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Irreversibility Reduction in Vapour Compression Refrigeration Systems Using Al_2O_3 Nano Material Mixed in R718 as Secondary Fluid

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ABSTRACT

The several methods are available in the literature for improving first law efficiency in terms of coefficient of performance. The second law efficiency is helped for finding the irreversibilities the systems. The uses of nano refrigerants in the vapour compression refrigeration play a very important role for reducing irreversibility in the system and improving its thermodynamic performances. This paper describes thermal modelling of vapour compression refrigeration system using energy - exergy analysis. In this system, the utility of ecofriendly twelve refrigerants in primary circuit is highlighted and Al2O3-Water based nanofluids in secondary circuit. This model takes care the nanoparticles mixed in the fluids as input conditions in the secondary evaporator circuit as geometric characteristics of the system such as size of nanoparticles and the compressor speed to predict the secondary fluids output temperatures, the operating pressures, the compressor power consumption and the system overall energy performance. Such design analysis is conveniently useful to compare the thermal performance of different nano-particles of Al2O3 based nano-fluid as a secondary fluid in a vapour compression refrigeration system. The influence of input variables on the irreversibilities in terms of exergy destruction ratio of the system is presented. Such a model can also be used to design various components viz. evaporator, compressor, condenser and throttle valve for vapour compression refrigeration systems for any desired cooling capacity. This model takes care of use of nanofluids as a secondary fluid in vapour compression refrigeration systems and simulate the non linear equations of the system. The use of R407c as ecofriendly refrigerants is quite adequate while first law performance improvement is around 13.491% by using nano particles. The % improvement in first law efficiency is found to be 11.04% by using nano particles as compared to without nano particles. While by using R134a 12.60% improvement. Similarly It was also observed that second law performance improvement is ranging between 15% to 39.13%. The better second law efficiency is 39.13% improvement due to, by using R1234yf as compared to 16.52% improvement by using R1234ze in the primary evaporator circuit. The reduction in the irreversibility in terms of exergy destruction ratio in the system and maximum exergy destruction ratio around 25.294% was observed by using R152a and exergy destruction ratio is 22.79% by using R290 hydrocarbon and 23.403% by using R407c as ecofriendly refrigerant. The Reduction in EDR is 20.09% by using R404a, and 21.37% by using R134a. The R1234ze and R1234yf have slightly less reduction in EDR as compared by using R134a.

Keywords: *Performance Improvement; Reduction in System Irreversibility, Energy-Exergy Analysis; Vapour Compression Refrigeration System; Ecofriendly Refrigerants; Second Lawefficiency Improvement*.

1.0 Introduction

Global warming potential and ozone layer depletion are one of the important issues in front of the researcher. As R22 and R12 is the most widely used as refrigerants in industrial and household applications .Lately it was found that these have high value of ozone depletion potential. Most of researches are going on searching better refrigerant and replacement of old refrigerants have high global warming potential and ozone depletion potential with modern one have low both GWP and ODP values . First law analysis (energy analysis) is restricted to calculate only coefficient of performance of system but exergy analysis is the one of the most useful analyses to evaluate the plant losses, the actual

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amount of energy flow through process exergetic efficiency and exergetic destruction ratio. Comparative analysis of three refrigerants (R134a, R1234yf and R1234ze) working in a multi-evaporators VCR system with subcooling and superheating and using of both energy and exergy analysis on multi-evaporators vapor compression refrigeration system emphasized on replacement of R134a with R1234ze and R1234yf is also a important Because R134a having high global warming potential (GWP=1426), on the other hand R1234ze has zero ODP & 6 GWP) and R1234yf (GWP =4 and zero ODP) respectively.

