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ORIGINAL ARTICLE

Effect of different loading conditions at different evaporators temperatures on thermal (energy-exergy) performances of VCR systems using ecofriendly refrigerants using multiple evaporators with individual compressors and individual/multiple expansion valves

R.S. Mishra

Department of Mechanical Engineering College, Delhi Technological University, Delhi, India

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Abstract

As replacements to R134a, HFO refrigerants R1234yf and R1234ze(E) were originally defined as non-flammable mixes. R515A, on the other hand, is a non-flammable mixture of R1234ze(E) and R227ea with a molar mass of 118.73 kg/kmol and a GWP of 402, according to the ASHRAE safety classification A1. Refrigerants with high GWP HFC content are also substituted with R513A, R450A, R454B, and R454C. A thermal analysis was conducted to evaluate the differences in energy efficiency (COP) and energy efficiency when the five low GWP mixes were substituted for R134a. In order to reduce global warming and ozone depletion, this paper primarily examines the thermal (energy-exergy) performances of modified VCR systems using eco-friendly low GWP blends of HFO+HFC in multiple evaporators at different temperatures compressors with multiple expansion valves using multiple compressors.

1. Introduction

The HFC and HFO blends (R134a substitutes R1234yf and R1234ze) were previously classified as non-flammable blends and are low GWP and ultra ODP refrigerants. In contrast, R515A, (a non-flammable mixture of R1234ze and R227ea) has a GWP of 402 and an ASHRAE safety classification of A1, with a molar mass of 118.73 kg/kmol. High GWP refrigerants are currently replaced with blends of HFC+HFOs (such as R513A, R450A, R454B, and R454C). By substituting the low GWP blends for R134a, few investigators conducted a thermal analysis to evaluate the energy efficiency (COP) and exergy efficiency. The thermal (energy-exergy) performances of modified VCR systems that use low-GWP, environmentally friendly blends of HFO and HFC to reduce global warming and ozone depletion in multiple evaporators at different temperatures using multiple compressors with multiple expansion valves have not been carried out by several investigators. The refrigeration industry has been forced to make changes to discover refrigerant materials with a lower environmental effect and higher or comparable thermal performances in the VCR systems. The use of a few different refrigerants in recent years, the various combinations of HC, HFC, HFO, and R744 are proposed due to the impact on the environment by using low GWP HFO blends with a reduced GWP, which will enhance the thermophysical properties at lower risk. The developed countries are increasingly employing natural refrigerants R717 and R744 by using highly advanced technologies and configurations, allowing for the efficient use of R744 blends; Because the usage of HFCs

Corresponding author: R.S. Mishra
Email Address: rsmishra@dtu.ac.in
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contributed an estimated 2% of greenhouse gas emissions in 2015 and could account for 20% of 2050. Therefore, few blends were taken to use the HFC blends [1].

Using R430A as a potential drop-in R134a, Mohanraj M. et al. [2] conducted an experimental investigation of household refrigerators to find their energy performance. It was discovered that the R430A has a 3.9% to 6.5% higher coefficient of performance and about 5% less energy usage than the R134a. It was also determined that R430A is a suitable replacement for R134a in the home refrigerator market. Refrigerants with lower greenhouse gas emissions are necessary to lessen the effect of refrigeration systems on global warming. Similarly, by using R513A and comparing the performance of R513A with R134a, Mota-Babiloni et al. [3,4] discovered that R513A, R515A, and R450A can replace HFC-134A, HFC-404A, and HFC-410A, respectively, by employing internal heat exchangers in VCR system. Juan M. Belman-Flores et al. [5] examined a home refrigerator's energy and thermal performance using low-GWP alternative refrigerants in place of R134a. They found that blends showed COP reductions of 28% using R516A and 25% for R134a, while R1234ze showed a decrease of about 1% to 3% when and 5 to 7% by using HFO-1234yf by replacing R134a.

Replace R134a with an HFC+HFO blend in a 190-liter single-evaporator residential refrigerator between 25 C and 45 while keeping the evaporator temperature between -10 C and -12oC. HFO/HFC blends are presently being studied as HFC substitutes in air conditioning and refrigeration systems. R513A has a lower global warming potential than R134a, and it is being considered a refrigerant of choice for water coolers. In the thermodynamic performance using a twin-screw compressor, Zhiping Zhang et al. [5] observed that the performance (COP) of R513A is somewhat less than R134a's. Therefore, R513A can directly replace R134a when accounting for GWP in the VCR systems.

