



ORIGINAL ARTICLE

Thermodynamic performances of cascaded vapor compression refrigeration system using eco-friendly low GWP blends of HFC+HFO refrigerants in higher temperature cycle using blends of HFC+HFO refrigerants in low GWP refrigerant

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Article Information

Received: 27 March 2022

Revised: 01 May 2022

Accepted: 05 May 2022

Available online: 07 May 2022

Keywords:

Cascaded vapor compression refrigeration system;
Blends of HFC+HFO refrigerants
Nonflammable refrigerants;
Energy-Exergy Performances

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 vapour compression refrigeration system for the ultra-low applications using ecofriendly 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 low temperature cycle have been investigated. It was observed that System44 gives highest thermodynamic first and second law performances. 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 of vapour compression refrigeration (system 41).

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1. Introduction

In current decades many countries have rewarded more consideration to environmental pollution caused by various fuels and CFCs. Burning fossil fuels cause water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), and sulfur dioxide (SO₂) 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), hydro chlorofluorocarbons (HCFC), hydrofluorocarbons (HFCs), methane (CH₄), 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 CO₂. GHGs act as a blanket of solar radiation on the earth's surface, thus making the average global temperature. It can be fulfilled that the more GHGs produced, the higher the average global temperature. CFCs and HCFCs used by conventional refrigeration systems have a global warming potential (GWP) and have a high value of ozone-depleting potential (ODP). Biomedical specimens must 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 cascade refrigeration system using NH₃ and CO₂ as

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<https://doi.org/10.36037/IJREI.2022.6302>

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 that a mixture of carbon dioxide and ethane can achieve the minimum temperature of -80°C of a mix of carbon dioxide and methane is an excellent alternative refrigerant. Nasruddin et al., [5] found. The best performance using carbon dioxide and propane compared to R410a and R134a, whereas R744 (CO_2) is flammable and a green refrigerant. Mishra [5] described thermodynamic analysis of cascade refrigeration systems with huge refrigerants, including CFC, HCFC, HFC, HFO refrigerants etc and optimizations conducted for such refrigerants. The huge number of refrigerants has been examined in a cascade system to determine the appropriate combination of refrigerants in high temperature and low-temperature cycles in both circuits of refrigerants. However, the trends show that the HFO refrigerants are natural refrigerants gaining more importance due to environmental conditions few natural refrigerants [3].

Exergy analysis is a useful way to determine the real thermodynamic losses and optimize environmental and economic performance in vapor compression refrigeration systems. Alptunganbaba et.al.[7] carried out exergy analysis of a two evaporator vapor compression refrigeration system 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 the 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 an evaporator

the temperature in a low-temperature cycle ranges from -145°C to -155°C by HFO-1336mzz(Z) and up to -160°C by HFO-1225ye(Z) refrigerants and using hydrocarbons in LTC. The optimal cascade vapor compression refrigeration system 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 vapor compression refrigeration systems to maximize the energy & exergy efficiencies have been presented.

2. Use of HFC+HFO Blends in Cascaded VCRs.

Cascaded vapor compression refrigeration systems are essential to chemical/petrochemical process industries because their thermodynamic performances are closely related to product quality and plant profitability previously.

Adrián Mota-Babiloni [9] carried out the analysis of the feasibility of R454C and R455A, two new low global warming potential (GWP of 148) refrigerants, in vapor compression refrigeration systems 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 vapour compression refrigerations have been considered for numerical computations.

System-1: Cascaded vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167\text{ kW}$, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-2: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167\text{ kW}$, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%

System- 3: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167\text{ kW}$, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%, Compressor efficiency_{LTC}=80%.

System-4: Cascaded vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167\text{ kW}$, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%, Compressor efficiency_{LTC}=80%.

System-5: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%, Compressor efficiency_{LTC}=80%.

System- 6: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 7: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-8: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-9: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 10: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-11: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-$

90°C , Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-12: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 13: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 14: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=0^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 15: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-90^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 16: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=0^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-2(a)-Table-2(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 system-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 vapour compression refrigeration system-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 vapour compression

refrigeration system--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-2(a) Thermodynamic performances of cascaded vapour compression refrigeration system for ultra-low temperature applications using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167 \text{ kW}$, $T_{\text{cond}}=50^\circ\text{C}$, $T_{\text{ambient}}=25^\circ\text{C}$, $T_{\text{Eva_HTC}}=-30^\circ\text{C}$, $T_{\text{Eva_LTC}}=-90^\circ\text{C}$)

