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ORIGINAL ARTICLE

Thermodynamic analysis two stages vapor compression refrigeration systems using HFC, HFC+HFO blends, HCFC, HC, HFO Refrigerants

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Abstract

The numerical computation was carried out for finding rational exergy destruction ratio based on system exergy of product, and exergy of product in terms of total work done by compressors and first law efficiency in terms of COP. The second law efficiency and exergetic efficiency using entropy generation concept and exergy-energy using methods and found that the compressors have for highest exergy destruction for all refrigerants The HCFO-1233zd(E) shows best (7.41% higher) first law performance than R134a and second law efficiency while R125 shows lowest first law performance among selected ecofriendly refrigerants The first and second law performance of using R1233mzz(Z) is 1.7%, better than R134a while R1243zf have slightly 4.13% lower and and R1225ye(Z) has 3.3%) lower thermodynamic performances.. The first law efficiency using R134a is 7.13%, lower than R152a and 5.94% lower than R245fa. Similarly, HFO+HFC blends also have slightly lower thermodynamic performances than R134a which can be used can be used for replacing R134a, R404a, and R507a Although hydrocarbons gives nearly similar performances than R134a which can replace R134a by using safety measures around 2030.

1. Introduction

Refrigeration technology is based on the principle of rejection of heat to the surrounding at higher temperatures and absorption of heat at low temperatures. Evaporator, expansion valve, condenser and compressor are the main four components of a single-stage vapour compression system. Vapor compression refrigeration systems consume a large amount of electricity. This difficulty can be removed by introducing vapor compression refrigeration using multistage compressors, expansion valves, water coolers, and flash chambers Kapil Chopra , et.al. [1] carried out studies on vapor compression refrigeration systems using HFC & HFO refrigerants to improve the performance parameters such as first law efficiency in terms of coefficient of performance (COP) [1] This paper mainly deals with comparative computation performance evaluation of HFO and HFO blends, with HFC and hydrocarbon ecofriendly refrigerants used in the two-stage vapor compression refrigeration system based on energetic and exergetic principles. The system and components' irreversibilities regarding the exergy destruction ratio have been computed and presented below.

2. Methods for Improving Thermal Performances of Two Stages Refrigeration Systems

In vapor compression refrigeration systems, the coefficient of performance (COP) can be enhanced either by minimizing the

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compressor's power consumption or increasing the refrigeration effect. However, the refrigeration effect can be increased by multi-staged throttling. On the other hand, the compressor's power consumption can be reduced by incorporating multi-stage compression processes—similarly, water intercoolers and flash chambers. Multiple evaporators and expansion valves with series and parallel combinations also enhance the thermodynamic performances. R.S. Mishra [2] analyzed three multi-stage vapor compression refrigerator and flash intercooler with individual or multiple throttle valves by using thermodynamic energy-exergy analysis in terms of COP, second law efficiency and irreversibility destruction ratio based on exergy of fuel and Exergy destruction based on exergy of product, and found that the energetic efficiency (COP) of vapor compression system with water intercooler liquid sub-cooler and flash intercooler is higher than the two-stage compression system with water intercooler, liquid sub-cooler and liquid flash chamber Also found that the COP of all systems increases with increase in evaporator temperature for chosen refrigerants and concluded that R134a shows better thermodynamic performances in terms of COP and exergetic efficiency and R-227ea gives low first law performance in term of COP and second law efficiency in terms of exergetic efficiency for all systems Similarly for irreversibility point of view, or exergy destruction based on exergy of fuel or exergy of output, the two-stage compression with water intercooler and liquid sub-cooler gives lowest thermodynamic performances than HFO-1234ze and R134a

The coefficient of performance and exergetic efficiency are two main parameters to calculate refrigeration systems' performance. The irreversibility of system components takes place due to the large temperature difference between the system and its surroundings. In order to improve the system performance, Irreversibility should be measured in the cycle because Exergy losses are responsible for the degradation of system performance. Coefficient of performance is commonly used to calculate the performance of vapor compression systems, but COP provides no information regarding thermodynamic losses in the system components. Energy and exergy efficiencies are different for different refrigerants for the same system. Using exergy analysis, one can quantify the exergy losses in vapor compression refrigeration systems. Exergy losses increase with the increasing temperature difference between systems and surroundings. Exergy is the available or useful energy, and loss of energy means loss of exergy in the system. Exergy losses are helpful to improve the performance of the system and better utilization of energy input given to the system, which is beneficial for environmental conditions and economics of energy technologies. R.S. Mishra [3] carried out the thermodynamic energy-exergy analysis of multi-stage vapor compression refrigerator and flash intercooler with individual or multiple throttle valves in terms of COP, second law efficiency and irreversibility destruction ratio based on exergy of fuel and Exergy destruction based on exergy of product and found that the three-stage compression with multiple expansion valves and flash inter cooling chambers in series gives better thermodynamic (first law performance (COP) and exergetic performances Also found that Three-stage Compression with multiple expansion Valves and water coolers using eco-friendly refrigerants gives better thermodynamic performances than the three-stage Compression with multiple expansion Valves and flash inter cooling chambers in parallel In this paper, two methods for computing first law performances of Two-stage vapor compression refrigeration system have been carried out.

3. Options for adopting HFC+HFO blends and HFO refrigerants for replacing high GWP refrigerants

In past decades, refrigerants such as R11, R12, R22, R502 etc are used in vapor 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. 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.

Table 1: Environmental parameters of HFC+HFO Blends

New Refrigerants	%(HFC+HFO Blends)	GWP Non flammable	ODP	Safety Code
R513A	56%R1234yf 44% 134a	631 (573)	Non ozone depleting	A1
R515A	88%R1234ze 12% 227ea	387 (573)	Non ozone depleting	A1
R448A	26% R32 26%R125 20% R1234yf 7%R1234ze(E)	1273 to 1387	Non ozone depleting	A1
R449A	23.3% R32 24.5%R125 24.3% R1234yf 25.5%R134a	1282 to 1387	Non ozone depleting	A1
R407H	32.5% R32 15%R125 52.5%R134a	1378 to 1495	Non ozone depleting	A1
R450A	58% R1234ze(E) 42% 134a	547 to 604	Non ozone depleting	A1
R454A	35% R32 65% R1234yf	238 -239	Non ozone depleting	A2L
R454B	21.5% R32 78.5% R1234yf	1377 to 1494	Non ozone depleting	A2L
R454C	21.5% R32 78.5% R1234yf	139 to 148	Non ozone depleting	A2L
R452A	11%R32 59%R125 30%R1234yf	676 to 698	Non ozone depleting	A1
R452B	12.5%R32 61%R125 26.5%R1234yf	676 to 698	Non ozone depleting	A1

