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ORIGINAL ARTICLE

Thermodynamic exergy analysis of two-stage vapour compression refrigeration systems using HFO refrigerants for replacing R134a

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Abstract

Global warming is one of the unkind environmental concerns that our earth planet is facing nowadays. Main of its causes is the second & third generation of refrigerants that, upon release, remain in the atmosphere for longer periods and contribute towards global warming. This issue could potentially be solved by replacing the earlier generation's high global warming potential (GWP) refrigerants with environmentally friendly refrigerants. In this paper comparative analysis of HFO refrigerants (i.e. R1225ye(Z), R1224yd(Z), R1336mzz(Z), R 1233zd(E), R1243zf, R1234yf, R1234ze(Z) and R1234ze(E)) in two stage vapour compression refrigeration system has been carried out using thermodynamic (energetic and exergetic) performances. The effect of performance parameters such as first law efficiency (COP), second law efficiency (exergetic efficiency) and exergy destruction ratio using ecofriendly refrigerants were investigated. It was found that both energy and exergy efficiencies of R1234ze(Z) is highest and using R1234yf is lowest at -40 ºC evaporating and 40 ºC condensing temperatures. The first law efficiency using R1234ze(Z) is 9.3 % higher than using R134a and R1234yf is 9.10 % lower than using R134a Similarly The second law efficiency using R1234ze(Z) is 8.087% higher than using R134a and R1234yf is 8.44% lower than using R-134a It was also found that for replacing high global warming potential R134a refrigerant. These ecofriendly HFO refrigerants work satisfactory.

1. Introduction

An eminent philosopher has defined Science as "Tapasaya" and Technology as "Bhog" whereas science is pure selfless and open to all search for truth whereas technology is the exploitation of scientific knowledge for selfish purposes and profit motive and hence it tends to be secretive in this competitive world of today with a throat cutting environment. Sustainable Development is a process in which development can be sustained for generations. It also focuses attention on inter-generational fairness in the exploitation of development opportunities while social development is a function of technological advancement, and also the technological advancement, in turn is a function of scientific know how for a streamlined development of the society [1]. Technology is one of the crucial determinants of sustainable development. Technological import through collaborations has been one of the most important sources of technological inputs for Indian conditions. The use of technologies originating in rich countries often ten to create many social, ecological and resource problems in poor countries. The exploitation of the vast natural resources through progressive development of science, engineering and technology that has brought about the vast changes in the civilization and society from the stone age to the present high technology era. In

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facts, the mad race for industrialization and economic development has resulted in over exploitation of natural resources, leading to a situation where the two worlds of mankind- the biosphere, lithosphere and hydrosphere of his inheritance and the techno sphere of his creation, are out of balance with each other, indeed on a collision path. To facilitate optimal utilization of finite natural resources for ensuring a sustainable benefit steam for better quality of life on the one hand and to simultaneously keep in mind the conservation of natural resources on the other hand, it is essential that the technology conservation process must be made as efficient as possible. Therefore, sustainable economic development depends on the careful choice of technologies and judicious management of resources for productive activities to satisfy the changing human needs without degrading the environment or depleting the natural resources base.

Refrigeration technology based on the principle of rejection of heat to the surrounding at higher temperature and absorption of heat at low temperature evaporator [1], 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. Coefficient of performance and exergetic efficiency are main two parameters to calculate the performance of refrigeration systems [2]

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 water coolers/ flash chamber. Collective effect of these two factors improves overall performance of vapour compression system [3] 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 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 [4]. In past decades, refrigerants such as R12, R12, R22 etc. are 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 Kyoto protocol [5].

