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RESEARCH PAPER

Thermal (exergy) performances of modified vapour compression refrigeration systems using multiple evaporators at the different temperatures with compound compression, multiple expansion valves VCRS using low GWP (HFC, HFO, HCFO) refrigerants for reducing global warming and ozone depletion

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Abstract

Extensive research has been conducted on the impact of extremely low GWP eco-friendly ultra-low GWP HFO, HCFO, and low GWP HFC refrigerants using first and second law (exergy) performances. The exergy destruction at different evaporators temperatures on thermal performances of VCRS using environmentally friendly refrigerants using multiple evaporators with compound compression and expansion valves of multiple type have not been studied in detail so far in the literature. This papers mainly deals with the detailed first law performance in terms of COP and exergy destruction in the various components of low GWP refrigerants in multiple evaporators, compound compression with multiple expansion types used in VCR systems have been studied in detail and effect of different evaporators load variations at different evaporators temperatures on thermal performances have been investigated.

1. Introduction

Refrigeration technology based on the principle of rejection of heat to the surrounding at higher temperature and absorption of heat at low temperature [1] evaporator, expansion valve, condenser and compressor are the main four components of single stage vapour compression system. Vapour compression refrigeration systems consume large amount of electricity. This difficulty can be removed by improve the performance parameters of system. First law efficiency (Coefficient of performance) and second law performance (exergetic efficiency) are main two parameters to calculate the performance of refrigeration systems. Coefficient of performance can be enhanced either by minimizing power consumption of compressor or increasing of refrigeration effect. Refrigeration effect can be increased by adoption of multi-stage throttling. On the other hand, power consumption of compressor can be enhanced by incorporation of multi-stage compression and flash chamber. Collective effect of these two factors improves overall performance of vapour compression system. It is presented that irreversibility in system components take place due to large temperature difference between system and surrounding. In order to improve the system performance Irreversibility should be measured in the cycle because exergy losses are responsible for degradation of system performance. Coefficient of performance is commonly used to calculate the performance of vapour compression system but COP provides no information regarding thermodynamic losses in the system components. Using exergy analysis one

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can be quantify the exergy losses in vapour compression refrigeration systems. Exergy losses increase with increasing of temperature difference between systems and surrounding. Exergy is the available or useful energy and loss of energy means loss of exergy in the system. Exergy losses are useful to improve the performance of system and better utilization of energy input given to the system which is beneficial for environmental conditions and economics of energy technologies. Utilization of green energy can be increased by this method [1]. In past decades, refrigerants such as R11, R12, R22 etc. used in vapour compression refrigeration system responsible for increasing of global warming and ozone depletion potential. An international society named Montreal protocol discussed and signed on the refrigerants having higher global warming and ozone depletion potential values for all countries. In order to control the emission of greenhouse gases one more committee was formed named as Kyto protocol [2]. After 90's a program was ran to phase out the higher GWP and ODP refrigerants (CFC and HCFC) for the purpose of environmental problems. To replace "old" refrigerants with "new" refrigerants lots of research has been conducted and lots of researches has been carried out [2]. Thermal performance parameters such as COP and exergetic efficiency with R290/R600 hydrocarbon mixture were evaluated on a domestic refrigerator designed to work with R134a and observed that performance of same system is higher with R290/R600a hydrocarbon mixture compared to R134a. In their analysis condenser, expansion valve and evaporator showing lower exergy destruction compared to compressor [3]. Theoretical analysis of R134a, R143a, R152a, R404A, R410A, R502 and R507A was carried out in vapour compression refrigeration system and effect on coefficient of performance and second law efficiency with variation of superheating of evaporator outlet, evaporator temperature and degree of sub-cooling at condenser outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature and concluded that COP and exergetic efficiency significantly affected with change of evaporator and condenser temperatures and also observed that R134a and R407C show highest and lowest performance in all respect.[4]. Kumar et al.[5] energy and exergy analysis of single stage vapour compression refrigeration system was also carried using CFC-11 and CFC-12 as working fluids [5]. The effect of condenser and evaporator temperatures on two-stage vapour compression refrigeration system using R22 and suggested that there is requirement to optimize the condenser and evaporator conditions. Through above literature, it was found that energy, exergy analysis of single stage and multi stages vapour compression refrigeration systems have been done. But no literature contributed for exergy analysis of two-stage vapour compression refrigeration system using HFO refrigerants. Present works analyze the system in terms of energy and exergy efficiencies and explain the effect of exergy losses occurred on two-stage vapour compression refrigeration system with HFO refrigerants [6].

