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RESEARCH ARTICLE

Thermodynamic performances comparison of VCR system using HFO& HCFO refrigerants in primary and nano mixed brine and glycol-based fluid flow in secondary circuit evaporator

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Abstract

Extensive research has been conducted on the impact of extremely low GWP eco-friendly HFO, HCFO, and low GWP HFO & HCFO refrigerants on their first and exergy performances. In the primary circuit of the evaporator and the secondary circuit, comparisons were made between two nano mixed fluid flows (brine water and glycol) and also without nano materials using eight eco-friendly low global warming potential refrigerants (five HFO, two HCFO, and three HFO & HCFO low GWP) and found that using HCFO-1233zd(E) refrigerant in the primary circuit and brine flow with mixed CuO nano materials in brine fluid flowing in the secondary circuit of the evaporator gives optimum (best) thermodynamic second law (exergy) performances. The improvement in energy efficiency (22.9%), exergy efficiency (25.625%), overall evaporator heat transfer (65.83%) and overall condenser heat transfer 9.1% by using CuO nano mixed brine water and energy efficiency (8.63 %) and exergy efficiency (13.25%), overall evaporator heat transfer (52.1%) and overall condenser heat transfer (7.9%) using CuO nano mixed glycol fluid and HCFO-1233zd(E) in primary circuit of evaporator respectively. The lowest improvement in energy efficiency (8.6%) exergy performances (10.05%), evaporator heat transfer (3.4%) and condenser heat transfer (1.96) were observed by using HFO-1234yf in primary circuit and TiO2 mixed glycol based nano fluid in the evaporator.

1. Introduction

A major part of the modern lifestyle we lead today involves refrigeration. It can be used for a great deal of things in both home and business settings. The majority of these systems function according to the work-based cycle principle of a VCR system. Natural refrigerants have been utilized for many years in several applications, including CFCs, HCFCs, HFCs, HCs, and their mixes. Several of these refrigerants have been found to be extremely dangerous for the environment, thinning the ozone layer and increasing the likelihood of global warming. Since then, researchers have been working to develop new refrigerants that will both solve the previously mentioned environmental issues and increase the efficiency of existing systems. The use of nanofluids is one of these more modern advances in refrigeration systems. Nanoparticles, which are only quantifiable at the nanoscale, are the building blocks of a nanofluid. Nano refrigerants, which are a colloidal suspension of nanoparticles in the base refrigerant, have gradually become one of the most promising and efficient heat transfer fluids in a range of thermal engineering applications due to their improved

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thermophysical properties [1]. Experimental research was done on the functionality and dependability of a home refrigerator that had nanoparticles in its working fluid. The use of mineral oil with TiO_2 nanoparticles mixtures instead of Polyol-ester (POE) oil. requiring 26.0% less energy with 0.1% mass fraction TiO_2 nanoparticles perform better than the HFC134a is investigated [2,3].

Several studies were conducted studies at varying concentrations by combining two different nanoparticles, such as ZnO and SiO_2 in a VCR system using R600a with ZnO and SiO_2 hybrid nano lubricants. on such compressor power consumption, cooling capacity, and coefficient of performance using hybrid nano lubricants, and found experimentally more than 40% improvement in the system's performance coefficient, and rise in cooling capacity and a reduction in compressor electrical power consumption by using 40 g of R600a refrigerant and 0.4 g/L of ZnO/SiO_2 and also, 0.6 g/L ZnO/SiO_2 with 60 g of R600a refrigerant [4]. The effectiveness of R134a-ZrO_2 nano refrigerants at a concentration of 0.2 g/l in a domestic refrigerator without altering the constituent parts examined experimentally. After charging 140 g of R134a and 0.2 g/L of ZrO_2 nanoparticles with a particle size of 1–10 nm, studies were conducted to examine the refrigerator's performance [5]. The suction and discharge pressures, refrigeration effect, power consumption, and COP) of usual refrigerants influenced by several nanoparticles such as TiO_2, Al_2O_3, CuO, SiO_2, ZnO, ZrO_2, ZnO/SiO_2, diamond. A novel fluid with unique properties, nanofluid finds application in a wide range of industrial heat transfer processes [6]. Four mixture nanofluid samples at four different volume concentrations were used and found that the two-step method of dispersing nanoparticles into Jatropha oil was responsible for the largest increase in thermal conductivity for CuO-Jatropha oil nanofluids. three factors: temperature, volume concentration, and volume concentrations of the mixture of nanoparticles interrupts the thermal conductivity of CuO-Jatropha oil nanofluids. The rise in thermal conductivity and viscosity was influenced by nanoparticles at temperatures ranging from 298 to 323 K, according to the results. The invention of nano refrigerants has significantly raised the productivity of refrigeration systems. Nano refrigerants have superior thermal and heat transfer properties. Thermal conductivity, viscosity, COP, and energy savings were assessed theoretically for volume concentrations of 0.5, 1, 2, and 3 vol% in HFC-134a and HFC-152a refrigerants using single walled carbon nanotubes (SWCNTs) nanoparticle [7]

