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Performance improvement of vapour compression refrigeration systems

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Abstract

The improvement of performance of system is too important for higher refrigerating effect or reduced power consumption for same refrigerating effect. Many efforts have to be done to improve the performance of vapour compression refrigeration system. For improving the coefficient of performance, it required reduced compressor work and increasing refrigeration effect. The decrease in condenser pressure and temperature, the refrigeration effect will increase and compressor input work also increases coefficient of performance (COP). To improve thermal performance of vapour compression refrigeration systems by improving first law efficiency (COP), second law efficiency (exergetic efficiency) by reducing of system defect in components of VCRS which results into reduction of work input through detailed analysis of vapour compression refrigeration systems using ecofriendly refrigerants. This paper mainly deals with the effect of various thermodynamic parameters (i.e. evaporator and condenser temperatures. effect of super heating in evaporator outlet and sub-cooling of condenser outlet, liquid vapour heat exchanger effectiveness, compressor efficiency) variation on first law efficiency (COP), second law efficiency (exergetic efficiency and rational exergy destruction ratio of vapour compression refrigeration system. Using energy-exergy analysis, it is found that thermodynamic performances of HFC-134a refrigerant is slightly higher than HFO refrigerants (i.e. R-1234ze & R-1234yf). Although thermal performances of HFO-1234ze is higher (around 5% to 10%) than HFO-1234yf. Therefore HFO-1234 refrigerants can replace HFC-134a refrigerant in vapour compression refrigerant without system modification.

Keywords: Thermodynamic performance improvements, Mixing Nano materials, Vapour Compression Refrigeration System.

1. Introduction

Refrigeration is a technology which absorbs heat at low temperature and provides temperature below the surrounding by rejecting heat to the surrounding at higher temperature. Vapour compression system which consists of four major components compressor, expansion valve, condenser and evaporator in which total cooling load is carried at one temperature by single evaporator but in many applications like large hotels, food storage and food processing plants, food items are stored in different compartment and at different temperatures. Therefore there is need of improving performances of vapour compression refrigeration system. The systems under vapour compression technology consume huge amount of electricity, this problem can be solved by improving performance of system. Thermodynamic performances of systems based on vapour compression refrigeration technology can be improved by following:

(i) The performance of refrigerator is evaluated in term of COP which is the ratio of refrigeration effect to the net work input given to the system. The COP of vapour compression refrigeration system can be improved either by increasing refrigeration effect or by reducing work input given to the system.
(ii) It is well known that throttling process in VCR is an irreversible expansion process. Expansion process is one of the main factors responsible for exergy loss in cycle performance because of entering the portion of the refrigerant flashing to vapour in evaporator which will not only reduce the cooling capacity but also increase the size of evaporator. This problem can be eliminated by adopting multi-stage expansion with flash chamber where the flash vapour is removed after each stage of expansion as a consequence there will be increase in cooling capacity and reduce the size of the evaporator.
(iii) Work input can also be reduced by replacing multi-stage compression or compound compression with single stage compression.

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(iv) The refrigeration effect can also be increased by passing the refrigerant through sub-cooler after condenser to evaporator.
(v) Use of Nano refrigerant in the primary circuit vapour compression refrigeration system /secondary circuit of evaporator improves thermodynamic performances.
(vi) Use of Nano refrigerant in the secondary circuit of evaporator /and secondary circuit of condenser improves thermodynamic performances

The vapour compression refrigeration system based applications make use of refrigerants which are responsible for greenhouse gases, global warming and ozone layer depletion. Montreal protocol was signed on the issue of substances that are responsible for depleting Ozone layer and discovered how much consumption and production of ozone depletion substances took place during certain time period for both developed and developing countries. Another protocol named as Kyoto aimed to control emission of greenhouse gases in 1997. The relationship between ozone depletion potential and global warming potential is the major concern in the field of GRT (green refrigeration technology) so Kyoto proposed new refrigerants having lower value of ODP and GWP. Internationally a program being pursued to phase out refrigerants having high chlorine content for the sake of global environmental problems .Due to presence of high chlorine content ,high global warming potential and ozone depletion potential after 90's CFC and HCFC refrigerants have been restricted. Thus, HFC refrigerants are used nowadays, showing much lower global warming potential value, but still high with respect to non-fluorine refrigerants. Lots of research work has been done for replacing "old" refrigerants with "new" refrigerants. [1]

2. Replacement of HFC-134a by HFO Ecofriendly Refrigerants

The European Union has approved a regulation (Regulation (EU) No 517/2014) which prohibits the use of fluorinated gases with a GWP more than 150 in domestic refrigerators and freezers w.e.f.1st Jan, 2015, and in new types of mobile air-conditioning systems from January 1, 2017. Therefore the low GWP and zero ODP alternative refrigerants R1234yf and R1234ze may be investigated as replacements of HFCs. The use of alternatives to HFCs in the refrigeration and air-conditioning systems controls environmental pollution as well as supports healthy nature and surroundings.

