.25	26.27

2.7 Optimum thermodynamic performances of vapour compression refrigeration system using low GWP ecofriendly HFC+HFO refrigerants in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in ultra-low temperature

Table-7 shows the comparison of first law efficiency (COPCascade) and exergetic efficiency of cascaded vapour compression refrigeration systems using following (HFC +HFO Blends) in high temperature cycle and following HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R452B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R452A in high temperature cycle and R513A in low temperature cycle gives lower first law efficiency (COP_Cascade) and exergetic efficiency and higher exergy destruction ratio. The thermodynamic performances using R452B and R515 in high temperature cycle and R513A in low temperature cycle gives slightly lower thermodynamic performances than using R454B in higher temperature cycle and R513A in the low temperature cycle.

Table 6(i): Effect of HFC+HFO blends on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R-452B (HFC+HFO blends) in higher temperature cycle using ecofriendly following HFC+HFO blends in 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%,

Effect of HFC +HFO Blends in VCRS	System-36	System37	System38	System39	System40
HFC +HFO Blends in HTC	R452B	R452B	R452B	R452B	R452B
HFC +HFO Blends in LTC	R515A	R513A	R454B	R454C	R449A
First Law Cascaded Efficiency COP_ Cascade	0.5609	0.5642	0.5433	0.5159	0.5156
Exergy Destruction Ratio(EDR_ Cascade)	1.839	1.823	1.931	2.087	2.089
Cascaded Exergetic Efficiency	0.3522	0.3542	0.3411	0.3239	0.3237
Exergy of Fuel “kW”	62.70	62.34	64.73	68.17	68.21
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.3618	0.3605	0.3693	0.3820	0.3822
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.1413	0.2184	0.2021
Q_Cond_HTC “kW”	97.87	97.50	99.89	103.3	103.40
Q_Cond_LTC “kW”	58.16	57.95	59.37	61.42	61.44
Q_Eva_HTC “kW”	58.16	57.95	59.37	61.42	61.44
Q_Eva_LTC “kW”	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.453	1.340	1.338
First Law HTC Efficiency COP_ HTC	1.465	1.465	1.465	1.465	1.465
HTCExergy Destruction Ratio(EDR_HTC)	2.017	2.017	2.017	2.017	2.017
HTC Exergetic Efficiency	0.3314	0.3314	0.3314	0.3314	0.3314
HTC Exergy of Fuel “kW”	39.70	39.55	40.52	41.92	41.94
HTC Exergy of Product “kW”	13.16	13.11	13.43	13.89	13.90
W_comp _HTC“kW”	39.70	39.55	40.52	41.92	41.94
W_comp_LTC “kW”	23.0	22.78	24.20	26.25	26.27

Table-7 optimum system’s thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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%,

