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Methods for enhancing energetic-exergetic performances of vapour compression refrigeration system using HFO-1336mzz(Z) refrigerant through Nano materials mixed with R-718 fluid in secondary circuit of evaporator

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Abstract

Lot of literature is available on the performance enhancement of vapour compression & vapour absorption refrigeration system (VCRS & VARS). In any case, investigators have experienced point by point first law investigation in term of coefficient of performance (COP) of VCRS. Researchers also have been studied the impact of Nano fluids on thermal conductivity enhancement. However, researchers did not go through irreversibility analysis using exergy destruction ratio of system ($EDR_{rational}$) that can be defined as a rational EDR (i.e. which is a ratio of summation of system's lost work in terms of exergy destruction of all components to exergy of fuel) as well as EDR_{system} (i.e. it is a ratio of total lost work to exergy of product) of VCRS using new low GWP refrigerants(i.e. HFO-1336mzz(Z), R1225ye(Z), R1224yd(Z), R1243zf, R1233zd€ , R1234ze€, R1234ze€ and R1234yf) for replacing HFC-134a.
This paper primarily deals with comparison between Nano materials that have been utilized in secondary circuit of cooling heat exchanger, which enhances cooling temperature as a result of increase in COP. The improvement in first law efficiency (i.e. COP) by using copper oxide (CuO), aluminum oxide (Al_2O_3), and Titanium oxide (TiO_2) was found to be as 18.5%, 17.5%, and 15.95%, respectively alongside enhancement in cooling heat exchanger overall heat transfer coefficient by using CuO, Al_2O_3, & TiO_2 was about 107.7%, 98.6%, and 86.4%, respectively. Similarly, enhancement in condenser overall heat transfer coefficient by using CuO, Al_2O_3, and TiO_2 was about 11.24%, 10.77%, and 9.94%, respectively. Furthermore, improvement in second law (exergetic) performance by using CuO, Al_2O_3, and TiO_2 was about 13.93 %, 12.94 %, and 11.5%, respectively. The comparison were also made for replacing R134a by new HFO refrigerants and it was found that the second law exergetic performance was improved by 8.16% without Nano materials using R-1233zd(E) 5.86% using R1224yd(Z) and 3.059% using HFO-1336mzz(Z)by replacing R134a.

Keywords: First & second law efficiency, COP, EDR, ecofriendly refrigerants, nano materials

1. Introduction

The concept of refrigeration is known by heat rejection from a space at a temperature lesser than temperature of surrounding. Now COP can be defined as ratio of effect of refrigeration produced at section of heat absorption to input work through compressor. Also, COP could be enhanced either by declining compressor's input work by multistage compression process/ cascade refrigeration or by increasing effect of refrigeration [1]. Further, HFO refrigerants (i.e. R1234yf & R1234ze) and hydrocarbons like propane (R290) & isobutene (R600a) refrigerants have a low mass flow rate as competed with R134a refrigerant. As can be seen, both specific volume and temperature of refrigerant decreases as mass flow rate going to be decrease. As a result, compressor work also reduces and COP increases. Besides, R600a is an environmental safety refrigerant, whose ozone depletion potential (ODP) & global warming potential (GWP) is less than three [2].
The new ecofriendly such as R1233zd(E) and R1224yd(Z) refrigerants are especially promising low-GWP alternatives to the HFC R134a and R245fa.For instance, the German Environment Agency intends to prohibit the application of R1233zd(E), due to its ODP of 0.00024. However, R1233zd(E) has several favorable aspects, such as a very low GWP and no flammability and toxicity (safety classification of A1). This proves, that the very small ODP by R1233zd(E) and R1224yd lead to no significant increase of the external costs. Thus, a general prohibition of potentially promising refrigerants with a very small ODP appears not be

