International Journal of Research in Engineering and Innovation (IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

Methods for improving thermal performances of vapour compression refrigeration systems using ecofriendly refrigerant in the expander

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Abstract

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. In this paper, the thermodynamic performance of a vapour compression system that uses an expander was investigated. In the analysis, an expander flow model was used. Eighteen ecofriendly refrigerants (such as R134a , R245fa, R236fa, R227ea, R152a, R125, R123, R717, R1234yf, R1234ze, R600, R290, R600a, R507a, R404a, R410a, R-32, R407c etc.),were selected as the refrigerants. According to the obtained results, for any operating condenser/evaporator temperature there are different optimum values coefficient of performance (COP). As the condenser temperature increases, the first law efficiency in terms of coefficient of performance (COP) and exergetic efficiency decreases and exergy destruction ratio based on exergy output is increased. Similarly evaporator temperature increases, the first law efficiency in terms of coefficient of performance (COP) and exergetic efficiency increases and exergy destruction ratio based on exergy output is decreased. The numerical computation for finding First law and second law efficiencies and exergy destruction ratio were carried out for two systems. The 22.34%. Improvement in COP was observed in system -2 while replacing throttle valve by expander as compared to system-1 containing throttle valve. The thermal performances of both systems using HFO refrigerants were compared for replacing R134a in near future and it was found that HFO-1234ze gives similar thermodynamic performances and R1234yf is slightly lower 6-8% than using R134a without any change in system configuration. Worst thermodynamic performances were found using R125 as ecofriendly refrigerant and best performance was observed using R245fa. Although Thermal performance of R123 is found to be best slightly higher than R245fa but it containing chlorine.
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Keywords: Thermodynamic performance analysis, Improvements in Efficiencies, VCRS

1. Introduction

Vapor compression refrigeration system is based on vapor compression cycle. Vapor compression refrigeration system is widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems. The Vapor Compression Refrigeration system involves four components: compressor, condenser, expansion valve/throttle valve and evaporator. It is a compression process, whose aim is to raise the refrigerant pressure, as it flows from an evaporator.as shown in Fig-1.

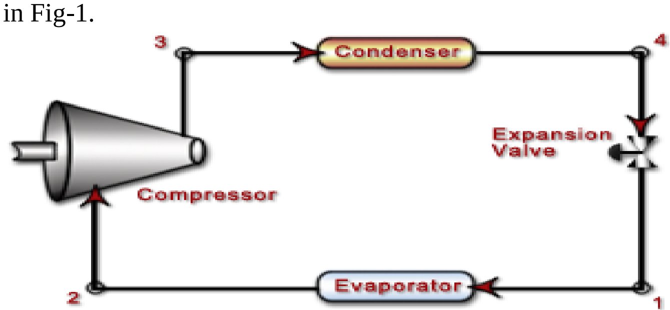

Figure 1: Vapour compression refrigeration system [1]

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The systems under vapor compression technology consume huge amount of electricity, this problem can be solved by improving performance of system.

2. Literature review

2.1 Performance improvement of vapour compression refrigeration systems

The improvement of thermal performance of vapour compression refrigeration system is too important for achieving higher refrigerating effect. Therefore there is need of multi evaporator vapour compression refrigeration system or one can get reduced power consumption by using expander between condenser and evaporator and also connecting with compressor shaft for same refrigerating effect. Many efforts have to be done to improve thermal performance of vapour compression refrigeration system. The use of nano particles can also improve the first law and second law performance significantly. The best thermodynamic performance is found using R123 and worst performance is observed using R125.

Due to flammable nature of R290, R600, R600a and R152a.the R134a was used for replacing R11, R12, and R22, R502 .It is well recognized that throttling process in VCRS 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 where the flash vapours is removed after each stage of expansion as a consequence there will be increase in cooling capacity and reduce the size of the evaporator or insert expander and remove throttle valve to the vapour compression refrigeration systems, which utilizes the work expended in direct expansion of a refrigerant to power a turbine which drives a compressor of a refrigeration system in compressing gaseous vapours from evaporator pressure to condenser pressure. Refrigeration effect can also be increased using nano particles mixed with R718 in the secondary evaporator circuit and R134a in the primary evaporator circuit.

In the vapour compression refrigeration system, the evaporator overall heat transfer coefficient is also increases which enhanced refrigeration effect due to nano particles mixed with R718 in the secondary evaporator circuit and R134a in the primary evaporator circuit.

2.2 Use of ecofriendly refrigerants

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

Mishra et al. [1-3] performed numerical analysis of vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A, and discussed the effect of evaporator temperature, degree of sub cooling at condenser outlet, superheating of evaporator outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature on COP and exergetic efficiency. They reported that evaporator and condenser temperature have significant effect on both COP and exergetic efficiency and also found that R134a has the better performance while R404a has poor performance in all respect.