To replace "old" refrigerants with "new" refrigerants, lots of research has been lots of investigations have been carried out]. The environmental parameters of HFC+HFO Blends are shown in Table 1, respectively.
The collective effect of these two factors improves the overall thermodynamic performance of vapor compression system using HFO and HFC of low GWP as reported by several investigators Fatouh and Kafafy [4] suggested replacing R134a with hydrocarbon mixtures such as propane, propane/isobutane/n-butane mixtures, butane, and various propane mass fractions in a domestic refrigerator. Pure butane showed high operating pressures and a low coefficient of performance among considered refrigerants.
Wongwises et al. [5] did an experimental investigation on automotive air-conditioners with isobutene, propane, and butane and suggested replacing R134a with these hydrocarbon mixtures. They observed that the mixture of propane 50%, butane 40%, and isobutane 10% was the best hydrocarbon mixture to replace R134a. Arcaklioglu, and Arcaklioglu et. al [6-7] suggested using pure hydrocarbon instead of their mixtures due to variation in condenser and evaporator temperature during phase changing at constant pressure. These Changes in condenser and evaporator temperature cause the problem in vapor compression refrigeration cycle.
Exergy analysis is a valuable way to determine the actual thermodynamic losses and optimize environmental and economic performance in vapor compression refrigeration systems. Reddy et al. [8]. Did a theoretical analysis of CFC -502 and HFC refrigerants (e.g. R134a, R143a, R404A, R410A, R507A) used in the vapour compression refrigeration system and found the effect of superheating of evaporator outlet and degree of subcooling at condenser outlet, the effectiveness of vapour-liquid heat exchanger and variation of evaporator &condenser temperatures on the coefficient of performance and second law efficiency with the variation of was discussed and observed that the COP and exergetic efficiency have significantly affected Also concluded that R134a gives highest and R407C show and the lowest performance in all respect and computed with the change of evaporator and condenser temperatures with COP and exergetic efficiency using R134a Kumar et al. [9] carried out energy and exergy analysis of single-stage vapor compression refrigeration system using CFC refrigerants (i.e. R11 and R12) as working fluids and computed COP, exergetic efficiency and exergy losses in different components (such as compressor, evaporator, expansion valve and condenser). Selladurai and Saravanakumar [10] evaluated performance parameters such as COP and exergetic efficiency with R290/R600 hydrocarbon mixture on a domestic refrigerator designed to work with R134a and observed that the performance of the same system is higher with R290/R600a hydrocarbon mixture compared to R134a and found that condenser, expansion valve and evaporator showing lower exergy destruction compared to the compressor.
Cornelissen [11] proposed that non-renewable energy sources are useful for minimizing the irreversibility of the system for sustainable development of systems vapor compression refrigeration systems.
Alptunganbaba et.al.[12] Exergy analysis of a two evaporator vapor compression refrigeration system using R1234yf, R1234ze and R134a as refrigerants. Nikolaidis and Probert [13] studied the change in evaporator and condenser temperatures in the two-stage vapor compression refrigeration plant analytically using R22 to find the plant's irreversibility
Through the above literature, it was found that energy, exergy analysis of single-stage vapor compression refrigeration systems has been done. But no literature contributed to energy and exergy analysis of a two-stage vapor compression refrigeration system using HFOs, HFC of low GWP refrigerants and Hydrocarbons for replacing high GWP refrigerants. Present works analyze the system in terms of energy and exergy efficiencies and explain the effect of exergy losses on a two-stage vapor compression refrigeration system with hydrocarbons for replacing R404a, R134a and R236fa.

4. Energy exergy analysis of two staged vapor compression refrigeration systems

The two stage vapor compression refrigeration system consist of low and high pressure compressor, condenser, evaporator, expansion valves, water-intercooler. To analyzed the twostage vapor compression refrigeration system based on energy and exergy method for improving thermodynamic performances, the following assumptions were taken:

- Effect of temperature and pressure losses are negligible.
- All components of two stages vapor compression refrigeration system are working under steady state conditions.
- Energy and exergy losses due to potential energyand kinetic energy are neglected.
- Thermal efficiencies of low and high pressure compressors are assumed to be 80%.

Two stage vapor compression refrigeration system and its P-H plot shown in Figure 1 and Figure 2 respectively.

5. Results and Discussion

The two staged vapor compression refrigeration system chosen for numerical computation using HFC, HC, HCFC and HFOs, HCFOs and HFO blends using following input data.

- Cooling load on evaporator =35 "kW"
- Isentropic efficiency of high pressure (H.P.) compressor=80%
- Isentropic efficiency of low pressure (L.P.) compressor=80%
- Condenser temperature=313K
- Evaporator temperature=233K

This paper mainly deals with thermodynamic energy& exergy performances of two-staged vapor compression using HFC, HC, HCFO, HFO & HFO+HFC blends. Table-1(a) shows the thermodynamic performances of two-staged vapor compression refrigeration systems using natural refrigerant and hydrocarbons with HFC-134a, and it was found that R717 gives the best first law performance and exergetic efficiency. In contrast, R290 gives the lowest thermodynamic performance. The exergy destruction in the condenser is highest than exergy destruction in other components. Similarly, exergy destruction in a high-pressure compressor using HC-290 is lowest using R600a. However, overall exergy destruction using R290 is higher and lowest using R717. Similarly, overall exergy destruction expansion valves using R290 are highest and lowest using R717. Similarly, exergy destruction in H.P. expansion valve is higher than in the low-pressure expansion valve. The mass flow rate in H.P compressor is higher than the mass flow rate in L.P compressor. Similarly, thermodynamic performances using the entropy generation method is also shown in table-1(b), respectively.

