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ORIGINAL ARTICLE

Methods for enhancing thermal (energy-exergy) performances of VCR systems using eco-friendly refrigerants in LVHE

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Abstract

The effect of variation evaporator temperature and condenser temperature, effect of sub cooling in condenser and super heating of evaporator fluid on thermal performances of VCR system for eco-friendly refrigerants (such as Low GWP (HFC) refrigerants, HFO blends and ultra-low GWP of HCFO & HFO refrigerants using liquid vapour heat exchanger using two methods have been studied in detail and it was found that second methods give lower exergy efficiency than using first method. The condenser & evaporator temperature variations on thermal exergy performances have been investigated. The effect of HFO refrigerants on energy performance system ($COP_{\_VCRS}$) & exergy performance of low GWP refrigerants in VCR systems have been studied in detail and also effect of different HFO+HFC blends, HFO refrigerants, low GWP refrigerants on thermal energy-exergy performances have been compared. It was found that HFO and HFO blends are future refrigerants during period of 2025 to 2050 for reducing global warming and ozone depletion.

1. Introduction

One of the cruelest environmental issues affecting our planet right now is global warming. The prior creation of refrigerant gases and carbon dioxide emissions is one of its sources. These gases contribute to global warming because they are released into the atmosphere and stay there for prolonged periods of time. Based on their life cycle analysis (LCA) and the effectiveness of refrigeration systems, these gases' effects on the environment can be classified according to their severity. Over the course of the next 100 years, Earth's temperature is anticipated to increase due to global warming. This will have an impact on agriculture, which will result in excessive rains, more heat waves, and possible sea level rise within the next century. Due to this, the Montreal Protocol's signatory nations decided in 2016 to phase down HFCs and HCFCs in order 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 HCFCs were ozone layer destroying substances that were eliminated after the Montreal and Kyoto Protocols, respectively.

Currently, HFCs like R134a, R23, R404A, R407A, R410A, R125, and R507A make up the majority of the different 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 former generation of commercial refrigeration systems, such as centrifugal chillers and central air conditioning systems used in buildings, used the

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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 [1, 2].
R134a is a globally accepted refrigerant for various types of refrigeration systems. 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 as well and will be completely phased out by 2034. R123 is an HCFC molecule with a B1 classification that is used in chillers because of its great thermodynamic efficiency and low risk of leaks. However, because long-term inhalation of R123 has been linked to pancreatic and liver cancers, it is expected to be phased out by 2025 [2]. 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 earlier generation of refrigerants [3]. HFO refrigerants were found to be necessary by Chopra Kapil and Mishra R.S. [4] because of their extremely low GWP and ODP. They also discovered that they could be used as a drop-in replacement for R134a and R404a on vapour compression refrigeration (VCRC) systems with variable speed compressors and input parameters for evaporator and condenser temperature. HFC-134a offers 3% to 5% higher first law efficiency (COP) when compared to R404a. Similar to R134a, R410a and R407c have 1% to 1.5% reduced system COP. The results confirmed that using R1234ze(Z), the energy efficiency (COP) was enhanced from 3 to 7% and that using R1234yf deteriorated to 5 to 10% [5]. Using energy-exergy analysis, Mishra [6] determined the thermodynamic performances of vapour compression refrigeration systems and discovered that using HFC-152a results in 2–6% higher output than using R134a. The input power of R152a was found to be 7.75% less than that of R134a. Similarly, the COP of systems using HCFO-1224yd(Z) some exhibited improvements of 2.35%, 3.15%, and 4.95% over R134a at compressor speeds of 2000, 2500, and 3000 rpms, respectively [7]. The HFO-1234yf, HFO-1234ze (E), R1234ze(Z), R1243zf, R1224yd, R1225ye, R1233zd(E), and HFO-1336mzz(Z) are well-suited for R134a replacements. The results revealed that R1234ze(E) and R1243zf performed most similar thermal performances to R1234ze(E) &R134a [8-10]. in comparison to. Using the EES software, it was determined that eight HFO refrigerants, including HFO-1234yf and HFO-1234ze(E), were suitable as R134a replacements since they increased performance without noticeably raising GWP [11–12]. R245fa has lower thermal performances than R1233zd (E)', R1224yd (Z), and R1234ze (Z) in terms of system COP, which was roughly 1% [13-14]
The energy performance of low GWP refrigerants using LVHE in VCR systems has been thoroughly studied, and the effects of various evaporator and condenser temperatures, as well as the effects of superheating the evaporator fluid prior to compressor inlet and the effects of sub-cooling at the condenser fluid outlet on thermal performances, have been examined.