Xiaohui et al [4] presented the performance study of vapour compression system where the expander work recovered during the expansion process was also employed for sub cooling of the system and found higher COP of the system while using R12, R32, R22, R134a refrigerants. Victor et al [5] presented a performance study on automobile air-conditioning based on vapor compression refrigeration cycle with R134a as refrigerant by incorporating an expander and predicted reasonable gains in cycle performance. Mishra R.S. et al. [6] also compared the performance between R134a and R290/R600a mixture in their thermodynamic analysis highest irreversibility is obtained in compressor and found that R290/R600a hydrocarbon mixture showed higher COP and exergetic efficiency than R134a. Mishra et al. [7] developed numerical model for comparison of thermodynamic performance parameters of two systems. System-1 consists of & system-2). Thermodynamic analysis in terms of energy and exergy analysis of multiple evaporators and compressors with individual expansion valves (system-1) and multiple evaporators and compressors with multiple expansion valves (system-2) have been carried out and following conclusions was drawn from present investigation. For same degree of sub cooling, fixed evaporators and condenser temperatures system-2 is the best system with comparisons of system-1. R600, R600a and R152A show better performances than other refrigerants for both systems (system-1 & system-2) but due to inflammable property of R600 and R600a, R134a is preferred for both systems. First law efficiency and second law efficiency of system-2 is 3%- 6% higher than System-1. Mishra et al. [8] performed thermal modeling of Vapor

Compression Refrigeration System using R134a in primary circuit and Al_2O_3 Water based nano-fluids in secondary circuit. The performances of vapour compression have been studies in details and conclusions were made that the optimum temperature of evaporator is found to be -50C. Similarly exergy destruction ratio is also decreases up to 273K and then increases. The optimum evaporator temperature to be found to be 273K for optimum EDR condenser temperature with performance parameters. Also found that as condenser temperature increases, the first law efficiency of vapour compression refrigeration system is decreases. Also second law efficiency is also decreases. Similarly exergy destruction ratio is also decreases. Use of nano particle suspended in the water used as refrigerant in the secondary circuit in the evaporator greatly affecting its first law performance. As evaporator temperature is increases, the first law efficiency and second law efficiency increases. The increasing condenser temperature the First law and second law performance decreases. Mishra et al.[9] investigates Thermodynamic analysis in terms of consists of multiple evaporators and compressors with individual expansion valves while system-2 consists of multiple evaporators and compressors with multiple expansion valves (system-2) and found that R134a, R407c, show better thermal performances than other eco-friendly refrigerants in vapour compression refrigeration system. Due to flammable property of R290 and R600a, HFC-134a, R407c and R410a and R404a are preferred for vapour compression refrigeration systems. It is also found that the first law efficiency in terms of COP and second law efficiency in terms of exergetic efficiency of Vapour compression using R407c is lower around 3% to 6% than using R134a. Mishra et al. [10] performed first law and second law analysis of vapour compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with eco-friendly refrigerants in the system and R718 (water used in secondary circuit with and without nano particles mixed with water used as refrigerant)and found that the First law efficiency in terms of COP and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using R718 mixed with nano particles gives better thermodynamic performance is than without nano particles used in the secondary circuit of water cooled evaporator for above mentioned ecofriendly refrigerants and also found that the vapour compression refrigeration systems using R152a refrigerant is higher but is has flammable nature similar to hydrocarbons and then safety measures to be taken while using R152a or hydrocarbons (R290, R600 and R600a). The thermodynamic performances can also improve by using TiO2 in the secondary evaporator circuit as compared to Al_2O_3 in the secondary circuit he found efficiency for R507a and R134a are nearly matching the same values are better than that for R125.For practical applications R-407c, R134a and R404a, R125 can be used instead of R-152a which was not applicable for commercial applications due to flammable nature and R717 is also toxic nature. Efficiency improved by using TiO2 is better than using Al_2O_3 with R718 refrigerant in the secondary evaporator circuit. Mishra et al. [11], investigated energy and exergy analysis of vapour compression refrigeration systems using R134a eco-friendly refrigerant in primary circuit and three nano particles mixed with R718 in the secondary evaporator is presented and found that copper oxide gives performance improvements in the range 11.23% to 18% without nano particles and better performance was found using copper oxide nano material in efficiency .The COP improvement is 18.35% and second law efficiency improvement is 18.31% observed using Al_2O_3 nano materials mixed with R718 in secondary circuit as compared to without nano refrigerants. Similarly 17.72% and 17.685% second law efficiency. Mishra et al [12] Analyzed, first law and second law analysis of vapour compression refrigeration system with and without nano particles using eco-friendly refrigerants (R134a, R1234yf, and R1234ze) and found that without Al_2O_3 nano particles mixed in R718 in the secondary evaporator circuit and eco-friendly refrigerants in the primary circuit (i.e. R134a and R1234ze) are matching the same values, both are better than that for R123yf which has low GWP (i.e. GWP =4) is showing 2–6% higher value of first law efficiency i.e. (COP) and second law efficiency i.e. (Exergetic efficiency) in comparison to R123yf.It was found that energetic and exergetic efficiency greatly affected by changes in evaporator and condenser temperature. R1234ze is the best among considered refrigerant since it has 218 times lower GWP values than R134a and R1234ze is eco-friendly has both ODP and GWP are lowest. The R1234yf and R1234ze can replace R-134a after 2030 due to low global warming potential.