Effect of HFC +HFO Blends in VCRS	System 1	System 6	System 10	System 14	System 17	System 22	System 27	System 32	System 37
HFC +HFO Blends in HTC	R513A	R454B	R449A	R454C	R515A	R448A	R450A	R452A	R452B
HFC +HFO Blends in LTC	R515A	R513A	R513A	R513A	R513A	R513A	R513A	R513A	R513A
First Law Cascaded Efficiency COP_ Cascade	0.540	0.5652	5219	0.4981	0.5610	0.5342	0.5524	0.4751	0.5642
Exergy Destruction Ratio(EDR_ Cascade)	1.949	1.818	2.052	2.197	1.839	1.981	1.883	2.352	1.823
Cascaded Exergetic Efficiency	0.3391	0.3549	0.3277	0.3128	0.3522	0.3355	0.3468	0.2943	0.3542
Exergy of Fuel “kW”	65.12	62.23	67.38	70.60	62.69	65.85	63.66	74.02	62.34
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6755	0.3557	0.5478	0.6133	0.6395	0.5174	0.6067	0.8286	0.3605
LTC Mass flow Rate (Kg/sec)	0.2541	0.2440	0.2440	0.2440	0.2440	0.2440	0.2440	0.2440	0.2440
Q_Cond_HTC “kW”	100.30	97.39	102.5	105.8	97.86	101.0	98.83	109.2	97.50
Q_Cond_LTC “kW”	58.16	57.95	57.95	57.95	57.95	57.95	57.95	57.95	57.95
Q_Eva_HTC “kW”	58.16	57.95	57.95	57.95	57.95	57.95	57.95	57.95	57.95
Q_Eva_LTC “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.529	1.544	1.544	1.544	1.544	1.544	1.544	1.544	1.544
First Law HTC Efficiency COP_ HTC	1.381	1.469	1.299	1.212	1.452	1.346	1.417	1.131	1.465
HTCExergy Destruction Ratio(EDR_HTC)	2.202	2.009	2.402	2.648	2.045	2.284	2.119	2.909	2.017
HTC Exergetic Efficiency	0.3123	0.3323	0.2939	0.2741	0.3285	0.3045	0.3206	0.2558	0.3314
HTC Exergy of Fuel “kW”	42.12	39.44	44.60	47.82	39.39	43.04	40.88	51.24	39.55
HTC Exergy of Product “kW”	13.16	13.11	13.11	13.11	13.11	13.11	13.11	13.11	13.11
W_comp _HTC“kW”	42.12	39.44	44.60	47.82	39.39	43.04	40.88	51.24	39.55
W_comp_LTC “kW”	23.0	22.78	22.78	22.78	22.78	22.78	22.78	22.78	22.78

2.8 Effect of HTC condenser temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in low temperature cycle

Table-8 shows the variation of HTC condenser temperature on the thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R513A refrigerant in the low temperature cycle(LTC) and ecofriendly low GWP R454B refrigerant in the high temperature cycle (HTC) and it was found that when condenser temperature is increasing, the system first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is decreasing while exergy of fuel (i.e. total compressor work of both compressors is increasing. Similarly, the percentage improvement in the exergetic efficiency is increasing when condenser temperature is increasing from 45ºC to 60ºC**.**

Table 8: Effect of HTC condenser temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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%,

HTC condenser temperature (ºC)	60	55	50	45	40	35	30
First Law Cascaded Efficiency $COP_{\_ Cascade}$	0.4784	0.5224	0.5652	0.6076	0.6503	0.6936	0.7381
Exergy Destruction Ratio($EDR_{\_ Cascade}$)	2.329	2.049	1.818	1.621	1.449	1.296	1.158
Cascaded Exergetic Efficiency	0.3004	0.3280	0.3549	0.3815	0.4083	0.4355	0.4635
Exergy of Fuel “kW”	73.51	67.32	62.23	57.88	54.08	50.7	47.65
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08	22.08	22.08
%improvement in exergetic efficiency(%)	16.254	11.451	6.801	2.142	-2.507	-7.242	-12.08
HTC Mass flow Rate (Kg/sec)	0.4150	0.3819	0.3557	0.3342	0.3160	0.3003	0.2866
LTC Mass flow Rate (Kg/sec)	0.2440	0.2440	0.2440	0.2440	0.2440	0.2440	0.2440
$Q_{\_Cond\_HTC}$ “kW”	108.7	102.5	97.39	93.05	89.25	85.87	82.81
$Q_{\_Cond\_LTC}$ “kW”	57.95	57.95	57.95	57.95	57.95	57.95	57.95
$Q_{\_Eva\_HTC}$ “kW”	57.95	57.95	57.95	57.95	57.95	57.95	57.95
$Q_{\_Eva\_LTC}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency $COP_{\_LTC}$	1.544	1.544	1.544	1.544	1.544	1.544	1.544
First Law HTC Efficiency $COP_{\_ HTC}$	1.142	1.301	1.469	1.651	1.852	2.076	2.331
HTCExergy Destruction Ratio($EDR_{\_HTC}$)	2.87	2.398	2.009	1.677	1.388	1.13	0.8968
HTC Exergetic Efficiency	0.2584	0.2943	0.3323	0.3735	0.4188	0.4695	0.5272
HTC Exergy of Fuel “kW”	50.73	44.54	39.44	35.10	31.3	27.92	24.86
HTC Exergy of Product “kW”	13.11	13.11	13.11	13.11	13.11	13.11	13.11
$W_{\_comp\ \_HTC}$“kW”	50.73	44.54	39.44	35.10	31.3	27.92	24.86
$W_{\_comp\_LTC}$ “kW”	22.78	22.78	22.78	22.78	22.78	22.78	22.78