Table 1(a): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water inter cooler

Refrigerant	R717	R290	R600a	R-1270	R134a
COP	1.988	1.73	1.784	1.758	1.768
EDR	0.9058	1.293	1.224	1.257	1.243
Exergetic Efficiency	0.5011	0.4362	0.4497	0.4431	0.4458
Exergy of fuel (kW)	17.61	20.23	19.62	19.91	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Comp (H.P.) (kg/s)	0.037	0.1803	0.1887	0.1708	0.3343
Mass flow rate in Low Pressure Comp. (L.P.) (kg/s)	0.02854	0.1038	0.1160	0.1008	0.1967
Total compressor work (kW)	17.61	20.23	19.62	19.91	19.79
High Pressure Compressor (H.P.)Work (kW)	9.676	12.34	10.84	12.12	11.75
Low Pressure Compressor (L.P.) Work (kW)	7.934	7.891	8.776	7.793	8.042
Exergy_Input (kW)	17.36	19.58	19.05	19.31	19.30
Second law efficiency	0.6824	0.5941	0.6125	0.6035	0.6072
Irreversibility Ratio	0.8035	1.072	1.009	1.039	1.027
Effectiveness second law	0.5545	0.4827	0.4976	0.4903	0.4933
EDR (using second method)	0.9068	1.219	1.159	1.189	1.187
Exergy Efficiency (using second method)	0.5081	0.4507	0.4633	0.4568	0.4707
Condenser Heat Rejected (kW)	49.16	59.74	59.89	58.08	58.71
Cooling Load	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	16.36	20.05	20.05	19.62	19.98
Exergy Destruction in H.P. compressors(%)	8.627	11.65	10.78	11.36	11.29
Exergy Destruction in L.P compressors(%)	7.682	8.407	9.689	8.256	8.683
Exergy Destruction in condenser (%)	18.6	15.06	15.15	15.26	15.10
Exergy Destruction in evaporator(%)	5.258	4.633	4.767	4.669	4.71
Total Exergy Destruction in expansion valves(%)	6.589	15.16	13.26	14.74	14.23
Exergy Destruction in H.P. expansion valves(%)	4.099	10.62	7.715	10.42	9.504
L.P. expansion valves(%)	2.489	4.538	5.55	4.323	4.725
Exergy Destruction in Water Cooler (%)	2.383	0.2214	0.1825	0.3034	0.2584
Total Exergy Destruction in VCRS(%)	49.19	55.13	53.84	54.59	54.28
Rational Efficiency (%)	50.81	44.87	46.16	45.41	45.72

The thermodynamic performances of two staged vapor compression refrigeration system (VCRS) using HFC refrigerants with HFC-134a have been shown in Table 2(a, b) respectively and it was found that R152a gives best first law performance and exergetic efficiency while R227ea gives lowest thermodynamic (energy & exergy) performances. The total exergy destruction in the compressors is highest than exergy destruction in other components. Similarly, total exergy destruction in the compressors is highest using R227ea and exergy destruction is lowest using R152a. The first law performance and exergetic efficiency using R152a is highest with lowest exergy destruction ratio and lower heat rejection by condenser. Similarly, overall exergy destruction using 404a in expansion valves is higher and using R227ea is slightly lower than using R404a. The exergy destruction in high pressure expansion valve is higher than low pressure expansion valve. The mass flow rate in high pressure compressor is higher by using R227ea lower by using R152a. The exergy destruction using second method is also shown in table-2(b) respectively. Table-3(a) shows thermodynamic performances of two staged VCRS using blends of HFO+HFC refrigerants with HFC-134a have been shown in table 3(a, b) respectively and it was found that R454b gives best first law performance and exergetic efficiency while R452a gives lowest thermodynamic (energy & exergy) performances. The total exergy destruction in the compressors is highest than exergy destruction in other components. Similarly, total exergy destruction in the compressors is highest using R515a and exergy destruction is lowest using R454b. Similarly, overall exergy destruction using 452a in expansion valves is higher and using R454b is lowest. The exergy destruction using second method is also shown in table 3(c, and d), respectively.

Table 1(b): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R717	R290	R600a	R-1270
COP	1.988	1.73	1.784	1.758
EDR	0.9058	1.293	1.224	1.257
Exergetic Efficiency	0.5011	0.4362	0.4497	0.4431
Exergy of fuel (kW)	17.61	20.23	19.62	19.91
Exergy of Product(kW)	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P.) (kg/sec)	0.037	0.1803	0.1887	0.1708
Mass flow rate in Low Pressure Compressor (L.P.) (kg/sec)	0.02854	0.1038	0.1160	0.1008
Total compressor work (kW)	17.61	20.23	19.62	19.91
High Pressure Compressor (H.P.)Work (kW)	9.676	12.34	10.84	12.12
Low Pressure Compressor (L.P.) Work (kW)	7.934	7.891	8.776	7.793
Exergy Input (kW)	17.36	19.58	19.05	19.31
Second law efficiency	0.6824	0.5941	0.6125	0.6035
Effectiveness second law	0.5545	0.4827	0.4976	0.4903
EDR (using second method)	0.9068	1.219	1.159	1.189
Exergy Efficiency (using second method)	0.5081	0.4507	0.4633	0.4568
Condenser Heat Rejected (kW)	49.16	59.74	59.89	0.58.08
Cooling Load	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	16.36	19.49	19.95	19.15
Exergy Destruction in H.P. compressors(%)	8.534	11.32	10.51	11.09
Exergy Destruction in L.P compressors(%)	7.599	8.713	9.44	8.056
Exergy Destruction in condenser (%)	18.34	14.64	14.76	14.89
Exergy Destruction in evaporator(%)	5.184	4.504	4.645	4.557
Total Exergy Destruction in expansion valves(%)	6.497	14.74	12.91	14.38
Exergy Destruction in H.P. expansion valves(%)	4.042	10.32	7.516	10.16
L.P. expansion valves(%)	2.455	4.412	5.407	4.219
Exergy Destruction in Water Cooler (%)	2.35	0.2150	0.1778	0.2961
Total Exergy Destruction in VCRS(%)	48.51	53.16	52.10	52.68
Rational Efficiency (%)	51.49	46.84	0.47.9	47.32

Table 2(a): Thermodynamic performances of multistage vapor compression refrigeration systems using HFC refrigerants water cooler