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justifiable based on the presented results. The electrical powers are lower by using HCFO-1233zd-E as compared to R134a As a conclusion, it can be stated, that both novel fluids R1233zd(E) and R1224yd(Z) are suitable for the drop-in replacement of R245fa in refrigeration systems . However, the results show, that the compatibility of R1233zd(E) and R1224yd(Z), with the is compared to replace R245fa and R134a, it is found that when R1233zd(E)is used, for finding the system performances , the highest power output is still obtained with the high-GWP fluid R245fa and R134a which is 7% to 9% The exergy of fuel with R245fa is 0.42% higher compared to R1233zd(E) and 8% higher compared to R1224yd(Z). In terms of thermal efficiency of the ORC system, R1233zd(E) leads to approximately 2% higher values compared to R245fa. In contrast to that, the thermal efficiency of R245fa and R1224yd(Z) is equal over a wide range of operation conditions. R1336mzz(Z) (also referred to as HFO1336mzz(Z)) provides approximate thermodynamic property data for cis-1,1,1,4,4,4-Hexafluoro-2-butene, MW 164.056 gm/mole, CAS# 692-49-9). The fundamentals of choosing a good working refrigerants are based on system optimization to maximize the thermodynamic performance characteristics in terms of first and second law efficiencies, these novel HFOs are being developed, like HFO-1336mzz(E) and R1336mzz(Z), to meet the more stringent regulations of low GWP and no ODP and they demonstrate the known characteristics of a good working fluids – stability, compatibility, favorable toxicity and performance even at high temperatures. The HFO-1336mzz(E) has 7.5ºC boiling point, critical temperature of 137.7ºC and critical pressure of 3.15 MPa. Whereas R-1336mzz(Z) has slightly higher boiling point of 33.4ºC, critical temperature of 171.3ºC and lower critical pressure of 2.90 MPa. The compressor efficiency, superheat (ΔTsh), sub cooling (ΔTsc) and lift temperatures were fixed variables is this calculation, the condensing temperatures were adjusted so higher temperature effects could be evaluated for each working fluid. HFO1336mzz isomers (E and Z) and had the excellent first law efficiency (COPs) amongst than the HFC Refrigerants (such as R134a, R410a, R404a, R407c, R507a, R125a) but lower than R245fa due to and power required to run compressors is 8.63% higher than R245fa. Similarly the HFO (hydrofluoroolefin) are going to be our future refrigerants with low ozone depletion potential (ODP) and low global warming potential (GWP). The basic properties of new future HFO refrigerants expected as R410a and R32 alternatives which are presently used in refrigerators and room air conditioners. R1243zf is expected to be a good alternative with its flammability, which is A2 category for replacing R134a. Triple point data of a refrigerant, is very important for refrigerating industry defined the lowest temperature range at which any refrigerant may circulate in liquid state. The triple point of R1243zf is 122.8K and the normal boiling temperature and critical pressure are 247.73 K and 3630.6 kPa, respectively.

Second method for enhancing COP of Refrigeration system is sub cooling in condensers that result in high heat rejection, it is further possible by arranging the more number of fins on condenser, high thermal conductivity material for condenser coil & fins. The implications of Nanoparticles in refrigeration systems are a new, innovative technique to augment the efficiency [3].

In order to enhance rate of heat transfer in VAR system, Nano fluids could be utilized, and as can be seen, their use can remarkably improve the thermo-physical and heat transfer capabilities. Nano fluids have an ability to show important characteristics, for e.g. high specific surface area due to which more heat transfer surface available amongst particles and fluids, dispersion stability can be also high, pumping power could be reduced in contrast to pure liquid and particle clogging could be also reduced [3]

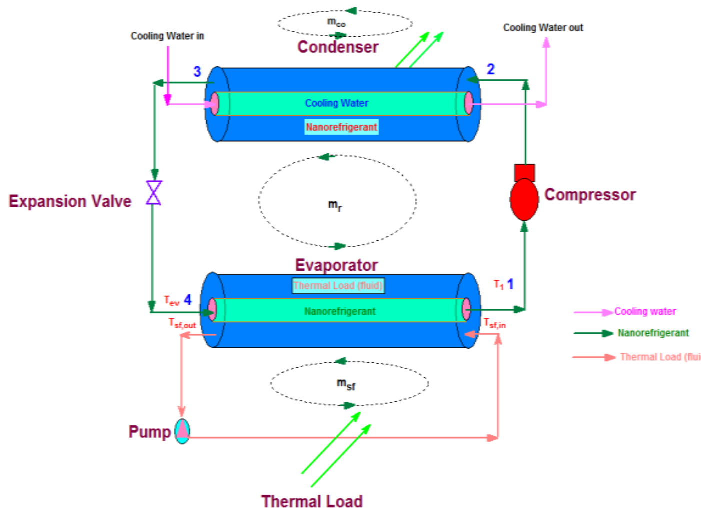

Figure 1: schematic of Vapour compression refrigeration system [3]

2. Methods for improving thermal performance of VCRS

To improve the thermal performance of VCRS, following methods can be employed:

