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ORIGINAL ARTICLE

Thermodynamic performances of VCRS using low GWP blends of HFC+HFO refrigerants in higher temperature cycle using blends of HFC+HFO refrigerants in low GWP refrigerant in low temperature cycle

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Abstract

Several alternatives are available in the literature for using HFC blends which for causing higher global warming potential without ozone depletion for replacing CFC refrigerants also have ultra-high global warming potential with ozone depletion. In this paper, thermodynamic energy-exergy performances of cascaded vapor compression refrigeration system for the ultra-low applications using eco-friendly low global warming potential GWP blends of HFC+HFO refrigerants in higher temperature cycle in the temperature range of 50°C to -30°C and also using blends of HFC+HFO refrigerants in low GWP in the low-temperature cycle have been investigated. It was observed that System44 gives the highest thermodynamic first and second law performances. The lowest thermodynamic performances were observed by using eco-friendly low GWP R452A refrigerants in higher temperature cycles using eco-friendly R448A low GWP refrigerant in low-temperature cycles in the cascaded of vapor compression refrigeration (system 41).

1. Introduction

In current decades many countries have rewarded more consideration to environmental pollution caused by various kinds of fuels and CFCs. Burning fossil fuels cause water vapor (H_2O), carbon dioxide (CO_2), methane (CH4), sulfur dioxide (SO_2) in the atmosphere to absorb radiation, leading to increased global warming. In addition, gases emitted from several industries especially containing perfluorocarbons (PFC) derivatives such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFCs), methane (CH_4), sulfur hexafluoride (SF6), etc. have also led to a more serious increase in global warming. The occurrence of gas in an atmosphere that absorbs and emits radiation within the thermal infrared range is called a greenhouse gas (GHG), whereas the comparative measure of how much heat a GHG traps in the atmosphere is defined as the Global Warming Potential (GWP). It compared the amount of heat trapped to the amount of heat trapped by CO_2. GHGs act as a blanket of solar radiation on the earth's surface, thus making the average global temperature increase. It can be fulfilled that the more GHGs produced, the higher the average global temperature. CFCs and HCFCs used by conventional refrigeration systems not only have a global warming potential (GWP) but also have a high value of ozone-depleting potential (ODP). biomedical specimens, it is necessary to achieve a storage temperature of around -80°C [1-2]. Cascade refrigeration is a method of refrigeration used to achieve temperatures below -40°C. J.Alberto Dopazo and Jose Fernandez-seara [3]designed developed a prototype of a

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cascade refrigeration system using NH3 and CO2 as refrigerants used to supply a 9 kW refrigeration capacity horizontal plate freezer at an evaporating temperature of −50 C and performed several experimental tests by fixing four CO_2 evaporating temperatures and found the influence of the operating parameters on the cascade system's performance. Nasruddin et al., [4] carried out the simulation studies a mixture of carbon dioxide and ethane can achieve the minimum temperature of -80° C of a mixture of carbon dioxide and methane is a promising alternative refrigerant. Alhamid, M et al., [5] found. the best performance using carbon dioxide and propane as compared to R410a and R134a, whereas R744 (CO_2) is inflammable and a green refrigerant described thermodynamic analysis of cascade refrigeration system with huge refrigerant sinking CFC, HCFC, HFC, HFC, and HFO refrigerants, etc. and optimizations conducted for such refrigerants. A huge number of refrigerants have been examined in a cascade system for determining the appropriate combination of refrigerants in high temperature and low-temperature cycle circuits of refrigerants however the trends show that the HFO refrigerants a natural refrigerant is gaining more importance due to environmental conditions few natural refrigerants [3].

Exergy analysis is a useful way for determining the real thermodynamic losses and optimizing environmental and economic performance in the systems such as vapor compression refrigeration systems (VCRS). Alptunganbaba et.al.[7] carried out exergy analysis of two evaporator VCRS using R1234yf, R1234ze, and R134a as refrigerants. In the calculation of losses occurring in different system components, besides the exergy efficiency of the refrigeration cycle and developed a computer code by using EES-V9.172-3D software package program and computed the effect of evaporator and condenser temperatures on the exergy destruction and exergy efficiency of the system using HFO-1234yf and HFO1234ze, which are good alternatives to R134a concerning their environmentally friendly properties. By cascading more than two VCR stages Mishra R.S. [8] numerically computed thermodynamic performances by using evaporator temperature in the low-temperature cycle in the range of -145°C to -155°C by using HFO-1336mzz(Z) and up to -160oC by using HFO-1225ye(Z) refrigerants and using hydrocarbons in LTC. The optimal cascade VCRS with multiple blended refrigerants and multiple temperature levels presents considerable challenges and systematic studies are still lacking. In this paper, the optimal HFO +HFC blends of such cascaded VCRSs to maximize the energy & exergy efficiencies have been presented.

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2. Use of HFC+HFO Blends in Cascaded VCRS

Cascaded VCRSs are very important to chemical/petrochemical process industries for the reason that their thermodynamic performances are closely related to product quality, and plant profitability previously. Adrián Mota-Babiloni [9] carried out analysis of the feasibility of R454C and R455A, two new low global warming potential (GWP of 148) refrigerants, in VCRSs as alternatives to R404A for warm countries and found that the R454C and R455A will be the most viable low GWP options to perform a direct replacement of R404A due to similar uniqueness and found experimental results show that the cooling capacity of the replacements is slightly lower than R404A, being the Coefficient of Performance (COP) of the new mixtures 10–15% higher than that of R404A, especially at higher condensation. The thermodynamic energy& exergy performances of vapor compression using nine blends have also been investigated in this paper.