Few investigators observed nucleate pool boiling, convective flow boiling, and condensation affected by physical properties (such as surface tension, specific heat, density, and viscosity of nano refrigerants and found the heat transfer was boosted. The overall heat transfer coefficient was increased as the mass fraction of nanoparticles in the refrigerant increased. Several investigators found that pure refrigerants have lower heat conductivities than nano refrigerants. The power consumption reduced by 2.5% while the performance coefficient increased by 4.5%. The performance of a refrigerator with 0.1% mass fraction of TiO_2 nanoparticles was found to be 26.1% better than that of a refrigerator with an HFC134a and POE oil system [8]. The improvement in the energy efficiency (COP) for both nano refrigerants was caused by the notable heat conductivity of nanoparticles. When compared to R134a-based nano refrigerants, R152a-based nano refrigerants have demonstrated the highest COP values. When compared to base refrigerant R152a, the R152a-based nano refrigerant demonstrated a maximum increase in COP of 1.43% [9].

For performance enhancement in VCR systems, HFC-134a in the primary circuit and an Al_2O_3 water-based nanofluid in the secondary circuit is used and a thermal model for determining the energy-exergy performances of VCR systems was developed [10]. This model predicts the operational pressure, temperature, power consumption, and overall system performance while accounting for the size of the nanoparticles, compressor speed, and other geometric parameters of the secondary fluid. The system energy performance was improved around 17% [10]; The effects of temperature and volume on the viscosity of R123-TiO_2 nano refrigerant at temperatures ranging from 5°C to 20°C and with a maximum volume concentration of 2% of nanoparticles. Investigations have also been conducted into the impact of pressure drop with increasing viscosity [11]. According to the investigation, the viscosity of the nano refrigerant reduces with rising temperatures and increases in proportion to increasing volume concentrations of nanoparticles. Also, as volume concentrations increase, pressure drop increases prominently. As a result, modest volume concentrations of nano refrigerant are recommended to improve refrigeration system performance [12].

The impact on the energy performance (C.O.P.) and the thermophysical features of various nanoparticles added to eco-friendly HFC refrigerants and their blended refrigerant mixtures. The experimental results validate in comparison to base refrigerant and found the specific heat of nano-refrigerant is slightly lower. Similar improvements were seen in the thermal conductivity, dynamic viscosity, and density of the eco-friendly refrigerant R134a, R407c, and R404a when combined with various nanoparticles like Cu, Al_2O_3, CuO, and TiO_2. These improvements ranged from 15% to 25%, 20%, and 12 to 35%, respectively. Furthermore, at 35%, the C.O.P. of the Al_2O_3/R134a Nano refrigerant is the greatest. Using various nanoparticles, R404a and R407c demonstrate improvements in C.O.P. of approximately 3 to 14% and 3 to 12%, respectively [13].

2. Use of Nano refrigerants in VCR systems

In a refrigeration system where, suspended nanoparticles are evenly distributed throughout a continuous base refrigerant, nano refrigerant fluid is utilized. Because of its lengthy history of improving thermodynamic energy and energy performances, it has played a significant role in the development and enhancement of current refrigeration systems. A great deal of important research has been done on the thermal conductivity of nanofluids and nanorefrigerants based on water. It has been shown that fluids without particles or fluids with oxide particles do not exhibit the dramatically enhanced thermal conductivity increases that nanofluids containing Cu nanoparticles directly distributed in ethylene glycol do [14]. The large improvement in effective conductivity obtained for nanofluids containing metallic particles holds significant potential for revolutionizing industries that are dependent on the performance of heat transfer fluidsThe thermal conductivity of CNT-based nano-refrigerants is enhanced compared to the base refrigerants fluid (W. Jiang et al. [15]).