2. Results and Discussion

The input numerical values have been taking to validate thermal model were shown in table 1.

Table 1: Multiple evaporators at the different Temperatures with compound compression, multiple expansion valves and flash inter cooler

S.No.	Iput value	Unit	Value
1	Cooling Load on First Evaporator(Q_{Eva_1})	'kW'	105
2	Cooling Load on second Evaporator(Q_{Eva_2})	'kW'	35
3	Cooling Load on second Evaporator(Q_{Eva_2})	kW	70
4	Isentropic Efficiency of first compressor ($Comp_{Eff\_1}$)	%	75%
5	Isentropic Efficiency of second compressor ($Comp_{Eff\_2}$)	%	75%
6	Isentropic Efficiency of third compressor ($Comp_{Eff\_3}$)	%	75%
7	Temperature of first evaporator	(°K)	263
8	Temperature of second evaporator	(°K)	278
9	Temperature of third evaporator	(°K)	283

Thermodynamic performances of above system have been computed for HFO refrigerants for replacing high GWP HFC-134a refrigerant is shown in Table-2(a) respectively. Similarly, the percentage of Exergy Destruction in components based on exergy of fuel and Rational exergetic efficiency of vapour compression refrigeration systems using HFO refrigerants is shown in Table-2(b) to Table-2(d) respectively.

Table-2(a): Effect of using HFO refrigerants on thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)

Performance Parameters	R1234 ze(Z)	R-1224 yd(Z)	R-1233 zd(E)	R-1225 ye(Z)	HFO-1336 mzz(Z)	R-1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.548	4.498	4.529	4.334	4.477	4.35	4.378	4.235	4.365
% Total Compressor Exergy Destruction	23.91	24.25	24.13	24.22	24.33	24.10	24.26	24.29	23.86
% Total condenser Exergy Destruction	25.4	24.62	25.01	23.49	24.37	23.76	23.75	22.72	24.26
% Total Exergy evaporator Destruction	8.99	8.891	8.8971	8.565	8.847	8.590	8.247	8.370	8.595
% Total Valve Exergy Destruction	6.127	6.921	6.464	8.989	7.316	8.721	8.764	10.28	8.405
% Rational Exergetic Efficiency	35.57	35.31	35.43	34.72	35.14	34.83	34.98	34.34	34.89

Table-2(b)*Exergy Destruction in components and Rational exergetic efficiency) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW)*

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO13 36 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.558	4.508	4.539	4.345	4.488	4.360	4.389	4.247	4.375
% Total Compressor Exergy Destruction	25.44	24.67	25.05	23.54	24.41	23.81	23.88	22.77	24.3
% Total condenser Exergy Destruction	23.89	24.23	24.12	24.2	24.31	24.08	24.24	24.27	23.84
% Total Exergy evaporator Destruction	9.006	8.908	8.988	8.583	8.866	8.607	8.266	8.399	8.612
% Total Valve Exergy Destruction	6.063	6.846	6.393	8.904	7.232	8.641	8.678	10.18	8.328
% Rational Exergetic Efficiency	35.59	35.34	35.45	34.77	35.18	34.86	35.01	34.38	34.92

Table-2(c) *Exergy Destruction in components and Rational exergetic efficiency of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants(for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW)*

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO1336 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.433	4.383	4.413	4.221	4.361	4.237	4.264	4.182	4.252
% Rational Efficiency	36.08	35.8	35.92	35.17	35.62	35.27	35.42	34.95	35.34
% Total Compressor Exergy Destruction	37.5	37.85	37.75	37.44	37.86	37.31	37.65	37.35	36.99
% Total condenser Exergy Destruction	38.91	37.55	38.21	35.47	37.04	35.94	36.0	37.38	36.72
% Total Exergy evaporator Destruction	13.79	13.57	13.72	12.94	13.46	13.0	12.5	10.68	13.02
% Total Valve Exergy Destruction	9.806	11.03	10.32	14.15	11.63	13.75	13.85	14.6	13.26
% Rational Exergetic Efficiency	36.08	35.8	35.92	35.17	35.62	35.27	35.42	34.95	35.34