Mishra et al[13] Performed first law and second law analysis of vapour compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with thirteen ecofriendly refrigerants have been presented and found that First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using R717 refrigerant is higher but is has toxic nature can be used by using safety measure for industrial applications also efficiency for R152a and R600 are nearly matching the same values are better than that for R125 at 313K condenser temperature and showing higher value of COP and exergetic efficiency in comparison to R125.For practical applications R-134a is recommended because it is easily available in the market has second law efficiency slightly lesser than R-152a which was not applicable for commercial applications. The worst component from the viewpoint of irreversibility is expansion valve followed by condenser, compressor and evaporators, respectively. The most efficient component found to be sub-cooler. The R-152a has least efficiency defects for 313K condenser temperature. The Performance evaluation of vapour compression refrigeration system when calculated nucleate heat transfer coefficient enhancement factor based on Al_2O_3 nanoparticle mixed in the ecofriendly refrigerant and implement into the program results is to be found as 23% using R134a and 18% when using R407c in the primary circuit. Performance evaluation of vapour compression refrigeration system when calculated nano-refrigerent property implement into the program based on Al_2O_3 nanoparticle mixed in the R134a ecofriendly refrigerant is 13% and Al_2O_3 nanoparticle mixed in the R407c is 9%. Performance evaluation of vapour compression refrigeration system when nanoparticle into refrigerant oil nanoparticle based on Al_2O_3 nanoparticle mixed in the ecofriendly R134a refrigerant is 11% The performance of vapour compression refrigeration systems using Al_2O_3 particles direct mixed in the R134a gives better first law performance than R407c and improvement in the first law performance is 28% using R134a and Al_2O_3 nano particles mixed with compressor oil and then used is 18.8% and 8% as heat transfer enhancement factor and implement into the refrigerant property and lowest improvement 2.64% when Al_2O_3 directly mixed with R407c, mixed with compressor oil and then used as refrigerant the primary circuit. Mishra et al [14] The computation modeling of vapor compression refrigeration systems was carried out for first and second law analysis in terms of energetic analysis i.e. COP (First law analysis) and exegetic analysis in terms of exergetic efficiency, exergy destruction ratio (EDR) and percentage exergetic destruction in each components (second law analysis). In this analysis we assumed negligible pressure losses and heat losses. The comparative performance of 4.75 KW window air conditioner is evaluated for condenser temperature varying between 300K to 327K with increment of 3 and evaporator temperature is varying from 274K to 278 K with increment of 1. The energy and exergy change in vapour compression refrigeration cycle have been calculated for various ecofriendly refrigerants such as R-1234yf, R-1234ze, R404a, R-290 (propane), R600 (butane), R-600a (isobutene) for environmental temperature of 298K. The variation of fist law efficiency in terms of cop and second law efficiency in terms of exergetic. As condenser temperature increases the first law efficiency decreases while second law efficiency decreases. Similarly with increasing evaporator temperature, the first law efficiency increases while second law efficiency decreases. Mishra et al [15] analyzed that first law and second law analysis of vapor compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with eco-friendly refrigerants in the system and R718 (water used in secondary circuit with and without nano particles mixed with water used as refrigerant) have been presented. He found that R718 mixed with nano particles gives better performance is than without nano particles used in the secondary circuit of water cooled evaporator for above mentioned eco-friendly refrigerants he also found that R152a refrigerant is higher but is has flammable nature similar to hydrocarbons then safety measures to be taken while using R152a or hydrocarbons (R290, R600 and R600a) efficiency improved by using TiO2 in the secondary evaporator circuit as compared to Al_2O_3 in the secondary circuit .

Alison et al [16] did an economic analysis based on thermodynamic performance by using expander in the refrigeration systems of a medium refrigerating load for ambient temperature of 35 °C, evaporating temperature of 7.2 °C and the condensing temperature of 54.4 °C was considered. Bjorn [17] presented a study by compared properties of hydrocarbons, namely propane, propene and isobutene with R134a, R22 and ammonia and predicted the higher performance of hydrocarbons over R134a and R22 in vapour compassion 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 throttle valve. This paper mainly deals with use of expander for replacing throttle valve so that net work done by vapour compression system is reduced which is a resultant of both compressor and expander work . We know that compressor is producing negative work and expander produced positive work. Therefore resultant work done by VCRS is reduced for same refrigerating capacity hence the first and second law efficiency [18]

Currently used third generation hydrofluorocarbon (HFC) refrigerants are known to be nonozone depleting agents, but are also characterized by their substantial global warming potential (GWP) values as shown in Fig.2 [19]