2. Results and Discussion

Thermal Performances of VCR systems using HFO refrigerants of using two methods of for evaluating exergy destruction ratios with following input data have been investigated.

- Evaporator temperature= (T_{eva})=253K.
- condenser temperature= (T_{Cond})=323K.
- $T_{superheating}$ = T_{eva} (K)+10,
- $T_{subcooling}$ = T_{Cond} (K)-10,
- $T_{Subcooled\_Liquid}$=313K and
- (vi) compressor efficiency=80%

Table -1(a): Effect of different HFO refrigerants on the actual Thermal performances of VCR systems using HFO *refrigerants using first method ((T_{eva1}=253K, $T_{super\ heating}$= T_{eva1}+10 and T_{Cond}=323K, $T_{Subcooled\_Liquid}$=313K, compressors isentropic efficiency= 80%)*

System COP $_{VCRS}$	R1336mzz(Z)	R1234ze(E)	R1243zf	R1225ye(Z)	HCFO1233zd(E)	R1234yf
System COP $_{VCRS}$	2.527	2.428	2.381	2.399	2.623	2.284
Exergy Destruction Ratio(EDR_{VCRS})	1.225	1.315	1.361	1.343	1.144	1.461
Exergetic Efficiency	0.4495	0.4319	0.4235	0.4267	0.4665	0.4063
Exergy of Fuel “kW”	48.6	49.98	57.27	43.68	56.06	44.69
Exergy of product“kW”	21.84	21.59	24.25	18.39	26.15	18.16

Table -1(b): Effect of different HFO refrigerants on the actual Thermal performances of VCR systems using HFO *refrigerants using second method ((T_{eva1}=253K, T_{super} heating= T_{eva1}+10 and T_{Cond}=323K, $T_{Subcooled\_Liquid}$=313K, compressors isentropic efficiency= 80%)*

Performance Parameters using	R1336mzz(Z)	R1234ze(E)	R1243zf	R1225ye(Z)	HCFO1233zd(E)	R1234yf
System COP $_{VCRS}$	2.527	2.428	2.381	2.399	2.623	2.284
Irreversibility Ratio	2.691	2.785	2.523	3.288	2.212	3.419
Total Exergy_Destruction(%)	58.79	60.12	61.19	60.45	57.87	62.78
Rational Exergetic Efficiency(%)	41.21	39.88	38.81	39.55	42.14	37.22
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	16.1	15.85	15.91	15.75	16.82	16.46
Exergy Destruction_Evaporator%)	6.786	6.146	7.65	6.442	7.051	5.577
Exergy Destruction_Valve(%)	15.91	18.13	17.63	18.26	13.98	20.74
Relative COP=$COP_{\_Actual}/COP_{\_Carnot}$)	0.7051	0.6822	0.6665	0.6760	0.7232	-------

2.1 Effect of HFO&HCFO refrigerants on VCRS

Thermal Performances of VCR systems using liquid-vapour heat exchanger using HFO- refrigerants are shown in Table-1(a)-table-1(b) respectively. It was found that VCR systems using R1233zd(E)gives maximum system $COP_{\_VCRS}$ with lowest electrical energy consumption in terms of total compressor work. Thermal Performances of VCR systems using HFO- refrigerants for different refrigerants are shown in Table-2 respectively. It was found that VCR systems using R1234ze(Z)gives maximum system COP & Exergy efficiency with lowest electrical energy consumption in terms of total compressor work.

Table -2(b): Effect of different HFO refrigerants on the actual Thermal c performances of VCR systems using HFO *refrigerants by second method ((T_{eva1}=273K, $T_{super\ heating}$= T_{eva1}+10 and T_{Cond}=333K, $T_{Subcooled\_Liquid}$=323K, compressors isentropic efficiency= 80%)*

