International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

ORIGINAL ARTICLE

Methods for improving thermal performances of VCRS using Low GWP Refrigerants

R. S. Mishra

Mechanical Engineering Department, Delhi Technological University, Delhi, India

Article Information

Received: 09 January 2024
Revised: 14 March 2024
Accepted: 21 March 2024
Available online: 25 March 2024

Keywords:

HFO+HFC blends
HCFO& HFO refrigerants
Cascaded VCR system
Energy-Exergy Analysis

Abstract

In this paper, energy-exergy performances using HFOs and HCFOs in HTC and using HFOs and HCFO-1233zd(E) in HTC for replacing HFCs (R134a, R407c, R410a, R125, R507a, R143a) have been investigated. Cascaded system using HFO-1234ze(Z) in HTC evaporator temperature of 273K and HCFO-1233zd(E) gives best results up to LTC evaporator temperature of 198K. The Cascaded system using HCFO-1233zd(E) in HTC evaporator temperature of 263K and HFO-1225ye(Z) HFO-1336mzz(Z) in LTC gives best results then HCFO-1224yd(Z) in HTC and HFO-1225ye(Z) HFO-1336mzz(Z) in LTC up to LTC evaporator temperature of 183K. The low global warming HFC 152a, HFC 245fa in HTC and HFC-32 in LTC gives better energy-exergy performances than using R134a in HTC and R404a, R125R410a, R507a in LTC. However HC 600a, HC 290, and HC 600 in high temperature cycle and Ethylene and Propylene in LTC can be used with security measures because they are combustible by nature for replacing R134a in HTC and R404a, R410a, R507a in LTC Similarly HFO mixed blends (R450a , R515a & R513a in HTC and R515a & R513a, R454b, R454c in LTC evaporator temperature up to183K can be used for replacing conventional cascaded VCRS systems using CFCs and HCFCs and HFC134a in HTC and R404a, R410a, R507a, R125 in LTC.

1. Introduction

The harmful effect that greenhouse gases cause to the ecosystem and the effects of climate change have drawn more attention to environmental preservation in recent years. The usage of refrigeration systems has sparked questions about high efficiency and environmental protection. The main refrigerant responsible for the depletion of the ozone layer and the greenhouse effect is CFC refrigerants. Another type of refrigerants that are widely utilized in refrigeration systems today are HCFC refrigerants. Developed countries are required by the Montreal Protocol to phase out all HCFCs by 2020, while developing countries are required to do the same by 2030. HFC can be used in place of CFC due to its zero ODP, but higher its GWP. The F-gas rules were abolished by the European Union in 2014. According to the regulations, starting of January 1, 2015, and January 1, 2022, respectively, refrigerators and freezers meant for residential use and those intended for commercial use that include HFCs and have a GWP value greater than 150 cannot be marketed. Said M. et al. [2] carried out an energy-exergy analysis of VCR systems and assessed the theoretical performances of HCFC123, HFC134a, CFC11, and CFC12 as coolants using CFC and other ecologically friendly refrigerants. They found that HCFC123 and HFC134a require greater compression work than CFC11 and CFC12 in order to attain a given quantity of

Corresponding author: R. S. Mishra
Email Address: rsmishra@dtu.ac.in
https://doi.org/10.36037/IJREI.2024.8205

target exergy. Even though these differences are not readily apparent at high evaporation temperatures, HCFC123 is still a good coolant choice. There is an optimal evaporation temperature that yields the best exergy efficiency for every condensation temperature. The value of exergetic efficiency for coolants such HCFC123, HFC134a, CFC11, and CFC12 is observed to decrease as the evaporator temperature rises. The maximal exergy efficiency occurs at the optimal evaporator temperature. The energy efficiency was lowered by 9.2, 12.0, 5.7, 13.8, 20.9, 9.5, 11.35, and 13.0%, respectively, when refrigerants such as HFC-134a, HFC--143a, HFC--152a, HFC--404A, HFC--407C, HFC-410A, R-502, and HFC--507A were utilized. Using the exergy technique, Probert and Nikoldas [3] studied the behaviour of a two-stage compound compression cycle with flash intercooling that uses R32. The condenser saturation temperature was changed from 298K to 308K. The impact of temperature fluctuations in the condenser and evaporator on the plant's irreversibility rate was determined. It has been demonstrated that the temperature differential between the evaporator and the cold chamber, or between the condenser and the atmosphere, increases with increasing irreversibility rate. Reductions in the irreversibility rate of the condenser yield an overall plant reduction in irreversibility rate of about 2.40 times greater magnitude, while reductions in the evaporators' non-reversible rate yield an overall plant reduction in non-reversible rate of 2.87 times greater magnitude. because changes in the condenser and evaporator's temperature have a significant impact on the plants' overall irreversibility. They pointed out that the parameters specified for the condenser and evaporator have a lot of opportunity for improvement. The R744-R717 cascade refrigeration system's heat exchanger. Condensing temperature, subcooling temperature, evaporating temperature, superheating temperature, and temperature differential have all had their design and operating characteristics optimized by Getu and Bansal [4]. carried out regression analysis to get the optimum thermal properties of the same system. HFO-1234yf was found to have a volumetric efficiency that was about 5% lower in a vapour compression system and a cooling capacity that was about 9% lower than that of HFC-134a in an experimental analysis carried out by Esbri et al. [5] and Y. Lee, D. Jung, [6] evaluated the performance of HFO-1234yf and HFO-1234yf/HFC-134a mixture in three compositions. The results demonstrated that HFO-1234yf and the mixture of refrigerants had similar COP, capacity, and discharge temperature to HFC-134a, with flammability decreasing as HFC-134a proportion increases. HFO-1234yf used 2.7% more energy than HFC-134a in performance evaluation and comparison of HFC-134a, Minor et al [7] suggested that HFO-1234yf and HFO-1234ze can be used as a drop-in replacement for HFC-134a in small refrigerators. Thermal analysis of a two-stage VCR system based on energetic and exergetic performances was carried out by Chopra Kapil et al. [8] using the first and second laws of eight environmentally friendly refrigerants: HFC152a, HC 600, HC 600a, HFC 410a, HC 290, HFO 1234yf, HFC 404a, and HFC 134a. Under various conditions the thermal performance parameters—entropy generation, first law efficiency with respect to COP, second-law efficacy with regard to exergy efficiency, and entropy were examined. It was found that compared to HFC152a and HC600, the energy and exergy efficiency of HFC134a are, respectively, 8.97% and 5.38% lower. The suggested thermal model was validated by the use of eco-friendly refrigerants in numerical computations. The findings demonstrated that the condenser temperature accounted for the majority of the thermal energy losses in the two-stage VCR system, with low irreversibility at higher evaporator temperatures. According to Mishra R. S. [9]'s first and second law analysis and comparison of eight eco-friendly refrigerants on multiple stage vapour compression refrigerators with flash intercooler and individual throttle valves (system-1) and multiple stage vapour compression refrigerators with flash intercooler and multiple throttle valves (system-2), irreversibility occurred in the system-1 is higher than the system-2 for the eight selected eco-friendly refrigerants. HFC 134a can therefore be used in real-world situations. While HFC 134A is nearly available, HFO 1234yf's (GWP four with zero ODP) thermal performance is marginally less than HFC 134a's. Mishra R.S. [10] evaluated the energy and exergy performances of sixteen environmentally friendly refrigerants that were a part of a two-stage VCR system in order to determine the irreversibility's of the system and its constituent parts using the entropy generation principle. The rational exergy destruction ratio ($EDR\_{Rational}$) was found numerically based on the system exergy contribution to the total work performed by the compressors, the exergy destruction ratio (based on the exergy of product and first law efficiency in terms of COP, and the second law efficiency in terms of exergetic efficiency at different input variations. It was found that, out of all the refrigerants considered, the flash chamber is the source of the greatest exergy degradation. It was discovered that HCFC 123 has the highest first-law efficiency and HFC 125 has the lowest first-law performance out of the sixteen environmentally friendly refrigerants that were selected. It was found that, out of the sixteen environmentally friendly refrigerants that were chosen, R123 exhibits the highest COP first law effectiveness and R125 the lowest first law efficiency . HFO-1234yf has a 100-year GWP of 4 relatives to CO2, making it a "near drop-in replacement" for HFC134a. R1234ze (of GWP = 6) offers superior first and second law efficiency than R1234yf (of GWP = 4) for applications needing higher temperatures. R1234yf and R1234ze refrigerants can be employed for medium- and higher-temperature applications, while R134a will probably become obsolete around 2030. Using HFO mixed blended refrigerants, which can be utilized to replace R404a, R410a, R407c, and R134a. In this paper performance evaluation of cascaded refrigeration systems using HFC 152a, HC 600a, HC 290, in HTC and propylene and ethylene in LTC have been compared can be used for replacing R134a in HTC and R404a, R410a, R407c, R125, R507a in LTC. Also, that HCFO & HFOs used in HTC and HCFO-1233zd(E), HFO-1225ye(Z)& HFO-1336mzz(Z) used in LTC for replacing R134a, R410a. Similarly, HFO mixed blends (R450A, R515A, R513a) in HTC and (R454b and R454c) LTC can be used for replacing R134a, R410a and R404a. Low GWP ecofriendly HFC152a and HFC 245fa in HTC,and HFC 32 in LTC can be used in cascaded VCR systems for replacing HFC 134a in HTC and R404a and R410a in LTC were prescribed for all purposes up until 2030.

2. Results and Discussion

For evaluating energy-exergy performances in the cascaded VCR systems used here for replacing HFC-134a in HTC and R404a, R410a, R407c, R507a, R125 in LTC, the following input parameters are used (Table-1).

Table 1: Input data used in CVCRS

S.No.	Input Parameter	Value
1	T_Cond_HTC (ºC)	50
2	T_Eva_HTC (ºC)	-10
3	T_ Eva _LTC (ºC)	-75
4	Q_ Eva _LTC (kW)	35.167
5	HTC compressor Efficiency (%)	80
6	LTC compressor Efficiency (%)	80

2.1 Effect of HTC evaporator temperature using low global warming potential HFO and HCFO refrigerants in cascaded VCR systems

Effect of HTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO- 1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-2(a) respectively and it was found that by increasing evaporator temperature from 263K to 283K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is increasing while HTC compressor work is decreasing. Mass flow rate of both (HTC and LTC) cycles are increasing. Heat rejected from HTC and LTC are increasing.