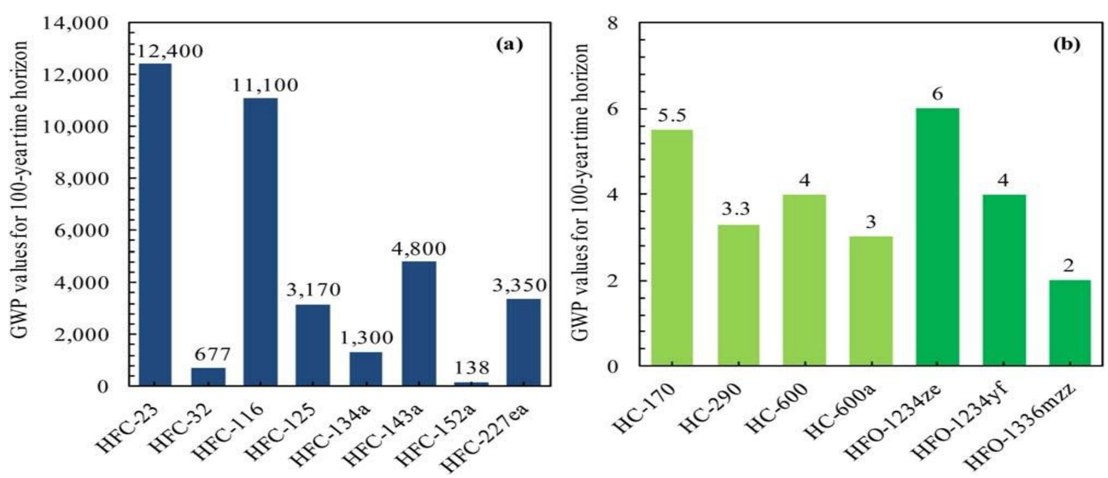

Figure 2: Hundred-year time horizon GWPs relative to CO2 of (a) HFC and (b) HC and HFO refrigerants [19]

Consequently, the year 2016 marked the launch of a global environmental deal to phase out the production and consumption of HFCs by years 2036 to 2047, starting in 2019. Most of the current effective (F-Gas in the European Union) and proposed (CARB and EC in North America) regulations target 150 GWP for refrigeration and 750 GWP for air conditioning applications, thus creating an immediate demand for developing new fourth generation refrigerants with low GWPs. In response to this need, the National Institute of Standards and Technology (NIST) recommended a list of new classes of refrigerants that would possess low values of GWPs based on estimates done using data on the chemical structure, the radiative efficiency, and the atmospheric lifetime of these molecules. Hydro-fluoro-olefins (HFOs) were included in the NIST list as one of the best candidates found so far, with GWP values comparable to those of hydrocarbon (HC)-based refrigerants. Furthermore, cycle performance tests carried out for HFOs shown in Fig.2 proved their suitability to act as a replacement for HFCs used in mobile air-conditioners, vending machines, and chillers. As a result, a major shift in the automobile industry is planned to start in the year 2017 to replace 1,1,1,2-tetrafluoroethane (HFC-134a) as a working fluid by 2,3,3,3-tetrafluoropropene (HFO-1234yf), a newly introduced fourth generation refrigerant. According to a roadmap report9 published in 2014 by the U.S. Department of Energy, the highest priority for research and development in refrigerants should focus on exploring and modeling the theoretical properties of low GWP azeotropic blends. Understanding the phase behavior and accurately predicting the thermo physical properties of these systems is essential for designing and evaluating refrigeration cycle performances and determining the optimal compositions. In addition, interfacial and transport properties of refrigerants play an important role in characterizing the two-phase heat transfer and fluid flow. Raabe and coworkers [20] have carried out a systematic study of thermo physical properties of selected HFOs and their mixtures by molecular simulations. The study includes vapor–liquid equilibrium (VLE) and thermo-physical properties of pure HFO refrigerants and their mixtures with carbon dioxide and HFCs. In terms of molecular theory, Lai and coworkers [21] applied the BACKBONE equation of state to predict the thermo-physical properties of pure HFO refrigerants. Moreover, Raabe [22] applied the perturbed chain form of the statistical associating fluid theory (PC-SAFT) to study the phase behavior of HFO-containing binary mixtures. However, multipolar interactions were not explicitly modeled within the SAFT framework.

To improve the coefficient of performance, its requires that the compressor work should decrease and refrigeration effect should increase. This paper mainly deals with replacing throttle valve by expander so that compressor work will reduced due to available net work done by the system which is compressor work minus expander work for same cooling capacity enhances first and second law efficiencies and increased exergy destruction ratio.

3. Results and Discussions

The performance of Vapour compression can be obtained by varying evaporator and condensing temperatures over the required range as shown in Table-1(a) to Table-13(c) respectively. Table-1(a-c) show the thermodynamic performances with various ecofriendly refrigerants for a given 50oC of condenser temperature and 0oC of evaporator temperature. The compressor and expander efficiency is taken to be 80% and it was observed that system-2 replace throttle valve has first law efficiency in terms of coefficient is higher (around 20% to 24%) than system-1 using throttle valve because of the effective net work done is reduced for same refrigeration effect hence increased and highest COP was found using R123 refrigerant. But R123 has chlorine content and second highest COP was observed by using R245fa and third highest COP was using hydrocarbon-R600. Although all three hydro-carbon have excellent first law performance (COP) but lower COP was observed between using hydrocarbons are by using hydrocarbon-R290. The first law efficiency (COP) of R134a is slightly less than hydrocarbon and but higher than R125, R407c, R410a and R404a, R-507a. Similar trends were observed for finding second law efficiency (in terms of exergetic efficiency) as shown in Table-1(b) respectively. The second law efficiency of system-2 using expander is higher than system -1 using throttle valve. The R245fa is second highest exergetic efficiency as shown in Table-1(b). Similarly EDR (exergy destruction ratio (i.e. which is a ratio of total exergy losses in the system to the exergy of product)) of the system is increased as exergetic efficiency is reduced as shown in table-1(c). Therefore, exergy destruction ratio using R123 refrigerant is reduced.