Performance Parameters using	HFO 1336 mzz(Z)	HFO 1234 ze(E)	HFO1243 zf	HFO 1225 ye(z)	HCFO 1233 zd(E)	HFO 1234yf	HCFO 1224 yd(Z)	HFO 1234 ze(Z)
System COP $_{VCRS}$	3.426	3.244	3.184	3.191	3.530	3.035	3.465	3.646
Exergy Destruction Ratio(EDR_{VCRS})	2.187	2.366	2.43	2.423	2.094	2.595	2.152	1.995
Exergetic Efficiency	0.3137	0.2971	0.2915	0.2922	0.3232	0.2779	0.3173	0.3339
Exergy of Fuel "kW"	36.69	37.35	42.28	32.09	42.19	33.26	35.92	45.65
Exergy of product"kW"	11.51	11.1	12.33	9.376	13.64	9.243	11.40	15.24
Irreversibility Ratio	5.937	6.274	5.71	7.442	4.986	7.674	5.992	4.424
Total Exergy_Destruction(%)	68.33	69.62	70.38	69.78	67.99	70.94	68.29	67.44
Rational Exergetic Efficiency(%)	31.67	30.38	29.62	30.22	32.01	29.06	31.71	32.56
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	33.06	31.85	31.63	31.48	33.96	30.29	33.39	35.42
Exergy Destruction_Evaporator%)	2.63	2.20	3.274	2.449	2.727	2.33	2.661	1.816
Exergy Destruction_Valve(%)	12.64	15.57	15.48	15.84	13.3	18.32	12.25	10.2
Relative COP	0.5255	0.5008	0.4897	0.4953	0.5360	0.4732	0.5286	0.5489

2.2 Effect of HFO blends on VCRS

Thermal Performances of VCR using blends of HFO-refrigerants are shown in Table-3 respectively. It was found that the VCR systems using R515A gives maximum coefficient of performance(COP) & exergy efficiency with lowest electrical energy consumption in terms of total compressor work. Thermal Performances of VCR systems for HFO- refrigerants are shown in Table-4(a) to table-4(b) respectively. It was found that the vapour compression refrigeration systems using R245fa gives maximum system COP & exergy efficiency with lowest electrical energy consumption in terms of total compressor work.

Table -3(a): Effect of HFO blends on the actual Thermal performances of VCR systems using HFO blended refrigerants using first method (T_{eva}=253K, $T_{super\text{-}heating}$ = T_{eva}+10 (K), and T_{Cond}=323K, $T_{Subcooled\_Liquid}$=313K, compressors isentropic efficiency= 80%)

Performance Parameters using	R513A	R515A	R450A	R452A	R454B	R454C	R448A	R449A
System COP $_{VCRS}$	2.345	2.424	2.349	2.0	2.271	2.024	2.159	2.117
Exergy Destruction Ratio(EDR_{VCRS})	1.398	1.319	1.393	1.81	1.475	1.778	1.604	1.656
Exergetic Efficiency	0.4170	0.4312	0.4178	0.3559	0.4040	0.360	0.3840	0.3765
Exergy of Fuel "kW"	48.83	48.87	52.84	49.23	84.82	63.01	65.76	64.11
Exergy of product"kW"	20.36	21.07	22.02	17.52	34.27	22.69	25.25	24.14

Table -3(b): Effect of HFO blends on the actual Thermal performances of VCR systems using HFO blended refrigerants using second method (T_{eva}=253K, $T_{super\text{-}heating}$ = T_{eva}+10 (K), and T_{Cond}=323K, $T_{Subcooled\_Liquid}$=313K, compressors isentropic efficiency= 80%)

Performance Parameters using	R513A	R515A	R450A	R452A	R454B	R454C	R448A	R449A
System COP $_{VCRS}$	2.345	2.424	2.349	2.0	2.271	2.024	2.159	2.117
Exergy Destruction Ratio(EDR_{VCRS})	1.398	1.319	1.393	1.81	1.475	1.778	1.604	1.656
Exergetic Efficiency	0.4170	0.4312	0.4178	0.3559	0.4040	0.360	0.3840	0.3765
Exergy of Fuel "kW"	48.83	48.87	52.84	49.23	84.82	63.01	65.76	64.11
Exergy of product"kW"	20.36	21.07	22.02	17.52	34.27	22.69	25.25	24.14
Irreversibility Ratio	3.012	2.857	2.781	3.805	1.855	2.944	2.57	2.715
Total Exergy_Destruction(%)	61.34	60.2	61.41	66.65	63.56	66.8	64.89	65.53
Rational Exergetic Efficiency(%)	38.66	29.8	38.59	33.35	36.44	33.2	35.11	34.47
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	15.73	16.33	15.9	16.17	21.45	19.17	19.79	18.96
Exergy Destruction_Evaporator%)	6.288	6.316	7.495	7.997	6.43	8.97	6.939	8.088
Exergy Destruction_Valve(%)	19.32	17.55	18.01	22.48	15.68	18.84	17.15	18.48
Relative COP=$COP_{\_Actual}/COP_{\_Carnot}$)	0.6615	0.6810	------	0.5718	0.6316	0.5732	------	------