- First law efficiency can be improved by sub-cooling of condenser, superheating of evaporator & by using liquid vapour heat exchanger.
- First law efficiency can be improved by using new HFO refrigerants
- Second law efficiency can be improved by the reduction of exergy destruction by improving cycle design and flow arrangement.
- Second law efficiency can be improved by using new HFO refrigerants

Arora and Kaushik [4] carried out theoretical analysis of actual VCRS with liquid vapour heat exchanger & also carried out analysis on basis of energy, entropy, & exergy in specific temperature range of evaporator and condenser. Besides, they concluded that R502 fluid was best refrigerant as compared to R404A and R507A fluid. Getu and Bansal [5] optimized operating parameters, for e.g. temperature of condenser sub cooling, evaporator superheating along with temperature overlapping in cascade heat exchanger R744-R717 fluid based cascade refrigeration cycle. Mohanraj et al. [6] investigated experimentally domestic refrigerator under different temperatures of environmental and they computed cycle's COP using mixture of R290 & R600a fluid in ratio of 45.2:54.8 by weight and found it up to 3.6% higher than same cycle via R134a. Anand and Tyagi [7] carried out detailed exergy analysis of 2TR window air conditioning test rig by via R22 fluid and assessed that compressor's irreversibility was highest among other components. Reddy et al. [8] performed numerical investigation of VCRS by using R134a, R143a, R152a, R404A, R410A, R502, & R507A fluid and reported that temperature of evaporator and condenser have crucial effect on both COP & exergetic efficiency. In addition, they found that R134a fluid has better performance than R407C fluid.

Mastani Joybari et al. [9] done experimental investigation on a domestic refrigerator and concluded that compressor's exergetic destruction was highest in contrast to other components. Ahamed et al [10] carried out exergy based investigation of the VCRS and evaluated thermodynamic performance of hydrocarbons, mixture of hydrocarbons, & R134a. Additionally, they found that higher exergy destruction occurred in compressor as rivaled with other VCRS' components. Elcock [11] employed TiO2 Nanoparticles as additives to enhance solubility of mineral oil & reported that the refrigeration cycles using a mixture of HFC134a fluid and mineral oil along with TiO2 Nanoparticles can provide better thermodynamic performance. Hindawi [12] conducted an experimental investigation on boiling heat transfer performance of R22 cooling fluid with Nanoparticles made up from Al2O3 and found that Nanoparticles has an ability to enhance cooling fluid heat transfer performance. Liu et al. [13] assessed effects of carbon Nanotubes on nucleate boiling heat transfer of R123 & HFC134a cooling fluid. They also described that carbon Nanotubes can enhanced coefficient based on nucleate boiling heat transfer for these cooling fluids. Besides, they noticed that large enhancements can be possible up to 36.6% at low heat fluxes less than 30 kW/m^2. Jiang et al**.** [14] experimentally found that thermal conductivity of carbon Nanotube Nano refrigerants is much superior to that of R113 Nano refrigerants and also found that thermal conductivity of Nano fluids also depend on Nanoparticles size & temperature. Huang et al. [15] compared thermal conductivity of Nano fluid with the base fluid and concluded that the multiwall carbon Nano tube has noticeably higher thermal conductivity than that of SiO_2 Nanoparticles in identical base fluid. Yoo et al**.** [16] argued that ratio of surface area to volume of Nanoparticles is a dominant factor that influences the Nano fluids thermal conductivity rather than Nanoparticles thermal conductivity. The ratio of surface area to volume is increased with smaller sizes of Nanoparticles. Choi et al. [17] reported a 150% thermal conductivity enhancement of poly (a-olefin) oil with addition of multiwall carbon Nanotubes (MWCNT) at 1% volume fraction. Yang, et.al, [18] observed that 200% thermal conductivity enhancement for poly (a-olefin) oil containing 0.35% MWCNT and also found that thermal conductivity enhancement was associated through a three order of magnitude increase in viscosity. Eastman et al. [19] found a 40% thermal conductivity enhancement for ethylene glycol with 0.3% copper Nanoparticles with 10 nm diameter. Kang et al. [20] reported an enhancement in thermal conductivity of about 75% for ethylene glycol through 1.2% concentration of diamond Nanoparticles between 30 and 50 nm in diameter. Lee et al. [21] found that thermal conductivity of Nano fluids can be affected by pH level and addition of surfactant. They achieved better dispersion of Nanoparticles through addition of surfactant such as sodium dodecylbenzene sulfonate. Moreover, they also stated that optimum combination of pH and surfactant can leads to enhancement in thermal conductivity. Wu et al. [22] observed that at low concentration of TiO2 Nanoparticles in R11 fluid, pool boiling heat transfer might be enhanced and it might be deteriorated under state of high concentration of Nanoparticles. Trisaksri and Wongwises [23] employed TiO_2 in HCFC 141b in a cylindrical copper tube and found that nucleate pool boiling heat transfer can be deteriorated with enhance in concentration of Nanoparticles concentrations. Hao et al. [24] carried out effect of Nanoparticles concentration, mass fluxes, heat fluxes, & inlet vapor qualities on the characteristics of heat transfer coefficient of refrigerant-based Nano fluid. Also they observed that it was larger than that of pure refrigerant by 29.7% along with 0–0.5 wt% mass fraction of Nanoparticles. Hao et al. [25] studied nucleate pool boiling heat transfer of refrigerant/oil mixture with diamond Nanoparticles and found that it was larger than that of R113/oil mixture by maximum of 63.4%. Wang et al. [26] carried out an experimental study of boiling heat transfer of R22 cooling fluid through the Al2O3 Nanoparticles and found that Nanoparticles can enhance the refrigerant heat transfer phenomenon. Li et al. [27] observed the pool boiling heat transfer of R11 cooling fluid through TiO2 Nanoparticles and showed that heat transfer enhancement can reached up to 20% at a particle loading of 0.01 g/L. Peng et al. [28] investigated the effect of Nanoparticles on heat transfer of cooling based Nano fluids and found that heat transfer coefficient was higher by about 29.7% than that of pure refrigerant. Kumar D.S. and Elansezhian R. [29] experimentally observed consequence of concentration of ZnO Nano particles in order of 0.1%, 0.3%, & 0.5% with size of 50 nm particle on VCRS and also found maximum COP of 3.56 & 21% decline of power input was obtained with 0.5% concentration of ZnO. Mahbubul et al. [30] studied physical properties based on pressure drop & investigated performance based on heat transfer of Al_2O_3 Nanoparticles suspended in R-134a fluid & found that thermal conductivity of Al_2O_3/R-134a Nano-refrigerant can enhance through the augmentation of particle concentration and temperature; however, it can decrease by rise in particle size. In addition, they assessed that a significant increment in viscosity, pressure drop, & coefficient of heat transfer of Nano-refrigerant by enhance of volume fractions.