2.9 Effect of temperature overlapping on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in low temperature cycle

Table-9 shows the variation of temperature overlapping (i.e.approach= LTC condenser temperature – HTC evaporator temperature) on the thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R513A refrigerant in the low temperature cycle(LTC) and ecofriendly low GWP R454B refrigerant in the high temperature cycle (HTC) and it was found that when temperature overlapping is increasing, the system first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is decreasing while exergy of fuel (i.e. total compressor work of both compressors is increasing. Similarly, the percentage improvement in the exergetic efficiency is decreasing when temperature overlapping is increasing from 0ºC to 15ºC.

Table 9: Effect of temperature overlapping on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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%,

Temperature overlapping (ºC)	0	3	4	5	6	8	9	10	12	15
First Law Cascaded Efficiency $COP_{\_ Cascade}$	0.6404	0.6169	0.6093	0.6017	0.5943	0.5795	0.5723	0.565	0.551	0.5304
Exergy Destruction Ratio($EDR_{\_ Cascade}$)	1.487	1.581	1.614	1.647	1.680	1.748	1.783	1.818	1.89	2.003
Cascaded Exergetic Efficiency	0.4021	0.3874	0.3826	0.3778	0.3731	0.3639	0.3594	0.354	0.346	0.3330
Exergy of Fuel “kW”	54.91	57.0	57.72	58.44	59.18	60.68	61.45	62.23	66.30	63.82
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08

%improvement in exergetic efficiency(%)	21.0	16.58	15.137	13.692	12.28	9.5095	8.1553	6.801	4.123	0.210
HTC Mass flow Rate (Kg/sec)	0.3290	0.3366	0.3393	0.3419	0.3446	0.3501	0.3529	0.355	0.361	0.3706
LTC Mass flow Rate (Kg/sec)	0.2246	0.2301	0.2319	0.2339	0.2358	0.2398	0.2419	0.244	0.255	0.2484
Q_{Cond_HTC} "kW"	90.08	92.17	92.89	93.61	94.35	95.85	96.61	97.39	98.99	101.5
Q_{Cond_LTC} "kW"	53.60	54.84	55.27	55.7	56.04	57.03	57.49	57.95	58.9	60.37
Q_{Eva_HTC} "kW"	53.60	54.84	55.27	55.7	56.14	57.03	57.49	57.95	58.9	60.37
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.16	35.16	35.167
First Law LTC Efficiency COP_{LTC}	1.908	1.787	1.750	1.713	1.677	1.609	1.576	1.544	1.482	1.395
First Law HTC Efficiency COP_{HTC}	1.469	1.469	1.469	1.469	1.469	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	2.009	2.009	2.009	2.009	2.009
HTC Exergetic Efficiency	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.332	0.332	0.3323
HTC Exergy of Fuel "kW"	36.48	37.33	37.62	37.91	38.21	38.82	39.13	39.44	40.09	41.09
HTC Exergy of Product "kW"	12.12	12.41	12.50	12.60	12.90	12.12	12.12	13.11	13.32	13.66
W_{comp_HTC}"kW"	36.48	37.33	37.62	37.91	38.21	38.82	39.13	39.44	40.09	41.09
W_{comp_LTC} "kW"	18.43	19.67	20.10	20.53	20.97	21.86	22.32	22.78	23.73	25.21