One of the top priorities to lessen the predicted climate change is to replace HFCs with reduced greenhouse gas (GWP) refrigerants in the upcoming years. Low-GWP blends and heat exchangers are required for refrigeration and air conditioning systems when blends of HFO are being used.

Juan M. Belman-Flores, et al. [2023], suggested the drop-in replacement of R134a in a household refrigerator with Low-GWP Refrigerants (R513A, R516A, R1234ze(E)), and coefficient of performance (COP) reduction of around 28% using R513A The modification in the primary cycle that improved energy performance; its advantages have been compared with those of R134a and hydrofluoroole blends, as shown by Sun Jian et al. [7] carried out the energy and energy analysis of VCR system using R513a as a drop-in replacement for R134a. The possibility for improving current installations and the viability of using alternative fluids can be determined by using exergy analysis of VCR systems. In an exergy analysis of HFO+HFC blends (R515A, R513A, R450A, R454b, R454c, R452a, R449A, and R448A), Mishra [8,9,10,11] discovered that R454c produced the lowest Thermal first and second law performances, while R-515A had the highest. This study focuses on the thermal performances of enhanced vapor compression systems that use multiple compressors and evaporators at varying temperatures to mitigate global warming and ozone depletion. In addition to using low-GWP, environmentally acceptable HFO+HFC blends, single and numerous compressors are employed.

2. Results and Discussion

Following two systems have been preferred for finding the effect of different load conditions using HFO+HFC blends.

System-1: VCR system using multiple evaporators with individual compressors and individual expansion valves) and

System-2: VCR system using multiple evaporators with individual compressors and multiple expansion valves.

Table-1(a) shows the variations in load conditions load conditions used in the system-1 and two respectively. Similarly, Table-1(b) shows the variations in the temperature conditions of the two systems using multiple evaporators at different temperatures with individual compressors, individual/multiple expansion Valves. The other input conditions also been shown in table-1 (c) respectively. The actual thermal performances have been computed for both systems are shown in tables-2 to tables-3 respectively.

Table-1(a)Multiple evaporators at different temperatures with individual compressors, individual/multiple expansion Valves

S.No	Cooling Load	I	II	III	IV	V	VI
1	First Evaporator($Q_{\_Eva\_1}$) ‘kW’	105	105	70	70	35	35
2	Second Evaporator($Q_{\_Eva\_2}$) ‘kW’	70	35	105	35	70	105
3	Third Evaporator($Q_{\_Eva\_2}$) ‘kW’	35	70	35	105	105	70

Table-1(b) *Multiple evaporators at different temperatures with multiple compressors, multiple expansion valves and back pressure valves (Isentropic Efficiency of compressor ($Comp_{\_Eff\_}$)=0.75%)*

S.No	Temperature conditions	I	II	III	IV	V	VI
1	Temperature of first evaporator (ºK)	263	263	263	268	268	268
2	Temperature of second evaporator (ºK)	273	273	278	273	273	278
3	Temperature of third evaporator (ºK)	278	283	283	278	283	283

Table-1(c) Input conditions used in the modified VCR systems using multiple evaporators at different temperatures with individual compressors compressor, individual/ multiple expansion valves

Input conditions	Value
Condenser temperature(K)	313K
Subcooled refrigerant out from condenser	303K
Compressors Efficiency	75%

2.1 Actual Thermal performances

Actual thermal performances of VCR systems using multiple evaporator individual compressors with individual expansion valves using HFO- blended refrigerants for different load conditions are shown in Table-2(a) to Table-2(c) for system-1 respectively. It was found that the VCR systems using multiple evaporator individual compressors with multiple expansion valves using R515A refrigerant for different load conditions of $Q_{\_eva1}$ =35 kW, $Q_{\_eva2}$ =70 kW, $Q_{\_eva3}$ =105 kW gives 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 while maximum exergy efficiency was found in different load conditions of $Q_{\_eva1}$=105 kW, $Q_{\_eva2}$=70 kW, $Q_{\_eva3}$=35 kW with maximum electrical energy consumption in terms of total compressors work for running whole system. However best first law efficiency (COP) of VCR systems using multiple evaporator individual compressors with individual expansion valves using R515A refrigerant for different evaporators loads (was obtained at different evaporators temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 278 K). Similarly exergy efficiency of VCR systems using multiple evaporator individual compressors with individual expansion valves using R-515A refrigerant for different evaporators loads ($Q_{\_eva1}$ =105 kW, $Q_{\_eva2}$ =70 kW, $Q_{\_eva3}$ =35) at was obtained at different evaporators temperatures (T_eva1= 263 K, T_eva2= 273 K, and T_eva3= 278 K) respectively.