3. Results and Discussion

Following Cascaded vapor compression refrigeration have been considered for numerical computations.

System-1: Cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System-2: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 3: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T_{\_cond}$=50ºC, T_ambient =25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor efficiency$_{_HTC}$ =80%, Compressor efficiency$_{_LTC}$=80%.

System-4: Cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%,

System-5: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-90ºC, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 6: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency$_{_HTC}$ =80%, Compressor efficiency$_{_LTC}$=80%.

System- 7: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System-8: Cascaded VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient=25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System-9: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 10: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System-11: Cascaded VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System-12: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 13: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency$_{_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 14: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-0^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%.

System- 15: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-90^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%,

System- 16: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva$_{_LTC}$=35.167 kW, T$_{_cond}$=50^{o}C, T_ambient= 25^{o}C, T$_{_Eva_HTC}$=-30^{o}C, T$_{_Eva_LTC}$=-0^{o}C, Temperature overlapping=10, Compressor efficiency $_{\_HTC}$=80%, Compressor efficiency$_{_LTC}$=80%,

Table-1(a)-Table-1(b) show the comparison of first law efficiency (COP$_{_Cascade}$) of cascaded VCRSs using HFC +HFO Blends in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRS-13 using R454B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRS-14 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. Although cascaded VCRS--1 using R450A in high temperature cycle and R513A in low temperature cycle gives slightly lower first law efficiency (COP$_{_Cascade}$) and exergetic efficiency and higher exergy destruction ratio than system-4.

Table-1(a) Thermodynamic performances of cascaded VCRS for ultra-low temperature using low GWP R450A refrigerants in higher temperature cycle using low GWP HFC+HFO blends in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-90ºC, temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%

Cascaded VCRS	System: 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8
HFC +HFO Blends in HTC	R450A	R450A	R450A	R450A	R448a	R448a	R448a	R448a
HFC +HFO Blends in LTC	R513A	R454B	R454C	R449a	R513A	R454B	R454C	R449a
First Law Cascaded Efficiency COP$_{Cascade}$	0.5524	0.5321	0.5053	0.5051	0.5342	0.5148	0.4892	0.4890
Cascade Exergy Destruction Ratio(EDR$_{Cascade}$)	1.883	1.993	2.184	2.153	1.981	2.094	2.256	2.257
Cascaded Exergetic Efficiency	0.3460	0.3341	0.3174	0.3172	0.3355	0.3232	0.3071	0.3070
Exergy of Fuel “kW”	63.66	66.09	69.58	69.62	65.83	68.32	71.89	71.91
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.6067	0.6216	0.6430	0.6432	0.5174	0.5301	0.5484	0.5485
LTC Mass flow Rate (Kg/sec)	0.2440	0.1413	0.2184	0.2021	0.2440	0.1413	0.2183	0.2021
W_{comp_HTC} “kW”	40.88	41.89	43.33	43.35	43.04	44.11	45.63	45.64
W_{comp_LTC} “kW”	22.78	24.20	26.25	26.25	22.78	24.21	26.25	26.27
Q_{Cond_HTC} “kW”	98.83	101.30	104.70	104.80	101.0	103.5	107.1	107.1
Q_{Cond_LTC} “kW”	57.95	59.37	61.42	61.44	57.95	59.38	61.43	61.44
Q_{Eva_HTC} “kW”	57.95	59.37	61.42	61.44	57.95	59.38	61.43	61.44
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.453	1.340	1.338	1.544	1.452	1.339	1.338
First Law HTC Efficiency COP$_{HTC}$	1.417	1.417	1.417	1.417	1.346	1.346	1.346	1.346
HTCExergy Destruction Ratio(EDR$_{HTC}$)	2.199	2.199	2.199	2.199	2.284	2.284	2.284	2.284
HTC Exergetic Efficiency	0.3206	0.3206	0.3206	0.3206	0.3045	0.3045	0.3045	0.3045
HTC Exergy of Fuel “kW”	40.88	41.89	43.33	43.35	43.04	44.11	45.63	45.64
HTC Exergy of Product “kW”	13.11	13.11	13.11	13.11	13.11	13.43	13.90	13.90

Table-1(b) Thermodynamic performances of VCRS for ultra-low temperature applications using low GWP R450A refrigerants in higher temperature cycle using low GWP HFC+HFO blends in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-90ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%

Cascaded VCRS	System: 9	System 10	System 11	System 12	System 13	System 14	System 15	System 16
HFC +HFO Blends in HTC	R452A	R452A	R452A	R452A	R452B	R452B	R452B	R452B
HFC +HFO Blends in LTC	R513A	R454B	R454C	R449A	R513A	R454B	R454C	R449a
First Law Cascaded Efficiency COP$_{Cascade}$	0.4751	0.4584	0.4364	0.4363	0.5642	0.5432	0.5157	0.5156
Cascade Exergy Destruction Ratio(EDR$_{Cascade}$)	2.352	2.474	2.649	2.650	1.823	1.932	2.088	2.089
Cascaded Exergetic Efficiency	0.2983	0.2878	0.274	0.2740	0.3542	0.3411	0.3238	0.3237
Exergy of Fuel “kW”	74.02	76.72	80.58	80.60	62.34	64.74	68.19	68.21
Exergy of Product “kW”	22.08	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.8286	0.8490	0.8784	0.8785	0.3605	0.3694	0.3821	0.3822
LTC Mass flow Rate (Kg/sec)	0.2440	0.1413	0.2183	0.2021	0.2440	0.1413	0.2183	0.2021
W_{comp_HTC} “kW”	51.24	52.50	54.32	54.33	39.55	40.53	41.93	41.94
W_{comp_LTC} “kW”	22.78	24.21	26.26	26.27	22.78	24.21	26.26	26.27
Q_{Cond_HTC} “kW”	109.2	111.9	115.7	115.8	97.5	99.91	103.4	103.4
Q_{Cond_LTC} “kW”	57.95	59.38	61.43	61.44	57.95	59.38	61.43	61.44
Q_{Eva_HTC} “kW”	57.95	59.38	61.43	61.44	57.95	59.38	61.43	61.44
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	1.544	1.452	1.339	1.338	1.544	1.452	1.339	1.338
First Law HTC Efficiency COP$_{HTC}$	1.131	1.131	1.131	1.131	1.465	1.465	1.465	1.465
HTCExergy Destruction Ratio(EDR$_{HTC}$)	2.352	2.352	2.352	2.352	2.017	2.017	2.017	2.017
HTC Exergetic Efficiency	0.2588	0.2588	0.2588	0.2588	0.3314	0.3314	0.3314	0.3314
HTC Exergy of Fuel “kW”	51.24	52.50	54.32	54.33	39.55	40.53	41.93	41.93
HTC Exergy of Product “kW”	13.11	13.11	13.90	13.90	13.11	13.43	13.90	13.90