2.10 Effect of HTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in low GWP refrigerant in low temperature cycle

Table-10(a) and Table-10(b) show the variation of HTC evaporator temperature on the thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R513A refrigerant in the low temperature cycle(LTC) and ecofriendly low GWP R454B refrigerant in the high temperature cycle (HTC) and it was found that when HTC evaporator temperature is increasing, the system first law (energy) performance ($COP\_{cascade}$) and exergetic performance is increasing and reaching to the -24°C optimum value of HTC evaporator and then decreasing while exergy of fuel (i.e. total compressor work of both compressors is decreasing lowest electrical energy consumption till 24°C and then increasing. Similarly, the percentage improvement in the exergetic efficiency is decreasing when HTC evaporator temperature is increasing

Table 10 (a) : Effect of HTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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%,

HTC Evaporator temperature (°C)	-30	-28	-27	-26	-25	-24	-23	-22	-21	-20
First Law Cascaded Efficiency $COP\_{Cascade}$	0.5652	0.566	0.566	0.566	0.567	0.567	0.567	0.566	0.5664	0.5659
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.818	1.813	1.811	1.809	1.809	1.809	1.809	1.810	1.812	1.809
Cascaded Exergetic Efficiency	0.3549	0.355	0.355	0.356	0.356	0.356	0.356	0.355	0.3555	0.3554
Exergy of Fuel "kW"	62.23	62.10	62.06	62.03	62.02	62.03	62.03	62.05	62.09	62.14
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
%improvement in exergetic efficiency(%)	6.801	7.173	7.363	7.553	7.716	7.942	8.141	8.374	8.55	8.851
HTC Mass flow Rate (Kg/sec)	0.3557	0.359	0.361	0.363	0.365	0.367	0.369	0.371	0.3735	0.3758
LTC Mass flow Rate (Kg/sec)	0.2440	0.248	0.250	0.252	0.255	0.257	0.260	0.262	0.2651	0.2677
Q_{Cond_HTC} "kW"	97.39	97.27	97.23	97.20	97.19	97.18	97.19	97.22	97.26	97.31
Q_{Cond_LTC} "kW"	57.95	68.90	59.38	59.87	60.37	60.88	61.40	61.93	62.46	63.0
Q_{Eva_HTC} "kW"	57.95	60.90	59.38	59.87	60.37	60.88	61.40	61.93	62.46	63.0
Q_{Eva_LTC} "kW"	35.167	35.16	35.16	35.16	35.16	35.16	35.16	35.16	35.167	35.167
First Law LTC Efficiency COP_{LTC}	1.544	1.482	1.452	1.423	1.395	1.368	1.341	1.314	1.288	1.263
First Law HTC Efficiency COP_{HTC}	1.469	1.535	1.569	1.604	1.640	1.677	1.715	1.755	1.795	1.837
HTCExergy Destruction Ratio(EDR_{HTC})	2.009	2.014	2.017	2.021	2.026	2.032	2.038	2.045	2.054	2.063
HTC Exergetic Efficiency	0.3323	0.331	0.331	0.331	0.330	0.329	0.329	0.328	0.3275	0.3265
HTC Exergy of Fuel "kW"	39.44	38.37	37.85	37.33	36.81	36.30	35.79	35.29	34.79	34.30
HTC Exergy of Product "kW"	13.11	12.73	12.54	12.36	12.16	11.97	11.78	11.59	11.39	11.20
W_{comp_HTC}"kW"	39.44	38.37	37.85	37.33	36.81	36.30	35.79	35.29	34.79	34.30
W_{comp_LTC} "kW"	22.78	23.73	24.21	27.84	25.21	25.72	26.23	26.76	27.29	27.84

Table 10 (b): Effect of HTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends in higher temperature cycle using ecofriendly HFC+HFO blends in 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%,