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 researches has been carried out [6]. Selladurai and Saravanakumar [7] evaluated thermal performance parameters such as COP and exergetic efficiency using hydrocarbons mixtures on a domestic refrigerator, which was designed to work with HFC-134a and observed that the thermodynamic performance is higher as compared to R134a. and found condenser, expansion valve and evaporator showing lower exergy destruction compared to compressor. Reddy et al. [8] carried out thermodynamic analysis of vapour compression refrigeration system using HFC refrigerants and computed the effect of HFC refrigerants on coefficient of performance and second law efficiency. Also found the effect of the variation of superheating of evaporator outlet, evaporator temperature and degree of sub cooling at condenser outlet, vapour liquid heat exchanger effectiveness and condenser temperature on COP and exergetic efficiency they observed that the R134a and R407C show highest and lowest performance in all respect. Kumar et al. [9] carried out energy and exergy analysis of single stage vapour compression refrigeration system using R11 and R12 as working fluids and computed COP, exergetic efficiency and exergy losses in different components. Nikolaidis and Probert [10] study, effect of condenser and evaporator temperatures on two-stage vapour compression refrigeration system using R22 was studied and suggested that there is requirement to optimize the condenser and evaporator conditions. Many researchers carried out researches on different proportion of hydrocarbons as working fluid in vapour compression refrigeration systems.

Based on the literature it was observed that researchers have gone through detailed first law analysis in terms of coefficient of performance and second law analysis in term of exergetic efficiency of simple vapour compression refrigeration system with single evaporator. Researchers did not go through the irreversibility analysis or second law analysis of multiple evaporators systems with multi-stage expansion in vapour compression refrigeration systems. Researchers did not go through irreversibility and second law analysis of multi-stage vapour compression refrigeration systems by using HFO refrigerants. The present works analyze the system in terms of energy and exergy efficiencies and explain the effect of exergy losses on two-stage vapour compression refrigeration system with HFO refrigerants for replacing R134a.

2. Modelling of Two stages Vapour compression refrigeration system

Some mathematical calculations are required to analyze the two-stage vapour compression refrigeration system based on energy and exergy method. Two stage vapour compression refrigeration system consist of low and high pressure compressor, condenser, evaporator, expansion valves, water-intercooler and flash chamber. Energy and exergy efficiencies are different for different HFO ecofriendly refrigerants for same system. Following assumptions are taken for thermodynamic analysis of the system:

- Temperature and pressure losses are not considered.
- All components are running under steady state conditions.
- Energy and exergy losses due to potential and kinetic energy are neglected.
- Mechanical efficiencies of low and high pressure compressors are assumed to be 80%.