Esbir et al. [2] carried out experimental analysis of R1234yf as a drop-in replacement for R134a in a vapour compression system and compared the energy performance of both refrigerants, R134a and R1234yf, in a observed vapour compression system under a extensive range of working conditions. Zhao et al. [3] had developed mini-channel evaporator model using HFO1234yf as working fluid and proposed simulation model of the mini-channel evaporator finite conception and effectiveness by using NTU method for calculating the heat transfer rate and also compared experimental data of six different samples using R1234yf under typical working conditions of an automotive air conditioning system. Nikolaidis and Probert [4] analytically studied the change in evaporator and condenser temperatures of two stage vapour compression refrigeration plant using R22 and found additional considerable effect on plant irreversibility and suggested that there is need for optimizing the conditions imposed upon the condenser and evaporator. Getu and Bansal [5] optimized the design and operating parameters such as condensing temperature, subcooling temperature, evaporating temperature ,superheating temperature and temperature difference in cascade refrigeration system using R717 in high temperature heat exchanger (condenser) and R744 cascading in low temperature heat exchanger (Evaporator) using regression analysis to obtain optimum thermodynamic parameters of two stage cascade vapour compression refrigeration system. Spatz and Motta [6] experimentally investigated replacement of R12 with R410a through of medium temperature vapour compression refrigeration cycles in terms of heat transfer and pressure drop characteristics comparison using thermodynamic analysis and found that the R410a gives best performance among R12, R404a and R290a. Mohanraj et al. [7] carried out experimental investigations on domestic refrigerator and found that under different environmental temperatures, the COP of system using mixture of R290 and R600a in the ratio of 45.2: 54.8 by weight showing up to 3.6% gives better performance than same system using R134a because discharge temperature of compressor with mixture of R290 and R600a is lower than same compressor with R134a. Mastani Joybari et al. [8] carried out experimental investigations on a domestic refrigerator using 145g R134a and concluded that the exergetic defect occurred in compressor was maximum as compare to other components and also found that instead of 145g of R134a if 60g of R600a is used in the considered system gave same performance which had economical advantages in terms of reduced risk of flammability of hydrocarbon refrigerants. Han et al. [9] found mixture of R32/R125/R161 showing higher COP, less pressure ratio and slightly high discharge compressor temperature without any modification in the same system under different working conditions could be replacement of R407C in vapour compression refrigeration system having rotor compressor by conducting experimental measurements. Halimic et al. [10] compared thermodynamic performance of vapour compression refrigeration system using R401A, R290 and R134A with R12 and found similar performance of R134a in comparison with R12,R134A in the same system without any medication in the system components and concluded that hydrocarbon (R290) gives top results in reference to greenhouse impact. Ahamed et al. [11] mainly emphasized on use of hydrocarbons and mixture of hydrocarbons and R134a in vapour compression refrigeration system and found that the compressor shows much higher exergy destruction as compared to other components of vapour compression refrigeration system and concluded that this exergy destruction can be minimized by using of nanofluid and nanolubricants in compressor. Ahamed et al. [12-13] had performed theoretical & experimental investigations of domestic refrigeration system using hydrocarbons (isobutene and butane) using energy and exergy analysis and found that the energy efficiency ratio of hydrocarbons is comparable with R134a. The exergy efficiency and sustainability index of hydrocarbons much higher than that of R134a at considered evaporator temperature and also found that the compressor shows highest system defect (69%) among other components of considered system. Reddy et al. [14] carried out numerical analysis of vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A to find out the the effect of evaporator temperature, degree of subcooling at condenser outlet, superheating of evaporator outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature on COP and exergetic efficiency and concluded that the evaporator and condenser temperatures have important effect on both COP and exergetic efficiency and also found that R134a has the