Table -4(a): Effect of different low GWP refrigerants on Thermal performances of VCR systems using R1234ze using first method (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters using	R1234yf	R1234ze	R124	R152A	R245fa	R32	R123	R134A
System COP $_{VCRS}$	2.31	2.428	2.495	2.577	2.588	2.369	2.668	2.449
Exergy Destruction Ratio(EDR_{VCRS})	1.434	1.315	1.253	1.181	1.172	1.181	1.107	1.296
Exergetic Efficiency	0.4109	0.4319	0.4338	0.4584	0.4603	0.4584	0.4746	0.4356
Exergy of Fuel "kW"	44.69	49.98	43.59	88.9	55.62	88.9	50.11	55.86
Exergy of product"kW"	18.36	21.59	19.35	40.75	25.6	40.75	23.79	24.33

Table -4(b): Effect of different low GWP refrigerants on Thermal performances of VCR systems using HFO-1234ze refrigerant using second method (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters using	R1234yf	R1234ze	R124	R152A	R245fa	R32	R123	R134A
System COP $_{VCRS}$	2.31	2.428	2.495	2.577	2.588	2.369	2.668	2.449
Exergy Destruction Ratio(EDR_{VCRS})	1.434	1.315	1.253	1.181	1.172	1.181	1.107	1.296
Exergetic Efficiency	0.4109	0.4319	0.4338	0.4584	0.4603	0.4584	0.4746	0.4356
Exergy of Fuel "kW"	44.69	49.98	43.59	88.9	55.62	88.9	50.11	55.86
Exergy of product"kW"	18.36	21.59	19.35	40.75	25.6	40.75	23.79	24.33
Irreversibility Ratio	3.419	2.785	3.068	1.446	2.272	1.443	2.411	2.477
Total Exergy_Destruction (%)	62.78	60.12	59.35	58.91	58.18	62.33	57.36	60.27
Rational Exergetic Efficiency(%)	37.22	39.88	40.65	41.09	41.82	37.67	42.64	39.73
Exergy Destruction_Comp(%)	20	20	20	20	20	20	20	20
Exergy Destruction_Condenser(%)	16.46	15.85	16.21	18.42	16.48	22.26	17.22	16.67
Exergy Destruction_Evaporator%)	5.577	6.146	6.439	6.916	6.863	6.364	6.996	6.56
Exergy Destruction_Valve(%)	20.74	18.13	16.70	13.58	14.84	13.7	13.14	17.04

2.3 *The effect of different evaporator temperature on thermal Performances*

The effect of different evaporator temperature on thermal Performances of VCR systems using R-1234yf refrigerant are shown in Table-5(a) to table-5(c) respectively. It was found that by increasing evaporator temperature of the VCR system, the system COP is increased while exergy efficiency is also increased and reaching to a optimum value and then decreasing with increasing electrical energy consumption in terms of total compressor work. According to Tables 6(a) to 6(c), the thermal performances of variable compression ratio (VCR) systems using three HCFO and HFO refrigerants were evaluated under different condenser temperatures. The results indicate that as the evaporator temperature of the VCR system increases, the first law efficiency, measured in terms of the coefficient of performance (COP), also increases. However, the exergy efficiency decreases with increasing evaporator temperature. This means that while the system is able to achieve higher cooling performance (reflected in the COP) at higher evaporator temperatures, the overall efficiency of converting input energy to useful work (exergy efficiency) decreases. Additionally, the increasing evaporator temperature leads to higher electrical energy consumption in terms of total compressor work. This suggests that the VCR system requires more energy input from the compressor to maintain the desired cooling effect at higher evaporator temperatures.