Effect of HTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO-1225ye(Z)refrigerants in LTC are shown in Table-2(b) respectively and it was found that by increasing evaporator temperature from 263K to 283K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is increasing while HTC compressor work is decreasing. Mass flow rate of both (HTC and LTC) cycles are increasing. Heat rejected from HTC condenser and LTC condenser are increasing. Similarly, effect of HTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-2(c) respectively and it was found that by increasing evaporator temperature from 263K to 283K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is increasing while HTC compressor work is decreasing. Mass flow rate of both (HTC and LTC) cycles are increasing. Heat rejected from HTC condenser and LTC are increasing.

Similarly, effect of HTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye(Z)refrigerants in LTC are shown in Table-2(c) respectively and it was found that by increasing evaporator temperature from 263K to 283K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is increasing while HTC compressor work is decreasing. Mass flow rate of both (HTC and LTC) cycles are increasing. Heat rejected from HTC condenser and LTC condenser are increasing. From Table-2(a) to Table-2(d), the overall cascaded first law performance using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye(Z) refrigerants gives best performance and lowest performances was observed using using low global warming potential HCFO- 1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC.

2.2 Effect of LTC evaporator temperature using low global warming potential HFO and HCFO refrigerants in cascaded VCR systems

Effect of LTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO- 1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-3(a) respectively and it was found that by increasing evaporator temperature from 198K to 223K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is constant and first law efficiency of LTC is increasing while HTC and LTC compressor work (both) are decreasing. Mass flow rate of both (HTC and LTC) cycles are decreasing. Heat rejected from HTC and LTC are decreasing. Effect of LTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO-1225ye(Z)refrigerants in LTC are shown in Table-3(b) respectively and it was found that by increasing evaporator temperature from 198K to 223K,, the overall cascaded first law efficiency and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is constant and first law efficiency of LTC is increasing while HTC and LTC compressor work (both) are decreasing. Mass flow rate of both (HTC and LTC) cycles are decreasing. Heat rejected from high temperature condenser cycle and low temperature condenser are decreasing.

Table 2 (a): Effect of HTC evaporator temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva_$_{LTC}$=35.167 “kW”, T_$_{HTC\_Cond}$ =323K, T_$_{HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T_$_{LTC\_Cond}$ - T_$_{HTC\_Eva}$) =10, HTC compressor efficiency=80%, LTC compressor efficiency=80%)

Variation of HTC evaporator temperature (K)	263	268	273	278	283
HTC Refrigerants	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.7686	0.7607	0.7482	0.7310	0.7094
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.576	1.603	1.646	1.709	1.791
Exergetic Efficiency	0.3882	0.3842	0.3779	0.3692	0.3583
Exergy of Fuel “kW”	45.75	46.23	47.0	48.11	49.58
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.360	1.233	1.118	1.013
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.996	3.448	4.002	4.698
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.982	2.167	2.473	3.016
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3354	0.3779	0.2879	0.249
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	22.34	20.37	18.48	16.65	14.87
Exergy of product $_{HTC\ VCRS}$ “kW”	7.796	6.831	5.833	4.793	3.703
Q_$_{HTC\_Condenser}$ “kW”	80.92	81.4	82.17	83.27	84.74
Q_$_{LTC\_Condenser}$ “kW”	58.58	61.03	61.7	66.63	69.87
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W_$_{Comp\_HTC}$)“kW”	23.41	20.37	18.48	16.65	14.87
LTC compressor work(W_$_{Comp\_HTC}$)“ “kW”	23.41	25.86	28.53	31.46	34.70
HTC Mass flow Rate (kg/sec)	0.5231	0.5297	0.5377	0.5474	0.5590
LTC Mass flow Rate (kg/sec)	0.2765	0.2905	0.3060	0.3233	0.3428

Table 2 (b): Effect of HTC evaporator temperature using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO- 1225ye(Z)refrigerants in LTC on thermal performances of VCR system (for Q_eva_$_{LTC}$=35.167 “kW”, T_$_{HTC\_Cond}$ =323K, T_$_{HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T_$_{LTC\_Cond}$ - T_$_{HTC\_Eva}$) =10, HTC compressor efficiency=80%, LTC compressor efficiency=80%)

Variation of HTC evaporator temperature (K)	263	268	273	278	283
HTC Refrigerants	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.7738	0.7648	0.7506	0.7311	0.7064
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.559	1.589	1.638	1.708	1.803
Exergetic Efficiency	0.3908	0.3863	0.3791	0.3692	0.3568
Exergy of Fuel “kW”	45.45	45.98	46.85	48.41	49.78
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.516	1.370	1.238	1.118	1.008
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.996	3.488	4.002	4.698
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.982	2.161	2.473	3.016
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3354	0.3157	0.2879	0.2490
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	22.25	20.31	18.44	16.650	14.91
Exergy of product $_{HTC\ VCRS}$ “kW”	7.766	6.811	5.8221	4.793	3.712
Q_$_{HTC\_Condenser}$ “kW”	80.61	81.15	82.02	83.27	84.95
Q_$_{LTC\_Condenser}$ “kW”	58.36	60.84	63.58	66.62	70.04
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W_$_{Comp\_HTC}$)“kW”	22.25	20.31	18.44	16.650	14.91
LTC compressor work(W_$_{Comp\_HTC}$)“ “kW”	23.19	25.67	28.41	31.45	34.87
HTC Mass flow Rate (kg/sec)	0.5211	0.5281	0.5367	0.5473	0.5604
LTC Mass flow Rate (kg/sec)	0.3080	0.3239	0.3419	0.3624	0.3860

Table 2 (c): Effect of HTC evaporator temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{LTC}$*=35.167 "kW", T*$_{HTC\_Cond}$ *=323K, T*$_{HTC}$*_Eva_ =263K, Temperature Overlapping (Approach= T*$_{LTC\_Cond}$ *- T*$_{HTC\_Eva}$*) =10, HTC compressor efficiency=80%*

Variation of HTC evaporator temperature (K)	263	268	273	278	283
HTC Refrigerants	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.7783	0.7686	0.7545	0.7359	0.7130
Exergy Destruction Ratio (EDR$_{VCRS}$)	1.544	1.576	1.624	1.691	1.777
Exergetic Efficiency	0.3931	0.3882	0.3810	0.3717	0.3601
Exergy of Fuel "kW"	45.18	45.75	46.6	47.79	49.32
Exergy of product"kW"	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.360	1.233	1.118	1.013
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	3.068	3.523	4.080	4.78
Exergy Destruction Ratio (EDR $_{HTC\ VCRS}$)	1.792	1.912	2.10	2.407	2.947
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3434	0.3226	0.2936	0.2534
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	21.77	19.89	18.08	16.33	14.62
Exergy of product $_{HTC\ VCRS}$ "kW"	7.796	6.831	5.833	4.793	3.703
Q_$_{HTC\_Condenser}$ "kW"	80.35	80.92	81.78	82.95	84.49
Q_$_{LTC\_Condenser}$ "kW"	58.58	61.03	63.70	66.63	69.87
Q_$_{LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	21.77	19.89	18.08	16.33	14.62
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.41	25.86	28.53	31.46	34.70
HTC Mass flow Rate (kg/sec)	0.4328	0.4393	0.4470	0.4561	0.4669
LTC Mass flow Rate (kg/sec)	0.2765	0.2905	0.3060	0.3233	0.3428

Table 2 (d): Effect of HTC evaporator temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO- 1225ye(Z)refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{LTC}$*=35.167 "kW", T*$_{HTC\_Cond}$ *=323K, T*$_{HTC}$*_Eva_ =263K, Temperature Overlapping (Approach= T*$_{LTC\_Cond}$ *- T*$_{HTC\_Eva}$*) =10, HTC compressor efficiency=80%*

Variation of HTC evaporator temperature (K)	263	268	273	278	283
HTC Refrigerants	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.7836	0.7728	0.7569	0.7360	0.7101
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.527	1.562	1.616	1.690	1.789
Exergetic Efficiency	0.3958	0.3903	0.3823	0.3717	0.3586
Exergy of Fuel "kW"	44.88	45.51	46.46	47.78	49.53
Exergy of product"kW"	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.516	1.370	1.238	1.118	1.008
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	3.068	3.523	4.08	4.78
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.792	1.912	2.10	2.407	2.947
Exergetic Efficiency $_{HTC\ VCRS}$	0.3581	0.3434	0.3226	0.2936	0.2534
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	21.69	19.83	18.05	16.33	14.55
Exergy of product $_{HTC\ VCRS}$ "kW"	7.766	6.811	5.822	4.793	3.712
Q_$_{HTC\_Condenser}$ "kW"	80.04	80.67	81.63	82.95	84.69
Q_$_{LTC\_Condenser}$ "kW"	58.36	60.84	63.58	66.62	70.04
Q_$_{LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	21.69	19.83	18.05	16.33	14.55
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.19	25.67	28.41	31.45	34.87
HTC Mass flow Rate (kg/sec)	0.4312	0.4379	0.4461	0.4560	0.4680
LTC Mass flow Rate (kg/sec)	0.3080	0.3239	0.3419	0.3624	0.3860

Similarly, effect of LTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-3(c) respectively and by increasing LTC evaporator temperature from 198K to 223K,, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency (COP) of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency (COP) of HTC is constant and first law efficiency (COP) of LTC is increasing while HTC and LTC compressor work (both) are decreasing. Mass flow rate of both (HTC and LTC) cycles are decreasing. Heat rejected from HTC and low temperature Heat rejected from condenser of HTC and low temperature condenser are decreasing.