System-17: Cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient= 25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-18: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System- 19: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10.

System-20: Cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R448A 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}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, compressor efficiency$_{LTC}$=80%.

System-21: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP 450A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%

System- 22: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP 450A refrigerants in higher temperature cycle using ecofriendly R452A 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}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System- 23: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP 450A refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency $\_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,

Table-2(a) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded VCRSs using R450A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRS using R450A in high temperature cycle and R513a in low temperature cycle (system-17) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRS (system-19) using R450A 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-2(a) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,

Cascaded VCRS	System: 17	System 18	System 19	System: 20	System 21	System 22	System 23
HFC +HFO Blends in HTC	R450A	R450A	R450A	R450A	R450A	R450A	R450A
HFC +HFO Blends in LTC	R513a	R454b	R454C	R448a	R449a	R452a	R452b
First Law Cascaded Efficiency $COP\_{Cascade}$	0.7425	0.7228	0.6791	0.6859	0.6885	0.6947	0.7350
Cascade Exergy Destruction Ratio ($EDR\_{Cascade}$)	1.680	1.959	2.149	2.118	2.106	2.078	1.909
Cascaded Exergetic Efficiency	0.3472	0.3380	0.3176	0.3208	0.3220	0.3248	0.3437
Exergy of Fuel "kW"	47.36	48.66	51.79	51.27	51.08	50.63	47.35
Exergy of Product "kW"	22.08	22.08	22.08	22.08	22.08	22.08	22.08
HTC Mass flow Rate (Kg/sec)	0.5066	0.5146	0.5338	0.5306	0.5294	0.5266	0.5096
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	0.2023	0.1888	0.1885	0.2461	0.1369
W_{comp_HTC} "kW"	34.12	34.67	35.97	35.76	35.57	35.49	34.64
W_{comp_LTC} "kW"	13.22	13.98	15.82	15.51	15.40	15.14	13.51
Q_{Cond_HTC} "kW"	82.53	83.82	86.95	86.44	86.24	85.79	83.01
Q_{Cond_LTC} "kW"	48.39	49.15	50.98	50.68	50.57	50.30	48.67
Q_{Eva_HTC} "kW"	48.39	49.15	50.98	50.68	50.57	50.30	48.67
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.223	2.267	2.284	2.323	2.604
First Law HTC Efficiency COP_{HTC}	1.417	1.417	1.417	1.417	1.417	1.417	1.417
HTCExergy Destruction Ratio(EDR_{HTC})	2.199	2.199	2.199	2.199	2.199	2.199	2.199
HTC Exergetic Efficiency	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206	0.3206
HTC Exergy of Fuel "kW"	34.14	34.67	36.97	35.76	35.57	35.49	34.34
HTC Exergy of Product "kW"	10.95	11.12	11.53	11.45	11.44	15.14	11.01

System-24: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R513a refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva$_{LTC}$=35.167 kW, T$_{cond}$=50ºC, T_ambient=25ºC, T$_{Eva_HTC}$=-30ºC, T$_{Eva_LTC}$=-75ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-25: Cascaded VCRS using ecofriendly low GWP R513A refrigerants in higher temperature cycle using ecofriendly low GWP R454C 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%.

System-26: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R513a refrigerants in higher temperature cycle using ecofriendly R448a 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%.

System-27: Cascaded VCRS using ecofriendly low GWP R513A refrigerants in higher temperature cycle using ecofriendly low GWP R449A 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%.

System-28: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R513a refrigerants in higher temperature cycle using ecofriendly R452a 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%.

System-29: Cascaded VCRS using ecofriendly low GWP R513A refrigerants in higher temperature cycle using ecofriendly low GWP R452A 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%.