2.0 Use of Nano Refrigerants in Vapour Compression Refrigeration System

Vapour compression is used to transfer heat from low temperature zone higher temperature zone. It has four thermodynamics process as below. Isobaric Evaporation, Isentropic Compression, Isobaric Condensation, Throttling (Expansion), Vapour compression cycle can be used in temperature range 50°C to -40°C easily. Nowadays, there is a high energy consumption associated with refrigeration and air conditioning systems. Most of these facilities are based on the vapour compression cycle. In order to reduce their consumption, it is necessary both to have efficient systems and to operate them properly. To achieve these objectives, it is convenient to use complete models, which take under consideration a large amount of factors and facilitate the design of efficient systems. The heat transfer from the refrigerant at the compressor discharge line to the condenser inlet has been modeled, due to the considerable length of the line in the experimental chiller facility, using expression. The condenser behavior is modeled by dividing the heat exchanger into two zones: the superheated vapor zone and the condensing zone, assuming no sub-cooling at the condenser outlet, as it has been stated in the assumptions.

The overall heat exchanger is then For the computation of the convection heat transfer coefficient associated to the refrigerant one can distinguish between the convection heat transfer coefficient in the superheated vapor zone modeled with two energy balances, one using the secondary fluid heat flow rate. By using nanofluid in secondary circuit we can increase the performance of VCS by 15-18 %. Comparison was made using other eco friendly refrigerant it may reached upto 22 %. Also by using nanoparticles, one can reduce the evaporator size as well as condenser size for the fixed cooling capacity which helps for reducing the minimum cost of manufacturing. Nanofluid is a fluid containing nanometer-sized particles, called nano-particles. These fluids are engineered colloidal suspensions of nano-particles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Knowledge of the rheological behaviour of nanofluids is found to be very critical in deciding their suitability for convective heat transfer applications.

In analysis such as computational fluid dynamics (CFD), nanofluids can be assumed to be single phase fluids. However, almost all of new research papers, uses two-phase assumption. Classical theory of single phase fluids can be applied, where physical properties of nanofluid are taken as a function of properties of both constituents and their concentrations. An alternative approach simulates nanofluids using a two-component model.

Synthesis of nanofluids:

Nanofluids are supplied by two methods called the one-step and two-step methods. Several liquids including water, ethylene glycol, and oils have been used as base fluids. Nanomaterials used so far in nanofluid synthesis include metallic particles, oxide particles, carbon nanotubes, grapheme nano-flakes and ceramic particles.

3.0 Literature Review

Few studies have been illustrated as a part of literature review related to theoretical study and experimental investigation of refrigeration systems based on first law and second law analysis with different ecofriendly refrigerants. M.Ghanbarpour (2014) investigated thermal properties and rheological behavior of water based Al2O3 nanofluid as a heat transfer fluid and found that Thermal conductivity and convective heat transfer of nanofluid increases due to increase in mass concentration of nanofluids. Mishra[12].

presented the Effect of different nano-particle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid, By analyzing the effect of nanoparticle in terms of volume fraction on overall heat transfer coefficient, entropy generation & heat transfer rate and found that by increasing the volume fraction of nanoparticle the overall heat transfer coefficient & heat transfer rate increases and entropy generation decreases. Mishra [13] had experimentally investigated increase in heat transfer coefficient by using Fe2O3/water nanofluid in an air finned heat exchanger concluded that the nanofluid have greater heat transfer coefficient compared with water and also found that the increasing the inlet liquid temperature decreases the overall heat transfer coefficient and increasing liquid and air Reynold number also increases the overall heat transfer coefficient