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

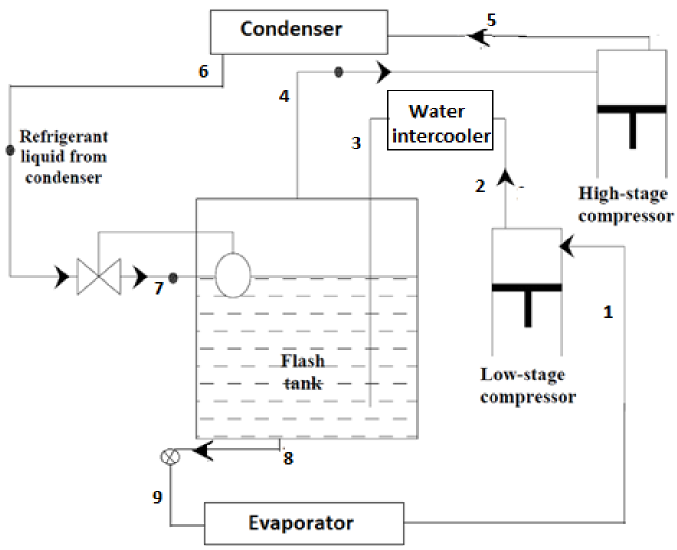

Figure 1: Two-stage vapour compression refrigeration system

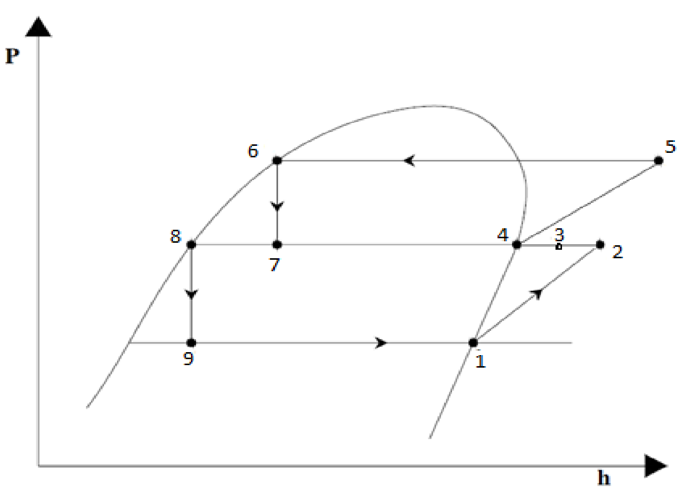

Figure 2: Pressure enthalpy diagram of two-stage VCRS

Exergy energy analysis can be done as follow:

Exergy at any point,

$$EX = (h - h_{amb}) - T_{amb}(s - s_{amb}) \quad (1)$$

For high and low temperature compressors

$$\left(T_{amb}\dot{S}_{gen}\right)_{HP} = \dot{W}_{HP} + m_{HP}((h_1 - h_2) - T_{amb}(s_1 - s_2)) \quad (2)$$

$$\left(T_{amb}\dot{S}_{gen}\right)_{LP} = \dot{W}_{LP} + m_{LP}((h_4 - h_5) - T_{amb}(s_4 - s_5) \quad (3)$$

For evaporator

$$\left(T_{amb}\dot{S}_{gen}\right)_{Evap} = \dot{m}_{LP}((h_9 - h_1) - T_{amb}(s_9 - s_1)) + Q\left(1 - \frac{T_{amb}}{T_L}\right) \quad (4)$$

For condenser

$$\left(T_{amb}\dot{S}_{gen}\right)_{Cond} = \dot{m}_{HP}((h_5 - h_6) - T_{amb}(s_5 - s_6)) - Q_{Cond}\left(1 - \frac{T_{amb}}{T_H}\right) \quad (5)$$

For expansion valves

$$\left(T_{amb}\dot{S}_{gen}\right)_{EV} = \dot{m}_{HP}((h_6 - h_7) - T_{amb}(s_6 - s_7)) + \dot{m}_{LP}((h_8 - h_9) - T_{amb}(s_8 - s_9)) \quad (6)$$

For water-intercooler

$$\left(T_{amb}\dot{S}_{gen}\right)_{WI} = \dot{m}_{LP}((h_2 - h_3) - T_{amb}(s_2 - s_3)) \quad (7)$$

For Water Intercooler

$$\left(T_{amb}\dot{S}_{gen}\right)_{FC} = \dot{m}_{LP}((h_3 - h_4) - T_{amb}(s_3 - s_4)) + (\dot{m}_{HP}h_7 - \dot{m}_{LP}h_8) - T_{amb}(\dot{m}_{HP}s_7 - \dot{m}_{LP}s_8) \quad (8)$$

Exergetic efficiency

$$\eta_{ex} = \frac{Q\left(1 - \frac{T_{amb}}{T_L}\right)}{W_{LP} + W_{HP}} \quad (9)$$

Coefficient of Performance (COP)

$$COP = \frac{\dot{m}_{LP}((h_1 - h_9)}{W_{LP} + W_{HP}}$$

Total entropy generation

$$\left(T_{amb}\dot{S}_{gen}\right)_{TOTAL} =$$

$$\sum\left(T_o\dot{S}_{gen}\right)_{HP}+\left(T_o\dot{S}_{gen}\right)_{LP}+\left(T_o\dot{S}_{gen}\right)_{Evap}+\left(T_o\dot{S}_{gen}\right)_{Cond}+\left(T_o\dot{S}_{gen}\right)_{EV}+\left(T_o\dot{S}_{gen}\right)_{WI}+\left(T_o\dot{S}_{gen}\right)_{FC} \quad (10)$$