Table-1(a): Variation of first law efficiency (in terms of coefficient of performance) COP with different ecofriendly refrigerants of vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Refrigerant	System-1	System-2
1	R134a	3.246	3..928
2	R1234ze	3.215	3.931
3	R1234yf	3.027	3.806
4	R600a	3.291	3.953
5	R600	3.447	4.017
6	R290	3.166	3.89
7	R227ea	2.833	3.723
8	R236fa	3.168	3.897
9	R245fa	3.459	4.032
10	R407c	2.698	3.559
11	R410a	2.952	3.711
12	R404a	2.695	3.658
13	R152a	3.451	3.996
14	R717	3.546	3.847
15	R125	2.444	3.518
16	R123	3.575	4.082
17	R32	3.141	3.715
18	R507a	2.723	3.670

Table-1(b): Variation of second law efficiency (in terms of exergetic efficiency) COP with different ecofriendly refrigerants of vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Refrigerant	System-1	System-2
1	R134a	0.2973	0.3597
2	R1234ze	0.2944	0.360
3	R1234yf	0.2772	0.3485
4	R600a	0.3014	03620
5	R600	0.3157	03679
6	R290	0.2899	0.3563
7	R227ea	0.2594	0.3409
8	R236fa	0.2901	0.3569
9	R245fa	0.3168	0.3692
10	R407c	0.2470	0.3259
11	R410a	0.2703	0.3398
12	R404a	0.2468	0.3350
13	R152a	0.3160	0.3660
14	R717	0.3245	0.3523
15	R125	0.2238	0.3222
16	R123	0.3275	0.3738
17	R32	0.2877	0.3402
18	R507a	0.2493	0.3360

Table-1(c): Variation of exergy destruction ratio (EDR) based on system exergy output with different eco-friendly refrigerants of vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Refrigerant	System-1	System-2
1	R134a	2.364	1.78
2	R1234ze	2.396	1.778
3	R1234yf	2.608	1.869
4	R600a	2.318	1.763
5	R600	2.168	1.718
6	R290	2.45	1.807
7	R227ea	2.855	1.933
8	R236fa	2.447	1.802
9	R245fa	2.157	1.709
10	R407c	3.048	2.068
11	R410a	2.699	1.943
12	R404a	3.051	1.985
13	R152a	2.164	1.732
14	R717	2.080	1.838
15	R125	3.467	2.104
16	R123	2.059	1.675
17	R32	2.476	1.939
18	R507a	3.011	1.976

3.1 Performance evaluation of both systems using ecofriendly R245fa refrigerant

The thermodynamic performances using R245fa is given in tables-2 respectively. It is seen that COP increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve. Table-2(a) to Table-3(c) show the effects of evaporator and condensing temperatures with variation of thermodynamic performances of vapour compression refrigeration systems using R245fa refrigerant. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-3 respectively

Table-2(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R245fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	6.803	7.442
2	15	5.605	6.223
3	10	4.708	5.309
4	5	4.013	4.599
5	0	3.459	4.032
6	-5	3.008	3.568
7	-10	2.634	3.182
8	-15	2.319	2.856
9	-20	2.051	2.577

Table-2(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R245fa in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.1161	0.1270
2	15	0.1946	0.2161
3	10	0.2496	0.2814
4	5	0.2887	0.3309
5	0	0.3168	0.3692
6	-5	0.3367	0.3994
7	-10	0.3505	0.4234
8	-15	0.3596	0.4427
9	-20	0.3648	0.4583

Table-2(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R245fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	7.613	6.875
2	15	4.138	3.628
3	10	3.007	2.553
4	5	2.464	2.022
5	0	2.157	1.709
6	-5	1.970	1.504
7	-10	1.853	1.362
8	-15	1.781	1.259
9	-20	1.742	1.182

Table-2(a) shows the variation of first law efficiency (COP) as defined “refrigeration effect to the net (i.e. effective) work done” by the vapor compression refrigeration system with variation of evaporator temperature. As shown in the table for a given condenser temperature as evaporator temperature the specific refrigeration effect increases marginally. It can be seen that for a given evaporator temperature, the refrigeration effect decreases as condenser temperature increases. It can also be observed that the volumetric refrigeration effect increases rapidly with evaporator temperature due to the increase in specific refrigeration effect and decrease in specific volume of refrigerant vapour at the inlet to the compressor. Volumetric refrigeration effect increases marginally as condenser temperature decreases it shows that the specific work of compression decreases rapidly as the evaporator temperature increases and condenser temperature and pressure decreases. For a given condenser temperature, the work of compression increases initially, reaches a peak, then starts decreasing. This is due to the fact that as evaporator temperature increases the specific work of compression decreases and the specific volume at the inlet to the compressor also decreases. As a result, an optimum evaporator temperature and pressure exists at which the work of compression reaches a maximum. Physically, the work of compression is analogous to mean effective pressure of the compressor, as multiplying this with the volumetric flow rate gives the power input to the compressor. For a given power input, a high work of compression implies smaller volumetric flow rates and hence a smaller compressor shows the effect of evaporator and condenser temperatures on COP of the VCRS cycle. As expected, for a given condenser temperature the COP increases rapidly with evaporator temperature. For a given evaporator temperature, the COP decreases as condenser temperature increases. However, the effect of condenser temperature becomes marginal at low evaporator temperatures. The above results show that at very low evaporator temperatures, the COP becomes very low and also the size of the compressor becomes large (due to small refrigeration effect). It can also be shown that the compressor discharge temperatures also increase as the evaporator temperature decreases.

