International Journal of Research in Engineering and Innovation Vol-6, Issue-6 (2022), 388-398

International Journal of Research in Engineering and Innovation (IJREI)

journal home page: http://www.ijrei.com

ISSN (Online): 2456-6934

ORIGINAL ARTICLE

Effect of different loading conditions at evaporators of different temperatures on thermal performances of VCRS using environmental friendly refrigerants using multiple evaporators with compressors of individual types and expansion valves of multiple types

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Article Information

Received: 30 Sep 2022
Revised: 25 Nov 2022
Accepted: 05 Dec 2022
Available online: 30 Dec 2022

Keywords:

Nano-fluids
Thermo-physical properties
VCRS
HFOs &HCFO refrigerants

Abstract

The effect of different loading conditions at different evaporator temperatures on the thermal performances of VCRS using environmentally friendly refrigerants using multiple evaporators with compressors of individual types and expansion valves of multiple type shave has yet to be studied in detail so far in the literature. This paper mainly deals with the detailed first law performance in terms of COP and exergy performance of low GWP refrigerants in multiple evaporators; compressors of individual types used in VCR systems have been studied in detail, and the effect of different evaporators load variations at different evaporators temperatures on thermal performances have been investigated.

1. Introduction

One of the cruelest environmental issues affecting our planet is global warming. One of its sources is the initial creation of refrigerant gases and carbon dioxide emissions. These gases contribute to global warming because they are released into the atmosphere and stay there for prolonged periods. Based on their life cycle analysis and the effectiveness of refrigeration systems, these gases' environmental effects can be classified according to their severity. Over the next 100 years, Earth's temperature is anticipated to increase due to global warming. This will impact agriculture, resulting in heavy rains, more heat waves, and a possible rise in sea level during the next century. Due to this, the Montreal Protocol's signatory nations decided in 2016 to phase down HFCs and HCFCs to prevent the ozone layer from being damaged by global warming and reduce net Earth warming by 0.5 °C by the year 2100. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) both destroyed the ozone layer after the Montreal and Kyoto Protocols, respectively [1].

Currently, HFCs like R134a, R23, R404A, R407A, R410A, R125, and R507A make up most of the various refrigerants used in residential, automotive, commercial, and industrial refrigeration and air-conditioning systems. HFCs have a high global warming potential (GWP) despite having no ozone depletion potential (ODP). The GWP of R134a is 1430, that of R23 is 14800, that of R404A is 3922, that of R410A is 2088, that of R407A is 2107, and that of R507A is 3985.

The commercial VCR systems, such as centrifugal chillers and central air conditioning systems used in buildings, use the

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https://doi.org/10.36037/IJREI.2022.6604.

HCFC refrigerant (R22), and the current generation uses R134a and R123. R22 is under the A1 safety rating for refrigerants, which means it has a high GWP of 1810 but very low toxicity and no flame propagation. A widely used refrigerant for several kinds of refrigeration systems is R134a. It has a higher safety rating than A1 and is less poisonous, does not spread fire, and has a GWP of roughly 1430.

It is an HFC and will be completely phased out by 2034. R123 is an HCFC molecule with a B1 classification used in chillers because of its excellent thermal efficiency and low risk of leaks. However, because long-term inhalation of R123 has been linked to pancreatic and liver tumors, it is expected to be phased out by 2025.

The USA's Environmental Protection Agency (EPA) has planned to gradually phase out HFCs to 50% by 2025, 80% by 2030, and 100% by 2040 due to the high GWP values of the fourth generation of refrigerants [2]. Therefore, a drop-in replacement for R134a on VCRS with a variable speed compressor and input parameters of the evaporator and condenser temperature has been discovered. This replacement refrigerant should have a low GWP for little environmental impact. HFC-134a provides 3% to 5% higher COP than R404a (COP). Similar to R134a, R410a and R407c have 1% to 1.5% poorer COP efficiency. The outcomes demonstrated that the COP (energy) efficiency (COP) was reduced with R1234yf to 5 to 10% and raised with R1234ze(Z) from 3 to 7% [3]. The thermal performances of VCR systems using R152a are 2 to 6% higher than those using R134a. It was observed that the input power of R152a was 7.724%, 7.72% and 7.752% less than that of R134a, and the COP of the system using R1224yd(Z) a showed a 2.35%, 3.15% and 4.95% improvement at compressor speeds of 2000, 2500 and 3000 rpms, respectively, as compared to R134a [4-10]. The HFO-1234yf and HFO-1234ze (E) and R1234ze(Z), R1243zf, R1224yd(Z), R1225ye(Z), R1233zd(E), HFO-1336mzz(Z) were analysed as potential replacements for R134a and the results showed that R1234ze(E) and R1243zf showed the closest performance to R134a. Compared to R1234ze(E) [11-16]. The suitability of eight HFO refrigerants, such as HFO-1234yf and HFO-1234ze(E), as potential alternatives to R134a, was studied using the EES software and showed that these refrigerants improved performance without significantly increasing the GWP [17-21. The use of R1233zd(E)', R1224yd (Z) and R1234ze (Z) in terms of first law efficiency to be around 1%, was better than R245fa [22-29].