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
$W_{\text{comp_HTC}}$ "kW"	40.88	41.89	43.33	43.35	43.04	44.11	45.63	45.64
$W_{\text{comp_LTC}}$ "kW"	22.78	24.20	26.25	26.25	22.78	24.21	26.25	26.27
$Q_{\text{Cond_HTC}}$ "kW"	98.83	101.30	104.70	104.80	101.0	103.5	107.1	107.1
$Q_{\text{Cond_LTC}}$ "kW"	57.95	59.37	61.42	61.44	57.95	59.38	61.43	61.44
$Q_{\text{Eva_HTC}}$ "kW"	57.95	59.37	61.42	61.44	57.95	59.38	61.43	61.44
$Q_{\text{Eva_LTC}}$ "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
HTC Exergy 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-2(b) Thermodynamic performances of vapour compression refrigeration system for ultra-low temperature applications using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167 \text{ kW}$, $T_{\text{cond}}=50^\circ\text{C}$, $T_{\text{ambient}}=25^\circ\text{C}$, $T_{\text{Eva_HTC}}=-30^\circ\text{C}$, $T_{\text{Eva_LTC}}=-90^\circ\text{C}$)

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
$W_{\text{comp_HTC}}$ "kW"	51.24	52.50	54.32	54.33	39.55	40.53	41.93	41.94
$W_{\text{comp_LTC}}$ "kW"	22.78	24.21	26.26	26.27	22.78	24.21	26.26	26.27
$Q_{\text{Cond_HTC}}$ "kW"	109.2	111.9	115.7	115.8	97.5	99.91	103.4	103.4
$Q_{\text{Cond_LTC}}$ "kW"	57.95	59.38	61.43	61.44	57.95	59.38	61.43	61.44
$Q_{\text{Eva_HTC}}$ "kW"	57.95	59.38	61.43	61.44	57.95	59.38	61.43	61.44
$Q_{\text{Eva_LTC}}$ "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
HTC Exergy 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 vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-18: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454B low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%

System- 19: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R454C low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-20: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-21: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%

System- 22: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R452A low GWP refrigerant in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System- 23: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R450A refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature

cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(a) shows the comparison of first law efficiency ($COP_{Cascade}$) of cascaded vapour compression refrigeration systems using R450A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration system 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 vapour compression refrigeration System (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.

System-24: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-25: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-26: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-27: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-28: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-29: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-75^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(b) shows the comparison of first law efficiency ($COP_{Cascade}$) of cascaded vapour compression refrigeration systems using R513A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R513A in high temperature cycle and R454B in low temperature cycle (System-29th) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems 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-3(a) Thermodynamic performances of cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80.

Cascaded VCERS	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	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
HTC Exergy 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

Table-3(b) Thermodynamic performances of cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Cascaded VCERS	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
HTC Exergy 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 vapour compression refrigeration system 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}=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-31: Cascaded thermodynamic performances of vapour compression refrigeration system 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}=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-32: Cascaded thermodynamic performances of vapour compression refrigeration system 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}=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-33: Cascaded vapour compression refrigeration system 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}=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-34: Cascaded thermodynamic performances of vapour compression refrigeration system 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}=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-35: Cascaded vapour compression refrigeration system 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}=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-3(c) shows the comparison of first law efficiency (COP_{Cascade}) of cascaded vapour compression refrigeration systems using R454B in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration system (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 vapour compression refrigeration systems 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.

System-36: Cascaded vapour compression refrigeration system 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}=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-37: Cascaded vapour compression refrigeration system 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}=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-38: Cascaded vapour compression refrigeration system 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}=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-39: Cascaded vapour compression refrigeration system 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}=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-40: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor

efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-41: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(c) Thermodynamic performances of cascaded vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=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
HTC Exergy 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

Table-3(d) shows the comparison of first law efficiency (COP_{Cascade}) of cascaded vapour compression refrigeration systems using R454C in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R454C in high temperature cycle and R513A in low temperature cycle (system-36) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems 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 .

System-42: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor

efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-43: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-44: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^\circ\text{C}$, $T_{ambient}=25^\circ\text{C}$, $T_{Eva_HTC}=-30^\circ\text{C}$, $T_{Eva_LTC}=-70^\circ\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-45: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-46: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-47: Cascaded vapour compression refrigeration system 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,

$T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(e) shows the comparison of first law efficiency ($COP_{Cascade}$) of cascaded vapour compression refrigeration systems using R448A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R448A in high temperature cycle and R513A in low temperature cycle(system-42) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems 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-3(d) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, 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
HTC Exergy 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-48: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-49: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-50: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$,

$T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$,
Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-51: Cascaded vapour compression refrigeration system using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167$ kW, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-52: Cascaded vapour compression refrigeration system using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R449A low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167$ kW, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-53: Cascaded vapour compression refrigeration

system using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly R452B low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167$ kW, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(f) shows the comparison of first law efficiency ($\text{COP}_{\text{Cascade}}$) of cascaded vapour compression refrigeration systems using R449A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R449A in high temperature cycle and R513A in low temperature cycle (system-48) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems using R449A in high temperature cycle and R454C in low temperature cycle (system-50) gives lower first law efficiency ($\text{COP}_{\text{Cascade}}$) and exergetic efficiency and higher exergy destruction ratio.