Table -5(a): Effect of different evaporator temperature (K) using HCFO-1233zd(E) refrigerant on thermodynamic performances of VCR systems using R1234ze refrigerant using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{\_superheating}$= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters using Evaporator temperature(K)	253K	258K	263K	268K	273K	278K
System COP $_{VCRS}$	2.623	2.988	3.429	3.97	4.648	5.523
Exergy Destruction Ratio(EDR_{VCRS})	1.144	1.158	1.191	1.25	1.349	1.517
Exergetic Efficiency	0.4665	0.4633	0.4563	0.4444	0.4257	0.3973
Exergy of Fuel "kW"	56.06	50.42	45.0	39.79	34.77	29.92
Exergy of product"kW"	26.15	23.36	20.54	17.68	14.8	11.89
Irreversibility Ratio	2.212	2.456	2.787	3.258	3.962	5.103
Total Exergy_Destruction(%)	57.86	57.37	57.24	57.6	58.64	60.66
Rational Exergetic Efficiency(%)	42.14	42.63	42.76	42.4	41.36	39.34
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	16.82	18.57	20.69	23.3	26.59	30.84
Exergy Destruction_Evaporator%)	7.051	6.228	5.372	4.49	3.591	2.69
Exergy Destruction_Valve(%)	13.98	12.57	11.18	9.807	8.456	7.126
Relative COP=$COP_{\_Actual}/COP_{\_Carnot}$)	0.7232	0.7273	0.7258	0.7163	0.6529	0.6579

Table -5(b): Effect of different evaporator temperature (K) using HFO-1336mzz(Z) refrigerant on thermodynamic performances of VCR systems using HFO-1234ze refrigerant using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10

Performance Parameters using Evaporator temperature(K)	253K	258K	263K	268K	273K	278K
System COP $_{VCRS}$	2.527	2.894	3.336	3.88	4.565	5.446
Exergy Destruction Ratio(EDR_{VCRS})	1.225	1.229	1.252	1.302	1.393	1.552
Exergetic Efficiency	0.4495	0.4486	0.444	0.4344	0.4791	0.39184
Exergy of Fuel "kW"	43.77	39.13	34.65	31.66	30.33	26.14
Exergy of product"kW"	19.64	17.37	15.05	12.59	12.59	10.24
Irreversibility Ratio	2.691	2.96	3.328	3.852	4.642	5.924
Total Exergy_Destruction (%)	58.79	58.13	57.82	57.99	58.84	60.68
Rational Exergetic Efficiency(%)	41.21	41.87	42.0	842.01	41.16	39.32
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	16.1	17.88	20.02	22.66	25.97	30.26
Exergy Destruction_Evaporator%)	6.786	6.02	5.212	4.37	3.503	2.626
Exergy Destruction_Valve(%)	15.91	14.24	12.59	10.96	9.362	7.793
Relative COP=$COP_{\_Actual}$/$COP_{\_Carnot}$)	0.7052	0.7122	0.7136	0.7071	0.6893	0.6545

Table -5(c): Effect of different evaporator temperature (K) using HFO-1234yf refrigerant on thermal performances of VCR systems using R1234ze refrigerant using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{\_superheating}$= T_{eva} +10

Performance Parameters using Evaporator temperature (K)	253K	258K	263K	268K	273K	278K
System COP $_{VCRS}$	2.284	2.628	3.043	3.553	4.195	5.024
Exergy Destruction Ratio(EDR_{VCRS})	1.461	1.455	1.47	1.514	1.603	1.767
Exergy Efficiency	0.4063	0.4074	0.4049	0.3977	0.3841	0.3614
Exergy of Fuel "kW"	44.69	40.18	35.84	31.66	27.63	23.75
Exergy of product"kW"	18.16	16.37	14.51	12.59	10.61	8.583

Table -6(a) : Effect of different condenser temperature (K) using R-1233zd(E) refrigerant on thermal performances of VCR systems using R-1234yf refrigerant using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10

Performance Parameters using condenser temp (K)	333 (K)	328 (K)	323 (K)	318 (K)	313 (K)
System COP $_{VCRS}$	2.114	2.35	2.623	2.941	3.32
Exergy Destruction Ratio(EDR_{VCRS})	1.66	1.392	1.144	0.9115	0.6935
Exergy Efficiency	0.3759	0.4180	0.4665	0.5232	0.5905
Exergy of Fuel "kW"	63.57	59.88	56.06	52.13	48.07
Exergy of product"kW"	23.91	25.03	26.15	27.27	28.39
Irreversibility Ratio	2.743	2.476	2.212	1.945	1.667
Total Exergy_Destruction(%)	65.56	61.98	57.86	53.04	47.31
Rational Exergetic Efficiency(%)	34.44	38.02	42.12	46.96	52.69
Exergy Destruction_Comp(%)	20.0	20.0	20.0	20.0	20.0
Exergy Destruction_Condenser(%)	22.93	20.21	16.82	12.59	4.262
Exergy Destruction_Evaporator%)	5.682	6.318	7.051	7.908	8.926
Exergy Destruction_Valve(%)	16.94	15.45	13.98	12.54	11.12
Relative COP=$COP_{\_Actual}$/$COP_{\_Carnot}$)	0.5953	0.6554	0.7232	0.8005	0.8899