Table-2 (a) Multiple evaporators at different temperatures with individual compressors, individual expansion Valves ($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters at different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.923	4.016	4.139	4.352	4.62	4.498
Exergy Destruction Ratio (EDR) (First Method)	1.871	1.908	1.942	2.031	2.130	2.075
Exergetic efficiency (First Method)	0.3483	0.3438	0.3399	0.3299	0.3194	0.3252
Exergy of Fuel “kW”	53.54	52.3	50.73	48.25	45.45	46.46
Exergy of Product “kW”	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work “kW”	31.51	31.51	21.06	21.06	10.53	10.53
Second Compressor Work “kW”	15.46	7.726	23.18	7.728	15.46	23.18
Third Compressor Work “kW”	6.488	12.98	6.488	19.47	19.47	12.98
Total Compressor Work “kW”	53.54	52.3	50.73	48.25	45.45	46.46
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Table-2(b) Multiple evaporators at different temperatures with individual compressors, individual expansion Valves ($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.855	3.947	4.070	4.281	4.547	4.426
Exergy Destruction Ratio (EDR) (First method)	1.922	1.959	1.992	2.082	2.181	2.125
Exergetic efficiency (First method)	0.3423	0.338	0.3342	0.3245	0.3144	0.320
Exergy of Fuel “kW”	54.48	53.21	51.60	49.06	4618	47.42
Exergy of Product “kW”	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work “kW”	32.94	32.19	21.46	21.46	10.73	10.73
Second Compressor Work “kW”	15.7	7.852	23.56	7.852	15.7	23.56
Third Compressor Work “kW”	6.582	13.16	6.582	19.75	19.75	13.16
Total Compressor Work “kW”	54.48	53.21	51.60	49.06	4618	47.42
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Table-2(c) Multiple evaporators at different temperatures with individual compressors, individual expansion Valves (T_Cond=313(K), T_Subcooling =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.801	3.890	4.009	4.213	4.470	4.352
Exergy Destruction Ratio (EDR) (First Method)	1.964	2.002	2.038	2.131	2.236	2.178
Exergetic efficiency (First Method)	0.3374	0.3331	0.3292	0.3194	0.3091	0.3147
Exergy of Fuel “kW”	55.25	53.99	52.39	49.85	46.98	48.25
Exergy of Product “kW”	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work “kW”	32.56	32.56	21.71	21.71	10.85	10.85
Second Compressor Work “kW”	15.46	7.726	23.18	7.987	15.97	23.96
Third Compressor Work “kW”	6.717	13.43	6.717	20.15	20.15	13.43
Total Compressor Work “kW”	55.25	53.99	52.39	49.85	46.98	48.25
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

2.2 Effect of different refrigerants used in of VCR systems

Actual Thermal performances of VCR systems using multiple evaporator individual compressors with multiple expansion valves (system-2) using blends of HFO refrigerants for different load conditions are shown in Table-3(a) to Table-3(c) respectively. It was found that the VCR systems using multiple evaporator individual compressors with multiple expansion valves using R515A refrigerant gives maximum first law (energy)efficiency in terms of coefficient of performance (COP) with lowest electrical energy consumption in terms of total compressors work for running whole system. and maximum electrical energy consumption in terms of total compressors work for running whole system was found using R450A refrigerant.

2.3 Exergy Destruction in Each component

Exergy Computation of both VCR systems using multiple evaporator individual compressors with multiple expansion valves using R515A refrigerant for different load conditions are shown in Table-4(a) to Table-4(c) respectively for systm-1 and it was found that the exergy destruction in the different load conditions in all components are increasing in the same fasion as first law efficiency of system-1 is increasing. and reaching to a maximum at load condition -V and then decreasing. Similarly rational exergy efficiency VCR system-1 using multiple evaporator individual compressors with individual expansion valves is decreasing and reaching to a minimum and then increasing. As comparing with three HFO blends it was found that R450A gives maximum exergy destruction as compared to R515A and R513A respectively.