Exergy Destruction Ratio (EDR)

$$\eta_{ex}=\frac{1}{1+EDR} \quad (11)$$

Where

Sustainability index (SI)

$$SI=\frac{1}{1-\eta_{ex}} \quad (12)$$

3. Results and Discussion

3.1 Performances of vapour compression refrigeration system using HFO refrigerants

Thermodynamic (energy-exergy) performances of two stage vapour compression refrigeration system using HFO refrigerants is shown in Table-1 respectively. As cleared that the first law efficiency (i.e. coefficient of performance) of two stages vapour compression refrigeration system is of R1234ze(Z) is 9.327% higher than using HFC-134a and the second law efficiency (i.e. exergetic efficiency) using R1234ze(Z) is 8.087% higher than using HFC-134a respectively. It means that R134a consumes more electricity than R1234ze(Z)
Although first law efficiency (i.e. coefficient of performance) using R1233zd(E) is 7.35%, using R1336mzz(Z) is 1.64% higher than using HFC-134a. Similarly, first law efficiency (i.e. coefficient of performance) using R1234yf is 9.1%, using R1243zf is 1.75% and using R1225ye(z) is 3.3% lower than using HFC-134a. The second law efficiency using R1234ze(Z) is 8.087%, R1233zd(E) is 5.88% higher than using HFC-134a respectively
Similarly, second law efficiency using R1234yf is -8.44%, using R1243zf is 1.75% and R-1234ze(E) is-3.25 and R1225ye(z) is 3.037% lower than using HFC-134a. Similarly, ambient condition plays an important role in electricity consumption of vapour compression refrigeration systems because higher the temperature difference between system and surrounding, results higher will be compressor work that's why COP of vapour compression refrigeration system increase with increase in evaporator temperature and decrease with decrease in evaporator temperature.

Table-1 Effect of system performance parameters using ecofriendly HFO refrigerants on the thermodynamic performances of vapour compression refrigeration systems for isentropic compressors efficiencies =80%. at condenser temperature T_{Cond} =40ºC and evaporator temperature -40ºC, and evaporator load =35kW, ambient temperature=25ºC

Performance Parameters	R1234 ze (Z)	R1234 ze(E)	R1225 ye (Z)	R1224 yd(Z)	R1233 zd (E)	R1336 mzz(Z)	R1243 zf	R1234 yf
First law Efficiency (COP_{Actual})	1.934	1.720	1.71	1.866	1.899	1.798	1.738	1.608
Work required to run HPCompressor (W_{CompHP}) "kW"	8.159	12.01	12.1	12.01	7.477	5.836	11.94	13.52
Work required to run LPCompressor (W_{CompLP}) "kW"	9.942	8.333	8.372	8.333	10.95	13.63	8.194	8.246
Work required to run whole system (W_{Comp}) "kW"	18.1	20.35	20.47	20.35	18.43	19.47	20.14	21.77
Condenser Heat "kW"	54.47	61.5	61.43	56.83	55.21	57.77	60.21	64.69
Evaporator load" kW"	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
HP Mass flow rate (kg/sec)	0.267	0.3891	0.4568	0.360	0.2956	0.359	0.344	0.4745
LP Mass flow rate (kg/sec)	0.188	0.2213	0.258	0.246	0.2114	0.267	0.1982	0.2485
Total System Exergy Destruction (ExD_{Total}) (%)	45.2	50.95	50.84	47.05	46.32	49.43	50.06	53.58
Exergy Destruction in condenser (ExD_{Cond}) (%)	14.93	15.0	15.02	14.91	14.71	14.48	15.03	14.9
Exergy Destruction in compressor (ExD_{comp})(%)	19.72	20.41	20.5	20.16	19.89	20.09	20.32	20.7
Exergy Destruction in HP compressor(ExD_{CompHP} (%)	8.583	11.46	11.54	8.43	7.793	5.753	11.49	12.22
Exergy Destruction in LP compressor(ExD_{Comp_LP}%)	11.14	8.954	8.956	11.73	12.1	14.34	8.83	8.475
Exergy Destruction in Valve ExD_{Valve} (%)	10.67	15.0	15.25	12.25	11.88	15.17	14.74	17.6
Exergy Destruction in HP Valve (ExD_{Valve_HP}(%)	6.372	9.688	10.03	4.46	3.647	2.271	9.824	12.31
Exergy Destruction in LP Valve (ExD_{Valve_LP} (%)	4.298	5.317	5.224	7.791	8.23	12.09	4.916	5.287
Exergy Destruction in Evaporator (ExD_{Eva} (%)	0.16	0.5182	0.1465	0.1161	0.1578	0.1507	0.1481	0.135
Exergy Destruction in Water intercooler ExD_{Wic}(%)	0.272	0.0181	0.0791	0.3928	0.3177	0.4538	0.1792	0.2526
Rational System Efficiency(%)	54.80	49.05	49.16	52.95	53.68	50.57	49.94	46.42