COP and exergy performance of low GWP refrigerants in multiple evaporator compressors of individual types used in VCR systems have been studied in detail, and the effect of different load variations on evaporators at separate evaporators' temperatures on thermal performances have been investigated.

2. Results and Discussion

Thermal Performances of VCR systems using HFO-1234ze refrigerant using multiple evaporators at different temperatures with compressors of individual types and expansion valves of multiple types of using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K, $Q_{\_eva1}$ = 70 “kW” , $Q_{\_eva2}$ =105 “kW” $Q_{\_eva3}$ = 35 “kW”) shown in table-1(a) respectively.

Table-1(a): *Validation of thermal performances of VCR systems using HFO-12 refrigerant using multiple evaporators at different temperatures with individual compressors & expansion valves of multiple types for (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K,* $Q_{\_eva1}$ = 70 “kW” , $Q_{\_eva2}$ =105 “kW” $Q_{\_eva3}$ = 35 “kW” *)*

S.N.	Performance Parameters	Ref [29]	Model	% variation
1	COP (Ideal)	6.25	6.485	3.76
2	Total compressor Work “kW”	33.6	32.38	-3.631 (Reduction)
3	First compressor Work “kW”	12.82	12.87	0.39
4	Second compressor Work “kW”	13.88	12.82	7.637
5	Third compressor Work “kW”	6.9	6.689	-3.058 (Reduction)

It was found that the developed model validates under an accuracy of less than 7.64%. The different load conditions are shown in table-1(b), and the other temperature conditions of evaporators Table -1(c), respectively.

Ideal thermal performances of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions are shown in Table-2(a) to Table-2(f), respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions of Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105 kW give maximum COP with lowest electrical energy consumption in terms of total compressors work for running whole system. In contrast, maximum exergy efficiency was found in different load conditions of Q_eva1=105 kW, Q_eva2=70 kW, and Q_eva3=35 kW with maximum electrical energy consumption in terms of total compressors work for running the whole system. However best first law efficiency (COP) of VCR systems using multiple evaporator compressors of individual types with expansion valves for numerous kinds using HFO-1234ze refrigerant for different evaporators loads (Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105) at was obtained at evaporators of different temperatures (T_eva1= 268 K, T_eva2= 278 K, and T_eva3= 283 K) shown in Table-2(f). Similarly, the exergy efficiency of VCR systems using multiple evaporator compressors of individual types with expansion valves for numerous kinds using HFO-1234ze refrigerant for different evaporators loads (Q_eva1 =105 kW, Q_eva2 =70 kW, Q_eva3 =35) at was obtained at evaporators of different temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 278 K) respectively.

Table-1(b) Different evaporators Load conditions used in VCRS using HFO-1234ze refrigerant using multiple evaporators at different temperatures with compressors of individual types and expansion valves of multiple types

S.N	Evaporator load Parameters	*Case-1*	*Case*-II	*Case*-III	*Case*-IV	*Case*-V	*Case*-VI
1	First Evaporator Load ($Q_{\_Eva1}$) "kW"	105	105	70	70	35	35
2	Second Evaporator Load ($Q_{\_Eva2}$)"kW"	70	35	105	35	70	105
3	Third Evaporator Load ($Q_{\_Eva3}$) "kW"	35	70	35	105	105	70

Table-1(c) Different evaporators load conditions used in VCRS using HFO-1234ze refrigerant using multiple evaporators at different temperatures with compressors of individual typesand expansion valves of multiple types