Table-3(a) Multiple evaporators at different temperatures with individual compressors, multiple expansion Valves (($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.165	4.25	4.351	4.540	4.762	4.656
Exergy Destruction Ratio (EDR) (First Method)	1.714	1.748	1.799	1.906	2.037	1.971
Exergetic efficiency (First Method)	0.3698	0.3639	0.3573	0.3442	0.3292	0.3366
Exergy of Fuel “kW”	50.42	49.42	48.26	46.26	44.10	45.10
Exergy of Product “kW”	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work “kW”	24.41	24.41	16.28	16.28	8.138	8.138
Second Compressor Work “kW”	13.22	6.957	19.25	6.725	12.76	19.02
Third Compressor Work “kW”	12.79	18.05	12.74	23.26	23.21	17.95
Total Compressor Work “kW”	50.42	49.42	48.26	46.26	44.10	45.10

Table-3(b) Multiple evaporators at different temperatures with individual compressors, multiple expansion Valves (($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.113	4.196	4.295	4.481	4.698	4.594
Exergy Destruction Ratio (EDR) (First Method)	1.739	1.783	1.835	1.944	2.079	2.011
Exergetic efficiency (First Method)	0.3650	0.3593	0.3527	0.3396	0.3248	0.3321
Exergy of Fuel “kW”	51.06	50.05	48.89	46.87	44.70	45.71
Exergy of Product “kW”	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work “kW”	24.39	24.39	16.26	16.26	8.13	8.13
Second Compressor Work “kW”	13.24	6.986	19.25	6.742	12.75	19.0
Third Compressor Work “kW”	13.43	18.67	13.38	23.87	23.82	18.58
Total Compressor Work “kW”	51.06	50.05	48.89	46.87	44.70	45.71

Table-3(c) Multiple evaporators at different temperatures with individual compressors, multiple expansion Valves (T_{Cond}=313(K), $T_{Subcooling}$ =303(K),T_{Eva1}= 263 (K), T_{Eva2}= 273(K), T_{Eva3}= 278 (K), $Comp_{Eff\_1}$=0.75, $Comp_{Eff\_2}$=0.75, $Comp_{Eff\_3}$=0.75)

Performance Parameters	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.059	4.139	4.236	4.412	4.622	4.523
Exergy Destruction Ratio (EDR) (First Method)	1.775	1.822	1.875	1.990	2.129	2.058
Exergetic efficiency (First Method)	0.3604	0.3544	0.3479	0.3345	0.3196	0.3270
Exergy of Fuel "kW"	51.73	50.74	49.57	47.59	45.43	46.42
Exergy of Product "kW"	18.64	17.98	17.24	15.92	14.52	15.18
First Compressor Work "kW"	25.04	25.04	16.69	16.69	8.347	8.347
Second Compressor Work "kW"	13.49	7.051	19.72	6.845	13.08	19.51
Third Compressor Work "kW"	13.21	18.65	13.17	24.05	24.01	18.57
Total Compressor Work "kW"	51.73	50.74	49.57	47.59	45.43	46.42
Cooling Load in First Evaporator "kW"	105	105	70	70	35	35
Cooling Load in second Evaporator "kW"	70	35	105	35	70	105
Cooling Load in third Evaporator "kW"	35	70	35	105	105	70

Table-4(a): Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, individual expansion Valves (T_{Cond}=313(K), $T_{Subcooling}$ =303(K),T_{Eva1}= 263 (K), T_{Eva2}= 273(K), T_{Eva3}= 278 (K), $Comp_{Eff\_1}$=0.75, $Comp_{Eff\_2}$=0.75, $Comp_{Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.923	4.016	4.139	4.352	4.62	4.498
Exergetic efficiency(second Method)	0.3544	0.350	0.3462	0.3363	0.3259	0.3316
Exergy Destruction Ratio (EDR)(second Method)	1.822	1.857	1.889	1.974	2.068	2.016
Exergy destruction in Compressors (%)	23.63	23.63	23.64	23.65	23.66	23.66
Exergy destruction in condenser (%)	22.63	23.05	23.61	24.57	25.77	25.22
Exergy destruction in evaporators (%)	7.566	7.695	7.873	8.165	8.548	8.377
Exergy destruction in expansion Valves (%)	9.614	9.470	9.077	8.736	8.082	8.284
Total Exergy destruction in VCRS (%)	63.44	63.85	64.22	65.12	66.07	65.54
Rational Exergy Efficiency (%)	36.56	36.15	35.8	34.88	33.93	34.46
Cooling Load in First Evaporator "kW"	105	105	70	70	35	35
Cooling Load in second Evaporator "kW"	70	35	105	35	70	105
Cooling Load in third Evaporator "kW"	35	70	35	105	105	70