Table-3(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R245fa in the vapour compressor refrigeration system (System-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	6.478	7.005
2	35	5.411	5.949
3	40	4.605	5.154
4	45	3.971	4.532
5	50	3.459	4.032
6	55	3.034	3.619
7	60	2.675	3.273

Table-3(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R245fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	0.5932	0.6415
2	35	0.4955	0.5448
3	40	0.4217	0.4720
4	45	0.3637	0.415
5	50	0.3168	0.3692
6	55	0.2779	0.3314
7	60	0.2450	0.2997

Table-3(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R245fa in the vapour compressor refrigeration system (system-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1	System-2
1	30	0.6858	0.5589
2	35	1.018	0.8356
3	40	1.377	1.119
4	45	1.75	1.409
5	50	2.157	1.709
6	55	2.599	2.017
7	60	3.082	2.337

Table-4(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R236fa in the vapour compressor refrigeration system using system-1(throttle valve) and System-2using expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	6.459	7.296
2	15	5.278	6.081
3	10	4.395	5.170
4	5	3.712	4.462
5	0	3.168	3.897
6	-5	2.726	3.435
7	-10	2.361	3.052
8	-15	2.054	2.728
9	-20	1.793	2.451

Table-4(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R236fa in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.1102	0.1245
2	15	0.1833	0.2111
3	10	0.2330	0.2740
4	5	0.2671	0.3210
5	0	0.2901	0.3569
6	-5	0.3052	0.3846
7	-10	0.3142	0.4061
8	-15	0.3184	0.4229
9	-20	0.3190	0.4360

Table-4(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using RR236fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	8.072	7.032
2	15	4.457	3.736
3	10	3.292	2.649
4	5	2.744	2.115
5	0	2.447	1.802
6	-5	2.277	1.60
7	-10	2.183	1.462
8	-15	2.14	1.365
9	-20	2.135	1.294

3.2 Performance evaluation of both systems using ecofriendly R236fa refrigerant

The thermodynamic performances using R236fa is given in tables-4(a) to 5(c) respectively. It is seen that first law efficiency (COP) and second law efficiency (exergetic efficiency) increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-5 respectively

Table-5(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R236fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	6.21	6.88
2	35	5.141	5.825
3	40	4.33	5.028
4	45	3.689	4.403
5	50	3.168	3.897
6	55	2.733	3.478
7	60	2.362	3.122

Table-5(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R236fa in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-20.630
1	30	0.687	0.630
2	35	0.708	0.5334
3	40	0.3965	0.4604
4	45	0.3379	0.4032
5	50	0.2901	0.3569
6	55	0.2503	0.3185
7	60	0.2163	0.2859

Table-5(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R236fa in the vapour compressor refrigeration system (system-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1	System-2
1	30	0.7585	0.5872
2	35	1.124	0.8748
3	40	1.522	1.172
4	45	1.96	1.480
5	50	2.447	1.802
6	55	2.995	2.14
7	60	3.622	2.497

3.3 Performance evaluation of both systems using ecofriendly R227ea refrigerant

The thermodynamic performances using R227a is given in tables-6(a) to 7(c) respectively. It is seen that first law efficiency (COP) and second law efficiency (exergetic efficiency) increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-6 respectively. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-7 respectively. It was observed that the thermodynamic performances using R245fa is higher than R236fa and R227ea and exergy d destruction is more while using R227ea in the vapour compression refrigeration systems.

Table-6(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R227ea in the vapour compressor refrigeration system using (system-1: expander) and System-2 throttle valve.

S.No	*Evaporator Temperature (^{0}C)*	*System-1*	*System-2*
1	20	6.009	7.07
2	15	4.868	5.874
3	10	4.016	4.977
4	5	3.357	4.28
5	0	2.833	3.723
6	-5	2.408	3.268
7	-10	2.056	2.889
8	-15	1.763	2.570
9	-20	1.514	2.298

Table-6(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R227ea in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.1025	0.1206
2	15	0.1690	0.2040
3	10	0.2128	0.2638
4	5	0.2415	0.3079
5	0	0.2594	0.3409
6	-5	0.2695	0.3658
7	-10	0.2737	0.3845
8	-15	0.2733	0.3985
9	-20	0.2692	0.4087

Table-6(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R227eain the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	8.752	7.289
2	15	4.917	3.903
3	10	3.698	2.791
4	5	3.141	2.248
5	0	2.855	1.933
6	-5	2.711	1.734
7	-10	2.654	1.601
8	-15	2.659	1.510
9	-20	2.714	1.447