better performance. Although the R407C has poor performance in all respect. Saravana kumar and Selladurai [15] compared the performance using R134a and R290/R600a mixture on a domestic refrigerator and found that the hydrocarbon mixture of R290/R600a showed advanced COP and exergetic efficiency than R134a and found maximum irreversibility in the compressor as compared to condenser, expansion valve and evaporator. Kumar et al. [16] carried out energy and exergy analysis for calculating the coefficient of performance and exergetic efficiency, various losses occurred in different components of vapour compression cycle using R11 and R12 as refrigerants by the use of exergy-enthalpy diagram. Anand and Tyagi [17] carried out detailed exergy analysis of window air conditioning test rig with R22 as working fluid of two ton of refrigeration capacity and concluded that the irreversibility in system components will be highest when the system is 100% charged and lowest when 25% charged andfound that the irreversibility in compressor is maximum among other system components. Xuan and Chen [18]presented in this manuscript about the replacement of R502 by mixture of HFC-161.Through experimental study it was found that mixture of HFC-161 gives same and higher performance than R404A at lower and higher evaporative temperature respectively on the vapour compression refrigeration system designed for R404A. Cabello et al. [19]studied the outcome of operating parameters on COP, work input and cooling capacity of single-stage vapour compression refrigeration system and found the excessive influence on constraints in energetic performance due change in suction pressure, condensing and evaporating temperatures. Cabello et al. [20]experimentally investigated the effect of condensing pressure, evaporating pressure and degree of superheating on single stage vapour compression refrigeration system using R22, R134a and R407C and found that the mass flow rate is greatly affected by change in suction conditions of compressor in results on refrigeration capacity because refrigeration capacity depended on mass flow rate through evaporator and also concluded that for higher compression ratio R22 gives lower COP than R407C. Stanciu et al. [21] carried out numerical and graphical investigation in terms of COP, compressor work, exergy efficiency and refrigeration effect on single stage vapour compression refrigeration system using R22, R134a, R717, R507a, R404a refrigerants. The effect of sub-cooling, superheating and compression ratio was also studied by them on the same system using considered refrigerants and presented system optimization of vapour compression refrigeration working with the specific refrigerant. Bolaji et al. [22] carried out experimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator and concluded that the R32 had lowest thermodynamic performance than R134a and R152a. However R134a and R152a showing nearly similar performance but greatest performance was obtained of VCRS system using R152a. Yumrutas et al. [23]carried out exergy analysis on vapour compression refrigeration cycle in terms of pressure losses, COP, second law efficiency and exergy losses based investigation of effect of condensing and evaporating temperature and found that the first law efficiency in terms of Coefficient of performance (COP) increases with increase in evaporator and exergy efficiency decreases . The total exergy losses of system increases with condenser temperature and evaporator temperatures. Padilla et al. [24] carried out exergy analysis for replacing R12 by R134a of domestic vapour compression refrigeration system using R12 and R R134a refrigerants and concluded that the performance in terms of power consumption, irreversibility and exergetic efficiency of R134a is slightly higher than R12. Arora and Kaushik [25] developed numerical model of actual vapour compression refrigeration system with liquid vapour heat exchanger and carried out energy and exergy analysis on the same system in the specific temperature range of evaporator and condenser and concluded that the R502 is the superlative refrigerant as compared to R404A and R507A and found that the compressor is the worst and liquid vapour heat exchanger is best component of the vapour compression refrigeration system. 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 simple compression in vapour compression refrigeration systems. To improve thermal performance of vapour compression refrigeration systems by improving first law efficiency (COP) , second law efficiency (exergetic efficiency) by reducing of system defect in components of VCRS which results into reduction of work input through detailed analysis of vapour compression refrigeration systems using ecofriendly refrigerants.