Table-4(b): Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, individual expansion Valves (T_{Cond}=313(K), $T_{Subcooling}$ =303(K),T_{Eva1}= 263 (K), T_{Eva2}= 273(K), T_{Eva3}= 278 (K), $Comp_{Eff\_1}$=0.75, $Comp_{Eff\_2}$=0.75, $Comp_{Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.855	3.947	4.070	4.281	4.547	4.426
Exergetic efficiency (second method)	0.3494	0.3451	0.3415	0.3319	0.322	0.3275
Exergy Destruction Ratio (EDR)(second method)	1.862	1.897	1.928	2.013	2.106	2.054
Exergy destruction in Compressors (%)	23.46	23.47	23.49	23.50	23.52	23.53
Exergy destruction in condenser (%)	21.67	22.06	22.58	23.49	24.63	24.11
Exergy destruction in evaporators (%)	7.766	7.914	8.093	8.409	8.815	8.632
Exergy destruction in expansion Valves (%)	10.84	10.69	10.28	9.925	9.246	9.459
Total Exergy destruction in VCRS (%)	63.74	64.13	64.45	65.32	66.21	65.71
Rational Exergy Efficiency (%))(third method)	36.26	35.87	35.55	34.68	33.79	34.29
Cooling Load in First Evaporator "kW"	105	105	70	70	35	35
Cooling Load in second Evaporator "kW"	70	35	105	35	70	105
Cooling Load in third Evaporator "kW"	35	70	35	105	105	70

Exergy Computation of both VCR systems using multiple evaporator individual compressors with multiple expansion valves using R515A refrigerant for different load conditions for system-2 are shown table-5(a)totable-5(c) for system-2 respectively. It was found that it was found that the exergy destruction in the different load conditions in all components are increasing in the same fasion as first law efficiency of system-2 is increasing. and reaching to a maximum at load condition -V and then decreasing. Similarly rational exergy efficiency VCR system-2 using multiple evaporator individual compressors with individual expansion valves is decreasing and reaching to a minimum and then increasing. As comparing with three HFO blends it was found that R450A gives maximum exergy destruction as compared to R515A and R513A respectively.

Table-4(c): Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, individual expansion Valves ($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	3.801	3.890	4.009	4.213	4.470	4.352
Exergetic efficiency(second Method)	0.3434	0.3391	0.3353	0.3255	0.3154	0.3209
Exergy Destruction Ratio (EDR)(second Method)	1.912	1.945	1.982	2.072	2.171	2.116
Exergy destruction in Compressors (%)	23.34	23.34	23.36	23.37	23.40	23.39
Exergy destruction in condenser (%)	21.83	22.2	22.73	23.62	24.73	24.22
Exergy destruction in evaporators (%)	9.203	9.355	9.563	9.909	10.35	10.15
Exergy destruction in expansion Valves (%)	10.14	9.995	9.607	9.261	8.611	8.816
Total Exergy destruction in VCRS (%)	64.51	64.91	65.26	66.16	67.09	66.58
Rational Exergy Efficiency (%)	35.49	35.09	34.74	33.84	32.91	33.42
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Table-5(a): Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, multiple expansion Valves (($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.165	4.25	4.351	4.540	4.762	4.656
Exergetic efficiency(second Method)	0.3568	0.3540	0.3450	0.3385	0.3245	0.3285
Exergy Destruction Ratio (EDR)(second Method)	1.803	1.825	1.898	1.954	2.082	2.044
Exergy destruction in Compressors (%)	23.64	23.64	23.65	23.66	23.67	23.67
Exergy destruction in condenser (%)	23.72	24.11	24.56	24.41	26.41	25.93
Exergy destruction in evaporators (%)	13.51	12.78	13.71	12.16	12.32	13.15
Exergy destruction in expansion Valves (%)	5.804	5.867	5.894	6.033	6.144	6.067
Total Exergy destruction in VCRS (%)	66.67	66.39	67.82	67.26	68.54	68.81
Rational Exergy Efficiency (%)	33.33	33.61	32.18	32.74	31.46	31.19
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Table-5(b): Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, multiple expansion Valves (($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.113	4.196	4.295	4.481	4.698	4.594
Exergetic efficiency(second Method)	0.3521	0.3496	0.3405	0.3344	0.3205	0.3243
Exergy Destruction Ratio (EDR)(second Method)	1.840	1.860	1.937	1.990	2.120	2.084
Exergy destruction in Compressors (%)	23.49	23.49	23.50	23.51	23.53	23.53
Exergy destruction in condenser (%)	22.77	23.13	23.55	24.35	25.28	24.83
Exergy destruction in evaporators (%)	14.14	13.35	14.36	12.69	12.86	13.75
Exergy destruction in expansion Valves (%)	6.794	6.864	6.902	7.055	7.185	7.10
Total Exergy destruction in VCRS (%)	67.19	66.83	68.32	67.61	68.86	69.21
Rational Exergy Efficiency (%)	32.81	33.17	31.68	32.39	31.14	30.79
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Table-5(c) Exergy computation in modified VCRS using multiple evaporators at different temperatures with individual compressors, multiple expansion Valves ($T_{\_Cond}$=313(K), $T_{\_Subcooling}$ =303(K),$T_{\_Eva1}$= 263 (K), $T_{\_Eva2}$= 273(K), $T_{\_Eva3}$= 278 (K), $Comp_{\_Eff\_1}$=0.75, $Comp_{\_Eff\_2}$=0.75, $Comp_{\_Eff\_3}$=0.75)