Table-2(b) shows the comparison of first law efficiency (COP$_{Cascade}$) of cascaded VCRSs using R513A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R513A in high temperature cycle and R454B in low temperature cycle (System-29th) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R513A in high temperature cycle and R454C in low temperature cycle(system-25th) gives lower first law efficiency (COP$_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio

Table-2(b) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R513A *refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva$_{LTC}$=35.167 kW, T$_{cond}$=50ºC, T_ambient=25ºC, T$_{Eva_HTC}$=-30ºC T$_{Eva_LTC}$=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.*

Cascaded VCRS	System:24	System25	System:26	System27	System28	System29
HFC +HFO Blends in HTC	R513A	R513A	R513A	R513A	R513A	R513A
HFC +HFO Blends in LTC	R454B	R454C	R448a	R449a	R452a	R452b
First Law Cascaded Efficiency COP$_{Cascade}$	0.7093	0.6868	0.6735	0.6760	0.6820	0.7213
Cascade Exergy Destruction Ratio(EDR$_{Cascade}$)	2.015	2.207	2.175	2.163	2.136	1.965
Cascaded Exergetic Efficiency	0.3371	0.3118	0.3149	0.3161	0.3189	0.3373
Exergy of Fuel "kW"	49.58	52.74	52.22	52.02	51.57	48.76
Exergy of Product "kW"	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.5708	0.5921	0.5886	0.5873	0.5842	0.5653
LTC Mass flow Rate (Kg/sec)	0.1353	0.2023	0.1888	0.1885	0.2461	0.1359
W$_{comp_HTC}$"kW"	35.59	36.92	36.70	36.92	36.43	35.25
W$_{comp_LTC}$ "kW"	13.98	15.82	15.51	15.40	15.14	13.51
Q$_{Cond_HTC}$ "kW"	84.74	87.91	87.39	87.19	86.73	83.92
Q$_{Cond_LTC}$ "kW"	49.15	50.98	50.68	50.57	50.30	48.67
Q$_{Eva_HTC}$ "kW"	49.15	50.98	50.68	50.57	50.30	48.67
Q$_{Eva_LTC}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.515	2.283	2.267	2.284	2.323	2.604
First Law HTC Efficiency COP$_{HTC}$	1.381	1.381	1.381	1.381	1.381	1.381
HTCExergy Destruction Ratio(EDR$_{HTC}$)	2.202	2.202	2.202	2.202	2.202	2.202
HTC Exergetic Efficiency	0.3123	0.3123	0.3123	0.3123	0.3123	0.3123
HTC Exergy of Fuel "kW"	35.59	36.92	36.70	36.62	35.49	35.25
HTC Exergy of Product "kW"	11.12	11.53	11.46	11.44	15.14	11.01

System-30: Cascaded VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R513A 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}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-31: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R452A 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}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-32: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-33: Cascaded VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R448a 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}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-34: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-35: Cascaded VCRS using ecofriendly low GWP R454B refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient= 25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,

Table-2(c) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded VCRSs using R454B in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRS (system-30) using R454B in high temperature cycle and R513A in low temperature cycle gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R454B in high temperature cycle and R454C in low temperature cycle(system-31) gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(c) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454B *refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,*

Cascaded VCRS	System:30	System31	System:32	System33	System34	System35
HFC +HFO Blends in HTC	R454B	R454B	R454B	R454B	R454B	R454B
HFC +HFO Blends in LTC	R513a	R454C	R448a	R449a	R452a	R452b
First Law Cascaded Efficiency $COP\_{Cascade}$	0.7487	0.6845	0.6914	0.6941	0.7002	0.7411
Cascade Exergy Destruction Ratio($EDR\_{Cascade}$)	1.856	2.124	2.093	2.081	2.054	1.886
Cascaded Exergetic Efficiency	0.3501	0.3201	0.3233	0.3246	0.3275	0.3415
Exergy of Fuel “kW”	46.97	51.38	50.86	50.67	50.22	47.45
Exergy of Product “kW”	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.3035	0.3198	0.3199	0.3172	0.3155	0.3053
LTC Mass flow Rate (Kg/sec)	0.2245	0.2023	0.1888	0.1885	0.2461	0.1359
W_{comp_HTC}“kW”	33.75	35.56	35.35	35.27	35.08	33.95
W_{comp_LTC} “kW”	13.22	15.82	15.51	15.40	15.14	13.51
Q_{Cond_HTC} “kW”	82.14	86.54	86.03	85.84	85.39	82.62
Q_{Cond_LTC} “kW”	48.39	50.98	50.68	50.57	50.30	48.67
Q_{Eva_HTC} “kW”	48.39	50.98	50.68	50.57	50.30	48.67
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.66	2.223	2.267	2.284	2.323	2.604
First Law HTC Efficiency COP_{HTC}	1.434	1.434	1.434	1.434	1.434	1.434
HTCExergy Destruction Ratio(EDR_{HTC})	2.083	2.083	2.083	2.083	2.083	2.083
HTC Exergetic Efficiency	0.3243	0.3243	0.3243	0.3243	0.3243	0.3243
HTC Exergy of Fuel “kW”	33.75	35.56	35.35	35.27	35.08	33.95
HTC Exergy of Product “kW”	10.95	11.53	11.46	11.44	15.38	11.01

System-36: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC, $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%.

System-37: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%.

System-38: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%.

System-39: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%,

System-40: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R452A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%,

System-41: Cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T\__{Eva\_HTC}$=-30ºC, $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%,

Table-2(d) shows the comparison of first law efficiency ($COP\__{Cascade}$) of cascaded VCRSs using R454C in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R454C in high temperature cycle and R513A in low temperature cycle (system-36) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R454C in high temperature cycle and R448A in low temperature cycle(system-38) gives lower first law efficiency ($COP\__{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(d) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient=25ºC, $T\__{Eva\_HTC}$=-30ºC $T\__{Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\__{HTC}$=80%, Compressor $efficiency\__{LTC}$=80%,