3. Result and Discussion

Table-1(a) shows the variation of condenser temperature with the variation of first law efficiency in terms of coefficient of performance (COP) of HFO refrigerants and HFC-134a refrigerant. The first law efficiency in terms of COP is decreasing as condenser temperature is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf. Table-1(b) shows the condenser temperature variation with rational exergy destruction ratio ($EDR\_{Rational}$) of HFO refrigerants and HFC-134a. The condenser temperature is increasing as rational exergy destruction ratio ($EDR\_{Rational}$) is also increasing. It is clear that rational exergy destruction ratio ($EDR\_{Rational}$) of HFC-134a is lower than HFO refrigerants. Although rational exergy destruction ratio ($EDR\_{Rational}$) of R1234ze is slightly higher than to R134a. The highest ($EDR\_{Rational}$) is found by using R1234yf as compared to HFC -134a. Table-1(c) shows the variation of condenser temperature variation of second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is decreasing as condenser temperature is increasing. It is clear that exergetic efficiency of HFC-134a is higher than HFO refrigerants. Although exergetic efficiency of R1234ze is slightly lower than R134a but higher than R1234yf.

Table-1(a) Comparison of first law efficiency (in terms of Coefficient of performance) of HFO refrigerants with HFC-123a in the vapour compression refrigeration using liquid vapour heat exchanger using R134a ecofriendly refrigerant. (For T_eva=253K, Compressor efficiency=0.8, Heat exchanger effectiveness = 0.80, T_super heat_Eva=10, T_sub_cool_Cond=10

T_Cond (K)	COP_R134a	COP_R1234ze	COP_R1234yf
333	1.922	1.889	1.755
328	2.168	2.141	2.015
323	2.449	2.428	2.310
318	2.774	2.761	2.649
313	3.159	3.154	3.047
308	3.622	3.827	3.524
303	4.194	4.211	4.111

Table-1(b) Comparison of exergy Destruction Ratio of HFO refrigerants with HFC-123a in the vapour compression refrigeration using liquid vapour heat exchanger using R1234ze ecofriendly refrigerant. (For T_eva=253K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_superheat_Eva=10, T_sub_cool_Cond=10

T_Cond (K)	EDR_ Rational R134a	EDR_Rational R1234ze	EDR_Rational R1234yf
333	0.6581	0.6640	0.6878
328	0.6143	0.6192	0.6415
323	0.5644	0.5681	0.5891
318	0.5065	0.5089	0.5288
313	0.4382	0.4390	0.4580
308	0.3558	0.3549	0.3732
303	0.2540	0.251	0.2689

Table-1(c) Comparison of second law efficiency (in terms of exergetic efficiency) of HFO refrigerants with HFC-123a in the vapour compression refrigeration using liquid vapour heat exchanger using R1234yf ecofriendly refrigerant. (For T_eva=253K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_superheat_Eva=10, T_sub_cool_Cond=10

T_Cond (K)	Exergetic Eff_ R134a	Exergetic Eff_ R1234ze	Exergetic Eff _R1234yf
333	0.3419	0.3360	0.3122
328	0.3857	0.3808	0.3585
323	0.4356	0.4319	0.4109
318	0.4935	0.4911	0.4712
313	0.5618	0.5610	0.5420
308	0.6442	0.6451	0.6268
303	0.7460	0.7490	0.7311

Table-2(a) shows the variation of evaporator temperature variation of first law efficiency in terms of coefficient of performance (COP) of HFO refrigerants and HFC-134a. The first law efficiency in terms of COP is increasing as evaporator temperature is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf.

Table-2(b) shows the evaporator temperature variation with rational exergy destruction ratio ($EDR\_{Rational}$) of HFO refrigerants and HFC-134a. The evaporator temperature is increasing as rational exergy destruction ratio ($EDR\_{Rational}$) is also increasing. It is clear that rational exergy destruction ratio ($EDR\_{Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR\_{Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR\_{Rational}$) of R1234ze is slightly higher than to R134a.

Table-2(c) shows the variation of evaporator temperature variation of second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is decreasing as evaporator temperature is increasing. It is clear that second law efficiency of HFC-134a is higher than HFO refrigerants. Although second law efficiency of R1234ze is similar to R134a but higher than R1234yf.

Table-2(a) Variation of evaporator temperature with thermal performance of vapour compression refrigeration using liquid vapour heat exchanger using R134a ecofriendly refrigerant. (For T_cond=323K , Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_superheat_Eva=10, T_sub_cool_Cond=10

T_{EVA} (K)	COP_actual R134a	COP_Actual R1234ze	COP_ R1234yf
253	2.449	2.428	2.31
258	2.796	2.783	2.656
263	3.215	3.21	3.075
268	3.73	3.736	3.59
273	4.376	4.396	4.237
278	5.21	5.246	5.072
283	6.325	6.384	6.191

Table-2(b) Comparison of exergy Destruction Ratio of HFO refrigerants with HFC-123a in the vapour compression refrigeration using liquid vapour heat exchanger using R1234ze ecofriendly refrigerant. (For T_cond=323K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80,T_superheat_Eva=10, T_sub_cool_Cond=10