Table-2(d) Percentage *Exergy Destruction in components based on total exergy* of fuel *modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants(for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO1336 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.956	4.909	4.939	4.739	4.892	4.752	4.787	4.638	4.767
% Total Compressor Exergy Destruction	23.69	24.04	23.92	24.0	24.12	23.86	24.04	24.07	23.63
% Total condenser Exergy Destruction	27.26	26.46	26.86	25.28	26.21	25.55	25.55	24.47	26.07
% Total Exergy evaporator Destruction	9.618	9.525	9.606	9.194	9.491	9.215	8.88	9.0	9.214
% Total Valve Exergy Destruction in Valve	5.515	6.223	5.801	8.187	6.554	7.956	7.96	9.394	7.664
% Total Valve Exergy Destruction	66.083	66.248	66.187	66.631	66.375	66.581	66.43	66.934	66.578
% Rational Exergetic Efficiency	33.917	33.752	33.813	33.369	33.625	33.419	33.57	33.066	33.422

The results presented in Tables 2(b), 2(c), and 2(d) provide a comparative analysis of exergy destruction and rational exergetic efficiency in a modified vapor compression refrigeration system equipped with multiple evaporators operating at different temperatures, compound compression, multiple expansion valves, and a flash intercooler using eco-friendly low GWP refrigerants. In Table-2(b), with evaporator loads of 70 kW, 105 kW, and 35 kW, the coefficient of performance (COP) ranges between 4.247 and 4.558, with R1234ze(Z) exhibiting the highest COP of 4.558. Compressor exergy destruction varies between 22.77–25.44%, indicating that the compressor contributes the largest share of losses, followed closely by the condenser (23.84–24.31%). Valve losses are significant (6.063–10.18%), whereas evaporator exergy destruction remains comparatively lower (8.266–9.006%). Rational exergetic efficiency is fairly consistent across refrigerants, lying between 34.38% and 35.59%. Table-2(c) shows the same system configuration but with performance shifts. COP values reduce slightly (4.182–4.433), while rational efficiency improves, peaking at 36.08%. Compressor losses increase substantially (36.99–37.85%), making them the dominant source of exergy destruction in this mode. Condenser destruction follows closely at 35.47–38.91%, while valve destruction increases markedly (9.806–14.6%). The evaporator still has the least contribution, though higher than in Table-2(b), ranging from 10.68% to 13.79%. This suggests that under these conditions, compressor and valve processes govern overall efficiency, and improvements in these areas could enhance system sustainability. In Table-2(d), where evaporator load distribution is modified to 105 kW, 70 kW, and 35 kW, the COP increases significantly, ranging from 4.638 to 4.956, with R1234ze(Z) again performing the best. Exergy destruction patterns shift, with compressors showing 23.63–24.12% losses, and condensers slightly higher at 24.47–27.26%. Evaporators contribute about 9–9.6%, and valves show relatively lower individual destruction (5.515–9.394%). However, when destruction is normalized to total exergy of fuel, the cumulative valve destruction dominates at ~66%, leaving rational efficiency between 33.066–33.917%. The thermodynamic evaluation of the vapor compression refrigeration system with multiple evaporators, compound compression, multiple expansion valves, and a flash intercooler using eco-friendly HFO refrigerants is summarized in Tables 3(a)–3(d). These results provide insights into COP, exergy destruction in different components, and rational exergetic efficiency under different evaporator load distributions. In Table-3(a), with evaporator loads of 105 kW, 70 kW, and 35 kW, COP values range between 4.215 and 4.514, with R245fa showing the best performance (4.514). The compressor exergy destruction is relatively moderate (23.40–23.86%) for R134a and R-152a but extremely low (0.318–0.341%) for R245fa and R-32, where condenser losses dominate (46.52–49.83%). Rational efficiency is stable (~35%) for R134a and R-152a but drastically lower for R245fa and R-32 due to disproportionately high condenser losses. Table-3(b), with redistributed loads (70 kW, 105 kW, 35 kW), shows improved COP values, ranging from 4.064 (R-32) to 4.524 (R245fa). Exergy destruction is more balanced: compressors (23.08–25.86%), condensers (23.39–25.65%), evaporators (~8–9%), and valves (6.664–8.328%). Rational efficiency improves slightly, lying between 34.92% and 35.45%, confirming a more thermodynamically balanced performance compared to Table-3(a). Table-3(c) reports similar load distribution but with slightly reduced COP (4.111–4.398). Here, compressor and condenser exergy destruction increase significantly (34.35–37.87% and 36.72–41.3%, respectively), while evaporator and valve losses also rise (~12–13%). Rational exergetic efficiency stabilizes around 35–36%, with R-245fa again performing the best (35.91%). This indicates higher irreversibilities in compression and condensation under these conditions. Finally, in Table-3(d) with evaporator loads (105 kW, 70 kW, 35 kW), COP further improves, peaking at 4.925 with R-245fa. Compressor exergy destruction is moderate (22.12–24.01%), condenser destruction remains dominant (26.07–29.53%), while evaporator (8.88–9.536%) and valve (6.12–7.664%) contributions are relatively small. This configuration yields the most balanced distribution of losses, with higher first-law efficiency compared to earlier cases.