Cascaded VCRS	System:36	System37	System:38	System39	System40	System41
HFC +HFO Blends in HTC	R454C	R454C	R454C	R454C	R454C	R454C
HFC +HFO Blends in LTC	R513a	R454B	R448a	R449a	R452a	R452b
First Law Cascaded Efficiency $COP\__{Cascade}$	0.6709	0.6538	0.6217	0.6240	0.6293	0.6644
Cascade Exergy Destruction Ratio($EDR\__{Cascade}$)	2.187	2.271	2.439	2.427	2.398	2.214
Cascaded Exergetic Efficiency	0.3138	0.3059	0.2937	0.2918	0.2943	0.3107
Exergy of Fuel "kW"	52.41	53.79	56.53	56.36	55.88	52.93
Exergy of Product "kW"	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.4979	0.5057	0.5215	0.5203	0.5176	0.5009
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	0.1888	0.1885	0.2461	0.1359
$W\__{comp\_HTC}$"kW"	39.19	39.81	41.05	40.96	40.74	39.42
$W\__{comp\_LTC}$ "kW"	13.22	13.98	15.51	15.40	15.14	13.51
$Q\__{Cond\_HTC}$ "kW"	87.58	88.96	91.73	91.52	91.05	88.10
$Q\__{Cond\_LTC}$ "kW"	48.39	49.15	50.68	50.57	50.30	48.67
$Q\__{Eva\_HTC}$ "kW"	48.39	49.15	50.68	50.57	50.30	48.67
$Q\__{Eva\_LTC}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.267	2.284	2.323	2.604
First Law HTC Efficiency $COP\__{HTC}$	1.235	1.235	1.235	1.235	1.235	1.235
HTCExergy Destruction Ratio($EDR\__{HTC}$)	2.581	2.581	2.581	2.581	2.581	2.581
HTC Exergetic Efficiency	0.2793	0.2793	0.2793	0.2793	0.2793	0.2793
HTC Exergy of Fuel "kW"	39.19	39.81	41.05	40.96	40.74	39.42
HTC Exergy of Product "kW"	10.95	11.12	11.45	11.44	11.38	11.01

System-42: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

System-43: Cascaded VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly low GWP R454B refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%.

System44: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%.

System-45: Cascaded VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%.

System-46: Cascaded VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R452A low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%.

System-47: Cascaded VCRS using ecofriendly low GWP R448A refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%.

Table-2(e) shows the comparison of first law efficiency ($COP_{\_Cascade}$) of cascaded VCRSs using R448A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R448A in high temperature cycle and R513A in low temperature cycle (system-42) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R448A in high temperature cycle and R452A in low temperature cycle(system-44) gives lower first law efficiency ($COP_{\_Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(e) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q\_Eva_{\_LTC}$=35.167 kW, $T_{\_cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency_{\_HTC}$=80%, Compressor $efficiency_{\_LTC}$=80%,

Cascaded VCRS	System:42	System43	System:44	System45	System46	System47
HFC +HFO Blends in HTC	R448A	R448A	R448A	R448A	R448A	R448A
HFC +HFO Blends in LTC	R513A	R454B	R454C	R449A	R452a	R452b
First Law Cascaded Efficiency $COP_{\_ Cascade}$	0.7153	0.6965	0.6550	0.6640	0.6698	0.7081
Cascade Exergy Destruction Ratio($EDR_{\_ Cascade}$)	1.99	2.070	2.265	2.220	2.192	2.020
Cascaded Exergetic Efficiency	0.3345	0.3257	0.3063	0.3105	0.3132	0.3312
Exergy of Fuel “kW”	49.17	50.49	53.69	52.96	52.50	49.66
Exergy of Product “kW”	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.4320	0.4388	0.4552	0.4515	0.4491	0.4345
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	0.2023	0.1885	0.2461	0.1359
$W_{\_comp\ \_HTC}$“kW”	35.94	36.51	37.87	37.56	37.36	36.15
$W_{\_comp\_LTC}$ “kW”	13.22	13.98	15.82	15.40	15.14	13.51
$Q_{\_Cond\_HTC}$ “kW”	84.33	85.66	88.86	88.13	87.67	84.83
$Q_{\_Cond\_LTC}$ “kW”	48.39	49.15	50.98	50.57	50.30	48.67
$Q_{\_Eva\_HTC}$ “kW”	48.39	49.15	50.98	50.57	50.30	48.67
$Q_{\_Eva\_LTC}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.223	2.284	2.323	2.604
First Law HTC Efficiency $COP_{\_ HTC}$	1.346	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	2.284
HTC Exergetic Efficiency	0.3045	0.3045	0.3045	0.3045	0.3045	0.3045
HTC Exergy of Fuel “kW”	35.94	36.51	37.87	37.56	37.36	36.15
HTC Exergy of Product “kW”	10.95	11.12	11.53	11.44	11.38	11.01

System-48: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50°C, T_ambient=25°C, T_{Eva_HTC}=-30°C T_{Eva_LTC}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,

System-49: Cascaded VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly low GWP R454B refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50°C, T_ambient= 25°C, T_{Eva_HTC}=-30°C, T_{Eva_LTC}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System50: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R454C 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}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-51: Cascaded VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R448A 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}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-52: Cascaded VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R449A 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}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

System-53: Cascaded VCRS using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R452B 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}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%.