[16] R-134a-CuO combination in the same horizontal tubes with POE as a lubricant and observed 100 %. improvement in heat transfer coefficient has been observed [17], the concentration of nanoparticles in the host refrigerant causes an increase in the conductivity ratio between pure and nano refrigerant [18]. On the other hand, eco-friendly HFC-134a with CuO nanoparticles has a maximum effectiveness factor of approximately 3.2 at 5 vol%, while CuO nanoparticle-based nano refrigerants have a higher conductivity ratio than other nanoparticles and are approximately two times higher than base refrigerant at 5 vol% concentration. In the secondary circuit of the evaporator, the copper mixed nano refrigerant has the largest convective heat transfer coefficient ratio compared to other nanoparticles mixed in brine water. The effectiveness factor also increases as the percentage of volume (vol%) grows. The thermal performance of low global warming potential (GWP) refrigerants, such as HFCs and HFOs, in the evaporator's primary and secondary circuits has been the subject of numerous studies. Thermal conductivity, dynamic viscosity, and density of nano-refrigerant (different nanoparticles, such as CuO, Al2O3, and TiO2) increased by approximately 15%, 20%, and 12%, respectively, in comparison to base refrigerant R134a, R407c, and R404A [19]. The effects of adding various nanoparticles combined with eco-friendly refrigerant and investigating their effects on coefficient of performance (C.O.P.). Hydro flouroolefins (HFOs) are the new HFC refrigerants' replacement. Compared to HFCs, these refrigerants have a much shorter atmospheric lifetime but have the potential to cause global warming. While some of these refrigerants are combustible and hazardous, HFO-1234yf is hard to light and has an unstable flame. It will so likely soon replace the R-134a, R404a, and R125 refrigerant for this specific use and is commonly utilised in refrigerated air conditioning systems. HFO-1336mzz(Z) and HFO-1234ze(E) are better suited for chiller applications since they are less poisonous and non-flammable. A novel class of refrigerants known as hydrochlorofluoro olefins (HCFOs) combines chlorine and fluorine and possesses a negligible ODP and a comparatively low GWP. HCFOs have been marketed as very short atmospheric lifespan refrigerants that are appropriate for chillers. HCFO-1233zd(E), with an ODP of less than 0.0004. HCFO-1224yz(Z) is another refrigerant from the same group that is used for replacing R134a [20]. The environmental properties of ecofriendly refrigerants are shown in Table-1.

Table-1: GWP and ODP of eco-friendly HFOs and HCFOs refrigerants in vapour compression refrigeration systems

S. No	HFO Refrigerants	GWP	ODP
1	HCFO 1233zd(E)	6	0.00034
2	HCFO 1224yd(Z)	1	0.00023
3	HFO 1336mzz(Z)	2	0
4	HFO 1243zf	9	0
5	HFO 1234ze(E)	7	0
6	HFO 1225ye(Z)	14	0
7	HFO 1234yf	4	0

3. Methods for thermal performance improvement in VCR systems

Compressor, expansion valve, condenser, and evaporator are the four main parts of a basic vapour compression system. One evaporator carries the entire cooling load at a single temperature in many applications, as shown in Fig. 1. The vapour compression system has a water-cooled condenser and an evaporator with a primary circuit that circulates refrigerant and a secondary circuit that circulates a brine or glycol-based fluid.