Table3 (a): Effect of LTC evaporator temperature using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{LTC}$=35.167 "kW", T$_{\_HTC\_Cond}$ =323K, T$_{\_HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%

Variation of LTC evaporator temperature (K)	198	203	208	213	218	223
HTC Refrigerants	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.7686	0.8376	0.9115	0.9909	1.076	1.186
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.576	1.551	1.535	1.529	1.532	1.507
Exergetic Efficiency	0.3882	0.3920	0.3944	0.3954	0.3949	0.3989
Exergy of Fuel "kW"	45.75	41.99	38.58	35.49	32.68	30.11
Exergy of product"kW"	17.76	16.46	15.22	14.03	12.91	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.70	1.930	2.20	2.521	2.909
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.622	2.622	2.622	2.622	2.622
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.866	1.866	1.866	1.866	1.866
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3490	0.3490	0.3490	0.3490	0.3490
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	22.34	21.30	20.36	19.51	18.73	18.02
Exergy of product $_{HTC\ VCRS}$ "kW"	7.796	7.433	7.105	6.809	6.536	6.289
Q$_{\_HTC\_Condenser}$ "kW"	80.92	77.15	73.75	70.66	67.84	65.28
Q$_{\_LTC\_Condenser}$ "kW"	58.58	55.85	53.39	51.15	49.12	47.26
Q$_{\_LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	22.34	21.30	20.36	19.51	18.73	18.02
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.41	20.69	18.22	15.98	13.95	12.09
HTC Mass flow Rate (kg/sec)	0.5231	0.4988	0.4768	0.4568	0.4386	0.422
LTC Mass flow Rate (kg/sec)	0.2765	0.2695	0.2627	0.2562	0.2499	0.2438

Table 3 (b): Effect of LTC evaporator temperature using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO-1225ye(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{LTC}$=35.167 "kW", T$_{\_HTC\_Cond}$ =323K, T$_{\_HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80

Variation of LTC evaporator temperature (K)	198	203	208	213	218	223
HTC Refrigerants	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)
LTC Refrigerants	HFO-1225 ye(Z)	HFO-1225 ye(Z)	HFO-1225 ye(Z)	HFO-1225 ye(Z)	HFO-1225 ye(Z)	HFO-1225 ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.7738	0.8413	0.9139	0.9919	1.076	1.167
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.559	1.540	1.529	1.526	1.533	1.549
Exergetic Efficiency	0.3908	0.3937	0.3954	0.3958	0.3949	0.3923
Exergy of Fuel "kW"	45.45	41.80	38.48	35.45	32.68	30.15
Exergy of product"kW"	17.76	16.46	15.22	14.03	12.91	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	1.516	1.711	1.938	2.204	2.520	2.903
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.622	2.622	2.622	2.622	2.622
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.866	1.866	1.866	1.866	1.866
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3490	0.3490	0.3490	0.3490	0.3490
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	22.25	21.25	20.33	19.50	18.73	18.03
Exergy of product $_{HTC\ VCRS}$ "kW"	7.766	7.415	7.095	6.804	6.537	6.292
Q$_{\_HTC\_Condenser}$ "kW"	80.61	76.96	73.65	70.62	67.85	65.31
Q$_{\_LTC\_Condenser}$ "kW"	58.36	55.72	53.32	51.12	49.12	47.28
Q$_{\_LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	22.25	21.25	20.33	19.50	18.73	18.03
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.19	20.55	18.15	15.96	13.95	12.12
HTC Mass flow Rate (kg/sec)	0.5211	0.4976	0.4761	0.4565	0.4386	0.4222
LTC Mass flow Rate (kg/sec)	0.3084	0.3009	0.2940	0.2873	0.2809	0.2747

Similarly, effect of LTC evaporator temperature on Energy-exergy performances of cascaded VCR systems using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye(Z) refrigerants in LTC are shown in Table-3(d) respectively and it was found that by increasing evaporator temperature from

198K to 223K,, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency of HTC is constant and first law efficiency of LTC is increasing while HTC and LTC compressor work (both) are decreasing. Mass flow rate of both (HTC and LTC) cycles are decreasing. Heat rejected from HTC and low temperature Heat rejected from condenser of HTC and low temperature are decreasing.

Table 3 (c): Effect of LTC evaporator temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{\_LTC}$=35.167 "kW", T$_{\_HTC\_Cond}$ =323K, T$_{\_HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%

Variation of LTC evaporator temperature (K)	198	203	208	213	218	223
HTC Refrigerants	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.7783	0.8486	0.9240	1.005	1.092	1.186
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.544	1.518	1.501	1.493	1.495	1.507
Exergetic Efficiency	0.3931	0.3971	0.3998	0.4011	0.4008	0.3989
Exergy of Fuel "kW"	45.18	41.44	38.06	34.99	32.20	29.65
Exergy of product"kW"	17.76	16.46	15.22	14.03	12.91	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.70	1.930	2.20	2.521	2.909
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	2.691	2.691	2.691	2.691	2.691
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.792	1.792	1.792	1.792	1.792	1.792
Exergetic Efficiency $_{HTC\ VCRS}$	0.3581	0.3581	0.3581	0.3581	0.3581	0.3581
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	21.77	20.76	19.84	19.01	18.25	17.56
Exergy of product $_{HTC\ VCRS}$ "kW"	7.796	7.433	7.105	6.809	6.536	6.289
Q$_{\_HTC\_Condenser}$ "kW"	80.35	76.61	73.23	70.16	67.37	64.82
Q$_{\_LTC\_Condenser}$ "kW"	58.58	55.85	53.39	51.15	49.12	47.26
Q$_{\_LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	21.77	20.76	19.84	19.01	18.25	17.56
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.41	20.69	18.22	15.98	13.95	12.09
HTC Mass flow Rate (kg/sec)	0.4328	0.4127	0.3945	0.3779	0.3629	0.3492
LTC Mass flow Rate (kg/sec)	0.2765	0.2695	0.2627	0.2562	0.2499	0.2438

Table 3 (d): Effect of LTC evaporator temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye (Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{\_LTC}$=35.167 "kW", T$_{\_HTC\_Cond}$ =323K, T$_{\_HTC}$_Eva_ =263K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%

Variation of LTC evaporator temperature (K)	198	203	208	213	218	223
HTC Refrigerants	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.7836	0.8524	0.9264	1.006	1.092	1.185
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.527	1.507	1.495	1.491	1.496	1.510
Exergetic Efficiency	0.3958	0.3989	0.4008	0.4015	0.4007	0.3984
Exergy of Fuel "kW"	44.88	41.26	37.56	34.95	32.21	29.69
Exergy of product"kW"	17.76	16.46	15.22	14.03	12.91	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	1.516	1.711	1.938	2.204	2.520	2.903
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	2.691	2.691	2.691	2.691	2.691
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.792	1.792	1.792	1.792	1.792	1.792
Exergetic Efficiency $_{HTC\ VCRS}$	0.3581	0.3581	0.3581	0.3581	0.3581	0.3581
Exergy of Fuel $_{HTC\ VCRS}$ "kW"	21.69	20.71	19.81	19.0	18.25	17.57
Exergy of product $_{HTC\ VCRS}$ "kW"	7.766	7.415	7.095	6.804	6.537	6.292
Q$_{\_HTC\_Condenser}$ "kW"	80.04	76.42	73.13	70.12	67.37	64.85
Q$_{\_LTC\_Condenser}$ "kW"	58.36	55.72	53.32	51.12	49.12	47.28
Q$_{\_LTC\_Evaporator}$ "kW"	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)"kW"	21.69	20.71	19.81	19.0	18.25	17.57
LTC compressor work(W$_{\_Comp\_HTC}$)" "kW"	23.19	20.55	18.15	15.96	13.95	12.12
HTC Mass flow Rate (kg/sec)	0.4312	0.4117	0.3939	0.3777	0.3629	0.3493
LTC Mass flow Rate (kg/sec)	0.3084	0.3009	0.2940	0.2873	0.2809	0.2747

2.3 *Effect of HTC condenser temperature using low global warming potential HFO and HCFO refrigerants in cascaded VCR systems*

Effect of HTC condenser temperature on energy-exergy performances of cascaded VCR systems using low global warming potential HCFO- 1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC and low global warming potential HCFO- 1224yd(Z) refrigerant in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-4(a) and Table-4(b) respectively and it was found that by decreasing HTC condenser temperature from 333K to 308K, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are increasing , while first law efficiency (COP) of LTC is constant and first law efficiency (COP) of HTC is decreasing. Similarly, HTC compressor work is decreasing. Mass flow rate of HTC refrigerant is decreasing. Mass flow rate of LTC refrigerant is constant. Heat rejected from condenser of HTC is decreasing. The effect of HCFO-1224yd(Z) and HCFO- 1233zd(E) in HTC using same HFO-1336mzz(Z) in LTC indicated that better thermal energy-exergy performances than using HCFO- 1233zd(E) have been found instead of using HCFO- 1224yd(Z).

Table 4 (a): Effect of HTC condenser temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1336mzz(Z)refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{\_LTC}$=35.167 “kW”, T$_{\_HTC\_Eva}$ =263K, T$_{_LTC_}$Eva$_{\_}$ =223K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%, LTC compressor efficiency=80%)

Variation of HTC condenser temperature (K)	333	328	323	318	313	308
HTC Refrigerants	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)	HCFO-1233zd(E)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.6944	0.7357	0.7783	0.8224	0.8683	0.9162
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.851	1.691	1.544	1.407	1.502	1.161
Exergetic Efficiency	0.3507	0.3716	0.3931	0.4154	0.4385	0.4627
Exergy of Fuel “kW”	50.65	47.8	45.18	42.76	40.50	38.38
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.502	1.502	1.502	1.502	1.502
First law Efficiency (COP $_{HTC\_VCRS}$)	2.151	2.402	2.691	3.028	3.429	3.914
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	2.493	2.128	1.792	1.481	1.192	0.920
Exergetic Efficiency $_{HTC\ VCRS}$	0.2863	0.3197	0.3581	0.4030	0.4563	0.5208
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	27.23	24.39	21.77	19.34	17.09	14.97
Exergy of product $_{HTC\ VCRS}$ “kW”	7.796	7.796	7.796	7.796	7.796	7.796
Q$_{\_HTC\_Condenser}$ “kW”	85.81	82.97	80.35	77.93	75.67	73.55
Q$_{\_LTC\_Condenser}$ “kW”	58.58	58.58	58.58	58.58	58.58	58.58
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	27.23	24.39	21.77	19.34	17.09	14.97
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	23.41	23.41	23.41	23.41	23.41	23.41
HTC Mass flow Rate (kg/sec)	0.4782	0.4543	0.4328	0.4134	0.3957	0.3796
LTC Mass flow Rate (kg/sec)	0.2765	0.2765	0.2765	0.2765	0.2765	0.2765