Refrigerant	R152a	R245fa	R32	R227ea	R134a	R236fa	R404a
COP	1.894	1.873	1.835	1.49	1.768	1.701	1.542
EDR	1.095	1.117	1.1162	1.662	1.243	1.332	1.572
Exergetic Efficiency	0.4774	0.4723	0.4626	0.3757	0.4458	0.4288	0.3889
Exergy of fuel (kW)	18.48	18.68	19.07	23.49	19.79	20.58	22.69
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Comp(H.P)(kg/s)	0.1898	0.3078	0.1746	0.7267	0.3343	0.4662	0.4785
Mass flow rate in Low Pressure Comp (L.P.)(kg/s)	0.1242	0.2103	0.1129	0.3498	0.1967	0.2712	0.2334
Total compressor work (kW)	18.48	18.68	19.07	23.49	19.79	20.58	22.69
High Pressure Compressor (H.P.)Work (kW)	10.43	8.126	11.31	14.58	11.75	11.18	14.68
Low Pressure Compressor (L.P.) Work (kW)	8.053	10.56	7.762	8.904	8.042	9.395	8.013
Exergy Input (kW)	18.11	18.46	18.65	22.57	19.30	19.97	21.88
Second law efficiency	0.6501	0.6432	0.6301	0.5117	0.6072	0.5840	0.5296
Effectiveness second law	0.5282	0.5226	0.5119	0.4157	0.4933	0.4745	0.4303
EDR (using second method)	1.052	1.093	1.113	1.558	1.187	1.263	1.480
Exergy Efficiency (using second method)	0.4873	0.4779	0.4732	0.3909	0.4707	0.4419	0.4246
Condenser Heat Rejected (kW)	54.69	56.51	53.0	70.29	58.71	62.70	64.24
Exergy Destruction in compressors(%)	19.28	20.0	18.09	20.95	19.98	20.76	20.24
Exergy Destruction in H.P. compressors(%)	10.41	8.363	10.23	12.30	11.29	10.66	12.45
Exergy Destruction in L.P compressors(%)	8.874	11.64	7.856	8.656	8.683	10.10	7.794
Exergy Destruction in condenser (%)	15.52	14.72	17.38	15.07	15.10	15.20	14.81
Exergy Destruction in evaporator(%)	5.028	4.888	4.891	4.184	4.71	4.560	4.565
Total Exergy Destruction in expansion valves(%)	11.21	12.21	11.95	19.69	14.23	15.22	20.03
Exergy Destruction in H.P. expansion valves(%)	7.089	4.427	8.461	13.29	9.504	8.298	15.09
L.P. expansion valves(%)	4.117	7.785	3.491	6.396	4.725	6.919	4.939
Exergy Destruction in Water Cooler (%)	0.2336	0.3863	0.3630	0.114	0.2584	0.1749	0.1869
Total Exergy Destruction in VCRS(%)	51.27	52.21	52.68	60.91	54.28	55.81	59.67
Rational Efficiency (%)	48.73	47.79	47.32	39.09	45.72	44.19	40.33

Table 2(b): Thermodynamic performances of multistage vapor compression refrigeration systems using HFC refrigerants water cooler

Refrigerant	R152a	R245fa	R32	R227ea	R134a	R236fa	R404a
COP	1.894	1.873	1.835	1.49	1.768	1.701	1.542
EDR	1.095	1.117	1.1162	1.662	1.243	1.332	1.572
Exergetic Efficiency	0.4774	0.4723	0.4626	0.3757	0.4458	0.4288	0.3889
Exergy of fuel (kW)	18.48	18.68	19.07	23.49	19.79	20.58	22.69
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Com.(H.P)(kg/s)	0.1898	0.3078	0.1746	0.7267	0.3343	0.4662	0.4785
Mass flow rate in Low Pressure .Comp (L.P)(kg/s)	0.1242	0.2103	0.1129	0.3498	0.1967	0.2712	0.2334
Total compressor work (kW)	18.48	18.68	19.07	23.49	19.79	20.58	22.69
High Pressure Compressor (H.P.)Work (kW)	10.43	8.126	11.31	14.58	11.75	11.18	14.68
Low Pressure Compressor (L.P.) Work (kW)	8.053	10.56	7.762	8.904	8.042	9.395	8.013
Exergy_Input (kW)	18.11	18.46	18.65	22.57	19.30	19.97	21.88
Second law efficiency	0.6501	0.6432	0.6301	0.5117	0.6072	0.5840	0.5296
Effectiveness second law	0.5282	0.5226	0.5119	0.4157	0.4933	0.4745	0.4303
EDR (using second method)	1.052	1.093	1.113	1.558	1.187	1.263	1.480
Exergy Efficiency (using second method)	0.4873	0.4779	0.4732	0.3909	0.4707	0.4419	0.4246
Condenser Heat Rejected (kW)	54.69	56.51	53.0	70.29	58.71	62.70	64.24
Cooling Load	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	18.89	19.77	17.69	20.73	19.48	20.14	19.52
Exergy Destruction in H.P. compressors(%)	10.2	8.266	10.0	11.82	11.01	10.34	12.0
Exergy Destruction in L.P compressors(%)	8.694	11.5	7.68	8.318	8.466	9.798	7.515
Exergy Destruction in condenser (%)	15.21	14.55	16.99	14.48	14.73	14.75	14.28
Exergy Destruction in evaporator(%)	4.926	4.831	4.781	4.021	4.593	4.425	4.402
Total Exergy Destruction in expansion valves(%)	10.98	12.07	11.68	18.92	13.88	14.77	19.32
Exergy Destruction in H.P. expansion valves(%)	6.945	4.375	8.271	12.77	9.268	8.052	14.55
L.P. expansion valves(%)	4.034	7.695	3.412	6.146	4.608	6.714	4.763
Exergy Destruction in Water Cooler (%)	0.2289	0.3818	0.3549	0.9742	0.250	0.07269	0.11803
Total Exergy Destruction in VCRS(%)	50.23	51.60	51.5	58.53	52.97	54.15	57.54
Rational Efficiency (%)	49.77	48.40	48.5	41.47	47.07	45.85	42.46

Table 3(a): Thermodynamic performances of multistage VCRS using HFO+HFC blends with water inter cooler