Mishra[7] presented an experimental analysis of the influence of an internal heat exchanger on the performance of a vapour compression system using R1234yf as a drop-in replacement for R134a and compared the energy performance of a monitored vapour compression system using both refrigerants,R134a and R1234yf, with and without the presence of an internal heat exchanger under a wide range of working conditions. He has carried out experimental tests by varying the condensing temperature, the evaporating temperature and the use of internal heat exchanger. And observed the reductions in cooling capacity and COP between 6% to 13%, when R134a is replaced by the drop-in fluid R1234yf, although the presence of an heat exchanger can help to lessen these reductions between 2 and 6%. Mishra [16] studied Heat transfer and flow characteristics of AL2O3–water nanofluid in a double tube heat exchanger and evaluated viscosity, relative viscosity of nanofluid at different mass fraction and sizes of nanoparticles and found that viscosity, Nusselt number increases due to mass fraction and size of nanoparticles. For a given refrigerating mass faction of nanoparticles, viscosity, Nusselt number. Reynolds number increases of base fluid. Chopra [1] explained the nature of the effect of fouling on performance parameters (such as compressor power consumption and COP) as well as properties (such as condenser pressure and superheat temperature at the compressor exit) using a simple vapour compression cycle in order to augment theoretical studies found in the open literature. The results of the experiments indicate that the above-mentioned quantities demonstrate a logarithmic behavioural change when the ambient and room temperatures are kept constant. Chopra[5] presented a comparable evaluation of R600a (isobutane), R290 (propane), R134a, R22, for R410a, and R32 and optimized finned-tube evaporator by analyzing the evaporator effect on the system coefficient of performance (COP) without accounting for evaporator effects, the COP spread for the studied refrigerants was as high as 11.7% by including evaporator effects, the COP of R290 was better than that of R22 around 3.5%, while the remaining refrigerants performed approximately within a 2% COP band of the R22 baseline for the two condensing temperatures considered. Mishra[15] had evaluated the performance parameters of a vapour compression refrigeration system with different lubricants including nanolubricants and derived conclusions that the R134a refrigerant and mineral oil mixture with nanoparticles worked normally and Freezing capacity of the refrigeration system is higher with SUNISO 3GS + alumina nanoparticles oil mixture compared the system with POE oil. The power consumption of the compressor reduces by 25% when the nanolubricant is used instead of conventional POE oil and the coefficient of performance of the refrigeration system also increases by 33% when the conventional POE oil is replaced with nano refrigerant (v) the energy enhancement factor in the evaporator is 1.53.

Mishra[13] had investigated the use of nanofluids as secondary coolants in vapor compression refrigeration systems and developed simulation model for a liquid-to-water heat pump, with reciprocating compressor and double-tube condenser and evaporator and conducted studied of different nanoparticles (Cu, Al2O3, CuO and TiO2) in terms of different volume fraction and particle diametersand observed that that, for a given refrigerating capacity, evaporator area and refrigerant-side pressure drop are reduced when: (i) the volume fraction of nanoparticles increase; (ii) the diameter of nanoparticles decrease. Similarly the nanofluid side pressure drop and, consequently, pumping power, increase with nanoparticle volume fraction and decrease with nanoparticle size. Mishra [17] had proposed a lumped model for vapour compression refrigeration system to find out the effect of variable compressor speed, mass flow rate of brine, mass flow rate of water, inlet water temperature, inlet brine temperature on the C.O.P of lumped model. Simulation program have been prepared and result are plotted for the same. Mishra [2, 4, 9] studied the performance degradation due to fouling in a vapour compression cycle has investigated for various applications. Considering the first set of refrigerants i.e. R134a, R410a and R407a, and found that from a first law stand point, the COP indicates that R134a always performs better unless only the evaporator is being fouled and also a second-law standpoint, the second-law efficiency indicates that R134a performs the best in all cases. For second set of refrigerants (i.e. R717, R404a and R290) from a first law standpoint, the COP of R717 is better unless only the evaporator is being fouled. In contrast to this, from a second-law standpoint, the second-law efficiency of R717 is best in all cases.

Volumetric efficiency of R410a and R717 remained the highest under the respective conditions and performance degradation of the evaporator has a larger effect on compressor power requirement while that of the condenser has an overall larger effect on the COP. A.S. Dalkilic et al (2010) also presented a theoretical performance studies on a traditional vapour compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a for various ratios and their results are compared with CFC12, CFC22, and HFC134a as possible alternative replacements.