3.2 Performances of vapour compression refrigeration system using HFC refrigerants

Thermodynamic (energy-exergy) Performances of two stage vapour compression refrigeration system using HFO refrigerants is shown in Table-2 respectively. As cleared that the first law efficiency (i.e. coefficient of performance) of two stages vapour compression refrigeration system is of R717is 12.38% higher than using HFC-134a.and the second law efficiency using R717 is 10.592% higher than using HFC-134a respectively. It means that R134a consumes more electricity than R717. Although first law efficiency (i.e. coefficient of performance) using R152a is

7.066%, using R245fa is 5.879%, using R32 is 3.73%, higher than using HFC-134a. Similarly, first law efficiency using R125 is 19.2%lower than using HFC-134a. The second law efficiency using R152a is 6.509%, R245fa is 4.674%, and R32 is 2.978%, higher than using HFC-134a respectively Similarly second law efficiency using R1234yf is 18.44, % lower than using HFC-134a.

Table-2 Effect of system performance parameters using ecofriendly refrigerants on the thermodynamic performance of vapour compression refrigeration systems for isentropic compressors efficiencies =80%. at condenser temperature $T_{\_Cond}$ =40^oC and evaporator temperature -40^oC, and evaporator load =35kW, ambient temperature=25^oC

Performance Parameters	R717	R134a	R152a	R245fa	R32a	R125
First law Efficiency ($COP_{\_ Actual}$)	1.988	1.769	1.894	1.873	1.835	1.429
HP Mass flow rate (kg/sec)	0.03703	0.3342	0.1898	0.3079	0.1746	0.6815
LP Mass flow rate (kg/sec)	0.02854	0.1967	0.1242	0.2103	0.1129	0.2974
Work required to run Compressor W_{CompLP}"kW"	7.933	8.04	8.052	10.56	7.762	8.055
Work required to run whole systemW_{Comp}"kW"	17.6	19.79	18.48	18.68	19.07	24.5
Condenser Heat $_{\_ HTC}$ "kW"	49.16	58.71	54.69	56.51	53.0	68.33
Evaporator load"kW"	35.0	35.0	35.0	35.0	35.0	35.0
Total System Exergy Destruction ($ExD_{\_Total}$) (%)	43.93	49.34	46.0	46.93	47.79	58.65
Exergy Destruction in condenser ($ExD_{\_Cond}$) (%)	18.51	15.13	15.55	14.78	17.33	14.21
Exergy Destruction in compressor ($ExD_{\_comp}$) (%)	16.32	20.01	19.31	20.04	18.04	20.45
Exergy Destruction in HP compressor(ExD_{CompHP}) (%)	8.633	11.32	10.42	8.395	10.02	13.06
Exergy Destruction in LP compressor ($ExD_{\_Comp\_LP}$)(%)	2.482	8.699	8.886	11.68	7.832	7.392
Exergy Destruction in Valve $ExD_{\_Valve}$ (%)	6.574	14.25	11.22	12.26	11.92	23.55
Exergy Destruction in HP Valve ($ExD_{\_Valve\_HP}$(%)	4.092	9.52	7.099	4.444	8.345	18.37
Exergy Destruction in LP Valve ($ExD_{\_ Valve\_LP}$ (%)	2.482	4.727	4.119	7.813	3.48	5.18
Exergy Destruction in Evaporator ($ExD_{\_ Eva\_}$ (%)	0.1571	0.1630	0.1651	0.2063	0.1522	0.1065
Exergy Destruction in Water intercooler ExD_{Wic}(%)	2.371	0.2586	0.2339	0.3877	0.3619	0.3304
Rational System Efficiency(%)	56.07	50.7	54.0	53.07	52.21	41.35