T_{EVA} (K)	EDR_Rational R134a	EDR_Rational R1234ze	EDR_Rational R1234yf
253	0.4490	0.5681	0.5891
258	0.5665	0.5686	0.5882
263	0.5721	0.5728	0.5808
268	0.5824	0.5818	0.5982
273	0.5992	0.5975	0.6120
278	0.6252	0.6226	0.6351
283	0.6647	0.6616	0.6719

Table-2(c) Comparison of second law efficiency (in terms of exergetic efficiency) of HFO refrigerants with HFC-134a in the. vapour compression refrigeration using liquid vapour heat exchanger (For T_cond=323K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_superheat_Eva=10, T_sub_cool_Cond=10

T_{EVA} (K)	Exergetic Efficiency	Exergetic Efficiency	Exergetic Efficiency
253	0.4356	0.4319	0.4109
258	0.4335	0.4314	0.4118
263	0.4279	0.4272	0.4092
268	0.4176	0.4182	0.4092
273	0.4008	0.4025	0.4018
278	0.3748	0.3774	0.388
283	0.3353	0.3334	0.3649

Table-3(a) shows the effect of super heating temperature variation of HFO refrigerants and HFC-134a. The first law efficiency in terms of COP is increasing as super heating temperature is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf.

Table-3(b) shows the super heating temperature variation with rational exergy destruction ratio ($EDR\_{Rational}$) of HFO refrigerants and HFC-134a. The super heating temperature is increasing as rational exergy destruction ratio ($EDR\_{Rational}$) is also decreasing. It is clear that rational exergy destruction ratio ($EDR\_{Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR\_{Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR\_{Rational}$) of R1234ze is slightly higher than to R134a. Table-3(c) shows the variation of super heating temperature variation of second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is increasing as super heating temperature is increasing. It is clear that second law efficiency of HFC-134a is higher than HFO refrigerants. Although second law efficiency of R1234ze is similar to R134a but higher than R1234yf.

Table-3(a) Comparison of First law efficiency (in terms of COP) of HFO refrigerants with HFC-134a in the vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_eva=253K, T_Cond=323K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_sub_cool_Cond=10

Super heating Temperature	COP_Actual R134a	COP_Actual R1234ze	COP_Actual R1234yf
0	2.448	2.407	2.278
5	2.449	2.417	2.293
10	2.450	2.428	2.310
15	2.451	2.44	2.328
20	2.452	2.452	2.347

Table-3(b) Effect of super heating of evaporator on comparison of exergey Destruction Ratio of vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_eva=253K, T_Cond=323K, Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, T_superheat_Eva=10, T_sub_cool_Cond=10

Super heating Temperature	EDR_ Rational R134a	EDR_ Rational R1234ze	EDR_ Rational R1234yf
0	0.5652	0.5718	0.5948
5	0.5651	0.5701	0.5922
10	0.5650	0.5681	0.5891
15	0.5649	0.5660	0.5859
20	0.5648	0.5648	0.5826

Table-3(c) Effect of super heating of evaporator on second law efficiency (in terms of exergetic efficiency) of HFO refrigerants with HFC-134a in the thermal performance of vapour compression refrigeration using liquid vapour heat exchanger using R1234yf ecofriendly refrigerant. (For T_eva=253K, T_Cond=323K Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, ,T_sub_cool_Cond=10

Super heating Temperature	Exergetic Efficienc R134a	Exergetic Efficiency R1234ze	Exergetic Efficiency R1234yf
0	0.4358	0.4282	0.4052
5	0.4359	0.4299	0.4078
10	0.4360	0.4319	0.4109
15	0.4361	0.4340	0.4141
20	0.4362	0.4362	0.4174

Table-4(a) shows the Effect of subcooling temperature variation with first law efficiency (COP) of HFO refrigerants and HFC-134a. The first law efficiency in terms of COP is increasing as subcooling temperature is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf. Table-4(b) shows the sub cooling temperature variation with rational exergy destruction ratio ($EDR\_{Rational}$) of HFO refrigerants and HFC-134a. The sub cooling temperature is increasing as rational exergy destruction ratio ($EDR\_{Rational}$) is also decreasing. It is clear that rational exergy destruction ratio ($EDR\_{Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR\_{Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR\_{Rational}$) of R1234ze is slightly higher than to R134a. Table-4(c) shows the variation of sub cooling temperature variation with second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is increasing as sub cooling temperature is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants. Although second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf.