In spite of the HC refrigerants' highly flammable characteristics, they are used in many applications, with attention being paid to the safety of the leakage from the system, as other refrigerants in recent years are not related with any effect on the depletion of the ozone layer and increase in global warming. Lot of theoretical results showed that all of the alternate refrigerants investigated in the analysis have a slightly lower performance coefficient (COP) than CFC12, CFC22, and HFC134a for the condensation temperature of 50 °C and evaporating temperatures ranging between −30 °C and 10 °C. Refrigerant blends of HC290/HC600a (40/ 60 by wt.%) instead of CFC12 and HC290/HC1270 (20/80 by wt.%) instead of CFC22 are found to be replacement refrigerants among other alternatives. The following conclusions were drawn from literature review

1 Performance analysis of VCS has been done for different type of refrigerant its combination/mixture.
2 Performance parameter of nanofluid for different concentration of nano particles.
3 Many of the literatures present also show heat transfer enhancement property using nanofluid.
4 But almost none of the literature represents the use of nanofluid (containing nanoparticle) as a secondary fluid in VCS (chiller system) for different types of eco friendly refrigerants and also the effect of this secondary fluid on the energetic efficiency of VCS and the effect of nanoparticle plated material used in condenser and evaporator on the performance of VCS.

4.0 Research Gaps Identified

Lots of researches have been done and going on based on the performance evaluation of various combinations of different types of refrigerant and also nanoparticle behavior on the nanofluid. On the other hand the performance of VCS using nanofluid (with different nanoparticle) for different types of eco friendly refrigerant is yet to be analyzed. Th use nano fluid in VCS (chiller system) is presented in this paper and, the performance evaluation of vapour compression refrigeration system is explored by using new and alternative ecofriendly refrigerants HFO1234yf, HFO1234ze backed by the fact that they are more environments friendly can replaced. R134a, R407c, R404a and R125 in the coming future. This paper presents following research objectives.

Thermodynamic analysis of simple vapour compression system using twelve ecofriendly alternative refrigerants.Thermodynamic analysis in terms of % improvement in first law efficiency and second law efficiency by using exergetic analysis of simple vapour compression system using Al2O3 as nanofluid and comparison of results of performance evaluation in terms of reduction in irreversibility without nanofluid and with nanofluids.

5.0 Results and Discussions

The performance **of** HFO1234yf, HFO1234ze backed by the fact that they are more environments friendly can replaced. R134a, without nano fluid are presented in the Fig-1-8 and with nano mixed with water is also presented in Table-1-4 respectively.

From Fig-(1), it was observed that first law efficiency in terms of COP increases with increasing evaporator temperature and decreases with increasing condenser temperature. Similarly from fig -2, the second law efficiency id decreases with increasing evaporator.

The system defect in terms of exergy destruction ratio is increases as shown in Fig-3. The increases in superheating in evaporator at condenser inlet, the first law efficiency (i.e. COP) and second law efficiency is increases as shown in Fig (4-5) respectively.

Similarly by increasing condenser temperature the first law efficiency (COP) and exergetic efficiency of system is decreases as shown in Fig-(6)& (7) respectively.

Fig: 1. Variation of COP with evaporators' Temperatures

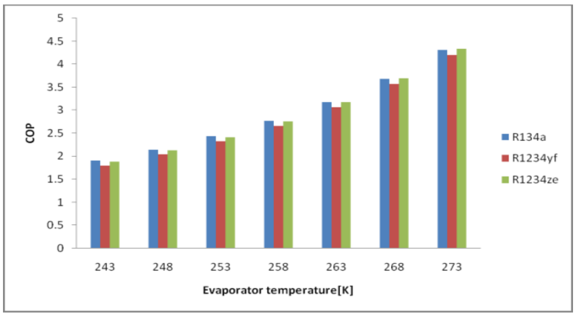

Fig: 2. Variation of exergetic efficiency with evaporators' temperatures

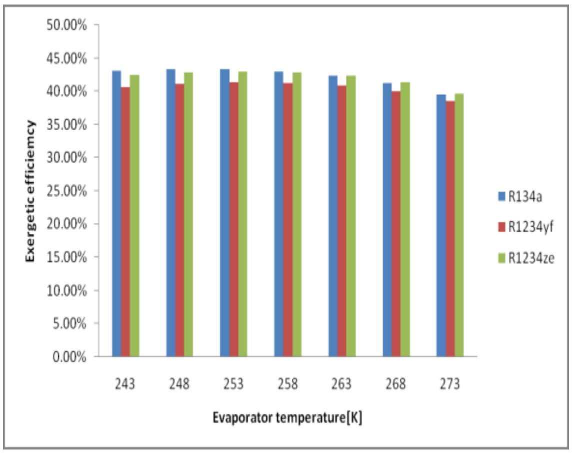

Fig: 5. Variation of exergetic efficiency with degree of subcooling at condenser outlet