Table 4 (b): Effect of HTC condenser temperature using low global warming potential HCFO-1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z)refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{\_LTC}$=35.167 “kW”, T$_{\_HTC\_Eva}$ =263K, T$_{_LTC_}$Eva$_{\_}$ =223K, Temperature Overlapping (Approach= T$_{\_LTC\_Cond}$ - T$_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%, LTC compressor efficiency=80%)

Variation of HTC condenser temperature (K)	333	328	323	318	313	308
HTC Refrigerants	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.6803	0.7239	0.7686	0.8146	0.8620	0.9113
Exergy Destruction Ratio (EDR$_{VCRS}$)	1.911	1.735	1.576	1.431	1.297	1.173
Exergetic Efficiency	0.3436	0.3656	0.3882	0.4114	0.4354	0.4602
Exergy of Fuel “kW”	51.70	48.58	45.75	43.17	40.80	38.59
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.502	1.502	1.502	1.502	1.502	1.502
First law Efficiency (COP $_{HTC\_VCRS}$)	2.071	2.328	2.622	2.965	3.370	3.86
Exergy Destruction Ratio (EDR $_{HTC\ VCRS}$)	2.628	2.228	1.866	1.534	1.230	0.9467
Exergetic Efficiency $_{HTC\ VCRS}$	0.2757	0.3098	0.3490	0.3946	0.4485	0.5137
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	28.28	25.16	22.34	19.76	17.38	15.18

Exergy of product $_{\text{HTC VCRS}}$ “kW”	7.796	7.796	7.796	7.796	7.796	7.796
Q$_{\text{\_HTC\_Condenser}}$ “kW”	86.86	83.74	80.92	78.34	75.96	73.76
Q$_{\text{\_LTC\_Condenser}}$ “kW”	58.58	58.58	58.58	58.58	58.58	58.58
Q$_{\text{\_LTC\_Evaporator}}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\text{\_Comp\_HTC}}$)“kW”	28.28	25.16	22.34	19.76	17.38	15.18
LTC compressor work(W$_{\text{\_Comp\_HTC}}$)“ “kW”	23.41	23.41	23.41	23.41	23.41	23.41
HTC Mass flow Rate (kg/sec)	0.5863	0.5528	0.5231	0.4968	0.4731	0.4519
LTC Mass flow Rate (kg/sec)	0.2765	0.2765	0.2765	0.2765	0.2765	0.2765

Effect of HTC condenser temperature on energy-exergy performances of cascaded VCR systems using low global warming potential HCFO- 1224yd(Z) refrigerants in HTC and low global warming potential HFO-1336mzz(Z) refrigerants in LTC are shown in Table-4(a) respectively and it was found that by decreasing evaporator temperature from 333K to 308K, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are increasing , while first law efficiency (COP) of LTC is constant and first law efficiency (COP) of HTC is decreasing. Similarly, HTC compressor work is decreasing. Mass flow rate of HTC refrigerant is decreasing. Mass flow rate of LTC refrigerant is constant. Heat rejected from condenser of HTC is decreasing. The effect of HCFO-1224yd(Z) and HCFO-1233zd(E) in HTC using same HFO-1225ye(Z)in LTC indicated that better thermal energy-exergy performances than using HCFO- 1233zd(E) have been found instead of using HFO- 1336mzz(Z).

2.4 Effect of temperature overlapping on cascaded VCR systems

Effect of temperature overlapping (approach) on energy-exergy performances of cascaded VCR systems using low global warming potential HCFO- 1224yd(Z) and HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye(Z) and HFO-1336mzz(Z) refrigerants in LTC are shown in Table-5(a)to table-5(d) respectively and it was found that by increasing temperature overlapping (approach) the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency (COP) of LTC is decreasing. The HTC compressor work and LTC compressor work (both) are increasing. Similarly, Heat rejected by HTC and LTC condensers and HTC and LTC mass flow rates are increasing.

Table 4 (c): Effect of HTC condenser temperature using low global warming potential HCFO-1233zd(E) refrigerants in HTC and low global warming potential HFO-1225ye(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva$_{\text{\_LTC}}$=35.167 “kW”, T$_{\text{\_HTC\_Eva}}$ =263K, T$_{\text{\_LTC}}$_Eva_ =223K, Temperature Overlapping (Approach= T$_{\text{\_LTC\_Cond}}$ - T$_{\text{\_HTC\_Eva}}$) =10, HTC compressor efficiency=80%, LTC compressor efficiency=80%)

Variation of HTC condenser temperature (K)	333	328	323	318	313	308
HTC Refrigerants	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{\text{VCRS}}$)	0.6989	0.7406	0.7836	0.8282	0.8745	0.9229
Exergy Destruction Ratio(EDR$_{\text{VCRS}}$)	1.833	1.674	1.527	1.391	1.264	1.145
Exergetic Efficiency	0.3530	0.3740	0.3958	0.4183	0.4417	0.4661
Exergy of Fuel “kW”	50.32	47.48	44.88	42.46	40.21	38.10
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{\text{LTC\_VCRS}}$)	1.516	1.516	1.516	1.516	1.516	1.516
First law Efficiency (COP $_{\text{HTC\_VCRS}}$)	2.151	2.402	2.691	3.028	3.429	3.914
Exergy Destruction Ratio(EDR $_{\text{HTC VCRS}}$)	2.493	2.128	1.792	1.481	1.192	0.920
Exergetic Efficiency $_{\text{HTC VCRS}}$	0.2863	0.3197	0.3581	0.4030	0.4563	0.5208
Exergy of Fuel $_{\text{HTC VCRS}}$ “kW”	27.13	24.29	21.69	19.27	17.02	14.91
Exergy of product $_{\text{HTC VCRS}}$ “kW”	7.766	7.766	7.766	7.766	7.766	7.766
Q$_{\text{\_HTC\_Condenser}}$ “kW”	85.49	82.65	80.04	77.63	75.38	73.27
Q$_{\text{\_LTC\_Condenser}}$ “kW”	58.36	58.36	58.36	58.36	58.36	58.36
Q$_{\text{\_LTC\_Evaporator}}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\text{\_Comp\_HTC}}$)“kW”	27.13	24.29	21.69	19.27	17.02	14.91
LTC compressor work(W$_{\text{\_Comp\_HTC}}$)“ “kW”	23.19	23.19	23.19	23.19	23.19	23.19
HTC Mass flow Rate (kg/sec)	0.4764	0.4526	0.4312	0.4118	0.3942	0.3781
LTC Mass flow Rate (kg/sec)	0.3080	0.3080	0.3080	0.3080	0.3080	0.3080

Table 4 (d): Effect of HTC condenser temperature using low global warming potential HCFO- 1224yd(Z)refrigerants in HTC and low global warming potential HFO-1225ye(Z) refrigerants in LTC on thermal performances of VCR system (for Q_eva_{LTC}=35.167 “kW”, $T_{\_HTC\_Eva}$ =263K, $T_{\_LTC}$_Eva_ =223K, Temperature Overlapping (Approach= $T_{\_LTC\_Cond}$ - $T_{\_HTC\_Eva}$) =10, HTC compressor efficiency=80%

Variation of HTC condenser temperature (K)	333	328	323	318	313	308
HTC Refrigerants	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)	HCFO-1224yd(Z)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.6847	0.7287	0.7738	0.8202	0.8682	0.9180
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.892	1.717	1.559	1.414	1.281	1.157
Exergetic Efficiency	0.3458	0.3680	0.3908	0.4143	0.4385	0.4636
Exergy of Fuel “kW”	51.36	48.26	45.45	42.87	40.51	38.31
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.516	1.516	1.516	1.516	1.516	1.516
First law Efficiency (COP $_{HTC\_VCRS}$)	2.071	2.328	2.622	2.965	3.370	3.860
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	2.628	2.228	1.866	1.534	1.230	0.9467
Exergetic Efficiency $_{HTC\ VCRS}$	0.2757	0.3098	0.3490	0.3946	0.4485	0.5137
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	28.17	25.07	22.25	19.68	17.32	15.12
Exergy of product $_{HTC\ VCRS}$ “kW”	7.766	7.766	7.766	7.766	7.766	7.766
Q$_{\_HTC\_Condenser}$ “kW”	86.53	83.43	80.61	78.04	75.67	73.48
Q$_{\_LTC\_Condenser}$ “kW”	58.36	58.36	58.36	58.36	58.36	58.36
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	28.17	25.07	22.25	19.68	17.32	15.12
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	23.19	23.19	23.19	23.19	23.19	23.19
HTC Mass flow Rate (kg/sec)	0.5841	0.5507	0.5211	0.4949	0.4713	0.4501
LTC Mass flow Rate (kg/sec)	0.3080	0.3080	0.3080	0.3080	0.3080	0.3080

Table 5 (a): Variation of temperature overlapping on cascaded VCR systems using HCFO-1233zd(E) in HTC and HFO-1225ye(Z) in LTC

Variation of temperature overlapping(K)	0	5	10	15
HTC Refrigerants	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.9043	0.8421	0.7836	0.7284
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.190	1.351	1.527	1.718
Exergetic Efficiency	0.4567	0.4253	0.3958	0.3679
Exergy of Fuel “kW”	38.89	41.76	44.88	48.28
Exergy of product“kW”	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.868	1.681	1.516	1.37
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	2.691	2.691	2.691
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.792	1.792	1.792	1.792
Exergetic Efficiency $_{HTC\ VCRS}$	0.3581	0.3581	0.3581	0.3581
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	20.06	20.84	21.69	22.61
Exergy of product $_{HTC\ VCRS}$ “kW”	7.185	7.464	7.768	8.097
Q$_{\_HTC\_Condenser}$ “kW”	74.06	76.93	80.04	83.45
Q$_{\_LTC\_Condenser}$ “kW”	53.99	56.09	58.36	60.84
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	20.06	20.84	21.69	22.61
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	18.83	20.92	23.19	25.67
HTC Mass flow Rate (kg/sec)	0.3989	0.4144	0.4312	0.4495
LTC Mass flow Rate (kg/sec)	0.2809	0.2937	0.3080	0.3239