Refrigerant	R448a	R449a	R450a	R452a	R134a
COP	1.626	1.606	1.682	1.434	1.768
EDR	1.439	1.470	1.359	1.673	1.243
Exergetic Efficiency	0.410	0.4029	0.4239	0.3742	0.4458
Exergy of fuel (kW)	21.52	21.79	20.81	22.58	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.3191	0.3346	0.3769	0.4883	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.1824	0.1852	0.2157	0.2413	0.1967
Total compressor work (kW)	21.52	21.79	20.81	22.58	19.79
High Pressure Compressor (H.P.)Work (kW)	13.30	13.57	12.81	15.23	11.75
Low Pressure Compressor (L.P.) Work (kW)	8.222	8.223	8.404	8.355	8.042
Exergy_Input (kW)	21.04	21.28	20.2	22.8	19.30
Second law efficiency	0.5583	0.5514	0.5774	0.5096	0.6072
Effectiveness second law	0.4536	0.4480	0.4691	0.414	0.4933
EDR (using second method)	1.385	1.412	1.289	1.584	1.187
Exergy Efficiency (using second method)	0.4193	0.4284	0.4369	0.387	0.4707
Condenser Heat Rejected (kW)	59.46	59.74	61.09	64.49	58.71
Exergy Destruction in compressors(%)	19.28	19.33	20.33	19.98	19.48
Exergy Destruction in H.P. compressors(%)	11.24	11.42	11.52	12.23	11.01
Exergy Destruction in L.P compressors(%)	8.034	7.912	8.807	7.746	8.466
Exergy Destruction in condenser (%)	17.89	17.27	14.93	15.62	14.73
Exergy Destruction in evaporator(%)	6.784	6.746	5.678	6.512	4.593
Total Exergy Destruction in expansion valves(%)	13.85	14.90	15.24	19.07	13.88
Exergy Destruction in H.P. expansion valves(%)	10.18	11.08	10.03	14.45	9.268
Exergy Destruction in L.P. expansion valves(%)	3.667	3.817	5.21	4.621	4.608
Exergy Destruction in Water Cooler (%)	0.2729	0.2945	0.127	0.1135	0.250
Total Exergy Destruction in VCRS(%)	58.07	58.54	56.31	61.3	52.97
Rational Efficiency (%)	41.93	41.46	43.69	38.7	47.07

Table 3(b): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R454b	R454c	R515a	R513a	R134a
COP	1.743	1.544	1.711	1.669	1.768
EDR	1.276	1.570	1.318	1.359	1.243
Exergetic Efficiency	0.4394	0.3892	0.4313	0.4208	0.4458
Exergy of fuel (kW)	20.08	22.67	20.46	20.97	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.2255	0.3601	0.3982	0.4165	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.1379	0.1895	0.2302	0.2268	0.1967
Total compressor work (kW)	20.81	22.67	20.46	20.97	19.79
High Pressure Compressor (H.P.)Work (kW)	12.14	14.24	12.04	12.84	11.75
Low Pressure Compressor (L.P.) Work (kW)	7.937	8.436	8.414	8.124	8.042
Exergy_Input (kW)	19.63	22.11	19.83	20.27	19.30
Second law efficiency	0.5984	0.530	0.5875	0.5731	0.6072
Effectiveness second law	0.4933	0.4536	0.4933	0.4656	0.4933
EDR (using second method)	1.225	1.506	1.247	1.297	1.187
Exergy Efficiency (using second method)	0.4495	0.3991	0.445	0.4354	0.4707
Condenser Heat Rejected (kW)	55.32	61.53	61.61	62.12	58.71
Exergy Destruction in compressors(%)	18.62	19.51	20.49	20.62	19.48
Exergy Destruction in H.P. compressors(%)	10.72	11.60	11.94	11.52	11.01
Exergy Destruction in L.P compressors(%)	7.893	7.909	8.545	9.10	8.466
Exergy Destruction in condenser (%)	17.93	18.4	15.01	15.59	14.73
Exergy Destruction in evaporator(%)	5.253	7.382	4.503	4.516	4.593
Total Exergy Destruction in expansion valves(%)	13.19	14.79	16.44	14.72	13.88
Exergy Destruction in H.P. expansion valves(%)	9.584	11.10	11.37	9.345	9.268
Exergy Destruction in L.P. expansion valves(%)	3.608	3.691	5.065	5.324	4.608
Exergy Destruction in Water Cooler (%)	0.13475	0.2635	0.11782	0.15813	0.250
Total Exergy Destruction in VCRS(%)	55.05	60.09	56.46	55.5	52.97
Rational Efficiency (%)	44.95	39.91	43.54	44.5	47.07

Table 3(c): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R448a	R449a	R450a	R452a	R134a
COP	1.626	1.606	1.682	1.434	1.768
EDR	1.439	1.470	1.359	1.673	1.243
Exergetic Efficiency	0.410	0.4029	0.4239	0.3742	0.4458
Exergy of fuel (kW)	21.52	21.79	20.81	22.58	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.3191	0.3346	0.3769	0.4883	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.1824	0.1852	0.2157	0.2413	0.1967
Total compressor work (kW)	21.52	21.79	20.81	22.58	19.79
High Pressure Compressor (H.P.)Work (kW)	13.30	13.57	12.81	15.23	11.75
Low Pressure Compressor (L.P.) Work (kW)	8.222	8.223	8.404	8.355	8.042
Exergy_Input (kW)	21.04	21.28	20.2	22.8	19.30
Second law efficiency	0.5583	0.5514	0.5774	0.5096	0.6072
Effectiveness second law	0.4536	0.4480	0.4691	0.414	0.4933
EDR (using second method)	1.385	1.412	1.289	1.584	1.187
Exergy Efficiency (using second method)	0.4193	0.4284	0.4369	0.387	0.4707
Condenser Heat Rejected (kW)	59.46	59.74	61.09	64.49	58.71
Cooling Load	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	18.85	18.88	19.73	19.32	19.48
Exergy Destruction in H.P. compressors(%)	10.99	11.15	11.18	11.83	11.01
Exergy Destruction in L.P compressors(%)	7.855	7.726	8.546	7.489	8.466
Exergy Destruction in condenser (%)	17.49	16.87	14.49	15.10	14.73
Exergy Destruction in evaporator(%)	6.633	6.587	5.51	6.296	4.593
Total Exergy Destruction in expansion valves(%)	13.54	14.54	14.79	18.44	13.88
Exergy Destruction in H.P. expansion valves(%)	9.951	10.82	9.738	13.97	9.268
Exergy Destruction in L.P. expansion valves(%)	3.586	3.727	5.056	4.468	4.608
Exergy Destruction in Water Cooler (%)	0.2669	0.2876	0.1232	0.1098	0.250
Total Exergy Destruction in VCRS(%)	56.76	57.16	54.65	59.27	52.97
Rational Efficiency (%)	43.24	42.84	45.35	40.72	47.07