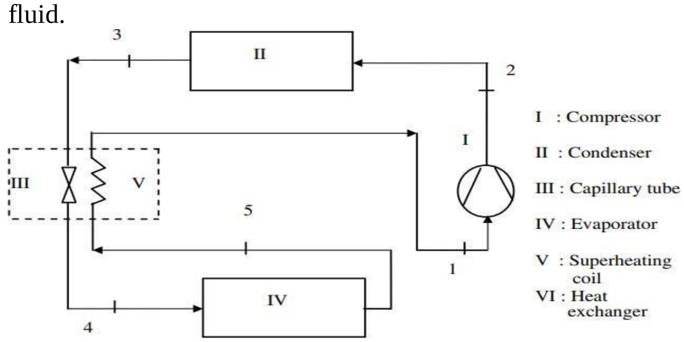

Figure 1: Vapour compression refrigeration system

Vapour compression systems consume a lot of electricity, but this problem can be fixed by improving system efficiency. Using the latent heat of phase shift and the fluid characteristics of the pressure-related boiling temperature, the vapour compression refrigeration system transfers heat from the cycle's lower temperature side to its higher temperature side. The refrigerant's boiling point fluctuates according to the pressure during the vapour compression cycle. When it first boils at low pressure, it takes heat from the area with a lower temperature. Later, when pressure is increased, the refrigerant condenses to a liquid, releasing energy into the warmer area. All vapour compression refrigeration and air conditioning systems, from little room air conditioners to enormous tonnage chillers, are based on this fundamental principle. There are numerous methods to raise the refrigeration system's coefficient of performance (COP), including expansion-stage energy recovery, refrigerant sub-cooling, and superheating. Increasing the compressor's efficiency is just one of them. There are four stages in the closed loop vapour compression cycle, and a circulating refrigerant is involved in each. During the initial phase, the low-pressure and vapour-state refrigerant enters the compressor and undergoes compression to a high-pressure vapour. The following step involves driving the refrigerant through the condenser coil as it enters the condenser as a high-pressure, high-temperature vapour. One fluid circulates concurrently across the other side of the coil, lowering the temperature of the refrigerant until it condenses into a high-pressure/temperature liquid. The refrigerant is then driven via an expansion mechanism as it enters the expansion stage in order to lower the refrigerant pressure and leave it as a low-pressure liquid. These include, among others, capillary tubes, electronic expansion valves, orifices, and thermal expansion valves. The refrigerant eventually exits the evaporator as a low-pressure superheated vapour after entering the fourth stage as a low-pressure liquid and absorbing heat from the cooling fluid or the conditioned zone. The following actions can be taken to enhance the thermal performance of systems that employ vapour compression refrigeration (VCR) technology: First law efficiency, also referred to as the coefficient of performance, is used to evaluate the refrigerator's performance. The term "coefficient of performance," or "COP," refers to the relationship between the cooling effect and the net work input provided to the system. The vapour compression refrigeration system's coefficient of performance (COP) can be raised by either increasing the refrigeration effect or lowering the work input given to the system. The vapour compression cycle could be improved by using several techniques. Several strategies to reduce or recover the energy lost in each cycle component in order to achieve it. Lowering the refrigerant temperature below the condensing temperature at a particular pressure is known as sub-cooling. Conversely, superheating occurs when a certain pressure is used to elevate the refrigerant temperature above the boiling point. Using a liquid vapour heat exchanger to boost an R-134a car air conditioning system with a 40 °C condenser temperature often resulted in a 5–10% increase in the system COP. In addition, HFO and HFCO refrigerants were used in place of R404a, R134a, and R410a, while R407^c was used in place of R-134a due to its similar thermodynamic properties but lower heat of vapourization. This means that it provides a reduced capacity for the same compressor size, which is appropriate for the heat exchanger for liquid vapour. In order to compensate for the capacity loss that occurs while utilising R-1234yf, the liquid vapour heat exchanger was added to R-134a and R-1234yf systems. This increased the system's cooling capacity by 2–9%, or its coefficient of performance. The study examined the impact of utilising a liquid vapour heat exchanger on the cooling capacity and coefficient of performance (COP) of R-1234yf and R-134a systems. It found that substituting R-1234yf for R-134a in the absence of a liquid vapour heat exchanger resulted in a 4.5% reduction in COP and a 7% loss in cooling capacity. It is possible to reduce system losses to 1.8% and 2.9% for the cooling capacity and the COP, respectively, when utilising a liquid vapour heat exchanger. Nevertheless, a thorough environmental lifetime assessment is required to determine whether the R-1234yf cycle with a liquid vapour heat exchanger is superior to the R-134a. The impact of sub-cooling on the performance of R-134a and R1234yf refrigeration systems was examined in 2015; it was discovered that the use of HFO in the liquid vapour heat exchanger increased energy efficiency, while the effectiveness of the sub-cooling was dependent on the characteristics of the refrigerant. First law (energy) performance (COP), exergy efficiency, and exergy destruction ratio were evaluated by implementing a liquid vapour heat exchanger on VCR system to improve system efficiency. In this study, HFOs, HCFOs and other refrigerants were used, and discovered that employing various thermostatic expansion valve settings increased the system's COP from 2.8% to 11.8%. This demonstrates unequivocally that the cycle parameters affect the performance of the liquid vapour heat exchanger in addition to the refrigerant's characteristics. The VCR's throttling mechanism is an expansion procedure that is irreversible. The expansion process, which causes a portion of the refrigerant to flash to vapour in the evaporator and limit cooling capacity while also increasing evaporator size, is one of the primary causes of energy loss in cycle performance. This issue can be resolved by using a multi-stage expansion strategy that includes a flash chamber to remove flash vapours after each stage of expansion. This will boost cooling capacity and decrease evaporator size. One further way to reduce work input is to use single stage compression in place of compound or multi-stage compression. By running the refrigerant via a subcooler after the condenser and before the evaporator, the refrigeration effect can also be improved. In response to various environmental resolutions, more eco-friendly refrigeration systems have been considered in recent years. Two aspects are of particular concern: eco-friendly refrigerants and electrical energy consumption. HFO & HCFO refrigerants have potential to replace R134a [21] and it was found that found that the thermodynamic performances using HCFO-1224yz(Z) is slightly lower than using HCFO-1233zd(E) and HFO-1234ze(Z). The thermal performance of vapour compression refrigeration sytem using seven HFCs and three hydrocarbon refrigerants have been computed and and the lowest thermal performance in terms of energy efficiency, exergy efficiency found lowest by using nano in the HFC-125 and best thermal performance in terms of first-law efficiency is found by using R152a. He has not compared with performance parameters by using glycol water-based fluid with brine water-based fluid flowing in the secondary circuit of evaporator [23]. The comparison between nano based fluids in the secondary circuit and HFO refrigerants in the primary circuits have been investigated in this paper.will be discussed in this paper.