Table-4(a) Effect of subcooling of condenser on the first law thermal performance(COP) of vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_eva=253K, T_Cond=323K Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, ,T_super_heating_evaporator=10

Sub cooling Temp	COP_Actual R134a	COP_Actual R1234ze	COP_Actual R1234yf
0	1.922	1.889	1.755
5	2.168	2.141	2.075
10	2.449	2.428	2.370
15	2.774	2.761	2.649
20	3.159	3.154	3.047

Table-4(b) Effect of subcooling of condenser on the exergy Destruction ratio of vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_eva=253K, T_Cond=323K Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, ,T_super_heating_evaporator=10

Sub cooling Temp	EDR_Rational R134a	EDR_Rational R1234ze	EDR_Rational R1234yf
0	0.6581	0.6640	0.6878
5	0.6143	0.6192	0.6415
10	0.5644	0.5681	0.5891
15	0.5065	0.5089	0.5288
20	0.4382	0.4390	0.4580

Table-4(c) Effect of subcooling of condenser on the second law Efficiency (i.e. exergetic efficiency) thermal performance of vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_eva=253K, T_Cond=323K Compressor efficiency=0.8, Heat exchanger effectiveness=0.80, ,T_super_heating_evaporator=100.5618

Sub cooling Temp	Exergetic Efficiency R134a	Exergetic Efficiency R1234ze	Exergetic Efficiency R1234yf
0	0.3419	0.3360	0.3122
5	0.3867	0.3808	0.3585
10	0.4356	0.4319	0.4109
15	0.4935	0.4911	0.4712
20	0.5618	0.5610	0.542

Table-5(a) shows the heat exchanger effectiveness variation with first law efficiency (COP) of HFO refrigerants and HFC-134a. The first law efficiency in terms of COP is increasing as heat exchanger effectiveness is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf. Table-5(b) shows the effectiveness of heat exchanger variation with rational exergy destruction ratio ($EDR\_{Rational}$) of HFO refrigerants and HFC-134a. The effectiveness of heat exchanger is increasing as rational exergy destruction ratio ($EDR\_{Rational}$) is decreasing. It is clear that rational exergy destruction ratio ($EDR\_{Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR\_{Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR\_{Rational}$) of R1234ze is slightly higher than to R134a. Table-5(c) shows the variation of effectiveness of heat exchanger temperature variation of second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is increasing as effectiveness of heat exchanger is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants. Although second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf.

Table-5(a) Variation of Effectiveness of heat exchanger with thermal performance of vapour compression refrigeration using liquid liquidvapour heat exchanger using R134a ecofriendly refrigerant. (For T_Eva=253 K ,T_cond=323K, Compressor efficiency=0.8, T_superheat_Eva=10, T_sub_cool_Cond=5

Effectiveness of heat exchanger	COP_{Actual_R134a}	$COP\_{Actual\_R1234ze}$	$COP_{Actual\_R1234yf}$
0.40	2.390	2.36	2.234
0.45	2.398	2.368	2.243
0.5	2.405	2.377	2.253
0.55	2.412	2.385	2.262
0.6	2.420	2.394	2.272
0.65	2.427	2.402	2.281
0.70	2.434	2.411	2.291
0.75	2.434	2.42	2.30
0.80	2.449	2.428	2.31
0.85	2.456	2.437	2.319
0.90	2.463	2.445	2.329
0.95	2.471	2.454	2.338
1.0	2.478	2.462	2.348

Table-5(b) Variation of Effectiveness of heat exchanger with thermal performance of vapour compression refrigeration using liquid liquidvapour heat exchanger using R1234ze ecofriendly refrigerant. (For T_cond=323K, T_Eva=253 K,Compressor efficiency=0.8, T_superheat_Eva=10, T_sub_cool_Cond=5

Effectiveness of heat exchanger	$EDR\_{Rational\ R134a}$	$EDR\_{Rational\ R1234ze}$	$EDR\_{Rational\ R1234yf}$
0.40	0.5748	0.5803	0.6027
0.45	0.5735	0.5788	0.6010
0.5	0.5722	0.5772	0.5993
0.55	0.5709	0.5757	0.5976
0.6	0.5696	0.5742	0.5959