HTC Evaporator temperature (ºC)	-30	-26	-25	-24	-20	-19	-18	-17	-16	-15	-10
First Law Cascaded COP_ Cascade	0.5652	0.566	0.567	0.567	0.565	0.565	0.564	0.563	0.562	0.562	0.554
Exergy Destruction Ratio(EDR_ Cascade)	1.818	1.809	1.809	1.809	1.809	1.817	1.821	1.825	1.830	1.836	1.874
Cascaded Exergetic Efficiency	0.3549	0.356	0.356	0.356	0.355	0.355	0.354	0.354	0.353	0.3527	0.347
Exergy of Fuel "kW"	62.23	62.03	62.02	62.03	62.14	62.21	62.28	62.38	62.49	62.61	63.47
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
%improvement in exergetic efficiency(%)	6.801	7.553	7.716	7.942	8.851	9.097	9.346	9.631	9.922	10.22	12.15
HTC Mass flow Rate (Kg/sec)	0.3557	0.363	0.365	0.367	0.375	0.378	0.375	0.375	0.375	0.3877	0.401
LTC Mass flow Rate (Kg/sec)	0.2440	0.252	0.255	0.257	0.267	0.270	0.267	0.267	0.267	0.2816	0.297
Q_Cond_HTC "kW"	97.39	97.20	97.19	97.18	97.31	97.37	97.45	97.55	97.65	97.65	98.64
Q_Cond_LTC "kW"	57.95	59.87	60.37	60.88	63.0	63.56	64.12	64.70	65.28	65.88	63.47
Q_Eva_HTC "kW"	57.95	59.87	60.37	60.88	63.0	63.56	64.12	64.70	65.28	65.88	63.47
Q_Eva_LTC "kW"	35.167	35.16	35.16	35.16	35.16	35.16	35.16	35.16	35.16	35.167	35.16
First Law LTC Efficiency COP_LTC	1.544	1.423	1.395	1.368	1.263	1.239	1.215	1.191	1.168	1.145	1.038
First Law HTC Efficiency COP_ HTC	1.469	1.604	1.64	1.677	1.837	1.880	1.924	1.969	2.016	2.065	2.333
HTCExergy Destruction Ratio(EDR_HTC)	2.009	2.021	2.026	2.032	2.063	2.073	2.084	2.097	2.110	2.125	2.223
HTC Exergetic Efficiency	0.3323	0.331	0.330	0.329	0.326	0.325	0.324	0.322	0.321	0.320	0.310
HTC Exergy of Fuel "kW"	39.44	37.33	36.81	36.30	34.30	33.81	33.33	32.85	32.37	31.90	29.60
HTC Exergy of Product "kW"	13.11	12.36	12.16	11.97	11.20	11.0	10.81	10.61	10.41	10.21	9.182
W_comp _HTC"kW"	39.44	37.33	36.81	36.30	34.30	33.81	33.33	32.85	32.37	31.90	29.60
W_comp_LTC "kW"	22.78	24.74	25.21	25.72	27.84	28.39	28.95	29.53	30.11	30.71	33.87

2.11 Effect of LTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly R454B of low GWP HFC+HFO blends in higher temperature cycle using ecofriendly of R513A (using HFC+HFO blends) in low GWP refrigerant in low temperature cycle

Table-11(a) and Table-11(b) show the variation of LTC evaporator temperature on the thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R513A refrigerant in the low temperature cycle(LTC) and ecofriendly low GWP R454B refrigerant in the low temperature cycle (LTC) and it was found that when LTC evaporator temperature is increasing, the system first law (energy) performance ($COP_{\_cascade}$) and exergetic performance is increasing and reaching to the -77ºC to -80ºc optimum value of LTC evaporator and then decreasing while exergy of fuel (i.e. total compressor work of both compressors is first decreasing and reaching to a optimum value and then increasing Similarly the percentage improvement in the exergetic efficiency is increasing when HTC evaporator temperature is increasing and reaching to a maximum (optimum) and then decreasing.