S.N	Evaporator Temperature Parameters	*Case-1*	*Case*-II	*Case*-III	*Case*-IV	*Case*-V	*Case*-VI
1	First Evaporator temperature ($T_{\_Eva1}$) "K"	263	263	263	268	268	268
2	Second Evaporator temperature T_{Eva2}) "kW"	273	273	278	273	273	278
3	Third Evaporator temperature ($T_{\_Eva3}$) "kW"	278	283	283	278	283	283

Table2(a): Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K, compressors isentropic efficiency= 100%)

Performance Parameters using R1234ze in given table-1(b)	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
First law Efficiency (COP $_{VCRS}$)	5.601	5.715	5.851	6.105	6.402	6.26
Exergy Destruction Ratio(EDR_{VCRS})	1.114	1.123	1.185	1.215	1.306	1.286
Exergetic Efficiency	0.4973	0.4893	0.4805	0.4628	0.4427	0.4526
Exergy of Fuel "kW"	37.49	36.75	35.89	34.4	32.8	33.55
Exergy of product "kW"	18.64	17.98	17.24	15.92	14.52	15.8
First compressor Work "kW"	18.06	18.06	12.04	12.04	6.02	6.02
Second compressor Work "kW"	9.792	5.16	14.25	4.984	9.44	14.07
Third compressor Work "kW"	9.641	13.53	9.604	17.38	17.34	13.45

Table -2(b): Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze in given table-1(b)	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	5.821	6.072	6.09	6.667	7.023	6.689
Exergy Destruction Ratio(EDR_{VCRS})	1.077	1.133	1.142	1.285	1.393	1.297
Exergy Efficiency	0.4991	0.4829	0.4816	0.4444	0.4214	0.4428
Exergy of Fuel "kW"	36.08	34.59	34.48	31.5	29.9	31.39
Exergy of product" kW"	18.0	16.7	16.61	14.0	12.6	13.9
First compressor Work "kW"	18.06	18.06	12.04	12.04	6.02	6.02
Second compressor Work "kW"	10.73	5.918	15.18	5.551	10.0	14.82
Third compressor Work "kW"	7.283	10.61	7.257	13.91	13.88	10.56

Table 2(c): Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze in given table-1(b)	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	6.064	6.193	6.516	6.826.	7.397	7.214
Exergy Destruction Ratio(EDR_{VCRS})	1.130	1.152	1.259	1.324	1.527	1.476
Exergetic Efficiency	0.4817	0.4730	0.4535	0.4331	0.3971	0.4093
Exergy of Fuel "kW"	34.63	33.91	32.23	30.79	28.39	29.11
Exergy of product" kW"	16.68	16.04	14.62	13.34	11.27	11.91
First compressor Work "kW"	18.77	18.77	12.51	12.51	6.257	6.257
Second compressor Work "kW"	8.598	4.541	12.49	4.38	8.275	12.33
Third compressor Work "kW"	7.259	10.6	7.22	13.9	13.86	10.52

Table -2(d): Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-I	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	5.999	6.13	6.134	6.414	6.565	6.419
Exergy Destruction Ratio(EDR_{VCRS})	1.235	1.251	1.275	1.314	1.364	1.341
Exergetic Efficiency	0.4716	0.4625	0.4621	0.4427	0.4318	0.4423

Exergy of Fuel "kW"	35.0	34.26	34.23	32.74	31.97	32.72
Exergy of product"kW"	16.51	15.84	15.82	14.49	1381	14.47
First compressor Work "kW"	15.64	15.64	10.43	10.43	5.213	5.213
Second compressor Work "kW"	9.782	5.15	14.24	4.977	9.437	14.07
Third compressor Work "kW"	9.584	13.47	9.566	17.34	17.32	13.43

Table -2(e): *Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

Performance Parameters using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	6.251	6.541	6.397	7.036	7.222	6.87
Exergy Destruction Ratio(EDR_{VCRS})	1.20	1.274	1.233	1.412	1.466	1.358
Exergetic Efficiency	0.4723	0.4536	0.4624	0.4213	0.4088	0.4315
Exergy of Fuel "kW"	33.6	32.11	32.83	29.85	29.08	30.57
Exergy of product"kW"	15.87	14.56	15.18	12.57	11.89	13.19
First compressor Work "kW"	15.64	15.64	10.43	10.43	5.213	5.213
Second compressor Work "kW"	10.71	5.897	15.17	5.537	9.993	14.81
Third compressor Work "kW"	7.244	10.57	7.231	13.88	13.87	10.54