Table-7(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R227ea in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	5.928	6.748
2	35	4.850	5.686
3	40	4.026	4.879
4	45	3.371	4.243
5	50	2.833	3.723
6	55	2.378	3.217
7	60	1.985	2.912

Table-7(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R227ea in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	0.5429	0.6179
2	35	0.4441	0.5207
3	40	0.3687	0.4468
4	45	0.3087	0.3885
5	50	0.2594	0.3409
6	55	0.2178	0.3010
7	60	0.1818	0.2666

Table-7(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R227ea in the vapour compressor refrigeration system (System-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1	System-2
1	30	0.8421	0.6183
2	35	1.252	0.92.6
3	40	1.712	1.238
4	45	2.239	1.574
5	50	2.855	1.933
6	55	3.592	2.322
7	60	4.501	2.750

3.4 Performance evaluation of both systems using ecofriendly R-134a refrigerant

The thermodynamic performances using R134a is given in tables-8(a) to 9(c) respectively. It is seen from tables-8 that first law efficiency (COP) and second law efficiency (exergetic efficiency) increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-8 respectively. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-9 respectively.

It was observed that the thermodynamic performances in terms of COP and exergetic efficiency using R245fa is higher than R134a and R134a has more exergy destruction ratio while using R 245fa has lower EDR in the vapour compression refrigeration systems.

Table-8(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R134a in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	6.429	7.278
2	15	5.286	6.08
3	10	4.43	5.182
4	5	3.732	4.485
5	0	3.246	3.928
6	-5	2.819	3.473
7	-10	2.464	3.473
8	-15	2.167	2.775
9	-20	1.914	2.502

Table-8(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R134a in the vapour compressor refrigeration system (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.1097	0.1242
2	15	0.1836	0.2111
3	10	0.2350	0.2747
4	5	0.2714	0.3226
5	0	0.2973	0.3597
6	-5	0.3155	0.3887
7	-10	0.3280	0.4118
8	-15	0.3359	0.4303
9	-20	0.3404	0.4451

Table-8(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R134a in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	8.115	7.051
2	15	4.448	3.737
3	10	3.256	2.641
4	5	2.685	2.10
5	0	2.364	1.78
6	-5	2.169	1.572
7	-10	2.049	1.428
8	-15	1.977	1.324
9	-20	1.938	1.247

Table-9(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R134a in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	6.26	6.895
2	35	5.20	5.844
3	40	4.396	5.051
4	45	3.762	4.43
5	50	3.246	3.928
6	55	2.816	3.511
7	60	2.448	3.159

Table-9(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R134a in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	0.5732	0.6314
2	35	0.4762	0.5352
3	40	0.4026	0.4626
4	45	0.3445	0.4057
5	50	0.2973	0.3597
6	55	0.2578	0.3215
7	60	0.224	0.2893

Table-9(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R134a in the vapour compressor refrigeration system (System-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1 With throttle Valve	System-2 with expander
1	30	0.7445	0.5838
2	35	1.10	0.8685
3	40	1.484	1.162
4	45	1.902	1.465
5	50	2.364	1.780
6	55	2.878	*2.11*
7	60	3.461	2.457

3.5 Performance evaluation of both systems using ecofriendly R-1234yf refrigerant

The thermodynamic performances using R1234yf is given in tables-10(a) to 11(c) respectively. It is seen from tables-10 that first law efficiency (COP) and second law efficiency (exergetic efficiency) increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-10 respectively. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-11 respectively. It was observed that the thermodynamic performances in terms of COP and exergetic efficiency using R134a is higher than R1234yf and R134a has less exergy destruction ratio (EDR) while using R 1234yf has higher EDR in the vapour compression refrigeration systems.

Table-10(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R-1234yf in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	6.179	7.129
2	15	5.047	5.94
3	10	4.201	5.049
4	5	3.547	4.358
5	0	3.027	3.806
6	-5	2.604	3.355
7	-10	2.255	2.981
8	-15	1.962	2.665
9	-20	1.714	2.396

Table-10(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R134a in the vapour compressor refrigeration system (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.1055	0.1217
2	15	0.1752	0.2062
3	10	0.2227	0.2676
4	5	0.2552	0.3135
5	0	0.2772	0.3485
6	-5	0.2915	0.3756
7	-10	0.3001	0.3967
8	-15	0.3042	0.4132
9	-20	0.3049	0.4261

Table-10(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R134a in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	8.483	7.22
2	15	4.707	3.849
3	10	3.491	2.736
4	5	2.919	2.19
5	0	2.608	1.869
6	-5	2.43	1.663
7	-10	2.332	1.521
8	-15	2287	1.42
9	-20	2.28	1.347

Table-11(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R-1234yf in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	6.099	6.79
2	35	5.0260	5.738
3	40	4.208	4.942
4	45	3.559	4.315
5	50	3.027	3.806
6	55	2.579	3.380
7	60	2.192	3.017

Table-11(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R-1234yf in the vapour compressor refrigeration system using (System-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	0.5585	0.6218
2	35	0.4602	0.5255
3	40	0.3853	0.4526
4	45	0.3259	0.3952
5	50	0.2772	0.3485
6	55	0.2362	0.3096
7	60	0.2008	0.2762