4. Results and Discussion

The energy-exergy performances of vapour compression refrigeration have been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic first law (energy) performance improvement along with refrigerants are shown in Table-2(a) and second law (exergy) performance using copper oxide (CuO) nano material shown in Table-2(b) respectively.

Table-1: Input data used in VCR system

S. No.	Description	Value with unit
1	Length of evaporator tube	7.20m
2	Length of condenser tube	12.5m
3	Mass flow rate of water flow	0.008kg/sec
4	Mass flow rate of brine flow	0.007kg/sec
5	Condenser water inlet temperature	27°C
6	Brine water inlet temperature	27°C

4.1 Energy-exergy performances of vapour compression refrigeration have been evaluated using low GWP HCFO & HFO refrigerants

The thermodynamic energy performance of vapour compression refrigeration have been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic first law performance improvement using low GWP ecofriendly HCFO &HFO refrigerants are shown in Table-2(a) and it was found that maximum (22.9%) energy performances by mixing CuO in the brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HCFO- 1233zd(E) refrigerant in primary circuit of evaporator lowest 10.35% by mixing TiO_2 in brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HFO-1234yf refrigerant in primary circuit of evaporator. While using HCFO-1233zd(E) in in primary circuit of evaporator and aluminium oxide mixed brine water the first law energy performances was found to be 17.2% respectively which is the higher than using TiO2 mixed nano material in the brine water.

Table-2(a) effect of ecofriendly HFO and HCFO refrigerants of ultra-low GWP flowing in the primary circuit and nano mixed brine water solution in the secondary circuit of evaporator on thermodynamic second law performance (exergy efficiency) of VCR system

Performance Parameters	With Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	3.645	22.930	3.475	17.20	3.327	12.209	2.965
R1224yd(Z)	3.636	22.93	3.465	17.140	3.305	11.731	2.958
R1336mzz(Z)	3.557	20.781	3.447	17.046	3.269	11.002	2.945
R1225ye(Z)	3.427	17.945	3.315	14.508	3.205	10.708	2.895
R-1243zf	3.475	18.278	3.361	14.062	3.269	10.858	2.938
R-1234ze(E)	3.477	18.306	3.385	15.175	3.267	11.160	2.939
R-1234yf	3.334	16.982	3.237	13.579	3.145	10.351	2.850

The thermodynamic energy performance of vapour compression refrigeration have been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol was flowing in the secondary circuit of evaporator and thermodynamic first law performance improvement using low GWP ecofriendly HCFO &HFO refrigerants are shown in Table-2(b) and it was found that maximum (19.616%) energy performances by mixing CuO in the glycol flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HCFO- 1233zd(E) refrigerant in primary circuit of evaporator lowest 10.35% by mixing TiO_2 in glycol flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HFO-1234yf refrigerant in primary circuit of evaporator. While using HCFO-1233zd(E) in in primary circuit of evaporator and aluminium oxide mixed glycol the first law energy performances was found to be 17.2% respectively which is the higher than using TiO2 mixed nano material in the mixed glycol.