Table-3(a): Thermodynamic performances (Exergy Destruction in components and Rational exergetic efficiency) of vapour compression refrigeration systems using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (f*or first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW) using HFO refrigerants.*

Performance Parameters	R134a	R-152a	R245fa	R-32
First law efficiency (COP)	4.365	4.462	4.514	4.215
% Total Exergy Destruction in Compressor	23.86	23.40	0.3406	0.318
% Total condenser Exergy Destruction	24.26	25.82	46.52	49.83
% Total Exergy Destruction in evaporator	8.595	8.809	0.6489	0.4051
% Total Exergy Destruction in Valve	8.405	6.726	0.8660	0.5506
% Rational Exergetic Efficiency	34.89	35.25	1.286	0.8335

Table-3(b)*Exergy Destruction in components and Rational exergetic efficiency)of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants(for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW)*

Performance Parameters	R134a	R-152a	R-245fa	R-124	R-32
First law efficiency (COP)	4.375	4.471	4.524	4.436	4.064
% Total Compressor Exergy Destruction	24.3	25.86	24.62	24.19	23.08
% Total condenser Exergy Destruction	23.84	23.39	24.21	24.24	25.65
% Total Exergy evaporator Destruction	8.612	8.824	8.90	8.515	8.096
% Total Valve Exergy Destruction	8.328	6.664	6.828	7.914	8.167
% Rational Exergetic Efficiency	34.92	35.26	35.45	35.14	35.01

Table-3(c) *Exergy Destruction in components and Rational exergetic efficiency of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants(for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW)*

Performance Parameters	R134a	R-152a	R-245fa	R-124	R32
First law efficiency (COP)	4.252	4.349	4.398	4.321	4.111
% Rational Efficiency	35.34	35.74	35.91	35.88	34.35
% Total Compressor Exergy Destruction	36.99	36.52	37.87	37.66	34.35
% Total condenser Exergy Destruction	36.72	39.35	37.53	36.77	41.3
% Total Exergy evaporator Destruction	13.02	13.44	13.57	12.91	12.48
% Total Valve Exergy Destruction	13.26	10.69	11.2	12.66	11.87
% Rational Exergetic Efficiency	35.34	35.74	35.91	35.88	34.51

Table-3(d) Percentage *Exergy Destruction in components based on total exergy* of fuel *modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants(for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R134a	R-152a	R-245fa	R-32
First law efficiency (COP)	4.767	4.859	4.925	4.578
% Total Compressor Exergy Destruction	23.63	23.15	24.01	22.12
% Total condenser Exergy Destruction	26.07	27.69	26.4	29.53
% Total Exergy evaporator Destruction	9.214	9.418	9.536	8.88
% Total Valve Exergy Destruction in Valve	7.664	6.12	6.206	7.062