Thermodynamic (energy-exergy) performances of two stage vapour compression refrigeration system using HFO refrigerants is shown in Table-3 respectively. As cleared that the first law efficiency of two stages vapour compression refrigeration system is using R236fa is 2.78%, using R227ea is 15.77% and using R404a is 12.83%, using R407c is 8.3% and R143a is 9.723% lower than using HFC-134a. The second law efficiency using R236fa is 3.826%, R227ea is 14.67% R404a is 11.95% and R-410a is2.94%, R407c is 8.126%, R507a is 12.367% and R143a is 9.171% lower than using HFC-134a respectively.

Table-3 Effect of system performance parameters using ecofriendly refrigerants on the thermodynamic performances of vapour compression refrigeration systems for isentropic compressors efficiencies =80%. at condenser temperature $T_{\_Cond}$ =40^oC and evaporator temperature -40^oC and evaporator load =35kW, ambient temperature=25^oC

Performance Parameters	R236fa	R227ea	R404a	R410a	R407c	R507a	R143a
First law Efficiency ($COP_{\_ Actual}$)	1.701	1.49	1.542	1.718	1.622	1.53	1.597
Work required to run Compressor W_{CompLP}"kW"	11.18	14.58	14.68	12.63	13.29	14.78	13.99
Work required to run whole systemW_{Comp}"kW"	9.395	8.904	8.013	7.745	8.292	7.98	7.929
Condenser Heat $_{\_ HTC}$ "kW"	62.7	70.29	64.24	57.27	58.66	64.68	62.69
Evaporator load"kW"	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Total System Exergy Destruction ($ExD_{\_Total}$) (%)	51.24	56.74	55.36	50.79	53.42	55.57	53.95
Exergy Destruction in condenser ($ExD_{\_Cond}$) (%)	15.15	15.07	14.82	16.02	16.96	14.67	14.92
Exergy Destruction in compressor ($ExD_{\_comp}$) (%)	20.69	23.49	20.25	19.15	19.26	20.26	20.08
Exergy Destruction in HP compressor(ExD_{CompHP}) (%)	10.63	14.58	12.45	11.29	11.27	12.51	12.19
Exergy Destruction in LP compressor ($ExD_{\_Comp\_LP}$)(%)	10.07	8.904	7.797	7.862	8.01	7.75	7.895
Exergy Destruction in Valve $ExD_{\_Valve}$ (%)	15.17	19.69	20.04	15.77	14.2	20.05	18.94
Exergy Destruction in HP Valve ($ExD_{\_Valve\_HP}$(%)	8.273	13.29	15.1	11.62	10.41	15.46	14.12
Exergy Destruction in LP Valve ($ExD_{\_ Valve\_LP}$ (%)	6.899	6.396	4.941	4.154	3.784	5.04	4.828
Exergy Destruction in Evaporator ($ExD_{\_ Eva\_}$ (%)	0.1492	0.017	0.2668	0.1229	3.272	0.115	0.1298
Exergy Destruction in Water intercooler ExD_{Wic}(%)	0.0747	1.04	0.0187	0.279	0.2769	0.032	0.1251
Rational System Efficiency(%)	48.76	43.26	44.64	49.21	46.58	44.43	46.05