Table 11(a): Effect of LTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly R454B of low GWP HFC+HFO blends in higher temperature cycle using ecofriendly of R513A (using HFC+HFO blends) in 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%,

LTC Evaporator temperature (ºC)	-81	-80	-79	-78	-77	-76	-75
First Law Cascaded Efficiency COP_ Cascade	0.6487	0.6585	0.6684	0.6783	0.6884	0.6986	0.7089
Exergy Destruction Ratio(EDR_ Cascade)	1.794	1.794	1.793	1.793	1.793	1.794	1.795
Cascaded Exergetic Efficiency	0.3579	0.3580	0.3580	0.3580	0.3580	0.3579	0.3577
Exergy of Fuel "kW"	54.21	53.40	52.62	51.84	51.08	50.34	49.61
Exergy of Product "kW"	19.40	19.12	18.84	18.56	18.29	18.02	17.75
%improvement in exergetic efficiency(%)	7.704	7.734	7.734	7.734	7.734	7.704	7.6437
HTC Mass flow Rate (Kg/sec)	0.3264	0.3285	0.3150	0.3118	0.3150	0.3123	0.3096
LTC Mass flow Rate (Kg/sec)	0.2349	0.2339	0.2301	0.2320	0.2310	0.2301	0.2291
Q_Cond_HTC "kW"	89..38	88.57	86.25	87.01	86.25	85.51	84.78
Q_Cond_LTC "kW"	53.18	52.70	51.32	51.77	51.32	50.88	50.44
Q_Eva_HTC "kW"	53.18	52.70	51.32	51.77	51.32	50.88	50.44
Q_Eva_LTC "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.952	2.006	2.177	2.118	2.177	2.238	2.302
First Law HTC Efficiency COP_ HTC	1.469	1.469	1.469	1.469	1.469	1.469	1.469
HTCExergy Destruction Ratio(EDR_HTC)	2.009	2.009	2.009	2.009	2.009	2.009	2.009

HTC Exergetic Efficiency	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323
HTC Exergy of Fuel "kW"	36.20	35.87	34.93	35.24	34.93	34.63	34.33
HTC Exergy of Product "kW"	12.03	11.92	11.61	11.71	11.61	11.51	11.41
W_{comp_HTC} "kW"	36.20	37.57	34.93	35.24	34.93	34.63	35.87
W_{comp_LTC} "kW"	18.01	17.59	16.15	16.60	15.61	15.71	0.7089

Table 11(b): Effect of LTC evaporator temperature on thermodynamic performances of vapour compression refrigeration system using ecofriendly R454B of low GWP HFC+HFO blends in higher temperature cycle using ecofriendly of R513A (using HFC+HFO blends) in 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%,