Performance Parameters for different load conditions	I	II	III	IV	V	VI
First Law Efficiency (COP)	4.059	4.139	4.236	4.412	4.622	4.523
Exergetic efficiency(second Method)	0.3469	0.3442	0.3351	0.3285	0.3145	0.3185
Exergy Destruction Ratio (EDR)(second Method)	1.883	1.906	1.984	2.044	2.180	2.14
Exergy destruction in Compressors (%)	23.36	23.36	23.38	23.39	23.41	23.40
Exergy destruction in condenser (%)	22.84	23.20	23.61	24.41	25.33	24.88
Exergy destruction in evaporators (%)	15.37	14.61	15.64	14.04	14.27	15.22
Exergy destruction in expansion Valves (%)	6.289	6.357	6.387	6.534	6.652	6.571
Total Exergy destruction in VCRS (%)	67.86	67.53	69.01	68.37	69.66	69.97
Rational Exergy Efficiency (%)(third Method)	32.14	32.47	30.99	31.63	30.34	30.03
Cooling Load in First Evaporator “kW”	105	105	70	70	35	35
Cooling Load in second Evaporator “kW”	70	35	105	35	70	105
Cooling Load in third Evaporator “kW”	35	70	35	105	105	70

Exergy destruction in all components in both systems have been compared and it was found that he VCR system-2 using multiple evaporator individual compressors with multiple expansion valves gives less exergy destruction in throttle valves than system-1 using multiple evaporator individual compressors with individual expansion valves for selected HFO blended refrigerants for different load conditions. Similarly highest exergy destruction in condenser was found which is slightly higher than exergy input for running whole system by three compressors.

3. Conclusions

The effect of different loading conditions at different evaporator temperatures in the VCR system using blends of eco-friendly HFO refrigerants in both systems (system-1(using multiple evaporators with individual compressors and individual expansion valves) and system-2 (using multiple evaporators with individual compressors and multiple expansion valves) have been studied in detail. The first law (energy) performance in terms of coefficient of performance (COP) and second law (exergy) performance of ultra-low GWP refrigerants as drop-in replacements by varying the value of the loading conditions at different evaporators temperature of a VCRS using HFO blends have been computed. The following conclusions were drawn.

- First law performance (Energetic) and exergy performance of system-2 are higher than system-1 for a selected temperature range of condensers and evaporators with chosen eco-friendly low GWP refrigerants.
- For both systems, R450A shows minimum COP, exergy efficiency, and exergy destruction in the components of both systems.
- Thermal Performances (COP) and exergy efficiency of R515A are better in comparison to other selected eco-friendly refrigerants (R513A and R450A) for system-1 and system-2.
- The COP of between system-2 is 6.1687% higher than and system-1 for R515A for a given load condition (Q_eva_1=105 kW at 263K, Q_eva_2=70 kW at 273K, Q_eva_3=35 kW at 278K.
- The exergy efficiency of between system-2 is 6.173% higher than and system-1 for R515A for a given load condition (Q_eva_1=105 kW at 263K,, Q_eva_2=70 kW at 273K, Q_eva_3=35 kW at 278K,
- The electrical energy consumption for running three compressors of system-2 is 5.83% less than system-1 for R515A for a given load condition (Q_eva_1=105 kW at 263K, Q_eva_2=70 kW at 273K, Q_eva_3=35 kW at 278K.
- Exergy destruction in throttle valves was found to be the lowest, and the highest Exergy destruction was found in the condenser.
- Despite the variations with load conditions, the exergy destruction in compressors has been found to slightly increase and reach a maximum at load conditions at Qeva1=35kW, Qeva2=70 kW, Qeva3=105kW, and then decrease.

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