0.65	0.5683	0.5727	0.5942
0.70	0.5670	0.5712	0.5925
0.75	0.5657	0.5696	0.5908
0.80	0.5644	0.5681	0.5891
0.85	0.5631	0.5666	0.5874
0.90	0.5618	0.5651	0.5858
0.95	0.5605	0.5636	0.5841
1.0	0.5592	0.5620	0.5824

Table-5(c) Variation of Effectiveness of heat exchanger with thermal performance of vapour compression refrigeration using liquid liquidvapour heat exchanger using R1234yf ecofriendly refrigerant. (For T_cond=323K, T_Eva=253 K,Compressor efficiency=0.8, T_superheat_Eva=10, T_sub_cool_Cond=5

Effectiveness of heat exchanger	Exergetic Efficiency	Exergetic Efficiency	Exergetic Efficiency
0.40	0.4252	0.4197	0.3973
0.45	0.425	0.4212	0.3990
0.5	0.4278	0.4229	0.4007
0.55	0.4291	0.4243	0.4024
0.6	0.4304	0.4258	0.4041
0.65	0.4317	0.4273	0.4058
0.70	0.4330	0.4288	0.4075
0.75	0.4343	0.4304	0.4092
0.80	0.4356	0.4319	0.4109
0.85	0.4369	0.4334	0.4126
0.90	0.4382	0.4349	0.4142
0.95	0.4395	0.4364	0.4159
1.0	0.4408	0.4380	0.4176

Table-6(a) shows the compressor efficiency variation with first law efficiency (COP) of HFO refrigerants and HFC-134a. The first law efficiency in terms of COP is increasing as Compressor efficiency is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf. Table-6(b) shows the Compressor efficiency variation with rational exergy destruction ratio ($EDR_{Rational}$) of HFO refrigerants and HFC-134a. The Compressor efficiency is increasing as rational exergy destruction ratio ($EDR_{Rational}$) is decreasing. It is clear that rational exergy destruction ratio ($EDR_{Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR_{Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR_{Rational}$) of R1234ze is slightly higher than to R134a. Table-6(c) shows the variation of compressor efficiency temperature variation of second law efficiency (exergetic efficiency) HFO refrigerants and HFC-134a. The second law efficiency (exergetic efficiency) is increasing as compressor efficiency is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants. Although second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf.

Table-6(a) Variation of compressor efficiency with First law thermal performance(COP) of vapour compression refrigeration using liquid liquidvapour heat exchanger using ecofriendly refrigerant.s (For T_cond=323K, T_Eva=253 K, Effectiveness of heat exchanger =0.8, T_superheat_Eva=10, T_sub_cool_Cond=5

Compressor efficiency	COP_{Actual} R134a	COP_{Actual} R1234ze	COP_{Actual} R1234yf
0.6	1.626	1.606	1.512
0.65	1.762	1.739	1.638
0.7	1.897	1.873	1.764
0.75	2.039	2.007	1.889
0.80	2.168	2.141	2.015
0.85	2.304	2.275	2.141
0.90	2.439	2.409	2.267
0.95	2.575	2.542	2.393
1.0	2.710	2.675	2.519

Table-6(b) Variation of compressor efficiency with thermal performance in terms of rational exergy destruction ratio of vapour compression refrigeration using liquid vapour heat exchanger using ecofriendly refrigerants. (For T_cond=323K, T_Eva=253 K, Effectiveness of heat exchanger =0.8, T_super heat_Eva=10, T_sub_cool_Cond=5

Compressor efficiency	$EDR_{Rational}$ R134a	$EDR_{Rational}$ R1234ze	$EDR_{Rational}$ R1234yf
0.6	0.7108	0.7144	0.7311
0.65	0.6867	0.6906	0.7087
0.7	0.6626	0.6668	0.6863
0.75	0.6384	0.6430	0.6639
0.80	0.6145	0.6182	0.6415
0.85	0.5902	0.5954	0.6191
0.90	0.5661	0.5716	0.5967
0.95	0.542	0.5478	0.5743
1.0	0.5179	0.524	0.5519

Table-6(c) Variation of compressor efficiency with second thermal performance(exergetic Efficiency) of vapour compression refrigeration using liquid liquidvapour heat exchanger using ecofriendly refrigerants. (For T_cond=323K, T_Eva=253 K, Effectiveness of heat exchanger =0.8, T_superheat_Eva=10, T_sub_cool_Cond=5

Compressor efficiency	Exergetic Efficiency R134a	Exergetic Efficiency R1234ze	Exergetic Efficiency R1234yf
0.6	0.2892	0.2856	0.2689
0.65	0.3133	0.3094	0.2913
0.7	0.3374	0.3332	0.3137
0.75	0.3616	0.357	0.3361
0.80	0.3857	0.3806	0.3585
0.85	0.4098	0.4046	0.3809
0.90	0.4339	0.4284	0.4033
0.95	0.4580	0.4522	0.4257
1.0	0.4821	0.4760	0.4481

4. Conclusion

The following conclusions were drawn from present investigations.