Table -6(b) : Effect of different condenser temperature (K) using HFO-1336mzz(Z) refrigerant on thermal performances of VCR systems using HFO-1234yf for (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{\_superheating}$= T_{eva} +10

Performance Parameters using condenser temp (K)	333 (K)	328 (K)	323 (K)	318 (K)	313 (K)
System COP $_{VCRS}$	2.005	2.248	3.043	2.527	2.005
Exergy Destruction Ratio(EDR_{VCRS})	1.804	1.824	1.461	1.144	0.862
Exergy Efficiency	0.3566	0.3540	0.4063	0.4664	0.5371
Exergy of Fuel "kW"	54.91	47.56	44.69	41.7	38.58
Exergy of product"kW"	19.58	16.84	18.16	19.45	20.22
Irreversibility Ratio	3.405	3.042	2.691	2.346	1.995
Total Exergy_Destruction(%)	66.68	63.02	58.79	53.87	48.04
Rational Exergetic Efficiency(%)	33.32	36.98	41.21	46.13	51.96
Exergy Destruction_Comp(%)	20	20	20	20	20
Exergy Destruction_Condenser (%)	21.93	19.36	16.1	11.98	6.755
Exergy Destruction_Evaporator%)	5.383	6.036	6.786	7.66	8.696
Exergy Destruction_Valve(%)	19.37	17.62	15.91	14.23	12.59

Table -6(c): Effect of different condenser temperature (K) using HFO-1234yf refrigerant on thermodynamic performances of VCR systems using HFO-1234yf refrigerant using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{_superheatin}$g= T_{eva} +10

Performance Parameters using condenser temperature (K)	333 (K)	328 (K)	323 (K)	318 (K)	313 (K)
System COP $_{VCRS}$	1.731	1.991	2.284	2.622	3.019
Exergy Destruction Ratio(EDR_{VCRS})	2.247	1.824	1.461	1.144	0.862
Exergy Efficiency	0.3080	0.3540	0.4063	0.4664	0.5371
Exergy of Fuel "kW"	50.31	47.56	44.69	41.7	38.58
Exergy of product"kW"	15.49	16.84	18.16	19.45	20.22

2.4 Effect of sub cooling in condenser fluid

According to Tables 7(a) to 7(c), the effect of subcooling in the condenser on the thermodynamic performances of vapor compression refrigeration systems using multiple evaporator individual compressors with multiple expansion valves and HCFO/HFO refrigerants were examined. The results indicate that as the subcooling effect in the condenser increases, the system coefficient of performance (COP) also increases. This means that the system becomes more efficient in converting input energy into cooling output. Additionally, the exergy efficiency of the system also increases with higher subcooling, indicating improved efficiency in utilizing the available energy. Moreover, the increasing subcooling effect results in a decrease in electrical energy consumption in terms of total compressor work. This implies that the system requires less electrical energy input to achieve the desired cooling performance. Overall, the findings suggest that incorporating higher subcooling in the condenser enhances the thermodynamic performances of the vapor compression refrigeration system, leading to improved COP, exergy efficiency, and reduced electrical energy consumption.

Table -7(a) : Outcome of sub-cooling of condenser fluid on thermodynamic performances of VCR systems for HCFO-1233zd(E) for (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{\_superheating}$= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters considering sub-cooling effect in evaporator temperature(K)	0	5	10	15
System COP $_{VCRS}$	2.114	2.35	2.623	2.841
Exergy Destruction Ratio(EDR_{VCRS})	1.66	1.392	1.144	0.9115
Exergy Efficiency	0.3759	0.4180	0.4665	0.5232
Exergy of Fuel "kW"	63.57	59.88	56.06	52.13
Exergy of product"kW"	23.9	25.03	13.98	27.27
Irreversibility Ratio	2.743	2.476	2.212	1.945
Total Exergy_Destruction(%)	65.56	61.98	57.86	53.04
Rational Exergetic Efficiency(%)	34.44	38.02	42.14	46.96
Exergy Destruction_Comp(%)	20	20	20	20
Exergy Destruction_Condenser(%)	22.93	20.21	16.82	12.59
Exergy Destruction_Evaporator%)	5.682	6.318	7.051	7.908
Exergy Destruction_Valve(%)	16.94	15.45	13.98	12.54
Relative COP=$COP_{\_Actual}$/$COP_{\_Carnot}$)	0.5953	0.6554	------	0.8005