Table-11(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R-1234yf in the vapour compressor refrigeration system (system-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1 With throttle Valve	System-2 with expander
1	30	0.7906	0.6082
2	35	1.173	0.9030
3	40	1.595	1.210
4	45	2.068	1.531
5	50	2.608	1.869
6	55	3.234	2.230
7	60	3.981	2.620

Table-12(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of evaporator temperature using R1234ze in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	6.446	7.308
2	15	5.287	6.10
3	10	4.421	5.196
4	5	3.75	4.493
5	0	3.215	3.931
6	-5	2.78	3.472
7	-10	2.42	3.09
8	-15	2.117	2.768
9	-20	1.86	2.493

Table-12(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R1234ze in the vapour compressor refrigeration system (System-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	0.110	0.1247
2	15	0.1836	0.2118
3	10	0.2343	0.2754
4	5	0.2697	0.3232
5	0	0.2944	0.360
6	-5	0.3112	0.3887
7	-10	0.3221	0.4113
8	-15	0.3283	0.4292
9	-20	0.3308	0.4434

Table-12(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R1234ze in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Evaporator Temperature (^{0}C)	System-1	System-2
1	20	8.091	7.019
2	15	4.447	3.721
3	10	3.268	2.631
4	5	2.707	2.094
5	0	2.396	1.778

6	-5	2.213	1.573
7	-10	2.105	1.431
8	-15	2.046	1.330
9	-20	2.023	1.255

3.6 Performance evaluation of both systems using ecofriendly R-1234ze refrigerant

The thermodynamic performances using R1234ze is given in tables-12(a) to 13(c) respectively. It is seen from tables-12 that first law efficiency (COP) and second law efficiency (exergetic efficiency) increases as evaporator temperature increases and exergy destruction ratio is decreases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-12 respectively. Similarly first law efficiency (COP) and second law efficiency (exergetic efficiency) decreases as condenser temperature increases and exergy destruction ratio is increases. It is seen that sytem-2 using expander gives better first law performance than system-1 using throttle valve as shown in Tables-13 respectively. It was observed that the thermodynamic performances in terms of COP and exergetic efficiency using R134a is slightly higher than R1234ze and R134a has slightly less exergy destruction ratio while using R 1234ze has higher EDR in the vapour compression refrigeration systems.

Table-13(a): Variation of first law efficiency (in terms of coefficient of performance) COP with variation of condenser temperature using R1234ze in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	6.264	6.928
2	35	5.192	5.868
3	40	4.379	5.067
4	45	3.737	4.439
5	50	3.215	3.931
6	55	2.779	3.51
7	60	2.407	3.154

Table-13(b): Variation of second law efficiency (in terms of exergetic efficiency with variation of evaporator temperature using R1234ze in the vapour compressor refrigeration system using (system-1: throttle valve) and System-2.expander

S.No	Condenser Temperature (^{0}C)	System-1	System-2
1	30	0.5736	0.6345
2	35	0.4755	0.5373
3	40	0.4010	0.4640
4	45	0.3422	0.4065
5	50	0.2944	0.360
6	55	0.2545	0.3214
7	60	0.2205	0.2888

Table-13(c): Variation of exergy destruction ratio (EDR) based on system exergy output with variation of evaporator temperature using R1234ze in the vapour compressor refrigeration system (System-1: throttle valve) and System-2.expander

S.No	Condenser temperature (^{0}C)	System-1 With throttle Valve	System-2 with expander
1	30	0.7434	0.5761
2	35	1.103	0.8611
3	40	1.494	1.155
4	45	1.922	1.460
5	50	2.396	1.778
6	55	2.929	2.111
7	60	3.536	2.463

4. Conclusion

Following conclusions were drawn from thermodynamic analysis of vapour compression refrigeration system using (system-1: throttle valve and system-2: expander).

(i) The first law efficiency of vapour compression refrigeration system using expander is higher than other VCRS (system-1) using throttle valve.

(ii) The exergy destruction ratio (EDR) of VCRS is decrease in condenser temperature/ pressure and hence second law efficiency is increased.

(iii) Increase in temperature of evaporator/ pressure, the first law efficiency of vapour compression refrigeration system and second law efficiency of vapour compression refrigeration system is increased while the work input and Exergy destruction ratio is will decrease.

(iv) Decrease in temperature of condenser/ pressure, the first law efficiency of vapour compression refrigeration system and second law efficiency of vapour compression refrigeration system is decreased while the work input and exergy destruction ratio is will increase.

(v) Using expander in system-2 replaced throttle valve has higher first law efficiency in terms of coefficient is higher and second law efficiency in terms of exergetic efficiency (around 20% to 24%) than system-1 using throttle valve. Using R123 refrigerant in the vapour compression refrigeration system has highest COP.

(vi) R123 refrigerant has chlorine content. Therefore HFO refrigerants gives better thermodynamic performances can replace R134a abnd other HFC refrigerants, R152a and hydrocarbons have flammable nature, therefore R1234ze and R1234yf can replace R134a in near future.

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