Mishra et al. [31] evaluated the VCRS' performance by utilizing Cu, Al_2O_3, CuO, & TiO_2 fluid based Nano refrigerants in primary circuit. Their experimental results found that overall C.O.P by using Al_2O_3/R134a Nano fluids was enhanced by 35% that was highest among all other Nano refrigerants. Sabareesh et al [32] experimentally found the 17% increase in COP by using 0.01% by volume concentration TiO2 Nano fluid in VCRS as a lubricant additive. Sajadi A.R. et.al. [33], observed the turbulent convective heat transfer coefficient and pressure drop of TiO_2 dispersed in water Nano fluid in the circular tube and also as contrast the experimental results with correlation of Nusselt number and not concluded that how much (%) convective coefficient of heat transfer can be improved.

Zeinali S Heris et.al [34] experimentally found the increment in convective heat transfer in laminar flow forced convection heat transfer because of increase in thermal conductivity of Nano fluid. Shengshan Bi et al. [35] assessed enhancement in performance of VCRS along with reduction in power utilization up to 25% by mixed mineral oil TiO2 as lubricant along with R600a refrigerant. Subramani & Prakash [36] observed enhancement in performance of domestic refrigerator via Al_2O_3 at 0.06% weight in the mineral oil. The improved COP of a domestic refrigerator by 19.6% & decline utilization of power by 11.5% due to an enhancement in coefficient of heat transfer by using Nano fluid Al2O3 & R600a/mineral oil as working fluid. Abbas et al. [37] performed study of an air conditioning cycle through concentration of 0.01-0.1wt% of carbon Nano tubes polyester oil with refrigerant R134a and found that 4.2% enhancement in COP by using carbon Nanotube particles with concentration of 0.1% by weight. Hussen [38] showed enhancement in conventional refrigeration system with Nano cooling fluid and found that compressor work decreases by about 13.3%. Sharif M.Z., et.al. [39], studied Mechanism for improvement in refrigeration system performance by using Nano refrigerants and Nano lubricants and found 14% improvement.