Table -2(f): Ideal thermal performances of VCR systems using multiple evaporator & compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	6.552	6.702	6.883	7.223	7.628	7.434
Exergy Destruction Ratio(EDR_{VCRS})	1.265	1.296	1.372	1.457	1.616	1.556
Exergetic Efficiency	0.4537	0.4437	0.4324	0.4097	0.3836	0.3965
Exergy of Fuel "kW"	32.05	31.33	30.51	29.07	27.53	28.25
Exergy of product"kW"	14.54	13.19	13.19	11.91	10.56	11.2
First compressor Work "kW"	16.24	16.24	10.83	10.83	5.415	5.415
Second compressor Work "kW"	8.588	4.532	12.49	4.373	8.272	12.33
Third compressor Work "kW"	7.218	10.56	7.193	13.87	13.84	10.51

Exergy destruction in components of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions are shown in Table-3(a) to Table-3(f), respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions of Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105 kW gives maximum exergy destruction in compressor with lowest in throttle expansion valves at Q_eva1=105 kW, Q_eva2=70 kW, Q_eva3=35 kW. Similarly, minimum total exergy destruction (%) with maximum rational exergy efficiency was found in different load conditions of Q_eva1=105 kW, Q_eva2=35 kW, Q_eva3=70 kW at evaporators of different temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 283 K) respectively.

Table -3(a): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K, compressors isentropic efficiency= 100%)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	28.96	29.46	30.06	31.17	32.48	31.86
Evaporator	18.36	17.36	18.68	16.55	16.81	17.94
Expansion Valves	8.048	8.135	8.177	8.369	8.526	8.419
Total Exergy Destruction	55.38	54.96	56.92	56.10	57.82	58.21
Rational Efficiency	44.62	45.08	43.08	43.90	42.18	41.79

Table -3(b): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	29.3	31.03	31.11	33.64	35.2	33.74
Evaporator	17.39	17.17	17.34	16.85	16.76	17.04
Expansion Valves	6.451	6.50	6.522	6.635	6.727	6.660
Total Exergy Destruction	53.77	54.7	54.98	57.13	58.69	57.44

Table 3(c): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	31.0	31.56	32.98	34.32	36.85	36.05
Evaporator	16.74	16.18	17.43	16.23	16.97	17.62
Expansion Valves	6.679	6.743	6.671	6.814	6.817	6.738
Total Exergy Destruction	54.42	54.48	57.09	57.36	60.64	60.41
Rational Efficiency	45.58	45.52	42.91	42.64	39.36	39.59

Table 3(d): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-I	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	30.71	31.28	31.3	32.53	33.21	32.55
Evaporator	19.38	18.37	19.39	17.19	17.14	18.29
Expansion Valves	8.145	8.241	8.249	8.455	8.574	8.463
Total Exergy Destruction	58.24	57.86	58.94	58.17	58.92	59.31
Rational Efficiency	41.76	42.14	41.06	41.83	41.08	40.69

Table 3(e): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	31.82	33.09	32.46	35.26	36.08	34.53
Evaporator	18.39	18.2	18.02	17.57	17.1	17.39
Expansion Valves	6.452	6.502	6.524	6.646	6.735	6.666
Total Exergy Destruction	56.6	57.79	57.0	59.48	59.94	58.59
Rational Efficiency	43.34	42.21	43.0	40.52	40.06	41.41

Table 3(f): Ideal Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K,*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	0.0	0.0	0.0	0.0	0.0	0.0
Condenser	33.14	33.8	34.59	36.09	37.86	37.01
Evaporator	17.81	17.22	18.22	16.98	17.4	18.05
Expansion Valves	6.426	6.491	6.494	6.636	6.723	6.645
Total Exergy Destruction	57.37	57.51	59.31	59.71	61.98	61.71
Rational Efficiency	42.63	42.49	40.69	40.29	38.02	38.29

Actual thermal performances of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions are shown in Table-4(a) to Table-4(f), respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions of Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105 kW give maximum first law efficiency in terms of coefficient of performance(COP) with lowest electrical energy consumption in terms of total compressors work for running whole system. In contrast, maximum exergy efficiency was found in different load conditions of Q_eva1=105 kW, Q_eva2=70 kW, and Q_eva3=35 kW with maximum electrical energy consumption in terms of total compressors work for running the whole system. However best first law efficiency (COP) of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different evaporators loads (Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105) at was obtained at evaporators of different temperatures (T_eva1= 268 K, T_eva2= 278 K, and T_eva3= 283 K) shown in Table-2(f). Similarly, the exergy efficiency of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different evaporators loads (Q_eva1 =105 kW, Q_eva2 =70 kW, Q_eva3 =35) at was obtained at evaporators of different temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 278 K) respectively.