Thermodynamic (energy-exergy) performances of two stage vapour compression refrigeration system using HFO refrigerants is shown in Table-4 respectively. As cleared that the first law efficiency of two stages vapour compression refrigeration system is of R123 is 9.158% higher than using HFC-134a.and the second law efficiency using R123 is 6.9 % higher than using HFC-134a respectively. It means that R134a consumes more electricity than R123. Although first law efficiency using R600a is 0.8087%, using R600a is 0.848% and using R141b is 13.6% higher than using HFC-134a. Similarly, first law efficiency using R1234yf is -2.205%, lower than using HFC-134a. The second law efficiency using R141b is 11.08%, higher than using HFC-134a respectively Similarly second law efficiency using R290 is 1.93%, using R124 is 0.1% lower than using HFC-134a.

Table-4 Effect of system performance parameters using ecofriendly refrigerants on the thermodynamic performance of two stages vapour compression refrigeration systems for isentropic compressors efficiencies =80%. at condenser temperature $T_{\_Cond}$ =40°C and evaporator temperature -40°C, ambient temperature=25°C and evaporator load =35kW

Performance Parameters	R123	R124	R600a	R290	R141b
First law Efficiency ($COP_{\_Actual}$)	1.931	1.78	1.784	1.73	2.01
Work required to run Compressor $W_{Comp\ HP}$ "kW"	6.034	10.91	11.08	12.34	5.029
Work required to run Compressor $W_{Comp\ LP}$ "kW"	12.81	8.49	8.804	7.898	12.39
Work required to run whole system W_{Comp} "kW"	18.12	19.67	19.62	20.23	17.42
Condenser Heat $_{\_HTC}$ "kW"	53.33	59.81	59.85	59.74	50.2
Evaporator load "kW"	35.0	35.0	35.0	35.0	35.0
HP Mass flow rate (kg/sec)	0.3175	0.425	0.1817	0.1803	0.2224
LP Mass flow rate (kg/sec)	0.2425	0.2559	0.116	0.1038	0.1813
Exergy Destruction in condenser ($ExD_{\_Cond}$) (%)	14.37	15.09	15.16	15.09	14.1
Exergy Destruction in compressor ($ExD_{\_comp}$) (%)	19.38	20.31	20.49	20.08	18.75
Exergy Destruction in HP compressor(ExD_{CompHP}) (%)	6.322	10.88	10.79	11.66	5.438
Exergy Destruction in LP compressor ($ExD_{\_Comp\_LP}$)(%)	13.05	9.435	9.695	8.419	13.31
Exergy Destruction in Valve $ExD_{\_Valve}$ (%)	11.79	13.63	13.21	15.18	9.758
Exergy Destruction in HP Valve ($ExD_{\_Valve\_HP}$(%)	2.472	8.141	7.719	10.63	1.533
Exergy Destruction in LP Valve ($ExD_{\_Valve\_LP}$ (%)	9.313	5.485	5.553	4.545	8.225
Exergy Destruction in Evaporator ($ExD_{\_Eva\_}$ (%)	0.3251	0.4717	0.1526	0.1499	0.1678
Exergy Destruction in Water intercooler ExD_{Wic}(%)	0.0605	0.1526	0.1826	0.2217	0.9072
Rational System Efficiency(%)	54.2	50.65	51.11	49.72	56.32

Table-5 shows the improvement in two stage vapour compression refrigerants using ecofriendly refrigerants as compared with the thermodynamic performances using R134a and it was found that R1234ze(Z) gives best thermodynamic performances and R1234yf gives lowest thermodynamic performances. It was also found that second law performances using R1336mzz(z) and R124 is nearly same but R-600a gives slightly higher but less than 1%.