Table -7(b): Outcome of subcooling of condenser fluid using R-1336mzz(Z) on thermal performances of VCR systems for (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{\_superheating}$= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters considering sub cooling effect in condenser	0	5	10	15
System COP $_{VCRS}$	2.005	2.248	2.527	2.853
Exergy Destruction Ratio(EDR_{VCRS})	1.804	1.501	1.225	0.9708
Exergy Efficiency	0.3566	0.3998	0.4494	0.5074
Exergy of Fuel "kW"	54.91	51.82	48.6	45.26
Exergy of product"kW"	19.58	20.72	21.84	22.97
Irreversibility Ratio	3.405	3.042	2.691	2.346
Total Exergy_Destruction(%)	66.68	63.02	58.79	53.87
Rational Exergetic Efficiency(%)	33.32	36.98	41.21	46.13
Exergy Destruction_Comp(%)	20	20	20	20
Exergy Destruction_Condenser(%)	21.93	19.36	16.1	11.98
Exergy Destruction_Evaporator%)	5.383	6.036	6.386	7.66
Exergy Destruction_Valve(%)	19.37	17.62	15.91	14.23
Relative COP=$COP_{\_Actual}$/$COP_{\_Carnot}$)	0.5720	0.6347	0.7052	0.7853

Table -7(c): Effect of subcooling of condenser fluid on thermal performances of VCR systems using g R-1234yf for (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{_superheating}$g=T_{eva} +10, compressors isentropic efficiency= 80%

Performance Parameters considering sub cooling effect in condenser	0	5	10	15
System COP VCRS	1.731	1.991	2.284	2.622
Exergy Destruction Ratio(EDRVCRS)	2.247	1.824	1.461	1.144
Exergy Efficiency	0.3080	0.3540	0.4063	0.4664
Exergy of Fuel "kW"	50.31	47.56	44.69	41.7
Exergy of product"kW"	15.49	16.84	18.16	19.45

2.5 Effect of super heating in evaporator fluid

According to Tables 8(a) to 8(c), the thermal performances of variable compression ratio (VCR) systems using R1234yf refrigerant were studied with respect to the superheating effect in the evaporator. The results indicate that as the evaporator temperature of the VCR system increases, the system coefficient of performance (COP) improves. This means that the system becomes more efficient in providing cooling output relative to the energy input. Furthermore, the exergy efficiency initially increases with increasing evaporator temperature, reaching an optimum value, and then starts to decrease. This suggests that there is an optimal superheating effect for achieving the highest exergy efficiency in the system. Additionally, the electrical energy consumption, in terms of total compressor work, decreases as the evaporator temperature increases. This implies that the system requires less electrical energy input to maintain the desired cooling performance at higher evaporator temperatures. Overall, the findings suggest that increasing the evaporator temperature in the VCR system using R1234yf refrigerant can enhance the system's COP, exergy efficiency (up to an optimum point), and reduce electrical energy consumption.

Table -8(a) : Effect of superheating of condenser fluid using HCFO-1233zd(E) refrigerant on thermal performances of VCR systems using R -1233zd(E) using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters considering super heating effect in evaporator temperature(K)	0	5	10	15
System COP VCRS	2.619	2.621	2.623	2.625
Exergy Destruction Ratio(EDRVCRS)	1.147	1.145	1.144	1.142
Exergy Efficiency	0.4659	0.4661	0.4665	0.4670
Exergy of Fuel "kW"	53.83	54.95	56.06	57.17
Exergy of product"kW"	25.08	25.61	26.15	26.70
Irreversibility Ratio	2.41	2.305	2.212	2.131
Total Exergy_Destruction(%)	60.44	59.04	57.86	56.89
Rational Exergetic Efficiency(%)	39.56	40.96	42.14	43.11
Exergy Destruction_Comp(%)	20	20	20	20
Exergy Destruction_Condenser(%)	16.38	16.54	16.82	17.23
Exergy Destruction_Evaporator%)	7.041	7.045	7.051	7.058
Exergy Destruction_Valve(%)	17.02	15.45	13.98	12.60
Relative COP=COP_Actual/COP_Carnot)	0.6950	0.710	0.7232	0.7344