Table 3(d) Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R454b	R454c	R515a	R513a	R134a
COP	1.743	1.544	1.711	1.669	1.768
EDR	1.276	1.570	1.318	1.359	1.243
Exergetic Efficiency	0.4394	0.3892	0.4313	0.4208	0.4458
Exergy of fuel (kW)	20.08	22.67	20.46	20.97	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.2255	0.3601	0.3982	0.4165	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.1379	0.1895	0.2302	0.2268	0.1967
Total compressor work (kW)	20.81	22.67	20.46	20.97	19.79
High Pressure Compressor (H.P.)Work (kW)	12.14	14.24	12.04	12.84	11.75
Low Pressure Compressor (L.P.) Work (kW)	7.937	8.436	8.414	8.124	8.042
Exergy_Input (kW)	19.63	22.11	19.83	20.27	19.30
Second law efficiency	0.5984	0.530	0.5875	0.5731	0.6072
Effectiveness second law	0.4933	0.4536	0.4933	0.4656	0.4933
EDR (using second method)	1.225	1.506	1.247	1.297	1.187
Exergy Efficiency (using second method)	0.4495	0.3991	0.445	0.4354	0.4707
Condenser Heat Rejected (kW)	55.32	61.53	61.61	62.12	58.71
Cooling Load	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	18.22	19.03	19.99	19.80	19.48
Exergy Destruction in H.P. compressors(%)	10.48	11.32	11.17	11.54	11.01
Exergy Destruction in L.P compressors(%)	7.715	7.713	8.82	8.26	8.466
Exergy Destruction in condenser (%)	17.53	17.69	15.10	14.51	14.73
Exergy Destruction in evaporator(%)	5.135	7.199	4.377	4.352	4.593
Total Exergy Destruction in expansion valves(%)	12.89	14.43	14.27	15.89	13.88
Exergy Destruction in H.P. expansion valves(%)	9.368	10.83	9.164	10.99	9.268
Exergy Destruction in L.P. expansion valves(%)	3.526	3.60	5.161	4.895	4.608
Exergy Destruction in Water Cooler (%)	0.1535	0.257	0.1563	0.1722	0.250
Total Exergy Destruction in VCRS(%)	53.81	58.6	53.80	54.57	52.97
Rational Efficiency (%)	46.19	41.4	46.20	45.43	47.07

Table 4(a): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R1233 Zd(E)	R1234yf	R1336mzz(Z)	R1225 Ye(Z)	R134a
COP	1.899	1.608	1.798	1.710	1.768
EDR	1.088	1.467	1.207	1.320	1.243
Exergetic Efficiency	0.4789	0.4053	0.4532	0.4310	0.4458
Exergy of fuel (kW)	18.43	21.77	19.47	20.47	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.2956	0.4804	0.3591	0.4568	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.2114	0.2495	0.2670	0.2580	0.1967
Total compressor work (kW)	18.43	21.77	19.47	20.47	19.79
High Pressure Compressor (H.P.)Work (kW)	7.477	13.52	5.836	12.10	11.75
Low Pressure Compressor (L.P.) Work (kW)	10.95	8.246	13.63	8.372	8.042
Exergy_Input (kW)	18.25	20.98	19.43	19.83	19.30
Second law efficiency	0.6522	0.552	0.6172	0.587	0.6072
Effectiveness second law	0.6522	0.552	0.6162	0.587	0.4933
EDR (using second method)	1.068	1.377	1.202	1.248	1.187
Exergy Efficiency(using second method)	0.4836	0.4206	0.4542	0.4622	0.4707
Condenser Heat Rejected (kW)	55.21	64.69	57.77	61.43	58.71
Exergy Destruction in compressors(%)	19.83	20.75	19.97	20.53	19.48
Exergy Destruction in H.P. compressors(%)	7.768	12.25	5.718	11.56	11.01
Exergy Destruction in L.P compressors(%)	12.06	8.498	14.25	8.968	8.466
Exergy Destruction in condenser (%)	14.66	14.94	14.39	15.04	14.73
Exergy Destruction in evaporator(%)	4.996	4.348	4.691	4.595	4.593
Total Exergy Destruction in expansion valves(%)	11.84	17.65	15.08	15.27	13.88
Exergy Destruction in H.P. expansion valves(%)	3.635	12.34	2.258	10.04	9.268
Exergy Destruction in L.P. expansion valves(%)	8.203	5.301	12.82	5.231	4.608
Exergy Destruction in Water Cooler (%)	0.257	0.2533	0.1722	0.17921	0.250
Total Exergy Destruction in VCRS(%)	51.64	57.94	54.58	55.51	52.97
Rational Efficiency (%)	48.36	42.06	45.42	44.49	47.07

Table 4(b): Thermodynamic performances of multistage VCRS using HFOrefrigerants and HCFO refrigerants with water inter cooler

Refrigerant	R1224yd(Z)	R1243zf	R1234Ze(E)	R1234Ze(Z)	R134a
COP	1.866	1.695	1.720	2.057	1.768
EDR	1.126	1.340	1.306	0.9283	1.243
Exergetic Efficiency	0.4703	0.4273	0.4337	0.5186	0.4458
Exergy of fuel (kW)	18.76	20.65	20.35	17.0	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.3603	0.3415	0.3891	0.2526	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.2463	0.1978	0.2213	0.1838	0.1967
Total compressor work (kW)	18.76	20.65	20.35	17.0	19.79
High Pressure Compressor (H.P.)Work (kW)	8.174	12.29	12.01	7.54	11.75
Low Pressure Compressor (L.P.) Work (kW)	10.59	8.453	8.333	9.474	8.042
Exergy_Input (kW)	18.54	20.07	19.70	16.75	19.30
Second law efficiency	0.6406	0.5820	0.5906	0.7063	0.6072
Irreversibility Ratio	0.9213	1.115	1.084	0.7426	1.027
Effectiveness second law	0.6406	0.4729	0.4799	0.5739	0.4933
EDR (using second method)	1.101	1.275	1.233	0.8983	1.187
Exergy Efficiency (using second method)	0.4820	0.455	0.4654	0.5342	0.4707
Condenser Heat Rejected (kW)	56.83	60.29	61.5	52.19	58.71
Exergy Destruction in compressors(%)	20.05	20.19	20.63	19.38	19.48
Exergy Destruction in H.P. compressors(%)	8.384	11.38	11.58	8.338	11.01
Exergy Destruction in L.P compressors(%)	11.66	8.875	9.047	11.04	8.466
Exergy Destruction in condenser (%)	14.83	14.64	15.16	15.41	14.73
Exergy Destruction in evaporator(%)	4.956	6.188	4.25	2.903	4.593
Total Exergy Destruction in expansion valves(%)	12.18	14.79	15.16	9.584	13.88
Exergy Destruction in H.P. expansion valves(%)	4.437	9.768	9.79	3.873	9.268
Exergy Destruction in L.P. expansion valves(%)	7.748	5.024	5.372	5.711	4.608
Exergy Destruction in Water Cooler (%)	0.3906	0.2368	0.0183	0.1477	0.250
Total Exergy Destruction in VCRS(%)	52.41	56.05	55.2	47.32	52.97
Rational Efficiency (%)	47.59	43.95	44.79	52.68	47.07