The percentage of Exergy Destruction in components based on total exergy destruction and Rational exergetic efficiency of vapour compression refrigeration systems using HFO refrigerants at different loading conditions are also shown in Table-4(a) to Table-4(h) respectively. The thermodynamic evaluation presented in Tables 4(a)–4(h) highlights the distribution of percentage exergy destruction across major components of the modified vapor compression refrigeration system operating with multiple evaporators at different temperatures, compound compression, multiple expansion valves, and a flash intercooler using low-GWP refrigerants. In general, the compressor and condenser emerge as the dominant sources of exergy destruction, with their combined contribution ranging between 70–80% of the system losses, depending on the refrigerant and load distribution. In Tables 4(a) and 4(b), COP values remain in the range of 4.2–4.55, with compressor exergy destruction averaging around 37% and condenser destruction between 36–39%, while evaporator and valve losses are relatively smaller (12–14% and 9–15%, respectively). When the load distribution changes, as seen in Table 4(c), COP slightly decreases (4.18–4.43), but valve irreversibility increases up to 14.6%, showing that throttling losses become more significant under this condition. Table 4(d) shows compressor losses stabilizing near 36%, condenser losses around 38–40%, and evaporator losses near 14%, while valve exergy destruction varies widely (8–12%), highlighting the influence of refrigerant type on throttling performance. In Tables 4(e)–4(h), where HFOs and blends are compared with traditional refrigerants, COP values remain within 4.0–4.5, with R245fa and R-152a consistently showing superior COP and better rational efficiency. However, condenser irreversibilities tend to be slightly higher for R-32 and R-124 (up to ~42%), reducing exergetic efficiency. The rational efficiency remains fairly steady for most refrigerants (~34–36%), except for cases with disproportionate condenser losses, where it drops significantly. Overall, the results emphasize that improving the compressor and condenser processes is critical for minimizing system exergy destruction, while refrigerants like R245fa and R-152a provide more favorable performance balance under eco-friendly conditions.

Table-4(a) : Percentage *exergy destruction in components based on total exergy destruction in the system and Rational exergetic efficiency) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R1234 ze(Z)	R-1224 yd(Z)	R-1233 zd(E)	R-1225 ye(Z)	HFO-1336 mzz(Z)	R-1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.548	4.498	4.529	4.334	4.477	4.35	4.378	4.235	4.365
% Total Compressor Exergy Destruction	37.11	37.49	37.37	37.11	37.51	36.98	37.31	36.99	36.64
% Total condenser Exergy Destruction	39.42	38.07	38.72	36.06	37.57	36.46	36.53	34.61	37.25
% Total Exergy evaporator Destruction	13.95	13.74	13.89	13.12	13.64	13.18	12.68	12.75	13.20
% Total Valve Exergy Destruction	9.511	10.07	10.01	13.77	11.28	13.38	13.48	15.65	12.91
% Rational Exergetic Efficiency	35.57	35.31	35.43	34.72	35.14	34.83	34.98	34.34	34.89

Table-4(b) -Percentage exergy destruction in components based on total exergy destruction (%) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO1336 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.558	4.508	4.539	4.345	4.488	4.360	4.389	4.247	4.375
% Total Compressor Exergy Destruction	37.10	37.48	37.36	37.10	37.5	36.97	37.31	36.99	36.63
% Total condenser Exergy Destruction	39.5	38.15	38.81	36.09	37.66	36.55	36.62	34.71	37.34
% Total Exergy evaporator Destruction	13.98	10.59	13.92	13.16	13.68	13.21	12.72	12.79	13.23
% Total Valve Exergy Destruction	9.413	10.59	9.904	13.65	11.16	13.27	13.35	15.22	12.80

Table-4(c)-Percentage exergy destruction in components based on total exergy destruction (%) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO1336 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
COP	4.433	4.383	4.413	4.221	4.361	4.237	4.264	4.182	4.252
% Total Compressor Exergy Destruction	37.35	37.85	37.5	37.75	37.44	37.86	37.31	37.65	36.99
% Total condenser Exergy Destruction	37.38	37.55	38.91	38.21	35.47	37.04	35.94	36.0	36.72
% Total Exergy evaporator Destruction	10.68	13.57	13.79	13.72	12.94	13.46	13.0	12.5	13.02
% Total Valve Exergy Destruction	14.60	11.03	9.806	10.32	14.15	11.63	13.75	13.85	13.26