(i) The first law efficiency in terms of COP is decreasing as condenser temperature is increasing. The first law efficiency (COP) of HFC-134a is higher than HFO refrigerants. The first law efficiency in terms of COP of R1234ze is similar to R134a but higher than R1234yf.

(ii) The condenser temperature is increasing as rational exergy destruction ratio ($EDR_{\_Rational}$) is also increasing. (v)The second law efficiency (exergetic efficiency) is decreasing as condenser temperature is increasing. The exergetic efficiency of HFC-134a is higher than HFO refrigerants. Although exergetic efficiency of R1234ze is slightly less than R134a but higher than R1234yf.

(iii) The first law efficiency in terms of COP is increasing as evaporator temperature is increasing. The evaporator temperature is increasing as rational exergy destruction ratio ($EDR_{\_Rational}$) is also increasing. The rational exergy destruction ratio ($EDR_{\_Rational}$) of HFC-134a is lower than HFO refrigerants. The highest ($EDR_{\_Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Rational exergy destruction ratio ($EDR_{\_Rational}$) of R1234ze is slightly higher than to R134a.

(iv) The second law efficiency (exergetic efficiency) is decreasing as evaporator temperature is increasing. The second law efficiency of HFC-134a is higher than HFO refrigerants. Although second law efficiency of R1234ze is slightly lower than R134a but higher than R1234yf.

(v) The first law efficiency in terms of COP is increasing as super heating temperature is increasing and rational exergy destruction ratio ($EDR_{\_Rational}$) is decreasing. It is clear that rational exergy destruction ratio ($EDR_{\_Rational}$) of HFC-134a is lower than HFO refrigerants.

(vi) The second law efficiency (exergetic efficiency) is increasing as super heating temperature is increasing. It is clear that second law efficiency of HFC-134a is higher than HFO refrigerants. Although second law efficiency of R1234ze is similar to R134a but higher than R1234yf.

(vii) The first law efficiency in terms of COP is increasing as subcooling temperature is increasing. The sub cooling temperature is increasing as rational exergy destruction ratio ($EDR_{\_Rational}$) is also decreasing. The rational exergy destruction ratio ($EDR_{\_Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR_{\_Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants.

(viii) The second law efficiency (exergetic efficiency) is increasing as sub cooling temperature is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants. Although second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf.

(ix) The first law efficiency in terms of COP is increasing as heat exchanger effectiveness is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf.

(x) The effectiveness of heat exchanger is increasing as rational exergy destruction ratio ($EDR_{\_Rational}$) is decreasing. It is clear that rational exergy destruction ratio ($EDR_{\_Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR_{\_Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR_{\_Rational}$) of R1234ze is slightly higher than to R134a.

(xi) The second law efficiency (exergetic efficiency) is increasing as effectiveness of heat exchanger is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants. Although second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf.

(xii) The first law efficiency in terms of COP is increasing as Compressor efficiency is increasing. It is clear that COP of HFC-134a is higher than HFO refrigerants. Although COP of R1234ze is similar to R134a but higher than R1234yf.

(xiii) The second law efficiency (exergetic efficiency) is increasing as compressor efficiency is increasing. It is clear that second law efficiency (exergetic efficiency) of HFC-134a is higher than HFO refrigerants.

(xiv) Second law efficiency (exergetic efficiency) of R1234ze is slightly lower to R134a but higher than R1234yf. The compressor efficiency is increasing as rational exergy destruction ratio ($EDR_{\_Rational}$) is decreasing.

(xv) The rational exergy destruction ratio ($EDR_{\_Rational}$) of HFC-134a is lower than HFO refrigerants. The high ($EDR_{\_Rational}$) is found by using R1234yf as compared to HFC-134a and HFO-1234ze refrigerants. Although rational exergy destruction ratio ($EDR_{\_Rational}$) of R1234ze is slightly higher than to R134a.

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