Table 4(c): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R1233Zd(E)	R1224yd(Z)	R1336mzz(Z)	R1225Ye(Z)	R134a
COP	1.899	1.866	1.798	1.710	1.768
EDR	1.088	1.126	1.207	1.320	1.243
Exergetic Efficiency	0.4789	0.4703	0.4532	0.4310	0.4458
Exergy of fuel (kW)	18.43	18.76	19.47	20.47	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.2956	0.3603	0.3591	0.4568	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.2114	0.2463	0.2670	0.2580	0.1967
Total compressor work (kW)	18.43	18.76	19.47	20.47	19.79
High Pressure Compressor (H.P.)Work (kW)	7.477	8.174	5.836	12.10	11.75
Low Pressure Compressor (L.P.) Work (kW)	10.95	10.59	13.63	8.372	8.042
Exergy_Input (kW)	18.25	18.54	19.43	19.83	19.30
Second law efficiency	0.6522	0.6406	0.6172	0.587	0.6072
Effectiveness second law	0.6522	0.6406	0.6162	0.587	0.4933
EDR (using second method)	1.068	1.101	1.202	1.248	1.187
Exergy Efficiency (using second method)	0.4836	0.4820	0.4542	0.4622	0.4707
Condenser Heat Rejected (kW)	55.21	56.83	57.77	61.43	58.71
Exergy Destruction in compressors(%)	19.63	19.82	19.93	19.89	19.48
Exergy Destruction in H.P. compressors(%)	7.692	8.287	5.705	11.20	11.01
Exergy Destruction in L.P compressors(%)	11.94	11.53	14.22	8.689	8.466
Exergy Destruction in condenser (%)	14.52	14.66	14.36	14.57	14.73
Exergy Destruction in evaporator(%)	4.947	4.899	4.681	4.452	4.593
Total Exergy Destruction in expansion valves(%)	11.72	12.04	15.04	14.80	13.88
Exergy Destruction in H.P. expansion valves(%)	3.60	4.385	2.253	9.729	9.268
Exergy Destruction in L.P. expansion valves(%)	8.123	7.658	12.790	5.068	4.608
Exergy Destruction in Water Cooler (%)	0.3156	0.386	0.1450	0.1767	0.250
Total Exergy Destruction in VCRS(%)	51.14	51.8	54.46	53.78	52.97
Rational Efficiency (%)	48.86	48.2	45.54	46.22	47.07

Table 4(d): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R1234yf	R1243zf	R1234Ze(E)	R1234Ze(Z)	R134a
COP	1.608	1.695	1.720	2.057	1.768
EDR	1.467	1.340	1.306	0.9283	1.243
Exergetic Efficiency	0.4053	0.4273	0.4337	0.5186	0.4458
Exergy of fuel (kW)	21.77	20.65	20.35	17.0	19.79
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Compressor (H.P)(kg/s)	0.4804	0.3415	0.3891	0.2526	0.3343
Mass flow rate in Low Pressure Compressor (L.P.) (kg/s)	0.2495	0.1978	0.2213	0.1838	0.1967
Total compressor work (kW)	21.77	20.65	20.35	17.0	19.79
High Pressure Compressor (H.P.)Work (kW)	13.52	12.29	12.01	7.54	11.75
Low Pressure Compressor (L.P.) Work (kW)	8.246	8.453	8.333	9.474	8.042
Exergy_Input (kW)	20.98	20.07	19.70	16.75	19.30
Second law efficiency	0.552	0.5820	0.5906	0.7063	0.6072
Irreversibility Ratio	1.230	1.115	1.084	0.7426	1.027
Effectiveness second law	0.552	0.4729	0.4799	0.5739	0.4933
EDR (using second method)	1.377	1.275	1.233	0.8983	1.187
Exergy Efficiency	0.4206	0.455	0.4654	0.5342	0.4707
Condenser Heat Rejected (kW)	64.69	60.29	61.5	52.19	58.71
Cooling Load	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	20.0	19.63	19.97	19.08	19.48
Exergy Destruction in H.P. compressors(%)	11.81	11.06	11.21	8.208	11.01
Exergy Destruction in L.P compressors(%)	8.189	8.57	8.761	10.87	8.466
Exergy Destruction in condenser (%)	14.39	14.53	14.68	15.17	14.73
Exergy Destruction in evaporator(%)	4.19	6.016	4.115	2.858	4.593
Total Exergy Destruction in expansion valves(%)	17.0	14.38	14.68	9.434	13.88
Exergy Destruction in H.P. expansion valves(%)	11.89	9.497	9.479	3.812	9.268
Exergy Destruction in L.P. expansion valves(%)	5.108	4.884	5.202	5.622	4.608
Exergy Destruction in Water Cooler (%)	0.2440	0.2303	0.177	0.1469	0.250
Total Exergy Destruction in VCRS(%)	55.83	54.49	53.46	46.54	52.97
Rational Efficiency (%)	44.17	45.51	46.54	53.46	47.07

Table-4(a-d) show thermodynamic performances using HFO refrigerants and it was found that R1233Zd(E) gives best first law performance and energetic efficiency while R1234yf gives lowest thermodynamic performances. The exergy destruction in the compressors is higher than other components. Similarly, overall exergy destruction using R1234yf in expansion valves is higher and lower by using R1233zd(E). Table-5(a, b) show thermodynamic performances using HFC refrigerants and it was found that R141b gives best first law performance and exergetic efficiency while R125 gives lowest thermodynamic performances. The exergy destruction in the compressors is higher than other components although overall exergy destruction using R125 is higher while exergy destruction in high pressure compressor is higher than low pressure compressors except reverse happens in using R141b. Similarly, overall exergy destruction using R125 in expansion valves is higher and lower by using R141b than while exergy destruction in high pressure expansion valve is higher than low pressure expansion valve except reverse happens in using R141b