Table -4(a): Actual thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze in given table-1(b)	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP_{VCRS}	4.201	4.286	4.388	4.578	4.802	4.695
Exergy Destruction Ratio(EDR_{VCRS})	1.784	1.804	1.878	1.933	2.059	2.023
Exergetic Efficiency	0.373	0.3670	0.3604	0.3471	0.3320	0.3394
Exergy of Fuel “kW”	49.99	49.0	47.86	45.87	43.73	44.73
Exergy of product“kW”	18.64	17.98	17.24	15.92	14.52	15.8
First compressor Work “kW”	24.28	24.28	16.05	16.05	8.026	8.026
Second compressor Work “kW”	13.06	6.88	19.0	6.645	12.59	18.76
Third compressor Work “kW”	12.85	18.04	12.81	23.17	23.12	17.94

Table 4(b): Actual thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze in given table-1(b)	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP_{VCRS}	4.366	4.554	4.568	5.0	5.267	5.017
Exergy Destruction Ratio(EDR_{VCRS})	1.745	1.823	1.834	2.035	2.184	2.05
Exergetic Efficiency	0.3743	0.3622	0.3612	0.3333	0.3160	0.3321
Exergy of Fuel “kW”	48.1	46.11	45.97	42.0	39.87	41.86
Exergy of product“kW”	18.0	16.7	16.61	14.0	12.6	13.9
First compressor Work “kW”	24.08	24.08	16.05	16.05	8.026	8.026
Second compressor Work “kW”	14.31	7.891	20.24	7.401	13.33	19.76
Third compressor Work “kW”	9.71	14.14	9.676	18.54	18.51	14.08

Table -4(c): Actual thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP_{VCRS}	4.548	4.645	4.887	5.115	5.548	5.411
Exergy Destruction Ratio(EDR_{VCRS})	1.822	1.857	1.994	2.094	2.366	2.29
Exergetic Efficiency	0.3612	0.3547	0.3401	0.3249	0.2978	0.3070
Exergy of Fuel “kW”	46.17	45.21	42.97	41.05	37.85	38.81
Exergy of product“kW”	16.68	16.04	14.62	13.34	11.27	11.91
First compressor Work “kW”	25.03	25.03	16.69	16.69	8.343	8.343
Second compressor Work “kW”	11.46	6.055	16.66	5.840	11.03	16.44
Third compressor Work “kW”	9.678	14.13	9.628	18.53	18.48	14.03

Table -4(d): : Actual thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-I	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP_{VCRS}	4.499	4.597	4.601	4.81	4.926	4.814
Exergy Destruction Ratio(EDR_{VCRS})	1.942	1.972	1.997	2.067	2.136	2.095
Exergetic Efficiency	0.3537	0.3468	0.3466	0.3320	0.3239	0.3317
Exergy of Fuel “kW”	46.67	45.68	45.64	43.66	42.63	43.62
Exergy of product“kW”	16.51	15.84	15.82	14.49	1381	14.47
First compressor Work “kW”	20.85	20.85	13.9	13.9	6.951	6.951
Second compressor Work “kW”	13.04	6.866	18.99	6.636	12.51	18.76
Third compressor Work “kW”	12.78	17.96	12.75	23.12	23.1	17.91

Table -4(e): Actual Thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP_{VCRS}	4.688	4.906	4.798	5.277	5.417	5.153
Exergy Destruction Ratio(EDR_{VCRS})	1.905	2.009	1.954	2.203	2.282	2.13
Exergetic Efficiency	0.3542	0.3402	0.3468	0.3160	0.3066	0.3236
Exergy of Fuel “kW”	44.79	42.81	43.77	39.79	38.77	40.76
Exergy of product“kW”	15.87	14.56	15.18	12.57	11.89	13.19
First compressor Work “kW”	20.85	20.85	13.9	13.9	6.951	6.951
Second compressor Work “kW”	14.28	7.863	20.23	7.382	13.32	19.75