Table -8(b) : Effect of superheating of condenser fluid using HFO-1336mzz(Z) on thermal performances of VCR systems using HFO-1233zd(E) using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, $T_{_superheatin}$g= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters considering super heating effect in evaporator temperature(K)	0	5	10	15
System COP VCRS	2.506	2.514	2.527	2.544
Exergy Destruction Ratio(EDRVCRS)	1.244	1.237	1.225	1.21
Exergy Efficiency	0.4457	0.4471	0.4495	0.4524
Exergy of Fuel "kW"	46.51	47.61	48.6	49.54
Exergy of product"kW"	20.73	21.29	21.84	22.41
Irreversibility Ratio	2.998	2.837	2.837	2.691
Total Exergy_Destruction(%)	62.16	60.38	60.38	58.79
Rational Exergetic Efficiency(%)	37.84	39.62	39.62	41.21
Exergy Destruction_Comp(%)	20.	20.	20.	20.
Exergy Destruction_Condenser(%)	15.84	15.96	16.10	16.33
Exergy Destruction_Evaporator%)	6.729	6.749	6.786	6.83
Exergy Destruction_Valve(%)	19.59	17.67	15.91	14.27
Relative COP=COP_Actual/COP_Carnot)	0.6679	0.6869	0.7052	0.722

Table -8(c): Effect of superheating of condenser fluid using HFO-1234yf on thermal performances of VCR systems using R1234yf using (T_{eva}=253K, and T_{Cond}=313K, $T_{Subcooled\_Liquid}$=313K, T_superheating= T_{eva} +10, compressors isentropic efficiency= 80%)

Performance Parameters considering super heating effect in evaporator temperature(K)	0	5	10	15
System COP $_{VCRS}$	2.25	2.266	2.303	2.284
Exergy Destruction Ratio(EDR_{VCRS})	1.499	1.481	1.442	1.461
Exergy Efficiency	0.4002	0.4031	0.4096	0.4063
Exergy of Fuel “kW”	42.28	43.53	45.83	44.69
Exergy of product“kW”	16.62	17.55	18.27	18.16

3. Conclusions

The improvement of the thermal performance of the VCRS employing LVHE low GWP (HFC), HFO blends, and HFO refrigerants has been discussed in detail, and the ensuing conclusions have been made.

- The performance coefficient (COP) is rising by using a liquid-vapor heat exchanger to sub-cool the VCRS condenser fluid.
- VCR systems that use super-heating in the evaporator fluid prior to the compressor input are experiencing an increase in actual coefficient of performance (COP).
- By raising the evaporator temperature in VCRS, the system's coefficient of performance (COP) is improved, and exergy efficiency increases initially before peaking at its highest level and subsequently declining.
- The HFO-1234ze(Z) often offers the maximum system COP and energy efficiency for applications requiring higher temperatures, such as 273K for the evaporator. However, using R1233zd(E) resulted in slightly worse thermal performances than R1234ze(Z).
- The thermodynamic performance of HCFO-1233zd(E) refrigerant is somewhat better than that of HCFO-1224yd(Z). However, up to an evaporator temperature of 263K, the thermal performances of HFO-1336mzz(Z) and HCFO-1224yd(Z) are remarkably similar.
- The coefficient of performance (COP) of HCFO-1233zd(E) and HFO-1336mzz(Z) offers a slightly higher system COP and exergy efficiency than utilising HFO1234ze(E) and HFO-1243zf for lower evaporator temperatures (less than 263K). However, using the refrigerant HFO-1234yf, the lowest thermodynamic performances were observed.
- HFO-1225ye(Z) has better thermodynamic properties than R-1234yf but is less effective than HFO-1243zf and HFO-1234ze(E).
- Exergy computation in VCR Systems employing Low GWP, HFC refrigerants on VCRS shows that R152a has the highest COP and exergy efficiency, whereas HFC-32 has the lowest.
- R245fa with low GWP HFC refrigerant was shown to have the lowest total exergy destruction (%) and highest rational exergy efficiency.
- When compared to using HFO refrigerants, HFO blends typically result in lowering system COP and exergy efficiency. However, R-515A and R513A are the best HFO refrigerants. R513A has a lower system COP than R515A. However, R454C HFO blends showed the lowest thermal performances.
- The COP of the vapour compression refrigeration systems decreases while exergy efficiency increases as the condenser temperature is increases.

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