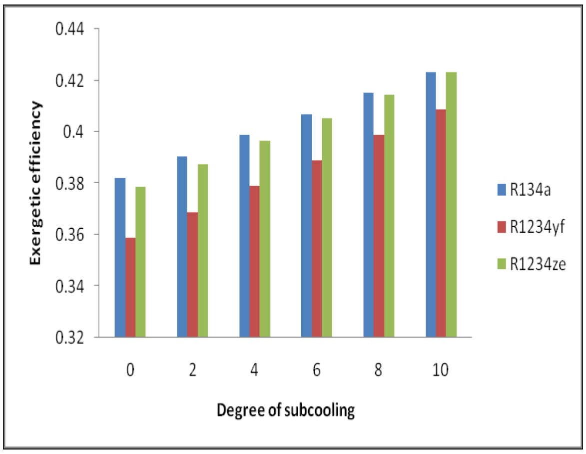

Fig: 3. Variation of system defect with evaporator temperatures

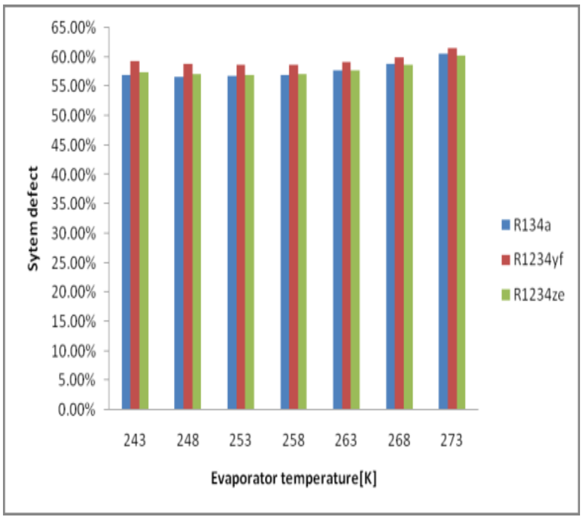

Fig: 6. Variation of COP with condenser temperature

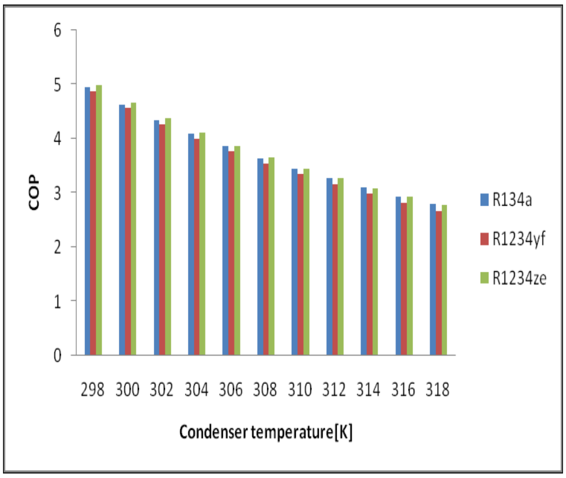

Fig: 4. Variation of COP with degree of subcooling at condenser outlet

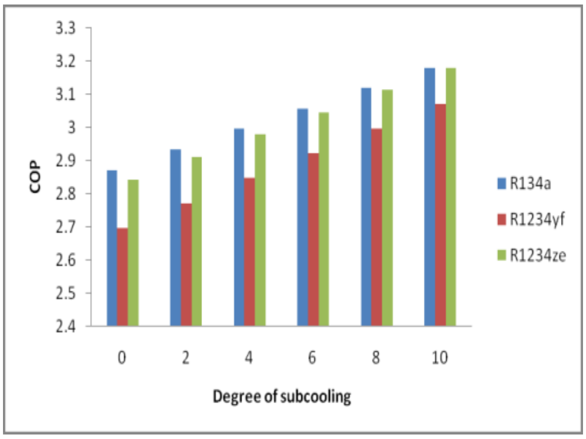

Fig: 7. Variation of exergetic efficiency with condenser temperature

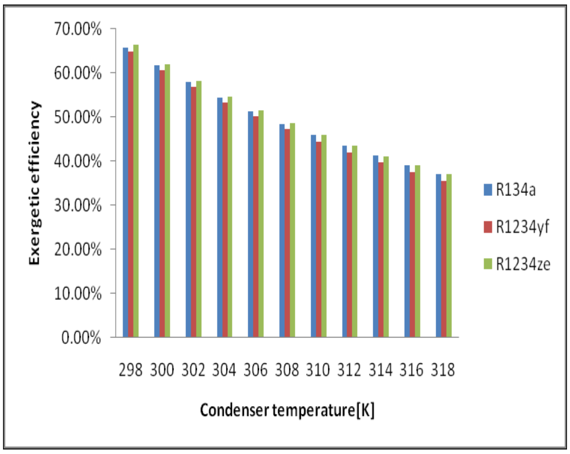

Table-1 shows the % improvement in first law efficiency in terms of cop improvement by using nano particles mixed with R718 in the secondary evaporator circuit it was observed that first law efficiency without nano particles using R152a is maximum while by using R410a is minimum however second highest is found to be by using R290 as hydrocarbon in the primary evaporator circuit. The use of R407c as ecofriendly refrigerants is quite adequate while first law performance improvement is around 13.491% by using nano particles. The % improvement in first law efficiency is found to be 11.04% by using nano particles as compared to without nano particles. While by using R134a 12.60% improvement was observed. The use of hydrocarbons (R290, R600a and R600) and R152a is prohibited due to flammable nature, therefore other ecofriendly R134a, R404a, R407c, R507a and R125 refrigerants are used due to reduction in global warming and ozone depletion. Due to1300 global warming potential of R134a, the next alternate refrigerant R1234yf (GWP=4, and ODP=0) is suitable which can replace R134a in the coming future. It was also observed that without using nano particles, the first law performance by using R1234ze is better than R1234yf.