Table -4(f): Actual Thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)

Performance Parameters using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
COP $_{VCRS}$	4.914	5.027	5.162	5.418	5.721	5.575
Exergy Destruction Ratio(EDR_{VCRS})	1.999	2.048	2.143	2.271	2.485	2.397
Exergetic Efficiency	0.3403	0.3328	0.3243	0.3073	0.2877	0.2974
Exergy of Fuel "kW"	42.73	41.78	40.68	38.76	36.71	37.67
Exergy of product"kW"	14.54	13.19	13.19	11.91	10.56	11.2
First compressor Work "kW"	21.66	21.66	14.44	14.44	7.219	7.219
Second compressor Work "kW"	11.45	6.042	16.65	5.831	11.03	16.44
Third compressor Work "kW"	9.624	1408	9.59	18.49	18.46	14.01

Actual exergy destruction (%) in each component of VCR systems was computed at 75% compressors efficiencies using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions are shown in Table-5(a) to Table-5(f) respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions of Q_eva1 =35 kW, Q_eva2=70 kW, Q_eva3 =105 kW gives maximum exergy destruction in compressor with lowest in throttle expansion valves at Q_eva1=105 kW, Q_eva2=70 kW, Q_eva3=35 kW. Similarly, minimum total exergy destruction (%) with maximum rational exergy efficiency was found in different load conditions of Q_eva1=105 kW, Q_eva2=35 kW, Q_eva3=70 kW at evaporators of different temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 283 K) respectively.

Table -5(a): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.67	23.67	23.68	23.68	23.7	23.69
Condenser	23.06	23.43	23.87	24.7	25.66	25.2
Evaporator	13.77	13.02	14.01	12.42	12.61	13.45
Expansion Valves	6.036	6.102	6.133	6.277	6.394	6.315
Total Exergy Destruction	66.53	66.22	67.69	67.07	68.36	68.66
Rational Efficiency	33.47	33.78	32.31	32.93	31.64	31.34

Table -5(b): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.67	23.67	23.68	23.69	23.7	23.7
Condenser	23.78	24.6	24.65	26.54	27.7	26.61
Evaporator	13.05	12.88	13.01	12.64	12.57	12.78
Expansion Valves	4.838	4.875	4.892	4.976	5.045	4.995
Total Exergy Destruction	65.33	66.03	66.23	67.85	69.02	68.08
Rational Efficiency	34.67	33.97	33.77	32.15	30.98	31.92
Second law efficiency(%)	58.1	60.60	60.79	66.54	70.09	66.77

Table -5(c): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.67	23.67	23.69	23.69	23.71	23.71
Condenser	24.58	25.0	26.05	27.05	28.92	28.33
Evaporator	12.15	12.13	13.08	12.17	12.73	13.22
Expansion Valves	5.009	5.057	5.004	5.11	5.113	5.054
Total Exergy Destruction	65.81	65.86	67.81	68.02	70.48	70.31
Rational Efficiency	34.19	34.14	32.19	31.98	29.52	29.69

Table -5(d): : Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=278K, T_{Cond}=313K, $T_{Subcooled\_Liquid}$=303K)*

% Exergy Destruction in components using R1234ze	Case-I	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.69	23.69	23.69	23.70	23.70	23.70
Condenser	24.35	24.77	24.79	25.7	26.2	25.71
Evaporator	14.54	13.75	14.54	12.89	12.86	13.72
Expansion Valves	6.109	6.181	6.187	6.341	6.43	6.348
Total Exergy Destruction	68.68	68.39	69.20	68.63	69.19	69.48
Rational Efficiency	31.32	31.61	30.80	31.37	30.81	30.52
Second Law efficiency (%)	50.37	51.46	51.50	53.85	55.15	53.89

Table -5(e): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K,*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.69	23.69	23.7	23.7	23.71	23.71
Condenser	25.17	26.12	25.65	27.74	28.35	27.19
Evaporator	13.79	13.65	13.51	13.18	12.84	13.04
Expansion Valves	4.839	4.878	4.895	4.984	5.051	5.0
Total Exergy Destruction	67.49	68.34	67.75	69.61	69.96	68.94
Rational Efficiency	32.51	31.66	32.25	30.39	30.04	31.04
Second Law Efficiency (%)	0.5248	0.5492	0.5371	0.5907	0.6060	0.5768