Table 5(b): Variation of temperature overlapping on cascaded VCR systems using HCFO-1224yd(Z) in HTC and HFO-1225ye(Z) in LTC

Variation of temperature overlapping(K)	0	5	10	15
HTC Refrigerants	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)
LTC Refrigerants	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)	HFO-1225ye(Z)
First law Efficiency (COP $_{VCRS}$)	0.8922	0.8312	0.7738	0.7195
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.219	1.382	1.559	1.752
Exergetic Efficiency	0.4506	0.4198	0.3908	0.3634

Exergy of Fuel “kW”	39.41	42.31	45.45	48.88
Exergy of product“kW”	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.868	1.681	1.516	1.37
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.622	2.622	2.622
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.866	1.866	1.866
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3490	0.3490	0.3490
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	20.59	21.39	22.25	23.20
Exergy of product $_{HTC\ VCRS}$ “kW”	7.185	7.464	7.768	8.097
Q$_{\_HTC\_Condenser}$ “kW”	74.58	77.47	80.61	84.04
Q$_{\_LTC\_Condenser}$ “kW”	53.99	56.09	58.36	60.84
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	20.59	21.39	22.25	23.20
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	18.83	20.92	23.19	25.67
HTC Mass flow Rate (kg/sec)	0.4821	0.5008	0.5211	0.5433
LTC Mass flow Rate (kg/sec)	0.2809	0.2937	0.3080	0.3239

*Table 5(c): Variation of temperature overlapping on cascaded VCR systems using HCFO-1233zd(E) in HTC and HFO-*1336 mzz(Z) *in LTC*

Variation of temperature overlapping(K)	0	5	10	15
HTC Refrigerants	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)	HCFO-1233 zd(E)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.8969	0.8356	0.7783	0.7245
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.208	1.370	1.544	1.733
Exergetic Efficiency	0.4530	0.4220	0.3931	0.3659
Exergy of Fuel “kW”	39.21	42.09	45.18	48.54
Exergy of product“kW”	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.845	1.662	1.502	1.360
First law Efficiency (COP $_{HTC\_VCRS}$)	2.691	2.691	2.691	2.691
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.792	1.792	1.792	1.792
Exergetic Efficiency $_{HTC\ VCRS}$	0.3581	0.3581	0.3581	0.3581
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	20.15	20.93	21.77	22.68
Exergy of product $_{HTC\ VCRS}$ “kW”	7.217	7.496	7.796	8.122
Q$_{\_HTC\_Condenser}$ “kW”	74.38	77.25	80.35	83.71
Q$_{\_LTC\_Condenser}$ “kW”	54.23	56.32	58.58	61.03
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	20.15	20.93	21.77	22.68
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	19.06	21.16	23.41	25.86
HTC Mass flow Rate (kg/sec)	0.4006	0.4161	0.4328	0.4509
LTC Mass flow Rate (kg/sec)	0.2523	0.2638	0.2765	0.2905

*Table 5 (d): Variation of temperature overlapping on cascaded VCR systems using HCFO-1224*yd(Z) *in HTC and HFO-*1336 mzz(Z) *in LTC*

Variation of temperature overlapping(K)	0	5	10	15
HTC Refrigerants	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)	HCFO-1224 yd(Z)
LTC Refrigerants	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)	HFO-1336 mzz(Z)
First law Efficiency (COP $_{VCRS}$)	0.8849	0.8248	0.7686	0.7157
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.237	1.40	1.576	1.766
Exergetic Efficiency	0.4469	0.4166	0.3882	0.3615
Exergy of Fuel “kW”	39.74	42.64	45.75	49.13
Exergy of product“kW”	17.76	17.76	17.76	17.76
First law Efficiency (COP $_{LTC\_VCRS}$)	1.845	1.662	1.502	1.360
First law Efficiency (COP $_{HTC\_VCRS}$)	2.622	2.622	2.622	2.622
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	1.866	1.866	1.866	1.866
Exergetic Efficiency $_{HTC\ VCRS}$	0.3490	0.3490	0.3490	0.3490
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	20.68	21.48	22.34	23.27
Exergy of product $_{HTC\ VCRS}$ “kW”	7.217	7.496	7.796	8.122
Q$_{\_HTC\_Condenser}$ “kW”	74.91	77.80	80.92	84.30
Q$_{\_LTC\_Condenser}$ “kW”	54.23	56.32	58.58	61.03

$Q\_{}_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work ($W_{\_Comp\_HTC}$)“kW”	20.68	21.48	22.34	23.27
LTC compressor work($W_{\_Comp\_HTC}$)“ “kW”	19.06	21.16	23.41	25.66
HTC Mass flow Rate (kg/sec)	0.4842	0.5030	0.5231	0.5450
LTC Mass flow Rate (kg/sec)	0.2523	0.2638	0.2765	0.2905

2.5 Effect of low GWP hydro carbon (HC) and HFC refrigerants on thermal performances of cascaded VCR systems for ultra-low temperature applications

The input values have been used for finding thermal performances of cascaded vapour compression refrigeration systems using low GWP ecofriendly refrigerants are shown in table-6. To compare the effect of different ecofriendly hydrocarbons (HCs) refrigerants in HTC on energy-exergy performances of twelve cascaded VCR systems using input data of table-6 and also using HFCs refrigerants in low temperature cycle are shown in Table-8(a) and Table-8(b) respectively and it was found that the overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-600a in HTC and propylene in LTC gives highest thermal performances, while cascaded system using R290 in HTC and ethylene in LTC gives lowest thermal performances

Table 6: Input variables used in cascaded VCR systems

S.No.	Input Parameter	Value
1	$T_{\_Cond\_HTC}$ (K)	323
2	$T_{\_Eva\_HTC}$ (K)	263
3	$T_{\_\ Eva\ \_LTC}$ (K)	198
4	Q_ Eva _LTC (kW)	35.167
5	HTC compressor Efficiency (%)	80
6	LTC compressor Efficiency (%)	80
7	Temp overlapping ($T_{\_LTC\_Cond}$-$T_{\_HTC\_Eva}$)	10

Table 7(a): Effect of low GWP hydro carbon (HC) and HFC refrigerants on thermal performances of cascaded VCR systems

Performance Parameters	System-1	System-2	System-3	System-4	System-5	System-6
HTC Refrigerants	R290	R600a	R290	R600a	R290	R600a
LTC Refrigerants	Ethylene	Ethylene	Propylene	Propylene	Ethane	Ethane
First law Efficiency ($COP_{\ VCRS}$)	0.5669	0.5801	0.7460	0.7654	0.6647	0.6812
Exergy Destruction Ratio(EDR_{VCRS})	2.493	1.971	1.654	1.587	1.979	1.971
Exergetic Efficiency	0.2863	0.2930	0.3768	0.3865	0.3357	0.3440
Exergy of Fuel “kW”	62.04	60.63	47.14	45.95	52.91	51.63
Exergy of product“kW”	17.76	17.76	17.76	17.76	17.76	17.76
First law Efficiency ($COP_{\ \_LTC\_VCRC}$)	1.05	1.05	1.531	1.531	1.301	1.301
First law Efficiency ($COP_{\ \_HTC\_VCRC}$)	2.404	2.529	2.404	2.529	2.404	2.529
Exergy Destruction Ratio(EDR_{VCRS})	2.125	1.971	2.125	1.971	2.125	1.971
Exergetic Efficiency	0.320	0.3366	0.320	0.3366	0.3357	0.3366
Exergy of Fuel “kW”	28.55	27.14	24.18	22.98	25.87	24.59
Exergy of product“kW”	9.136	9.136	7.736	7.736	8.278	8.278
$Q\_{}_{HTC\_Condenser}$ “kW”	97.2	95.79	82.31	81.12	88.07	86.8
$Q\_{}_{LTC\_Condenser}$ “kW”	68.65	68.65	58.13	58.13	62.2	62.2
$Q\_{}_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work ($W_{\_Comp\_HTC}$)“kW”	28.55	27.14	24.18	22.98	25.87	24.59
LTC compressor work($W_{\_Comp\_HTC}$)“ “kW”	33.48	33.48	22.97	22.97	27.04	27.04
HTC Mass flow Rate (kg/sec)	0.304	0.3139	0.2574	0.2656	0.2754	0.2844
LTC Mass flow Rate (kg/sec)	0.1747	0.1747	0.1175	0.1175	0.1375	0.1375

Table 7(b): Effect of low GWP hydro carbon (HC) and HFC refrigerants on thermal performances of cascaded VCR systems

Performance Parameters	System-7	System-8	System-9	System-10	System-11	System-12
HTC Refrigerants	R290	R600a	R290	R600a	R290	R600a
LTC Refrigerants	Ethylene	Ethylene	Propylene	Propylene	Ethane	Ethane
First law Efficiency ($COP_{\ VCRS}$)	0.9039	0.9296	1.109	1.144	1.024	1.055
Exergy Destruction Ratio(EDR_{VCRS})	2.289	2.199	1.68	1.598	1.905	1.819
Exergetic Efficiency	0.3040	0.3126	0.3731	0.3849	0.3443	0.3547
Exergy of Fuel “kW”	38.90	37.83	31.7	30.73	34.36	33.35
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency ($COP_{\ VCRS}$)	2.051	2.051	2.917	2.917	2.524	2.524
First law Efficiency ($COP_{\ VCRS}$)	2.404	2.529	2.404	2.529	2.404	2.529
Exergy Destruction Ratio(EDR_{VCRS})	2.125	1.971	2.125	1.971	2.125	1.971
Exergetic Efficiency	0.320	0.3366	0.320	0.3366	0.320	0.3366
Exergy of Fuel “kW”	21.76	20.68	19.64	18.67	20.42	19.41
Exergy of product“kW”	17.15	17.15	12.06	12.06	13.93	13.93
$Q\_{}_{HTC\_Condenser}$ “kW”	74.07	73.0	66.86	65.9	69.52	68.51

Q_$_{LTC\_Condenser}$ “kW”	52.31	52.31	47.22	47.22	49.1	49.1
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	21.76	20.68	19.64	18.67	20.42	19.41
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	17.15	17.15	12.06	12.06	13.93	13.93
HTC Mass flow Rate (kg/sec)	0.2316	0.2392	0.2091	0.2159	0.2174	0.2245
LTC Mass flow Rate (kg/sec)	1.637	1.637	1.076	1.076	0.1257	0.1257

2.6 Effect of HFC and natural refrigerants on thermal performances of cascaded VCR systems

To compare the effect of different ecofriendly HFCs refrigerants in HTC on energy-exergy performances of nine cascaded VCR systems using input data of table-6(a) and also using HFCs refrigerants in low temperature cycle are shown in Table-8(a) and Table-8(b) respectively and it was found that the overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-134a in HTC and R-123 in LTC gives highest thermal performances, while cascaded system using HFC-134a in HTC and R407c in LTC gives lowest thermal performances.