The above researchers have not yet studied properly effect of Nano particles on performance of VCR system using HFO-1336mzz(z). Based on the literature, it was observed that investigators have gone through detailed first and second law analysis of simple VCRS with single evaporator. Also, Investigators analyzed effect of Nano fluids on simple VCRS; however, they did not go through irreversibility analysis in terms of EDR. Therefore present investigation has been carried out with aim of overall thermal performance enhancement in terms of first law efficiency and second law efficiency along with various efficiencies of compressor.

3. Results and Discussion

The following input values have been taken for numerical computations

- Mass flow rate of brine flow in secondary circuit of evaporator is ranging from 0.006 (kg/sec) to 0.012 (Kg/sec)
- Mass flow rate of water flow in secondary circuit of condenser is ranging from 0.006 (kg/sec) to 0.015 (Kg/sec)
- Inlet brine flow temperature in secondary circuit of evaporator is 27^{o}C
- Inlet water flow temperature in secondary circuit of evaporator is 27^{o}C
- Inlet pressure of brine evaporator temperature=2 (bar)
- Inlet pressure of water flow in condenser temperature=2 (bar)
- Length of evaporator heat exchanger= 0.72 m
- Length of condenser heat exchanger= 1.2 m
- Air pressure= 1.05 (bar)

The properties of Nano fluid is computed as shown in Table-1.

Table 1: *Properties of Nanomixed fluid obtained in VCRS*

Performance Parameters	CuO	Al_2O_3	TiO_2
Effective mixture density (kg/m^3)	13.93	1145	1155
Effective mixture specific heat (J/KgK)	2965	3590	3558
Effective mixture thermal conductivity (W/mK)	31.33	16.62	9.727
Effective mixture viscosity	0.00365	0.00365	0.00365
Prandtl No of Nano Mixture	0.3457	0.7795	1.336
Effective mixture density (Kg/m^3)	1393	1145	1155

Table-2 shows the variations of Reynolds number in capillary tube by using different Nano materials mixed with in R718 fluid flowing in the secondary circuit of evaporator and HFO1336mzz(Z) fluid flowing in primary circuit of evaporator. By comparing results of system's properties with-and- without Nanoparticles, higher Reynolds number was observed by using copper oxide and lowest by using TiO_2. It has also been found that enhancement in Reynolds number by using CuO, Al_2O_3, and TiO_2 is about 48 %, 45.7%, and 42.3%, respectively. Similarly, enhancement in Reynolds number for condenser tube by using CuO, Al_2O_3, and TiO_2 is about 3.2%, 3.11%, 2.96%, respectively.

Table-2: Variations of Reynolds numbers with Nano materials in VCRS

Reynolds numbers	CuO	Al_2O_3	TiO_2	Without Nanoparticles
Reynolds number in Capillary Tube	27097	26671	26047	18309
Reynolds number in Condenser Tube	206819	206601	206312	200375
Reynolds number of brine flow	104.3	104.3	104.3	104.3

Table-3 shows the variations of first law performance by using different Nano materials mixed with in R718 fluid flowing in secondary circuit of evaporator and HFO1336mzz(Z) fluid flowing in primary circuit of evaporator. By comparing results of system's properties with-and- without Nanoparticles, higher COP was observed by using CuO and lowest by using TiO_2. It has also been found that enhancement in COP by using CuO, Al_2O_3, and TiO_2 is about 18.5%, 17.5%, and 15.95%, respectively. Similarly, enhancement in second law in condenser tube is by using CuO, Al_2O_3, and TiO_2 is about 13.9%, 12.9%, and 11.5%.

Table-4 demonstrates variations of compressor efficiencies with Nano particles mixed with in R718 fluid flowing in secondary circuit of evaporator and HFO1336mzz(Z) fluid flowing in primary circuit of evaporator. It has been found that compressor efficiencies by using CuO is highest and by using TiO_2 is lowest that significantly affecting first and second law efficiency of VCR system.

Table 3: Variations in first law efficiency, second law efficiency, and other performance parameters of VCRS by using HFO1336mzz(Z) ecofriendly refrigerant

Performance Parameters	CuO	Al_2O_3	TiO_2	HFO1336mzz(Z) without Nanoparticles
1st Law efficiency $(COP)_{\_Actual}$	3.507	3.477	3.432	2.960
Exergetic Efficiency	0.3923	0.3892	0.3842	0.3436
Overall evaporator heat transfer coefficient $U_{\_Eva}$ (W/m^2K)	1380.01	1320.01	1239.0	664.62
Over All Condenser heat transfer coefficient $U_{\_Cond}$ (W/m^2K)	717.61	714.01	708.64	644.56

Table 4: variations of compressor efficiencies with Nano particles mixed with in R718 fluid flowing in secondary circuit of evaporator and HFO1336mzz(Z) fluid flowing in primary circuit of evaporator.