Table-2(f) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded VCRSs using R449A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R449A in high temperature cycle and R513A in low temperature cycle (system-48) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R449A in high temperature cycle and R454C in low temperature cycle (system-50) gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(f) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50°C, T_ambient=25°C, T_{Eva_HTC}=-30°C T_{Eva_LTC}=-70°C, Temperature overlapping=10, Compressor efficiency$_{HTC}$=80%, Compressor efficiency$_{LTC}$=80%,

Cascaded VCRS	System:48	System49	System:50	System51	System52	System53
HFC +HFO Blends in LTC	R449A	R449A	R449A	R449A	R449A	R449A
HFC +HFO Blends in LTC	R513A	R454B	R454C	R448A	R452A	R452A
First Law Cascaded Efficiency $COP\_{Cascade}$	0.6969	0.6788	0.6387	0.6450	0.6530	0.690
Cascade Exergy Destruction Ratio($EDR\_{Cascade}$)	2.069	2.150	2.348	2.315	2.275	2.099
Cascaded Exergetic Efficiency	0.3259	0.3174	0.2987	0.3016	0.3054	0.3227
Exergy of Fuel “kW”	50.46	51.81	55.06	54.52	53.85	50.97
Exergy of Product “kW”	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.4575	0.4646	0.4820	0.4791	0.4755	0.4601
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	0.2023	0.1888	0.2461	0.1359
W_{comp_HTC}“kW”	37.24	37.83	39.24	39.01	38.72	37.46
W_{comp_LTC} “kW”	13.22	13.98	15.82	15.51	15.14	13.51
Q_{Cond_HTC} “kW”	85.63	86.988	90.22	89.69	89.02	86.13
Q_{Cond_LTC} “kW”	48.39	49.15	50.98	50.68	50.30	48.67
Q_{Eva_HTC} “kW”	48.39	49.15	50.98	50.68	50.30	48.67
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.223	2.267	2.323	2.604
First Law HTC Efficiency COP_{HTC}	1.299	1.299	1.299	1.299	1.299	1.299
HTCExergy Destruction Ratio(EDR_{HTC})	2.402	2.402	2.402	2.402	2.402	2.402
HTC Exergetic Efficiency	0.2939	0.2939	0.2939	0.2939	0.2939	0.2939
HTC Exergy of Fuel “kW”	37.24	37.83	39.24	39.01	38.72	37.46
HTC Exergy of Product “kW”	10.95	11.12	11.63	11.46	11.38	11.01

System-54: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R513A 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}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,
System-55: Cascaded VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly low GWP R454B refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient= 25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-56: Cascaded thermodynamic performances of VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-57: Cascaded VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R448A 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}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-58: Cascaded VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient= 25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-59: Cascaded VCRS using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient= 25ºC, T_{Eva_HTC}=-30ºC, T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

Table-2(g) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded VCRSs using R452A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R452A in high temperature cycle and R513A in low temperature cycle (system-54) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R452A in high temperature cycle and R452A in low temperature cycle (system-56) gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(g) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,

Cascaded VCRS	System:54	System55	System:56	System57	System58	System59
HFC +HFO Blends in LTC	R452A	R452A	R452A	R452A	R452A	R452A
HFC +HFO Blends in LTC	R513A	R454B	R454C	R448A	R449a	R452B
First Law Cascaded Efficiency $COP\_{Cascade}$	0.6293	0.6122	0.5775	0.5829	0.5850	0.6219
Cascade Exergy Destruction Ratio($EDR\_{Cascade}$)	2.398	2.493	2.703	2.668	2.655	2.438
Cascaded Exergetic Efficiency	0.2936	0.2863	0.270	0.2726	0.2736	0.2908
Exergy of Fuel “kW”	56.01	57.44	60.90	60.33	60.11	56.55
Exergy of Product “kW”	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.6919	0.7028	0.7290	0.7247	0.7230	0.6960
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	0.2023	0.1888	0.1885	0.1359
W_{comp_HTC}“kW”	42.79	43.46	45.08	44.81	44.71	43.04
W_{comp_LTC} “kW”	13.22	13.98	15.82	15.51	15.40	13.51
Q_{Cond_HTC} “kW”	91.18	92.61	96.07	95.50	95.28	91.71
Q_{Cond_LTC} “kW”	48.39	49.15	50.98	50.68	50.57	48.67
Q_{Eva_HTC} “kW”	48.39	49.15	50.98	50.68	50.57	48.67
Q_{Eva_LTC} “kW”	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.223	2.257	2.284	2.604
First Law HTC Efficiency COP_{HTC}	1.131	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	2.909
HTC Exergetic Efficiency	0.2558	0.2558	0.2558	0.2558	0.2558	0.2558
HTC Exergy of Fuel “kW”	42.79	43.46	45.08	44.81	44.71	43.04
HTC Exergy of Product “kW”	10.95	11.12	11.53	11.46	11.44	11.01

System-60: Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%.

System-61: Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-7oºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-62: Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

Table-63: Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%.

System-64: Cascaded VCRS using ecofriendly low GWP 452B refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%.

System-65: Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R452A low GWP refrigerant in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient= 25ºC, $T_{\_Eva\_HTC}$=-30ºC, $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,

Table-2(h) shows the comparison of first law efficiency ($COP\_{Cascade}$) of cascaded VCRSs using R452B in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded VCRSs using R452B in high temperature cycle and R513A in low temperature cycle (system-60) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded VCRSs using R452B in high temperature cycle and R452A in low temperature cycle (system-62) gives lower first law efficiency ($COP\_{Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

Table-2(h) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, $T\__{cond}$=50ºC, T_ambient=25ºC, $T_{\_Eva\_HTC}$=-30ºC $T_{\_Eva\_LTC}$=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,