Table 5(a): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R410a	R407c	507a	R125	R141b	R143a
COP	1.718	1.622	1.538	1.429	2.010	1.597
EDR	1.310	1.446	1.579	1.776	0.9737	1.484
Exergetic Efficiency	0.4330	0.4089	0.3877	0.3602	0.5067	0.4025
Exergy of fuel (kW)	20.38	21.58	22.76	24.49	17.42	21.92
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Comp. (H.P)(kg/s)	0.2904	0.3066	0.4983	0.6813	0.2224	0.4038
Mass flow rate in Low Pressure Com (L.P.) (kg/s)	0.1649	0.1751	0.2401	0.2914	0.1813	0.2046
Total compressor work (kW)	20.38	21.58	22.76	24.49	17.42	21.92
High Pressure Compressor (H.P.)Work (kW)	12.63	13.29	14.78	16.44	5.029	13.99
Low Pressure Compressor (L.P.) Work (kW)	7.745	8.292	7.98	8.055	12.39	7.929
Exergy_Input (kW)	19.90	21.08	21.93	23.56	17.28	21.2
Second law efficiency	0.5897	0.5569	0.528	0.4906	0.690	0.5482
Irreversibility Ratio	1.087	1.210	1.331	1.509	0.7836	1.245
Effectiveness second law	0.4791	0.4525	0.4290	0.3986	0.5607	0.4454
EDR (using second method)	1.256	1.389	1.485	1.670	0.9583	1.403
Exergy Efficiency	0.4563	0.4322	0.4242	0.3983	0.5106	0.4162
Condenser Heat Rejected (kW)	57.27	58.66	64.68	64.33	50.2	62.69

Cooling Load	35.0	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	19.09	19.16	20.3	20.49	18.81	20.08
Exergy Destruction in H.P. compressors(%)	11.25	11.2	12.53	13.09	5.456	12.19
Exergy Destruction in L.P compressors(%)	7.838	7.955	7.768	7.408	13.36	7.896
Exergy Destruction in condenser (%)	15.97	16.87	14.71	14.24	14.14	14.92
Exergy Destruction in evaporator(%)	4.602	7.716	4.173	3.885	5.274	4.306
Total Exergy Destruction in expansion valves(%)	15.72	14.12	20.54	23.6	9.791	18.95
Exergy Destruction in H.P. expansion valves(%)	11.58	10.35	15.49	18.41	1.538	14.12
Exergy Destruction in L.P. expansion valves(%)	4.142	3.763	5.052	5.191	8.252	4.828
Exergy Destruction in Water Cooler (%)	0.2782	0.2754	0.13215	0.330	0.9102	0.1251
Total Exergy Destruction in VCRS(%)	55.67	58.14	59.76	62.55	48.98	58.38
Rational Efficiency (%)	45.33	41.86	40.24	37.45	51.01	41.62

Table 5(b): Thermodynamic performances of multistage VCRS using natural refrigerant and hydrocarbons water cooler

Refrigerant	R410a	R407c	507a	R125	R141b	R143a
COP	1.718	1.622	1.538	1.429	2.010	1.597
EDR (using first method)	1.310	1.446	1.579	1.776	0.9737	1.484
Exergetic Efficiency	0.4330	0.4089	0.3877	0.3602	0.5067	0.4025
Exergy of fuel (kW)	20.38	21.58	22.76	24.49	17.42	21.92
Exergy of Product(kW)	8.824	8.824	8.824	8.824	8.824	8.824
Mass flow rate in High Pressure Comp. (H.P)(kg/s)	0.2904	0.3066	0.4983	0.6813	0.2224	0.4038
Mass flow rate in Low Pressure Com (L.P.) (kg/s)	0.1649	0.1751	0.2401	0.2914	0.1813	0.2046
Total compressor work (kW)	20.38	21.58	22.76	24.49	17.42	21.92
High Pressure Compressor (H.P.)Work (kW)	12.63	13.29	14.78	16.44	5.029	13.99
Low Pressure Compressor (L.P.) Work (kW)	7.745	8.292	7.98	8.055	12.39	7.929
Exergy_Input (kW)	19.90	21.08	21.93	23.56	17.28	21.2
Second law efficiency	0.5897	0.5569	0.528	0.4906	0.690	0.5482
Irreversibility Ratio	1.087	1.210	1.331	1.509	0.7836	1.245
Effectiveness second law	0.4791	0.4525	0.4290	0.3986	0.5607	0.4454
EDR (using second method)	1.256	1.389	1.485	1.670	0.9583	1.403
Exergy Efficiency	0.4563	0.4322	0.4242	0.3983	0.5106	0.4162
Condenser Heat Rejected (kW)	57.27	58.66	64.68	64.33	50.2	62.69
Cooling Load	35.0	35.0	35.0	35.0	35.0	35.0
Exergy Destruction in compressors(%)	18.65	18.71	19.56	19.71	18.67	19.43
Exergy Destruction in H.P. compressors(%)	10.99	10.94	12.08	12.59	5.414	11.79
Exergy Destruction in L.P compressors(%)	7.655	7.77	7.484	7.126	13.25	7.637
Exergy Destruction in condenser (%)	15.60	16.48	14.17	13.70	14.04	14.43
Exergy Destruction in evaporator(%)	4.495	7.536	4.021	3.737	5.222	4.165
Total Exergy Destruction in expansion valves(%)	15.36	13.79	19.79	22.7	9.714	18.33
Exergy Destruction in H.P. expansion valves(%)	11.319	10.11	14.93	17.71	1.526	13.65
Exergy Destruction in L.P. expansion valves(%)	4.045	3.675	4.867	4.993	8.188	4.67
Exergy Destruction in Water Cooler (%)	0.2717	0.269	0.03084	0.318	0.903	0.121
Total Exergy Destruction in VCRS(%)	54.37	58.66	57.58	60.17	48.55	56.47
Rational Efficiency (%)	45.63	41.34	42.42	39.83	51.45	43.53

6. Conclusions

Using first and second law analysis on two stage refrigeration system was carried out using sixteen ecofriendly refrigerants and following conclusions and recommendation are presented below:

- The first law efficiency using R152a is 7.127% and using R245fa is 5.939% is higher than R134a.
- R152a shows best first law efficiency and R125 shows lowest first law performance among selected sixteen ecofriendly refrigerants.
- The first law efficiency using R1336mzz(Z)=1.697% and R1233Zd(E)=7.4095% is higher than R134a while using R1243zf (-4.129%), R1225Ye(Z) = (-3.2805%), R1234yf= (-9.049%), is lower than R134a
- Exergy destruction for R134a is higher than R152a. (v) R152a, R600a, R290, R600 are flammable in nature can be used by using safety measures.
- Therefore, R1233Zd(E) and R1336mzz(Z) R1234yf, R1234ze (E), R1243zf are recommended for replacing R134a in all kind of applications.
- The HFC refrigerants of Low GWP (such as R152a, R32, R152a) can be used for replacing R134a.
- The HFO+HFC blended refrigerants (such as R515a, R513a, R454b, R449a, R448a) can be used for replacing R134a

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