Table-3(e) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R449A refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167$ kW, $T_{\text{cond}}=50^{\circ}\text{C}$, $T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Cascaded VCERS	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 $\text{COP}_{\text{Cascade}}$	0.7153	0.6965	0.6550	0.6640	0.6698	0.7081
Cascade Exergy Destruction Ratio($\text{EDR}_{\text{Cascade}}$)	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
$W_{\text{comp_HTC}}$ “kW”	35.94	36.51	37.87	37.56	37.36	36.15
$W_{\text{comp_LTC}}$ “kW”	13.22	13.98	15.82	15.40	15.14	13.51
$Q_{\text{Cond_HTC}}$ “kW”	84.33	85.66	88.86	88.13	87.67	84.83
$Q_{\text{Cond_LTC}}$ “kW”	48.39	49.15	50.98	50.57	50.30	48.67
$Q_{\text{Eva_HTC}}$ “kW”	48.39	49.15	50.98	50.57	50.30	48.67
$Q_{\text{Eva_LTC}}$ “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
HTC Exergy 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-54: Cascaded thermodynamic performances of vapour compression refrigeration system using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R513A low GWP refrigerant in low temperature cycle ($Q_{\text{Eva_LTC}}=35.167$ kW, $T_{\text{cond}}=50^{\circ}\text{C}$,

$T_{\text{ambient}}=25^{\circ}\text{C}$, $T_{\text{Eva_HTC}}=-30^{\circ}\text{C}$, $T_{\text{Eva_LTC}}=-70^{\circ}\text{C}$,
Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-55: Cascaded vapour compression refrigeration

system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System56: Cascaded thermodynamic performances of vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-57: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-58: Cascaded vapour compression refrigeration system 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,

$T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-59: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(g) shows the comparison of first law efficiency ($COP_{Cascade}$) of cascaded vapour compression refrigeration systems using R452A in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R452A in high temperature cycle and R513A in low temperature cycle (system-54) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems 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-3(f) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, 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
HTC Exergy 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

Table-3(g) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Cascaded VCERS	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
HTC Exergy 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 vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-61: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-62: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-63: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor

efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-64: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

System-65: Cascaded vapour compression refrigeration system 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, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Table-3(h) shows the comparison of first law efficiency (COP_{Cascade}) of cascaded vapour compression refrigeration systems using R452B in high temperature cycle and HFC +HFO Blends in low temperature cycle and it was found that cascaded vapour compression refrigeration systems using R452B in high temperature cycle and R513A in low temperature cycle (system-60) gives higher first law efficiency and exergetic efficiency lower exergy destruction ratio and cascaded vapour compression refrigeration systems 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 EDR.

Table-3(h) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Cascaded VCERS	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
HTC Exergy 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

3.1 Computational optimal thermodynamic Performances of cascaded vapour compression refrigeration system using ecofriendly low GWP HFC+HFO blends (refrigerants) in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle

Table-4(a) and Table-4(b) show the Optimum thermodynamic (energy-exergy) performances of cascaded vapour compression refrigeration system 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 vapour compression refrigeration system 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 vapour compression refrigeration system-14 using ecofriendly low GWP R452A refrigerants in higher temperature cycle using ecofriendly R448A low GWP refrigerant in low temperature cycle .

Table-4(a) Thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_{HTC}=80%. Compressor efficiency_{LTC}=80%.

Optimal Cascaded VCERS	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-4(b) Optimum (Minimum) thermodynamic performances of cascaded vapour compression refrigeration system using ecofriendly low GWP R454C refrigerants in higher temperature cycle using ecofriendly low GWP HFC+HFO blends (refrigerants) in low temperature cycle ($Q_{Eva_LTC}=35.167$ kW, $T_{cond}=50^{\circ}\text{C}$, $T_{ambient}=25^{\circ}\text{C}$, $T_{Eva_HTC}=-30^{\circ}\text{C}$, $T_{Eva_LTC}=-70^{\circ}\text{C}$, Temperature overlapping=10, Compressor efficiency_HTC=80%. Compressor efficiency_LTC=80%.

Optimal Cascaded VCERS	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

4. Conclusions

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

- Optimal Cascaded vapour compression refrigeration system 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 vapour compression refrigeration system 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 vapour compression refrigeration (system-41)

- Cascaded vapour compression refrigeration system using R454B in high temperature cycle and R513A in low temperature cycle (system13) at -90°C gives higher first law efficiency and exergetic efficiency and lower exergy destruction ratio.
- Cascaded vapour compression refrigeration system-14 using R452A in high temperature cycle and R449A in low temperature cycle (system-12) at -90°C gives lower first law efficiency (COP_Cascade) and exergetic efficiency and higher exergy destruction ratio.

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Cite this article as: R. S. Mishra, Thermodynamic performances of vapor compression refrigeration system using eco-friendly low GWP blends of HFC+HFO refrigerants in higher temperature cycle using blends of HFC+HFO refrigerants in low GWP refrigerant, International journal of research in engineering and innovation (IJREI), vol 6, issue 3 (2022), 151-165.
<https://doi.org/10.36037/IJREI.2022.6302>.