Cascaded VCRS	System:60	System61	System:62	System63	System64	System65
HFC +HFO Blends in LTC	R452B	R452B	R452B	R452B	R452B	R452B
HFC +HFO Blends in LTC	R513A	R454B	R454C	R448a	R449a	R452A
First Law Cascaded Efficiency $COP\_{Cascade}$	0.7603	0.7399	0.6948	0.7018	0.7045	0.7109
Cascade Exergy Destruction Ratio($EDR\_{Cascade}$)	1.812	1.890	2.078	2.049	2.035	2.008
Cascaded Exergetic Efficiency	0.3556	0.3460	0.3249	0.3282	0.3295	0.3324
Exergy of Fuel “kW”	46.25	47.53	50.62	50.11	49.92	49.47
Exergy of Product “kW”	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.3010	0.3057	0.3171	0.3153	0.3146	0.3129
LTC Mass flow Rate (Kg/sec)	0.2245	0.1353	48.39	49.19	50.98	0.2461
$W_{\_comp\ \_HTC}$“kW”	33.03	33.55	34.80	34.59	34.51	34.33
$W_{\_comp\_LTC}$ “kW”	13.22	13.98	15.82	15.51	15.40	15.14
$Q_{\_Cond\_HTC}$ “kW”	81.42	82.70	85.78	85.27	85.08	84.64
$Q_{\_Cond\_LTC}$ “kW”	48.39	49.19	50.98	50.68	50.57	50.30
$Q_{\_Eva\_HTC}$ “kW”	48.39	49.19	50.98	50.68	50.57	50.30
$Q_{\_Eva\_LTC}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.515	2.223	2.267	2.284	2.3231
First Law HTC Efficiency COP_{HTC}	1.465	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	2.017
HTC Exergetic Efficiency	0.3314	0.3314	0.3314	0.3314	0.3314	0.3314
HTC Exergy of Fuel “kW”	33.03	33.55	34.80	34.59	34.51	34.33
HTC Exergy of Product “kW”	10.95	11.12	11.53	11.46	11.44	11.38

Table-3(a) Thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,

Optimal Cascaded VCRS	System: 17	System 29	System 30	System: 36	System 42	System 48	System 54	System: 60
HFC +HFO Blends in LTC	R450A	R513A	R454B	R454C	R448A	R449A	R452A	R452B
HFC +HFO Blends in LTC	R513a	R452b	R513a	R513a	R513A	R513A	R513A	R513A
First Law Cascaded Efficiency $COP\_{Cascade}$	0.7425	0.7213	0.7487	0.6709	0.7153	0.6969	0.6293	0.7603
Exergy Destruction Ratio($EDR\_{Cascade}$)	1.680	1.965	1.856	2.187	1.99	2.069	2.398	1.812
Cascaded Exergetic Efficiency	0.3472	0.3373	0.3501	0.3138	0.3345	0.3259	0.2936	0.3556
Exergy of Fuel "kW"	47.36	48.76	46.97	52.41	49.17	50.46	56.01	46.25
Exergy of Product "kW"	22.08	16.45	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.5066	0.5653	0.3035	0.4979	0.4320	0.4575	0.6919	0.3010
LTC Mass flow Rate (Kg/sec)	0.2245	0.1359	0.2245	0.2245	0.2245	0.2245	0.2245	0.2245
W_{comp_HTC}"kW"	34.12	35.25	33.75	39.19	35.94	37.24	42.79	33.03
W_{comp_LTC} "kW"	13.22	13.51	13.22	13.22	13.22	13.22	13.22	13.22
Q_{Cond_HTC} "kW"	82.53	83.92	82.14	87.58	84.33	85.63	91.18	81.42
Q_{Cond_LTC} "kW"	48.39	48.67	48.39	48.39	48.39	48.39	48.39	48.39
Q_{Eva_HTC} "kW"	48.39	48.67	48.39	48.39	48.39	48.39	48.39	48.39
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.660	2.604	2.66	2.660	2.660	2.660	2.660	2.660
First Law HTC Efficiency COP_{HTC}	1.417	1.381	1.434	1.235	1.346	1.299	1.131	1.465
HTC Exergy Destruction Ratio(EDR_{HTC})	2.199	2.202	2.083	2.581	2.284	2.402	2.909	2.017
HTC Exergetic Efficiency	0.3206	0.3123	0.3243	0.2793	0.3045	0.2939	0.2558	0.3314
HTC Exergy of Fuel "kW"	34.14	35.25	33.75	39.19	35.94	37.24	42.79	33.03
HTC Exergy of Product "kW"	10.95	11.01	10.95	10.95	10.95	10.95	10.95	10.95

Table-3(b) Optimum (Minimum) thermodynamic performances of cascaded VCRS using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle (Q_Eva_{LTC}=35.167 kW, T_{cond}=50ºC, T_ambient=25ºC, T_{Eva_HTC}=-30ºC T_{Eva_LTC}=-70ºC, Temperature overlapping=10, Compressor $efficiency\_{HTC}$=80%, Compressor $efficiency\_{LTC}$=80%,