Compressor efficiency	CuO	Al_2O_3	TiO_2
Isentropic Efficiency	0.8169	0.8131	0.8094
Volumetric Efficiency	0.6299	0.6289	0.6275

Apart from this, Table 5 illustrates variation in evaporator heat transfer coefficient, condenser heat transfer coefficient first and second law efficiencies, EDR of system, and rational EDR percentage enhancement by using CuO, Al_2O_3, and TiO_2.

Table 5: variations in enhancement in Performance parameters VCRS

% Enhancement in the Performance Parameters	CuO	Al_2O_3	TiO_2
First law Efficiency	18.48	17.47	15.95
Second law Efficiency	13.93	12.94	11.49
Exergy Destruction Ratio	6.07	6.83	6.06
Evaporator Overall heat transfer coefficient (W/m^2K)	107.66	98.63	86.44
Condenser Overall heat transfer coefficient (W/m^2K)	11.24	10.77	9.94

Table-6: Comparison between ecofriendly refrigerants with HFC-134a in VCRS

Performance Parameters	COP	Exergetic Efficiency	EDR
HFO-1336mzz(Z)	2.960	0.3436	1.91
R1234ze(E)	2.80	0.3293	2.037
R1233zd(E)	3.080	0.3608	1.772
R1243zf	2.76	0.3247	2.08
R1225ye(Z)	2.754	0.3240	2.086
R1224yd(Z)	3.10	0.353	1.833
R1234yf	2.59	0.3060	2.265
R134a	2.835	0.3334	1.999

Table-6 shows the variations of first and second law performances by using different low GWP refrigerants mixed with in R718 fluid flowing in secondary circuit of evaporator and found that R1224yd(Z) gives best first law thermodynamic performances and slightly higher than R1233zd(E). However second law exergetic performance is lower. Similarly R1233zd(E) gives better second law exergetic performance as compared to R1224yd(Z). However thermodynamic performances of HFO1336mzz(Z) fluid flowing in primary circuit of evaporator is also lower than R1233zd(E) and higher than R1243zf, R1234yf and R1225ye(Z) and R-134a. The lowest first law performance was observed by using R1234yf.

Table-7(a) and Table-7(b) show the performance improvement in the first and second law performances by using different low GWP refrigerants mixed with in R718 fluid flowing in secondary circuit of evaporator and found that the second law exergetic performance was improved by 8.16% without Nano materials using R-1233zd(E) 5.86 using R1224yd(Z) and 3.059% using HFO-1336mzz(Z)by replacing R134a

Table-7(a): Percentage improvement using following ecofriendly low GWP refrigerants with HFC-134a in VCRS

Performance Parameters	% improvement of first law Efficiency(COP)	% improvement/ of second law Exergetic Efficiency
HFO-1336mzz(Z)	4.409	3.059
R1233zd(E)	8.642	8.22
R1224yd(Z)	9.347	5.87
R134a	0.0	0.0

Table-7(b): Percentage decrement using following ecofriendly low GWP refrigerants with HFC-134a in VCRS

Performance Parameters	% decrement of first law Efficiency (COP)	% decrement of second law Exergetic Efficiency
R1234ze(E)	-1.234	-1.23
R1243zf	-2.65	-2.61
R1225ye(Z)	-2.857	-2.82
R1234yf	-8.862	-8.22
R134a	0.0	0.0

4. Conclusions

The following results have been concluded from research work: It has been pointed out that enhancement in first law efficiency by using CuO, Al_2O_3, and TiO_2 is about 18.5%, 17.5%, and 15.95%, respectively. Furthermore, improvement in evaporator overall heat transfer coefficient by using CuO, Al_2O_3, and TiO_2 is about 107.7%, 98.6%, and 86.4%, respectively. Moreover, improvement in condenser overall heat transfer coefficient by using CuO, Al_2O_3, and TiO_2 is about 11.2%, 10.8%, and 9.9%, respectively. Lastly, improvement in second law efficiency by using CuO, Al_2O_3, and TiO_2 is about 13.9%, 12.9%, and 11.5%, respectively. For comparison between ecofriendly refrigerants for replacing HFC-134a, it is found that R1224yd(Z) gives best first law thermodynamic performances and slightly higher than R1233zd(E). However second law exergetic performance is lower. Similarly R1233zd(E) gives better second law exergetic performance as compared to R1224yd(Z).

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