Table -5(f): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO-1234ze refrigerant using (T_{eva1}=268K, T_{eva3}=273K, T_{eva3}=283K, T_{Cond}=313K,*

% Exergy Destruction in components using R1234ze	Case-1	Case-II	Case-III	Case-IV	Case-V	Case-VI
Compressor	23.7	23.7	23.71	23.71	23.72	23.72
Condenser	26.16	26.65	27.24	28.35	29.67	29.04
Evaporator	13.36	12.92	13.67	12.74	13.05	13.54
Expansion Valves	4.82	4.868	4.871	4.977	5.043	4.963
Total Exergy Destruction	68.03	68.14	69.48	69.78	71.48	71.28
Rational Efficiency	31.97	31.86	30.52	30.22	28.52	28.72

2.1 Effect of different low GWP environmental friendly refrigerants used in of VCR systems

Actual thermal performances of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions are shown in Table-6(a) to Table-6(c), respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1233zd(E) refrigerant give maximum first-law efficiency in terms of coefficient of performance(COP) with the lowest electrical energy consumption in terms of total compressors work for running the whole system. The maximum was found using R32 refrigerant.

Table-6(a): Actual thermal performances of multiple evaporator compressors of individual expansion valves of VCR systems using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $Q_{\_eva1}$ = 70 "kW", $Q_{\_eva2}$ =105 "kW" $Q_{\_eva3}$ = 35 "kW" at compressors efficiencies of 75%

Performance Parameters using	R1234ze	R1234yf	R152a	R245fa	R-32	R12
COP $_{VCRS}$	4.887	4.767	4.893	4.986	4.588	4.864
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.994	2.066	1.978	1.938	2.153	1.954
Exergetic Efficiency	0.3402	0.3318	0.3405	0.3405	0.3193	0.3385
Exergy of Fuel "kW"	42.97	44.05	42.92	42.12	45.77	43.17
Exergy of product"kW"	14.62	14.62	14.62	14.62	14.62	14.62

Table-6(b): Actual Thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, $Q_{\_eva1}$ = 70 "kW", $Q_{\_eva2}$ =105 "kW" $Q_{\_eva3}$ = 35 "kW" at compressors efficiencies of 75%

Performance Parameters	R1233 zd(E)	R1336 mzz(Z)	R1225 ye(Z)	R1243 zf	R-1224 yd(Z)
COP $_{VCRS}$	4.987	4.966	4.841	4.756	4.97
Exergy Destruction Ratio(EDR$_{VCRS}$)	1.936	1.956	2.02	2.072	1.947
Exergetic Efficiency	0.3471	0.340	0.3369	0.3310	0.3459
Exergy of Fuel "kW"	42.11	42.29	43.38	44.15	42.26
Exergy of product"kW"	14.62	14.62	14.62	14.62	14.62

Table-6(c): Actual Thermal performances of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO & HFC blends (refrigerants) using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, Q_eva1 = 70 "kW" , Q_eva2 =105 "kW" Q_eva3 = 35 "kW" at compressors efficiencies of 75%)

Performance Parameters	R513a	R515a	R454b	R452a	R450a
COP $_{VCRS}$	4.788	4.843	4.455	4.293	4.712
Exergy Destruction Ratio(EDR_{VCRS})	2.05	2.017	2.246	2.415	2.109
Exergetic Efficiency	0.3333	0.3371	0.3101	0.2988	0.328
Exergy of Fuel "kW"	43.8	43.36	47.14	48.91	44.57
Exergy of product"kW"	14.62	14.62	14.62	14.62	14.62

Exergy destruction (%) in Each component of VCR systems using multiple evaporator compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant for different load conditions are shown in Table-7(a) to Table-7(c) respectively. It was found that the VCR systems using multiple evaporator compressors of individual types with expansion valves of multiple types using HFC-32 refrigerant give maximum exergy destruction in condenser with lowest in throttle expansion valves. Similarly, minimum total exergy destruction (%) with maximum rational exergy efficiency was found using HCFO-1233zd(E).