Optimal Cascaded VCRS	System-19	System 25	System 31	System: 38	System 44	System 50	System 56	System: 62
HFC +HFO Blends in LTC	R450A	R513A	R454B	R454C	R448A	R449A	R452A	R452B
HFC +HFO Blends in LTC	R454C	R448a	R454C	R448a	R454C	R454C	R448a	R454C
First Law Cascaded Efficiency $COP\_{Cascade}$	0.6791	0.6735	0.6845	0.6217	0.6550	0.6550	0.5829	0.6948
Exergy Destruction Ratio($EDR\_{Cascade}$)	2.149	2.175	2.124	2.439	2.265	2.265	2.668	2.078
Cascaded Exergetic Efficiency	0.3176	0.3149	0.3201	0.2937	0.3063	0.3063	0.2726	0.3249
Exergy of Fuel "kW"	51.79	52.22	51.38	56.53	53.69	53.69	60.33	50.62
Exergy of Product "kW"	22.08	16.45	16.45	16.45	16.45	16.45	16.45	16.45
HTC Mass flow Rate (Kg/sec)	0.5338	0.5886	0.3198	0.5215	0.4552	0.4552	0.7247	0.3171
LTC Mass flow Rate (Kg/sec)	0.2023	0.1888	0.2023	0.1888	0.2023	0.2023	0.1888	48.39
W_{comp_HTC}"kW"	35.97	36.70	35.56	41.05	37.87	37.87	44.81	34.80
W_{comp_LTC} "kW"	15.82	15.51	15.82	15.51	15.82	15.82	15.51	15.82
Q_{Cond_HTC} "kW"	86.95	87.39	86.54	91.73	88.86	88.86	95.50	85.78
Q_{Cond_LTC} "kW"	50.98	50.68	50.98	50.68	50.98	50.98	50.68	50.98
Q_{Eva_HTC} "kW"	50.98	50.68	50.98	50.68	50.98	50.98	50.68	50.98
Q_{Eva_LTC} "kW"	35.167	35.167	35.167	35.167	35.167	35.167	35.167	35.167
First Law LTC Efficiency COP_LTC	2.223	2.267	2.223	2.267	2.223	2.223	2.257	2.223
First Law HTC Efficiency COP_{HTC}	1.417	1.381	1.434	1.235	1.346	1.346	1.131	1.465
HTC Exergy Destruction Ratio(EDR_{HTC})	2.199	2.202	2.083	2.581	2.284	2.284	2.909	2.017
HTC Exergetic Efficiency	0.3206	0.3123	0.3243	0.2793	0.3045	0.3045	0.2558	0.3314
HTC Exergy of Fuel "kW"	36.97	36.70	35.56	41.05	37.87	37.87	44.81	34.80
HTC Exergy of Product "kW"	11.53	11.46	11.53	11.45	11.53	11.53	11.46	11.53

3.1 Computing optimal thermodynamic Performances of cascaded VCRS using low GWP HFC+HFO blends in higher temperature cycle using low GWP HFC+HFO blends in low temperature cycle

Table-3(a) and Table-3(b) show the Optimum thermodynamic (energy-exergy) performances of cascaded VCRS using ecofriendly low GWP HFC+HFO blends refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle was obtained and it was found that cascaded VCRS 44 using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle gives highest (optimum) thermodynamic first law energy performance (COP) and second law (exergetic efficiency) performances. However lowest thermodynamic performances of cascaded VCRS-14 using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle.

4. Conclusions

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

- Optimal Cascaded VCRS using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle (system-60) gives best (optimum) thermodynamic first law energy performance (COP) and second law (exergetic efficiency) performances.
- Second cascaded VCRS using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513a low GWP refrigerant in low temperature cycle (system-17) gives slightly less thermodynamic performances. than system-4 using ecofriendly low GWP R452B refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle
- The lowest thermodynamic performances were observed by using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle in the Cascaded thermodynamic performances of vapor compression refrigeration (system-41)
- Cascaded VCRS using R454B in high temperature cycle and R513A in low temperature cycle (system13) at -90ºC gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio.
- Cascaded VCRS-14 using R452A in high temperature cycle and R449A in low temperature cycle (system-12) at -90ºC gives lower first law efficiency ($COP_{\_Cascade}$) and exergetic efficiency and higher exergy destruction ratio.

References

[1] Niu, Boulian, Zhang, Yufeng, 2006. Experimental Study of the Refrigeration Cycle Performance for R744/R290 Mixtures, International Journal of Refrigeration, Volume 30, pp. 37-42.

[2] Bhattacharyya, Souvik, Mukhopadhyay, S., Kumar, A., Kurana, R.K., Sarkar, J., 2005. Optimization of CO2-C3H8 Cascade System for Refrigeration and Heating. International Journal of Refrigeration, Volume 28, pp. 1284-1292

[3] J. Alberto Dopazo José Fernández-Seara[2011] Experimental evaluation of a cascade refrigeration system prototype with CO_2 and NH_3 for freezing process applications, International Journal of Refrigeration, Volume 34, Issue 1, January 2011, Pages 257-267

[4] Nasruddin, Darwin R.B. Syaka., Alhamid, M.I., 2011. A Cascade Refrigeration System using Mixtures of Carbon Dioxide and Hydrocarbon for Low Temperature Application, Journal of Engineering and Applied Sciences, Volume 6(6), pp. 379 – 386

[5] Alhamid, M., Nasruddin, N., R.B.S., D., & Lubis, A. (2013). Characteristics and COP Cascade Refrigeration System using Hydrocarbon Refrigerant (Propane, Ethane and CO_2) at Low Temperature Circuit (TC). International Journal of Technology, 4(2), 112-120.

[6] R. S. Mishra [2013] , "Thermodynamic analysis of three stages cascade vapour Compression refrigeration system for biomedical applications", Journal of Multi-Disciplinary Engineering Technologies Volume 7 No.1 Jan. 2013 639.

[7] Alptug Yataganbaba, Ali Kilicarslan, İrfan Kurtbaş[2015]Exergy analysis of R1234yf and R1234ze as R134a replacements in a two evaporator vapour compression refrigeration system, December 2015,International Journal of Refrigeration 60:26-37.

[8] R.S. Mishra, Designing of Cascade vapour compression refrigeration systems or ultra-low temperature applications using new HFO ultra low GWP refrigerants, International Journal of Research in Engineering and Innovation, vol 4, issue 6(2020).

[9] Adrian Mota Babiloni, et.al [2018] experimental drop in replacement of R404a for warm countries using low GwP mixtures of R454C and R455A, International Journal of refrigeration, 91.

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