Table 8(a): Effect of low HFC refrigerants on thermal performances of cascaded VCR systems using HFC refrigerants

Performance Parameters	System-1	System-2	System-3	System-4	System-5
HTC Refrigerants	R-134a	R-134a	R-134a	R-134a	R-134a
LTC Refrigerants	R410A	R404A	R407C	R125	R507a
First law Efficiency (COP $_{VCRS}$)	1.112	1.088	1.025	1.08	1.096
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.674	1.734	1.90	1.753	1.713
1.627Exergetic Efficiency	0.3739	0.3658	0.3448	0.3632	0.3686
Exergy of Fuel “kW”	31.63	32.33	34.3	32.57	32.09
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	2.848	2.737	2.468	2.702	2.774
First law Efficiency (COP $_{HTC\_VCRS}$)	2.464	2.464	2.464	2.464	2.464
Exergy Destruction Ratio(EDR$_{VCRS}$)	2.049	2.049	2.049	2.049	2.049
Exergetic Efficiency	0.328	0.328	0.328	0.328	0.328
Exergy of Fuel “kW”	19.28	19.48	20.05	19.55	19.41
Exergy of product“kW”	6.324	6.390	6.576	6.412	6.367
Q_$_{HTC\_Condenser}$ “kW”	66.8	67.5	69.46	67.73	65.81
Q_$_{LTC\_Condenser}$ “kW”	47.52	48.02	49.41	48.18	47.84
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	19.28	19.48	20.05	19.55	19.41
LTC compressor work(W$_{\_Comp\_LTC}$)“ “kW”	12.35	12.85	14.25	13.01	12.68
HTC Mass flow Rate (kg/sec)	0.3926	0.3967	0.4083	0.3981	0.3953
LTC Mass flow Rate (kg/sec)	0.1758	0.2559	0.1936	0.3305	0.2627

Table 8(b): Effect of HFC refrigerants on thermal performances of cascaded VCR systems *using HFC and HCFC refrigerants*

Performance Parameters	System-6		System-7	System-8	System-9
HTC Refrigerants	R-134a		R-134a	R-134a	R-134a
LTC Refrigerants	R123		R124	R143a	R141b
First law Efficiency (COP $_{VCRS}$)	1.148		1.132	1.106	1.164
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.591		1.627	1.689	1.555
Exergetic Efficiency	0.386		0.3807	0.3718	0.3914
Exergy of Fuel “kW”	30.64		31.07	31.81	30.22
Exergy of product“kW”	11.83		11.83	11.83	11.83
First law Efficiency (COP $_{VCRS}$)	3.02		2.943	2.464	2.464
First law Efficiency (COP $_{VCRS}$)	2.464		2.464	2.464	2.464
Exergy Destruction Ratio(EDR$_{VCRS}$)	2.049		2.049	2.049	2.049
Exergetic Efficiency	0.328		0.328	0.328	0.328
Exergy of Fuel “kW”	19.0		19.12	19.33	18.87
Exergy of product“kW”	6.23		6.27	6.34	6.19
Q_$_{HTC\_Condenser}$ “kW”	65.81		66.23	66.98	65.38
Q_$_{LTC\_Condenser}$ “kW”	46.81		47.11	47.64	46.51
Q_$_{LTC\_Evaporator}$ “kW”	35.167		35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	19.0		19.12	19.33	18.87
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	11.65		11.95	12.48	11.34
HTC Mass flow Rate (kg/sec)	0.3868		0.3893	0.3936	0.3843
LTC Mass flow Rate (kg/sec)	0.2310		0.2695	0.2218	0.1723

To compare the effect of different HFCs and HFO-1234ze refrigerants in HTC on energy-exergy performances of four cascaded VCR systems using input data of table-6(a) and also using low global warming potential HFCs and HFO-1234yf refrigerants in low temperature cycle are shown in Table-9 respectively and it was found that the overall cascaded COP and exergy efficiency (both) using R-717 in HTC and R-32 in LTC gives highest thermal performances, while cascaded system using R-1234ze(E) in HTC and R1234yf in LTC gives lowest thermal performances.

Table 9: Effect of and HFO refrigerants on thermal performances of cascaded VCRS using low GWP ecofriendly refrigerants systems

Performance Parameters	System-1	System-2	System-3	System-4
HTC Refrigerants	R-152a	R-245fa	R717	R-1234ze
LTC Refrigerants	R-32	R-32	R32	R1234yf
First law Efficiency (COP $_{VCRS}$)	1.159	1.160	1.174	1.014
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.567	1.564	1.534	1.694
Exergetic Efficiency	0.3896	0.3901	0.3947	0.3712
Exergy of Fuel “kW”	30.36	30.32	29.7	31.86
Exergy of product“kW”	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{VCRS}$)	2.249	2.249	2.249	2.188
First law Efficiency (COP $_{VCRS}$)	3.451	3.459	3.544	3.215
Exergy Destruction Ratio(EDR$_{VCRS}$)	2.164	2.157	2.081	2.396
Exergetic Efficiency	0.3160	0.3168	0.3246	0.2944
Exergy of Fuel “kW”	14.72	14.69	14.33	15.76
Exergy of product“kW”	4.652	4.652	4.652	4.692
Q_$_{HTC\_Condenser}$ “kW”	65.52	65.49	65.13	67.03
Q_$_{LTC\_Condenser}$ “kW”	50.8	50.8	50.8	51.24
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	14.72	14.69	14.33	15.90
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	15.63	15.63	15.63	16.07
HTC Mass flow Rate (kg/sec)	0.2356	0.3677	0.04973	0.4497
LTC Mass flow Rate (kg/sec)	0.1258	0.1258	0.1258	0.3013

2.7 Effect of HFO+HFC Blended refrigerants on thermal performances of cascaded VCR systems

To compare the effect of different ecofriendly low global warming potential HFO+HFC blended refrigerants in HTC on energy-exergy performances of sixteen cascaded VCR systems using input data of table-6(a) and also using low global warming potential HFO+HFC blended refrigerants in refrigerants in low temperature cycle are shown in Table-10(a)to table-10(c) respectively and it was found that the overall cascaded COP and exergy efficiency (both) using R-515A in HTC and R-513A in LTC gives highest thermal performances, while cascaded system using R454cin HTC and R454b in LTC gives lowest thermal performances.

Table 10(a): Effect of HFO+HFC Blended refrigerants on thermal performances of cascaded VCR systems

Performance Parameters	System-1	System-2	System-3	System-4	System-5	System-6
HTC Refrigerants	R515A	R515A	R515A	R513A	R513A	R513A
LTC Refrigerants	R513A	R454b	R454c	R515A	R454b	R454c
First law Efficiency (COP $_{VCRS}$)	1.112	1.098	1.010	1.096	1.076	0.9899
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.674	1.707	1.945	1.713	1.763	2.004
Exergetic Efficiency	0.3739	0.3694	0.3395	0.3685	0.3619	0.3329
Exergy of Fuel “kW”	31.63	32.02	34.83	32.09	32.68	35.52
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{LTC\_VCRS}$)	2.230	2.189	1.931	2.251	2.189	1.931
First law Efficiency (COP $_{HTC\_VCRS}$)	3.212	3.212	3.212	3.084	3.084	3.084
Exergy Destruction Ratio(EDR $_{HTC\ VCRS}$)	2.40	2.40	2.40	2.541	2.541	2.541
Exergetic Efficiency $_{HTC\ VCRS}$	0.2941	0.2941	0.2941	0.2824	0.2824	0.2824
Exergy of Fuel $_{HTC\ VCRS}$ “kW”	15.86	15.95	16.62	16.47	16.62	17.31
Exergy of product $_{HTC\ VCRS}$ “kW”	4.665	4.692	4.888	4.651	4.692	4.888
Q_$_{HTC\_Condenser}$ “kW”	66.80	67.19	70.0	67.26	67.85	70.69
Q_$_{LTC\_Condenser}$ “kW”	50.94	51.24	53.38	50.79	51.24	53.38
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	15.86	15.95	16.62	16.47	16.62	17.31
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	15.77	16.07	18.21	15.62	16.07	18.21
HTC Mass flow Rate (kg/sec)	0.4560	0.4587	0.4779	0.4832	0.4874	0.5078
LTC Mass flow Rate (kg/sec)	0.2695	0.1569	0.2399	0.2709	0.1569	0.2399

Table 10(b): Effect of HFO+HFC Blended refrigerants on thermal performances of cascaded VCR systems