Table-7(a): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFOs & HFCs refrigerants and comparison with CFC-12 for (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, Q_eva1 = 70 "kW", Q_eva2 =105 "kW" Q_eva3 = 35 "kW" at compressors efficiencies of 75%*

Exergy Destruction in components R1234ze	R1234ze	R1234yf	R152a	R245fa	R-32	R12
Compressor (%)	23.69	23.73	22.58	23.64	23.52	23.05
Condenser (%)	26.05	25.07	28.31	26.75	30.80	27.12
Evaporator (%)	13.08	13.69	12.59	13.16	11.85	12.80
Expansion Valves (%)	5.003	6.082	3.877	3.719	4.796	4.544
Total Exergy Destruction (%)	67.81	68.56	67.35	67.27	68.77	67.52
Rational Efficiency(%)	32.19	31.44	32.65	32.63	31.23	32.48
Irreversibility Ratio (I.R)	2.106	2.18	2.063	2.062	2.202	2.079

Table-7(b): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types *of VCR systems using HFO refrigerants using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, Q_eva1 = 70 "kW" Q_eva2 =105 "kW" Q_eva3 = 35 "kW" at compressors efficiencies of 75%)*

% Exergy Destruction in components	R1233 zd(E)	R1336 mzz(Z)	R1225 ye(Z)	R1243 zf	R-1224 yd(Z)
Compressor	23.52	23.80	23.64	23.38	23.68
Condenser	27.18	26.55	25.79	25.7	26.8
Evaporator	13.01	13.37	13.44	14.34	13.14
Expansion Valves	3.469	3.896	5.205	5.177	3.734
Total Exergy Destruction	67.17	67.62	68.08	68.59	67.36
Rational Efficiency	32.81	32.38	31.92	31.41	32.64

Table-7(c): Actual Exergy Destruction (%) in Each components of multiple evaporator compressors of individual types expansion valves of multiple types of VCR systems using HFO+HFC blended refrigerants using HFO & HFC blends (refrigerants) using (T_{eva1}=263K, T_{eva3}=278K, T_{eva3}=283K, T_{Cond}=313K, Q_eva1 = 70 "kW", Q_eva2 =105 "kW" Q_eva3 = 35 "kW" at compressors efficiencies of 75%)

% Exergy Destruction in components	R513a	R515a	R454b	R452a	R450a
Compressor	23.52	23.66	21.79	23.64	22.9
Condenser	25.68	26.79	31.29	25.27	25.68
Evaporator	13.38	12.74	11.5	17.0	14.82
Expansion Valves	5.72	4.798	5.062	6.998	5.256
Total Exergy Destruction	68.3	67.99	69.64	72.17	69.15
Rational Efficiency	31.7	32.01	30.36	27.83	30.85

3. Conclusions

Follow conclusions were drawn

(i) The best first law efficiency (COP) of VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different evaporators loads (Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105) at evaporators of different temperatures (T_eva1= 268 K, T_eva2= 278 K, and T_eva3= 283 K) was found.

(ii) Actual thermodynamic performances of VCRS systems at 75% of all compressors efficiencies using multiple evaporator compressors of individual types with expansion valves of multiple types using HFO-1234ze refrigerant for different load conditions are given maximum COP with lowest electrical energy consumption in terms of total compressors work for running the whole system. The maximum was found using R32 refrigerant.

(iii) The VCR systems using multiple evaporator compressors of individual types with expansion valves of various types using HFC-32 refrigerant give maximum exergy destruction in condenser with lowest in throttle expansion valves.

(iv) Minimum total exergy destruction (%) in VCR system with maximum rational exergy efficiency was found by using ultra-low GWP HCFO-1233zd(E) refrigerant.

(v) Exergy destruction computation in each component of VCR systems using multiple evaporators, compressors of individual types with expansion valves of various types using HFO-1234ze refrigerant for different load conditions (of Q_eva1 =35 kW, Q_eva2 =70 kW, Q_eva3 =105) gives maximum exergy destruction in compressor with lowest in throttle expansion valves (at Q_eva1=105 kW, Q_eva2=70 kW, Q_eva3=35 kW).

(vi) The minimum total exergy destruction (%) in the VCR system with maximum rational exergy efficiency was found at different load conditions of Q_eva1=105 kW, Q_eva2=35 kW, Q_eva3=70 kW at evaporators of different temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 283 K) respectively.

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Cite this article as: R. S. Mishra, Effect of different loading conditions at evaporators of different temperatures on thermal performances of VCRS using environmental friendly refrigerants using multiple evaporators with compressors of individual types and expansion valves of multiple types, International Journal of Research in Engineering and Innovation Vol-6, Issue-6 (2022), 388-398. *https://doi.org/10.36037/IJREI.2022.6604*.