Table: 1. Performance evaluation (% Improvements in first law efficiency) of vapour compression refrigeration system using ecofriendly refrigerant in the primary circuit and water flowing in the condenser in secondary circuit and brine flow in the secondary circuit in the evaporator using Al2O3 as nano material of 10 micron size

Refrigerant	COP with Al_2O_3 nano	COP without nano	% Improvement in first law efficiency
R1234yf	4.002	3.604	11.0432
R1234ze	3.836	3.434	11.7064
R134a	4.36	3.872	12.6033
R404a	4.316	3.862	11.7555
R407c	4.736	4.173	13.4914
R152a	5.169	4.531	14.0807
R507a	4.328	3.868	11.8924
R125	4.044	3.646	10.916
R600a	4.009	3.617	10.8377
R600	3.605	3.217	12.0609
R290	4.826	4.274	12.9153

Table-2: shows the second law efficiency in terms of exergetic efficiency for twelve ecofriendly refrigerant and second law performance improvement while by using nano particles, in terms of exergetic efficiencyand maximum exergetic efficiency is found by using R152a as ecofriendly refrigerant and second highest is also found by using R290 hydrocarbon as ecofriendly refrigerant in the primary evaporator circuit. The second law performance by using R134a, R404a, R507a and R125 as nearly similar with small variations. while R152a and hydrocarbon is prohibited due to flammable nature, and also R134a, R404a , R507a and R125 are having higher global warming potential , therefore R1234yf and R1234ze can replace these refrigerants in the future. It was also observed that second law performance is better due to 39.13% improvement by using R1234yf as compared to 16.52% improvement by using R1234ze in the primary evaporator circuit.