Table-2(b) effect of ecofriendly HFO and HCFO refrigerants of ultra-low GWP flowing in the primary circuit and nano mixed glycol solution in the secondary circuit of evaporator on thermodynamic second law performance (exergy efficiency) of VCR systemusing

Performance Parameters	With Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	3.427	19.616	3.325	16.056	3.228	12.670	2.865
R1224yd(Z)	3.405	19.139	3.305	15.640	3.215	12.491	2.858
R1336mzz(Z)	3.397	18.984	3.295	15.411	3.169	10.998	2.855
R1225ye(Z)	3.340	17.399	3.240	13.884	3.140	10.369	2.845
R-1243zf	3.361	17.930	3.261	14.421	3.151	10.561	2.850
R-1234ze(E)	3.387	18.551	3.287	15.051	3.167	10.851	2.857
R-1234yf	3.235	13.908	3.135	10.387	3.085	8.627	2.840

The thermodynamic exergy performance of vapour compression refrigeration have been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic exergy performance (exergy efficiency) improvement using low GWP ecofriendly

HCFO &HFO refrigerants are shown in Table-3(a) and it was found that maximum (25.625%) exergy efficiency by mixing CuO in the brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HCFO- 1233zd(E) refrigerant in primary circuit of evaporator lowest 13.25% by mixing TiO_2 in brine water flowing in the secondary circuit of evaporator and ultra-low GWP eco-friendly HFO-1234yf refrigerant in primary circuit of evaporator. While using HCFO-1233zd(E) in in primary circuit of evaporator and aluminium oxide mixed brine water the exergy performances was found to be 20.17% respectively which is the higher than using TiO_2 mixed nano material in the brine water (16.6%).

Table-3(a) effect of ecofriendly HFO and HCFO refrigerants of ultra-low GWP flowing in the primary circuit and nano mixed glycol solution in the secondary circuit of evaporator on thermodynamic second law performance (exergy efficiency) of VCR system

Performance Parameters	With Nano Cuo	Without Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	0.3735	0.2976	25.625	0.3545	20.170	0.3471	16.633	0.2976
R1224yd(Z)	0.3725	0.2887	20.453	0.3525	19.586	0.3365	16.557	0.2887
R1336mzz(Z)	0.3685	0.2883	18.453	0.3445	19.494	0.3357	16.441	0.2883
R1225ye(Z)	0.3495	0.2776	15.785	0.3325	19.056	0.3265	16.390	0.2776
R-1243zf	0.3527	0.2884	20.055	0.3405	18.0652	0.3357	16.401	0.2884
R-1234ze(E)	0.3528	0.2885	20.170	0.3407	18.09	0.3359	16.430	0.2885
R-1234yf	0.3455	0.2887	15.286	0.3265	15.286	0.3264	13.250	0.2883

The thermodynamic exergy performance of vapour compression refrigeration have been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol was flowing in the secondary circuit of evaporator and thermodynamic exergy performance (exergy efficiency) improvement using low GWP ecofriendly HCFO &HFO refrigerants are shown in Table-3(a) and it was found that maximum (23.3%) exergy efficiency by mixing CuO in the brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HCFO- 1233zd(E) refrigerant in primary circuit of evaporator lowest 10.05% by mixing TiO_2 in brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HFO-1234yf refrigerant in primary circuit of evaporator. While using HCFO-1233zd(E) in in primary circuit of evaporator and aluminium oxide mixed brine water the exergy performances was found to be 19.60% respectively which is the higher than using TiO_2 mixed nano material in the brine water (15.7%).