Table-4(d) Percentage *exergy destruction in components* based on total exergy destruction (%) *of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R1234 ze(Z)	R1224 yd(Z)	R1233 zd(E)	R1225 ye(Z)	HFO 1336 mzz(Z)	R1243 zf	R1234 ze(E)	R1234 yf	R134a
% Total Compressor Exergy Destruction	35.76	36.29	36.29	36.29	36.29	35.85	36.29	35.85	35.85
% Total condenser Exergy Destruction	39.44	38.29	40.58	37.92	39.49	38.17	38.46	36.56	39.16
% Total Exergy evaporator Destruction	14.148	14.83	14.51	13.79	14.3	13.84	13.37	13.44	13.84
% Total Valve Exergy Destruction in Valve	8.324	9.393	8.765	12.28	9.785	11.95	11.98	14.03	11.51

Table-4(e): Percentage *exergy destruction in components based on total exergy destruction in the system and Rational exergetic efficiency) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R134a	R-152a	R-245fa	R-32
COP	4.365	4.462	4.514	4.215
% Total Compressor Exergy Destruction	36.64	36.14	37.51	33.98
% Total condenser Exergy Destruction	37.25	39.87	38.05	41.83
% Total Exergy evaporator Destruction	13.20	13.60	13.76	12.62
% Total Valve Exergy Destruction	12.91	10.39	10.69	11.57
% Rational Exergetic Efficiency	34.89	35.25	0.5053	0.4718

Table-4(f)-Percentage exergy destruction in components based on total exergy destruction in the components (%) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 70 kW, second evaporator load is 105 kW, third evaporator load is 35 kW

Performance Parameters	R134a	R-152a	R-245fa	R-32	R-124
COP	4.375	4.471	4.524	4.064	4.436
% Total Compressor Exergy Destruction	36.63	36.13	37.5	35.51	33.3
% Total condenser Exergy Destruction	37.34	39.95	38.13	39.47	37.38
% Total Exergy evaporator Destruction	13.23	13.63	13.79	12.46	13.13
% Total Valve Exergy Destruction	12.80	10.29	10.58	12.57	12.19

Table-4(g)-Percentage exergy destruction in components based on total exergy destruction in the components (%) of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)

Performance Parameters	R134a	R-152a	R-245fa	R32	R-124
COP	4.252	4.349	4.398	4.111	4.321
% Total Compressor Exergy Destruction	36.99	36.52	37.87	34.35	37.66
% Total condenser Exergy Destruction	36.72	39.35	37.53	41.3	36.77
% Total Exergy evaporator Destruction	13.02	13.44	13.57	12.48	12.91
% Total Valve Exergy Destruction	13.26	10.69	11.02	11.87	12.66

Table-4(h) Percentage exergy destruction in components based on total exergy destruction *in the components* (%) *of modified vapour compression refrigeration system using multiple evaporators at the Different Temperatures with compound compression, multiple expansion valves and flash inter cooler using low GWP ecofriendly refrigerants (for first evaporator load is 105 kW, second evaporator load is 70 kW, third evaporator load is 35 kW)*

Performance Parameters	R134a	R152a	R-245fa	R-124
COP	4.252	4.349	4.398	4.111
% Total Compressor Exergy Destruction	35.85	34.88	36.29	32.73
% Total condenser Exergy Destruction	39.16	41.72	39.91	43.68
% Total Exergy evaporator Destruction	13.44	13.84	14.19	14.41
% Total Valve Exergy Destruction	14.03	11.51	9.219	9.381

3. Conclusions

Energetic and exergetic analysis of refrigeration system was carried out with different HFO refrigerants and following conclusion and recommendation are presented below:

(i) R32 shows lowest exergetic performance among selected HFO and HFC refrigerants.
(ii) The percentage exergy destruction in condenser is higher as compared to other components for all HFO & HFC refrigerants.
(iii) The percentage exergy destruction in compressors using HCFO-1233zd(E), HFO 1225ye(Z) is higher than using other HFO refrigerants.
(iv) Exergetic and energetic efficiency of R1234ze(Z) is highest among selected HFO and HFC refrigerants.
(v) Flash chamber responsible for lowest exergy destruction for all HFO refrigerants taken under consideration.

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