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ORIGINAL ARTICLE

Thermodynamic analysis of vapour compression refrigeration systems using HFO+HFC blends low temperature applications

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Abstract

As a result of environmental problems related to global warming and depletion of the ozone layer caused by the use of synthetic refrigerants (CFC's, HCFC's and HFC's) knowledgeable over the last decades, the return to the use of HFO+HFC blends for refrigeration and air conditioning systems are necessary. It must be a better solution to use environmentally harmless HFO+HFC blends as alternatives refrigerants in the vapour compression refrigeration systems. 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 -30° and condenser temperature of 50°C at 80% of compressor efficiency. 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° 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.

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.
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 maximize system performance. Synthetic refrigerants prominently 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 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,

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Lorentzen and Petterson [1] 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 [2-3]. 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. Regarding 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. 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 -80 °C are required to freeze and store blood and for precipitation hardening of special alloy steels, temperatures as low as -90°C are required. To obtain such low temperature by conventional system as mentioned earlier becomes difficult because of extremely low evaporator pressures. R.S. Mishra [4] 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 COPsystem 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.

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 of HFC+HFO blends used in cascade 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

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.

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$_{cond}$=50°C, T_ambient=25°C, T$_{Eva_HTC}$=-30°C, T$_{Eva_LTC}$=-75°C, 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	0.3314	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”	0.7955	0.7086	0.6251	0.5449	0.4677	0.3934	0.3215
Second Law Efficiency	0.4820	0.4943	0.5064	0.5182	0.5296	0.5408	0.5517
Mass flow Rate (Kg/sec)	0.02188	0.02152	0.02120	0.02091	0.02064	0.0204	0.02019
Q$_{Cond_HTC}$ “kW”	5.917	5.667	5.437	5.226	5.031	4.850	4.683
Q$_{Eva_LTC}$ “kW”	3.5167	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

Table-2(b) 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$_{cond}$=50°C, T_ambient=2°°C, T$_{Eva_HTC}$=-30°C , T$_{Eva_LTC}$=-75°C, 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 VCRS using ecofriendly low GWP R515 refrigerants (HFC+HFO blends) using ecofriendly HFC+HFO blends (Q_Eva$_{LTC}$=35.167 kW, T$_{cond}$=50°C, T_ambient=25°C, T$_{Eva_HTC}$=-30°C, T$_{Eva_LTC}$=-75°C, 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	0.4241
Second Law Efficiency	0.4778	0.4967	0.5154	0.5339	0.5521	0.5701	0.5879
Mass flow Rate (Kg/sec)	0.03881	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

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.

Table-2(d) Effect of HFC+HFO blends on thermodynamic performances VCRS using low GWP R513B refrigerants 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=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	0.533	0.5521	0.5701	0.5879
Mass flow Rate (Kg/sec)	0.0388	0.0373	0.0359	0.0347	0.0325	0.0324	0.0314
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	3.516	3.5167	3.5167	3.516

Table-3(a) Effect of condenser temperature in VCRS using *on thermodynamic performances of vapour compression refrigeration system using 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

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 (40°C) 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-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, $T_{\_cond}$=50°C, T_ambient=25°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
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 VCRS 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 VCRS 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%

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

Table-5(a) Effect of HFC+HFO blends on thermodynamic performances of VCRS 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

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(b) Effect of HFC+HFO blends on thermodynamic performances of VCRS using low GWP 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}=-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

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^{o}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 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 increased while 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 R515A in low temperature cycle gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio
- 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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