Performance Parameters	System-7	System-8	System-9	System-10
HTC Refrigerants	R450A	R450A	R450A	R450A
LTC Refrigerants	R515A	R513A	R454b	R454c
First law Efficiency (COP $_{\_CASCADED\_VCRS}$)	1.101	1.094	1.081	0.9942
Exergy Destruction Ratio (EDR $_{CASCADED\_VCRS}$)	1.701	1.718	1.751	1.991
Exergetic Efficiency$_{\_CASCADED\_VCRS}$	0.3702	0.3679	0.3635	0.3344
Exergy of Fuel $_{CASCADED\_VCRS}$ “kW”	31.95	32.15	32.54	35.37
Exergy of product $_{CASCADED\_VCRS}$ “kW”	11.83	11.83	11.83	11.83
First law Efficiency ((COP$_{\_LTC\_VCRS}$))	2.251	2.230	2.189	1.931
First law Efficiency (COP$_{\_HTC\_VCRS}$)	3.111	3.111	3.111	3.111
Exergy Destruction Ratio(EDR$_{VCRS}$)	2.510	2.510	2.510	2.510
Exergetic Efficiency	0.2849	0.2849	0.2849	0.2849
Exergy of Fuel “kW”	16.33	16.38	16.47	17.16
Exergy of product“kW”	4.651	4.655	4.692	4.888
Q$_{\_HTC\_Condenser}$ “kW”	67.12	67.31	67.71	70.54
Q$_{\_LTC\_Condenser}$ “kW”	50.79	50.94	51.24	53.38
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	16.33	16.38	16.47	17.16
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	15.62	15.77	16.07	18.21
HTC Mass flow Rate (kg/sec)	0.4384	0.4397	0.4423	0.4608
LTC Mass flow Rate (kg/sec)	0.2709	0.2695	0.1569	0.2399

Table 10 (c): Effect of HFO+HFC Blended refrigerants on thermal performances of cascaded VCR systems

Performance Parameters	System-11	System-12	System-13	System-14	System-15	System-16
HTC Refrigerants	R454b	R454b	R454b	R454c	R454c	R454c
LTC Refrigerants	R515A	R513A	R454c	R515A	R513A	R454b
First law Efficiency (COP $_{VCRS}$)	1.073	1.066	0.970	0.9999	0.9940	0.9825
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.772	1.789	2.065	1.974	1.991	2.026
Exergetic Efficiency	0.3607	0.3585	0.3262	0.3363	0.3343	0.3304
Exergy of Fuel “kW”	32.79	32.99	36.25	35.17	35.38	35.79
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{VCRS}$)	2.251	2.230	1.931	2.251	2.230	2.189
First law Efficiency (COP $_{VCRS}$)	2.959	2.959	2.959	2.598	2.598	2.598
Exergy Destruction Ratio(EDR$_{VCRS}$)	2.691	2.691	2.691	3.204	3.204	3.204
Exergetic Efficiency	0.2709	0.2709	0.2709	0.2379	0.2379	0.2379
Exergy of Fuel “kW”	17.17	17.22	18.04	19.55	19.61	19.72
Exergy of product“kW”	4.651	4.665	4.888	4.651	4.665	4.692
Q$_{\_HTC\_Condenser}$ “kW”	67.95	68.16	71.42	70.34	70.55	70.96
Q$_{\_LTC\_Condenser}$ “kW”	50.79	50.94	58.17	50.79	50.94	51.24
Q$_{\_LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	17.17	17.22	18.04	19.55	19.61	19.72
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	15.62	15.77	18.21	15.62	15.77	16.07
HTC Mass flow Rate (kg/sec)	0.2951	0.2960	0.3102	0.4404	0.4417	0.4443
LTC Mass flow Rate (kg/sec)	0.2709	0.2695	0.2399	0.2709	0.2695	0.1569

2.8 Effect of HFO refrigerants on thermal performances of cascaded VCR systems

To compare the effect of different ecofriendly ultra-low global warming potential HFO refrigerants in HTC on energy-exergy performances of twenty eight cascaded VCR systems using input data of table-6(a) and also using low global warming potential HFO- 1336mzz(Z), HFO-1225ye(Z),HCFO-1233zd(E) , HFO-1234yf refrigerants in low temperature cycle are shown in Table-11(a)to table-11(d) respectively and it was found that the overall cascaded first law efficiency (COP) and exergy efficiency (both) using HFO-1234ze(Z) in HTC and HCFO-1233zd(E) in LTC gives highest thermal performances, while cascaded system using HFO-1225ye(Z) in HTC and R1234yf in LTC gives lowest thermal performances.

Table 11(a): Effect of HFO&HCFO refrigerants in HTC and HFO1336mzz(Z)on thermal performances of cascaded VCR systems

Performance Parameters	System-1	System-2	System-3	System-4	System-5	System-6	System-7
HTC Refrigerants	R-1234 ze(Z)	R-1234 ze(E)	R-1243zf	R-1233 zd(E)	R-1224 yd(Z)	R-1225 ye(Z)	R1234yf
LTC Refrigerants	R1336 mzz(Z)	R1336 mzz(Z)	R1336 mzz(Z)	R1336 mzz(Z)	R1336 mzz(Z)	R1336 mzz(Z)	R1336 mzz(Z)
First law Efficiency (COP_{VCRS})	1.206	1.131	1.122	1.183	1.170	1.121	1.088
Exergy Destruction Ratio (EDR_{VCRS})	1.466	1.630	1.649	1.514	1.540	1.653	1.732
Exergetic Efficiency	0.4056	0.3802	0.3774	0.3978	0.3936	0.3769	0.3661
Exergy of Fuel “kW”	29.16	31.11	31.34	29.73	30.05	31.38	32.31
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP_{VCRS})	2.286	2.286	2.286	2.286	2.286	2.286	2.286
First law Efficiency (COP_{VCRS})	3.669	3.215	3.169	3.523	3.448	3.16	2.986
Exergy Destruction Ratio(EDR_{VCRS})	1.977	2.396	2.446	2.10	2.167	2.456	2.657
Exergetic Efficiency	03359	0.2944	0.2902	0.3226	0.3157	0.2897	0.2735
Exergy of Fuel “kW”	13.78	15.72	15.95	14.35	14.66	16.0	16.97
Exergy of product“kW”	4.629	4.629	4.629	4.629	4.629	4.629	4.629
$Q\_{HTC\_Condenser}$ “kW”	64.33	66.27	66.50	64.91	65.21	66.55	67.48
$Q\_{LTC\_Condenser}$ “kW”	50.55	50.55	50.55	50.55	50.55	50.55	50.55
$Q\_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W_{Comp_HTC})“kW”	13.78	15.72	15.95	14.35	14.66	16.0	16.97
LTC compressor work(W_{Comp_HTC})“ “kW”	15.38	15.38	15.38	15.38	15.38	15.38	15.38
HTC Mass flow Rate (kg/sec)	0.3144	0.4446	0.3987	0.3547	0.4267	0.5269	0.5416
LTC Mass flow Rate (kg/sec)	0.2665	0.2665	0.2665	0.2665	0.2665	0.2665	0.2665

Table 11(b): Effect of HFO & HCFO refrigerants in HTC and HFO1225ye(Z)on thermal performances of cascaded VCR systems

Performance Parameters	System-8	System-9	System-10	System-11	System-12	System-13	System-14
HTC Refrigerants	R-1234 ze(Z)	R-1234 ze(E)	R-1243zf	R-1233 zd(E)	R1336 mzz(Z)	R-1224 yd(Z)	R1234yf
LTC Refrigerants	R-1225 ye(Z)	R-1225 ye(Z)	R-1225 ye(Z)	R-1225 ye(Z)	R-1225 ye(Z)	R-1225 ye(Z)	R-1225 ye(Z)
First law Efficiency (COP_{VCRS})	1.20	1.125	1.117	1.177	1.157	1.165	1.083
Exergy Destruction Ratio(EDR_{VCRS})	1.478	1.642	1.662	1.526	1.569	1.553	1.745
Exergetic Efficiency	0.4036	0.3784	0.3757	0.3959	0.3892	0.3917	0.3644
Exergy of Fuel “kW”	29.31	31.25	31.48	29.88	30.39	30.19	32.46
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP_{VCRS})	2.269	2.269	2.269	2.269	2.269	2.269	2.269
First law Efficiency (COP_{VCRS})	3.669	3.215	3.169	3.525	3.402	3.448	2.989
Exergy Destruction Ratio(EDR_{VCRS})	1.977	2.396	2.446	2.10	2.210	2.167	2.657
Exergetic Efficiency	03359	0.2944	0.2902	0.3226	0.3116	0.3157	0.2735
Exergy of Fuel “kW”	13.81	15.76	15.99	14.38	14.89	14.7	16.97
Exergy of product“kW”	4.639	4.639	4.639	4.639	4.639	4.639	4.639
$Q\_{HTC\_Condenser}$ “kW”	64.47	66.42	66.65	65.05	65.55	65.36	67.63
$Q\_{LTC\_Condenser}$ “kW”	50.66	50.66	50.66	50.66	50.66	50.66	50.66
$Q\_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W_{Comp_HTC})“kW”	13.81	15.76	15.99	14.38	14.89	14.7	16.97
LTC compressor work(W_{Comp_HTC})“ “kW”	15.5	15.5	15.5	15.5	15.5	15.5	15.5
HTC Mass flow Rate (kg/sec)	0.3151	0.4456	0.3996	0.3555	0.4257	0.4277	0.5428
LTC Mass flow Rate (kg/sec)	0.3015	0.3015	0.3015	0.3015	0.3015	0.3015	0.3015

Table 11(c): Effect of HFO & HCFO refrigerants in HTC and HCFO1233zd(E)on thermal performances of cascaded VCR systems

Performance Parameters	System-15	System-16	System-17	System-18	System-19	System-20	System-21
HTC Refrigerants	R-1234 ze(Z)	R-1234 ze(E)	R-1243zf	R-1224 yd(Z)	R1336 mzz(Z)	R-1225 ye(Z)	R1234yf
LTC Refrigerants	R-1233 zd(E)	R-1233 zd(E)	R-1233 zd(E)	R-1233 zd(E)	R-1233 zd(E)	R-1233 zd(E)	R-1233 zd(E)
First law Efficiency (COP_{VCRS})	1.233	1.155	1.146	1.196	1.188	1.145	1.111
Exergy Destruction Ratio(EDR_{VCRS})	1.402	1.574	1.594	1.486	1.502	1.597	1.675
Exergetic Efficiency	0.4147	0.3885	0.3856	0.4023	0.3997	0.3850	0.3738
Exergy of Fuel “kW”	28.52	30.45	30.67	29.40	29.59	30.72	31.64

Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{VCRS}$)	2.363	2.363	2.363	2.363	2.363	2.363	2.363
First law Efficiency (COP $_{VCRS}$)	3.669	3.215	3.169	3.448	3.402	3.16	2.984
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.977	2.396	2.446	2.167	2.210	2.456	2.657
Exergetic Efficiency	03359	0.2944	0.2902	0.3157	0.3116	0.2894	0.2735
Exergy of Fuel “kW”	13.64	15.57	15.79	14.52	14.71	15.84	16.76
Exergy of product“kW”	4.583	4.583	4.583	4.583	4.583	4.583	4.583
Q_$_{HTC\_Condenser}$ “kW”	63.69	65.61	65.84	64.57	64.76	65.89	66.81
Q_$_{LTC\_Condenser}$ “kW”	50.05	50.05	50.05	50.05	50.05	50.05	50.05
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	13.64	15.57	15.79	14.52	14.71	15.84	16.76
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	14.88	14.88	14.88	14.88	14.88	14.88	14.88
HTC Mass flow Rate (kg/sec)	0.3113	0.4402	0.3947	0.4225	0.4205	0.5216	0.5362
LTC Mass flow Rate (kg/sec)	0.2239	0.2239	0.2239	0.2239	0.2239	0.2239	0.2239

Table 11(d): Effect of HFO&HCFO refrigerants in HTC and R1234yf in LTC on thermal performances of cascaded VCR systems

Performance Parameters	System-22	System-23	System-24	System-25	System-26	System-27	System-28
HTC Refrigerants	R-1234 ze(Z)	R-1234 ze(E)	R-1233 zd(E)	R-1224 yd(Z)	R1336 mzz(Z)	R-1225 ye(Z)	R-1243zf
LTC Refrigerants	R1234yf	R1234yf	R1234yf	R1234yf	R1234yf	R1234yf	R1234yf
First law Efficiency (COP $_{VCRS}$)	1.171	1.099	1.149	1.137	1.130	1.089	1.091
Exergy Destruction Ratio (EDR$_{VCRS}$)	1.540	1.706	1.588	1.615	1.632	1.730	1.726
Exergetic Efficiency	0.3938	0.3695	0.3863	0.3824	0.3799	0.3664	0.3669
Exergy of Fuel “kW”	30.04	32.01	30.93	30.93	31.13	32.28	32.0
Exergy of product“kW”	11.83	11.83	11.83	11.83	11.83	11.83	11.83
First law Efficiency (COP $_{VCRS}$)	2.188	2.188	2.188	2.188	2.188	2.188	2.188
First law Efficiency (COP $_{VCRS}$)	3.669	3.215	3.525	3.448	3.402	3.160	3.169
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.977	2.396	2.10	2.167	2.210	2.456	2.446
Exergetic Efficiency	03359	0.2944	0.3226	0.3157	0.3116	0.2894	0.2902
Exergy of Fuel “kW”	13.97	15.94	14.55	14.86	15.06	16.21	16.17
Exergy of product“kW”	4.692	4.692	4.692	4.692	4.692	4.692	4.692
Q_$_{HTC\_Condenser}$ “kW”	65.2	67.17	65.78	66.10	66.30	67.45	67.41
Q_$_{LTC\_Condenser}$ “kW”	51.24	51.24	51.24	51.24	51.24	51.24	51.24
Q_$_{LTC\_Evaporator}$ “kW”	35.167	35.167	35.167	35.167	35.167	35.167	35.167
HTC compressor work (W$_{\_Comp\_HTC}$)“kW”	13.97	15.94	14.55	14.86	15.06	16.21	16.17
LTC compressor work(W$_{\_Comp\_HTC}$)“ “kW”	16.07	16.07	16.07	16.07	16.07	16.07	16.07
HTC Mass flow Rate (kg/sec)	0.3187	0.4506	0.3595	0.4325	0.4305	0.5340	0.4041
LTC Mass flow Rate (kg/sec)	0.3013	0.3013	0.3013	0.3013	0.3013	0.3013	0.3013

3. Conclusions

The following conclusion were drawn from present investigation

- The overall cascaded first law efficiency (COP) and exergy efficiency (both) using HFO-1234ze(Z) in HTC and HCFO-1233zd(E) in LTC gives highest thermal performance.
- By decreasing HTC condenser temperature, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are increasing, while first law efficiency (COP) of LTC is constant and first law efficiency (COP) of HTC is decreasing. Similarly, HTC compressor work is decreasing. Mass flow rate of HTC refrigerant is decreasing. Mass flow rate of LTC refrigerant is constant. Heat rejected from condenser of HTC is decreasing.
- The effect of HCFO- 1224yd(Z) and HCFO- 1233zd(E) in HTC using same HFO- 1225ye(Z)in LTC indicated that better thermal energy-exergy performances than using HCFO- 1233zd(E) have been found instead of using HFO-1336mzz(Z)
- By increasing temperature overlapping (approach) in the cascaded VCR systems HCFO-1233zd(E) in HTC (HTC) and HFO-1225ye(Z) in Lower temperature cycle (LTC), the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency (COP) of LTC is decreasing. The HTC compressor work and LTC compressor work (both) are increasing. Similarly, Heat rejected by HTC and LTC condensers and HTC and LTC mass flow rates are increasing.
- cascaded system using HFO-1225ye(Z) in HTC and R1234yf in LTC gives lowest thermal performances
- cascaded first law efficiency (COP) and exergy efficiency (both) using HCFO-1233zd(E) in HTC and HFO-1225ye(Z) in LTC gives excellent thermal performances and higher than using HCFO-1233zd(E) in HTC and HFO-1336mzz(Z) in LTC.
- By increasing evaporator temperature, using HFOs and HCFOs in HTC and also HFOs and HCFO-1233zd(E) in

- LTC, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency (COP) of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency (COP) of HTC is increasing while HTC compressor work is decreasing. Mass flow rate of both (HTC and LTC) cycles are increasing. Heat rejected from HTC and LTC are increasing.
- The overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-717 in HTC and R-32 in LTC gives highest thermal performances, while cascaded system using R-1234ze(E) in HTC and R1234yf in LTC gives lowest thermal performances.
- Overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-515A in HTC and R-513A in LTC gives highest thermal performances, while cascaded system using R454cin HTC and R454b in LTC gives lowest thermal performances.
- Overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-134a in HTC and R-123 in LTC gives highest thermal performances, while cascaded system using HFC-134a in HTC and R407c in LTC gives lowest thermal performances.
- Overall cascaded first law efficiency (COP) and exergy efficiency (both) using R-600a in HTC and propylene in LTC gives highest thermal performances, while cascaded system using R290 in HTC and ethylene in LTC gives lowest thermal performances
- By increasing low temperature evaporator (LTC) temperature, using HFOs & HCFOs in HTC and LTC, the overall cascaded first law efficiency (COP) and exergy efficiency (both) are decreasing, while first law efficiency (COP) of LTC is decreasing while LTC compressor work is increasing. Similarly, first law efficiency (COP) of HTC is constant and first law efficiency (COP) of LTC is increasing while HTC and LTC compressor work (both) are decreasing. Mass flow rate of both (HTC and LTC) cycles are decreasing. Heat rejected from HTC and low temperature Heat rejected from condenser of HTC and low temperature condenser are decreasing.
- For Replacing HFCs (R134a, R404a, R407c, R410a, R507a, R143a) in the cascaded VCR systems, HFO and HCFO gives better results.
- For Replacing HFCs (R134a,R404a, R407c, R410a, R507a, R125,R143a) in the cascaded VCR systems, HFC-R152a, R245fa in HTC and R32 in LTC gives better results than using R134a in HTC and R404a, R410a, R407c, R125 in LTC
- HFO blended refrigerants also be used for replacing HFCs
- (R134a, R404a, R407c, R410a, R507a, R143a) cascaded VCR systems, R513a, R450a, R515a in HTC and R515a, R513a,R454b, R454c in LTC gives better results than using R134a in HTC and R404a, R410a, R407c, R125 in LTC.

References

[1] Said SAM and Ismail B**.,[**1994**],** Exergetic assessment of the coolants HCFC123, HFC134a, CFC11, and CFC12, Energy**,** Volume 19, Issue 11, November 1994, Pages 1181-1186, https://doi.org/10.1016/0360-5442(94)90074-4

[2] C. Nikolaidis, D. Probert-Exergy method analysis of a two-stage vapour-compression refrigeration-plants performance. Int J Applied Thermal Engineering.1998; 60:241-256.

[3] H.M Getu, P.K Bansal. Thermalanalysis of an R744-R717 cascade refrigeration system. Int J Refrigeration.2008; 31:45-54.

[4] J. Navarro-Esbrí, et al.[2013]Experimental analysis of R1234yf as a drop-in replacement for R134a in a vapor compression system, Int. J. Refrig., 36 (3) (2013), pp. 870-880

[5] Y. Lee, D. Jung, [2012]A brief performance comparison of R1234yf and R134a in a bench tester for automobile applications, Appl. Therm. Eng., 35 (2012), pp. 240-242

[6] M. Spatz, B. Minor [2008]HFO-1234yf low GWP refrigerant update-Honeywell & Dupont joint collaboration, International Refrigerant & Air Conditioning Conference, Purdue, July (2008).

[7] Chopra K, Sahni B. Mishra R.S., [2015] Energy, Exergy and Sustainability Analysis of Two-stage Vapour Compression Refrigeration System, Journal of thermal engineering, Volume: 1 Issue: 4, 440 - 445,.

[8] Mishra R.S., Chopra K [2019] Energy & Exergy analysis (Thermodynamic analysis) of a multi-evaporators vapour compression refrigeration system using ecofriendly refrigerants (R410a, R290, R600, R600a, R1234yf, R502, R404a and R152a),IJREI, DOI:10.36037/IJREI.2019.3510

[9] Mishra R.S., Chopra K [2019] Evaluation of thermodynamic energy-exergy performances in modified vapour compression refrigeration systems, DOI:10.36037/IJREI.2019.3603

***Cite this article as*:** R. S. Mishra, Methods for improving thermal performances of VCRS using Low GWP Refrigerants, International Journal of Research in Engineering and Innovation Vol-8, Issue-2 (2024), 70-87. *https://doi.org/10.36037/IJREI.2024.8205*.