Table: 2a. Performance evaluation (% Improvements in second law efficiency) of vapour compression refrigeration system using ecofriendly refrigerant in the primary circuit and water flowing in the condenser in secondary circuit and brine flow in the secondary circuit in the evaporator using Al2O3 as nano material of 10 micron size

Eco friendly Refri-gerants	Exergetic efficiency with Al2O3 nano particles	Exergetic efficiency without nano	% improve-ment in second law efficiency
R1234yf	0.3360	0.2415	39.1304
R1234ze	0.3174	0.2724	16.5198
R134a	0.3761	0.3215	16.9828
R404a	0.3712	0.3204	15.8551
R407c	0.4162	0.3552	17.1734
R152a	0.4666	0.3952	18.0668
R507a	0.3725	0.3211	16.0074
R125	0.3407	0.2962	15.0236
R600a	0.3368	0.2930	14.9488
R600	0.2916	0.2481	17.5332
R290	0.4282	0.3665	16.8349

Table: 2b. Performance evaluation (% Improvements) of vapour compression refrigeration system using ecofriendly refrigerant in the primary circuit and water flowing in the condenser in secondary circuit and brine flow in the secondary circuit in the evaporator using Al2O3 as nano material of 10 micron size

Refrige Eco Friendly refri-gerants	Exergetic efficiency with nano	Exergetic efficiency without nano	% improve Ment in second law effectiveness
R1234yf	0.4479	0.4035	11.0037
R1234ze	0.4294	0.3844	11.7065
R134a	0.4880	0.4334	12.59806
R404a	0.4831	0.4323	11.7511
R407c	0.5301	0.4671	13.487476
R152a	0.5786	0.5072	14.077287
R507a	0.4844	0.4330	11.87067
R125	0.4527	0.4087	10.765843
R600a	0.4486	0.4049	10.79279
R600	0.4036	0.3601	12.07998
R290	0.5402	0.4784	12.91806

Table: 3. Reduction in irreversibility in terms of exergy destruction ratio of vapour compression refrigeration system using ecofriendly refrigerant in the primary circuit and water flowing in the condenser in secondary circuit and brine flow in the secondary circuit in the evaporator using Al2O3 as nano material of 10 micron size

Refrigerant	EDR with nano	EDR without nano	% reduction In EDR
R1234yf	1.976	2.43	18.6831
R1234ze	2.15	2.67	19.4756
R134a	1.659	2.11	21.3744
R404a	1.694	2.12	20.0943
R407c	1.391	1.816	23.403
R152a	1.143	1.53	25.2941
R507a	1.685	2.114	20.2932
R125	1.935	2.377	18.5948
R600a	1.969	2.413	18.4003
R600	2.429	3.03	19.8349
R290	1.335	1.729	22.7877

Table: 3. represents the reduction in the irreversibility in terms of exergy destruction ratio in the system and maximum exergy destruction ratio around 25.294% was observed by using R152a and exergy destruction ratio is 22.79% by using R290 hydrocarbon and 23.403% by using R407c as ecofriendly refrigerant. The Reduction in EDR is 20.09% by using R404a and 21.37% by using R134a. The R1234ze and R1234yf have slightly less reduction in EDR as compaired by using R134a

6. Conclusions

In this paper, first law and second law analysis of vapour compression refrigeration system with and without nano particles using ecofriendly refrigerants (R134a, R1234yf, and R1234ze) have been presented. And following conclusions have been drawan:

(i) First law and second law efficiency for vapour compression refrigeration system without Al2O3 nano particles mixed in R718 in the secondary evaporator circuit and ecofriendly 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.

(ii) Both energetic and exergetic increase with increase in degree of subcoolingIt 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 ecofriendly has both ODP and GWP are lowest.

(iii) The R1234yf and R1234ze can replace R-134a after 2030 due to low global warming potential.

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