Table-5: Improvement in first and second law efficiency using Ecofriendly refrigerants as compared to R134a Rational System Efficiency

Eco-friendly refrigerants	Improvement in First Law Efficiency (%)	Improvement in Rational System Efficiency (%)
R1234ze (Z)	9.327	8.087
R1224 yd(Z)	5.483	4.438
R1233zd (E)	7.35	5.88
R1336 mzz(Z)	1.64	-0.256
R717	12.38	10.592
R152a	7.066	6.509
R245fa	5.879	4.674
R123	9.158	6.903
R124	0.622	-0.099
R600a	0.848	0.8087
R141b	13.6	11.085
R245fa	5.879	4.674
R32a	3.73	2.978

Table-6 shows the improvement in two stage vapour compression refrigerants using ecofriendly refrigerants as compared with the thermodynamic performances using R134a and it was found that R125 gives lowest thermodynamic performances

Table-6: Decrement in first and second law efficiency using Ecofriendly refrigerants as compared to R134a Rational System Efficiency

Eco-friendly refrigerants	Improvement in First law Efficiency(%)	Improvement in Rational System Efficiency(%)
R1234ze(E)	-2.77	-3.254
R1225ye (Z)	-3.335	-3.037
R1243zf	-1.752	-1.499
R1234yf	-9.10	-8.442
R125	-19.22	-18.44
R236fa	-2.78	-3.826
R227ea	-15.77	-14.67
R404a	-12.83	-11.95
R410a	-2.883	-2.94
R407c	-8.31	-8.126
R507a	-13.51	-12.367
R143a	-9.723	-9.171
R290	-2.205	-1.933

The output parameters computed are compressors work as exergy input ($W_{\_Comp\_HP}$ and $W_{\_Comp\_LP}$), and Compressor and the coefficient of performance (COP) cycle and energy performance of two stages vapour compression refrigeration systems ($COP_{two\ stages}$) have been carried out. The second law performances (exergetic efficiency and exergy destruction ratios) of two stages vapour compression refrigeration system have been computed Results showed that R1234ze (Z) and R1233zd(E) gives better thermodynamic performances. Than using HFC -134a. However, R1224yd (Z) of seven GWP overcome favourable thermodynamic (energy and exergy) performances, above -10ºC of evaporator can suitably replace R134a. Similarly, HFO-1336mzz(Z) also gives better energy-exergy performances as compared to HFC-134a. However, R1234yf although gives 4% to 10% lesser thermodynamic (energy and exergy) performances than using high GWP ecofriendly HFC-134a refrigerant. Therefore, these ultra-low GWP ecofriendly HFO refrigerants can serve as new alternative refrigerants for replacing HFC-134a in the vapour compression refrigeration systems for a sustainable environment.

3. Conclusions

Exergetic analysis of two stage refrigeration system was carried out with different HFO refrigerants and following conclusion and recommendation are presented below:

- R1234ze (Z) and R1233zd(E) gives better thermodynamic performances. Than using HFC -134a. However, R1224yd (Z) of seven GWP overcome favorable thermodynamic (energy and exergy) performances, above -10ºC of evaporator can suitably replace R134a.
- Similarly, HFO-1336mzz(Z) also gives better energy-exergy performances as compared to HFC-134a. However, R1234yf although gives 4% to 10% lesser thermodynamic (energy and exergy) performances than using high GWP ecofriendly HFC-134a refrigerant
- R1234yf shows lowest thermodynamic (energy and exergetic performances) among selected HFO refrigerants
- Exergy destruction for R1234yf is higher than R1234ze(Z).
- Exergetic and energetic efficiency of R152a is highest among selected refrigerants.
- Compressors responsible for highest exergy destruction for all refrigerants taken under consideration.
- Therefore, these ultra-low GWP ecofriendly HFO refrigerants can serve as new alternative refrigerants for replacing HFC-134a in the vapour compression refrigeration systems for a sustainable environment
- Exergetic analysis of two stage refrigeration system was carried out with different HFO refrigerants and found that the R1234yf shows lowest thermodynamic (energy and exergetic performances) among selected HFO refrigerants
- Exergy destruction for R1234yf is higher than R1234ze(Z)
- Compressors responsible for highest exergy destruction for all refrigerants taken under consideration.
- Lowest exergy destruction for all refrigerants found in evaporator for all considered ecofriendly refrigerants.

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