LTC Evaporator temperature (°C)	-95	-90	-85	-80	-75	-70	-65	-60	-55	-50
First Law Cascaded Eff $COP\_{Cascade}$	0.5220	0.5652	0.6106	0.6585	0.7089	0.7619	0.8176	0.8762	0.9379	1.003
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.844	1.818	1.801	1.794	1.795	1.807	1.829	1.862	1.907	1.967
Cascaded Exergetic Efficiency	0.3516	0.3549	0.3570	0.3580	0.3577	0.3563	0.3535	0.3494	0.3439	0.3370
Exergy of Fuel "kW"	67.37	62.23	57.59	53.40	49.61	46.16	43.01	40.13	35.50	35.07
Exergy of Product "kW"	23.69	22.08	20.56	19.12	17.75	16.45	15.21	14.02	12.90	11.82
% improvement in exergetic eff (%)	5.808	6.801	7.433	7.734	7.6437	7.22	6.379	5.146	3.4908	1.414
HTC Mass flow Rate (Kg/sec)	0.3745	0.3557	0.3388	0.3285	0.3096	0.2970	0.2856	0.2750	0.2654	0.2565
LTC Mass flow Rate (Kg/sec)	0.2493	0.2440	0.2389	0.2339	0.2291	0.2245	0.2220	0.2156	0.2114	0.2074
Q_{Cond_HTC} "kW"	102.5	97.39	92.76	88.57	84.78	81.33	78.18	75.30	72.66	70.24
Q_{Cond_LTC} "kW"	61.01	57.95	57.59	52.70	50.44	48.39	46.52	44.80	43.23	41.79
Q_{Eva_HTC} "kW"	61.01	57.95	57.59	52.70	50.44	48.39	46.52	44.80	43.23	41.79
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_{LTC}	1.361	1.544	1.756	2.006	2.302	2.660	3.098	3.649	4.359	5.308
First Law HTC Efficiency COP_{HTC}	1.469	1.469	1.469	1.469	1.469	1.469	1.469	1.469	1.469	1.469
HTCExergy Destruction Ratio(EDR_{HTC})	2.009	2.009	2.009	2.009	2.009	2.009	2.009	2.009	2.009	2.009
HTC Exergetic Efficiency	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323	0.3323
HTC Exergy of Fuel "kW"	41.63	39.44	37.57	35.87	34.33	32.94	31.66	30.50	29.43	28.45
HTC Exergy of Product "kW"	13.80	13.11	12.48	11.92	11.41	10.95	10.52	10.13	9.78	6.625
W_{comp_HTC} "kW"	41.63	41.63	39.44	37.57	35.87	34.33	32.94	31.66	30.50	29.43
W_{comp_LTC} "kW"	25.85	22.78	20.56	17.59	15.28	13.22	11.35	9.638	8.068	6.625

3. Conclusions

Following Conclusions were drawn from present investigation

- The first law efficiency (COP) of vapour compression refrigeration systems using eight HFC +HFO Blends, at dead state temperature of 313K (40°C) the R515A gives highest first law efficiency(COP) and exergetic efficiency with lowest exergy destruction ratio
- By increasing the condenser temperature, the first law efficiency (COP) and exergetic efficiency decreases while exergy destruction ratio(EDR) of vapour compression refrigeration systems is increases. Similarly, compressor work in form of exergy of input and heat rejected by the condenser increased. The exergy destruction in compressor and evaporator decreased while exergy destruction in condenser and expansion (throttle) valve and mass flow rate increased.
- By increasing dead state temperature, the second law efficiency and exergetic efficiency is increased in the vapour compression refrigeration systems while first law efficiency (COP). does not affect
- By increasing the evaporator temperature of vapour compression refrigeration systems, the first law efficiency (COP) and exergy destruction ratio(EDR) increased while the exergetic efficiency is decreased.
- The compressor work in form of exergy of input and heat rejected by the condenser is decreases, when evaporator temperature is increases in the the vapour compression refrigeration systems.
- The exergy destruction in compressor and evaporator increased by increasing evaporator temperature in the vapour compression refrigeration systems
- The exergy destruction in condenser and expansion (throttle) valve (both) and mass flow rate is decreased by increasing evaporator temperature in the vapour compression refrigeration systems
- By increasing dead state temperature, the second law efficiency and exergetic efficiency in the vapour compression refrigeration systems is increasedwhile first law efficiency (COP) remains same (i.e. does not affect)
- The first law efficiency ($COP_{Cascade}$) of cascaded vapour compression refrigeration systems using HFC +HFO Blends in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio
- The thermodynamic performances using R452B and R515 in high temperature cycle and R513A in low

temperature cycle gives slightly lower thermodynamic performances than using R454B in higher temperature cycle and R513A in the low temperature cycle

- The cascaded vapour compression refrigeration systems using R454B in high temperature cycle and R454C in low temperature cycle gives lower first law efficiency ($COP_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

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