Table-3(b) effect of ecofriendly HFO and HCFO refrigerants of ultra-low GWP flowing in the primary circuit and nano mixed glycol solution in the secondary circuit of evaporator on thermodynamic exergy performance (exergy efficiency) of VCR system

Performance Parameters	With Nano Cuo	% enhancement	With Nano Al2O3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	0.3545	23.2615	0.3440	19.61	0.3327	15.72	0.2876
R1224yd(Z)	0.3345	20.0215	0.3368	19.411	0.3215	15.35	0.2787
R1336mzz(Z)	0.3285	18.038	0.3285	18.04	0.3197	14.87	0.2783
R1225ye(Z)	0.3025	13.084	0.3021	12.93	0.3002	12.243	0.2675
R-1243zf	0.3295	16.226	0.3267	15.238	0.3257	14.885	0.2835
R-1234ze(E)	0.3299	16.244	0.3269	15.187	0.3265	15.05	0.2838
R-1234yf	0.3145	12.845	0.3075	10.333	0.3067	10.047	0.2787

The thermodynamic exergy performance of vapour compression refrigeration depends upon the nature of nano fluid flowing in the secondary circuit of evaporator as shown in the table-4(a) and table-4(b) respectively. By using low GWP eco-friendly refrigerants in the primary circuit and nano fluids flowing in the secondary circuit of evaporator, the overall heat transfer coefficient is highest (65.829%)by using CuO in brine fluid flow in secondary circuit of evaporator and HCFO-1233zd(E) in primary circuit of evaporator and found lowest (38.3%)by using HFO-1234yf in primary circuit of evaporator and TiO_2 mixed glycol fluid flow in secondary circuit of evaporator

Table-4(a)evaporator heat transfer coefficient of vapour compression refrigeration using nano mixed brine water

Performance Parameters	With Nano using CuO	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	1120.50	65.829	1092.25	61.6484	1045.98	54.80	675.695
R1224yd(Z)	1075.48	65.286	1049.27	61.2574	1016.75	56.260	650.680
R1336mzz(Z)	1065.05	64.266	1045.25	61.212	1008.35	55.521	648.37
R1225ye(Z)	1032.5	63.035	1005.7	58.803	981.5	54.034	633.3
R-1243zf	1045.05	63.673	1020.5	59.828	985.50	54.346	638.5
R-1234ze(E)	1047.1	64.045	1021.3	60.003	987.25	54.67	638.3
R-1234yf	1005.25	59.235	1001.7	58.672	972.1	53.984	631.3

Table-4(b)evaporator heat transfer coefficient of vapour compression refrigeration using nano mixed glycol water

Performance Parameters	With Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	1020.5	52.080	992.25	47.942	945.9	41.032	670.7
R1224yd(Z)	975.4	51.084	949.35	47.05	910.75	41.005	645.9
R1336mzz(Z)	965.1	50.233	944.1	46.964	905.1	40.8935	642.4
R1225ye(Z)	932.5	47.454	905.7	43.216	881.5	39.3896	632.4
R-1243zf	945.5	49.251	920.5	45.303	885.5	39.80	633.5
R-1234ze(E)	947.3	49.510	921.3	45.407	887.25	40.033	633.6
R-1234yf	905.2	43.546	901.7	42.991	872.1	38.297	630.6

The effect of low GWP HFO and HCFO refrigerants in the primary circuit of evaporator and nano mixed brine fluid flowing in the secondary circuit of evaporator on condenser overall heat transfer coefficient is shown in Table-5(a) and and nano mixed glycol-based fluid flowing in the secondary circuit of evaporator on condenser overall heat transfer coefficient is table-5(b) respectively.

Table-5(a) condenser heat transfer coefficient (COP) of vapour compression refrigeration using nano mixed brine water

Performance Parameters	With CuO Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	679.7	9.112	663.09	6.35	650.64	4.35	623.5
R1224yd(Z)	673.4	8.281	658.65	6.153	646.9	4.252	621.9
R1336mzz(Z)	672.6	8.153	657.6	5.740	645.9	3.859	620.5
R1225ye(Z)	667.4	8.821	650.8	5.77	637.7	3.640	615.3
R-1243zf	668.6	8.059	654.7	5.70	642.6	3.762	619.3
R-1234ze(E)	670.6	8.087	655.6	5.827	643.3	3.842	619.5
R-1234yf	660.3	8.00	644.3	5.390	633.5	3.427	611.35

Comparing table(5(a) and Table-5(b) it was found that by mixing CuO in the brine water flowing in the secondary circuit of evaporator and ultra-low GWP ecofriendly HCFO-1233zd(E) refrigerant in primary circuit of evaporator gives highest (9.1%) overall condenser heat transfer coefficient and lowest 1.64% by mixing TiO_2 in glycol fluid flowing in the secondary circuit of evaporator and ultralow GWP ecofriendly HFO-1234yf refrigerant in primary circuit of evaporator

Table-5(b) condenser heat transfer coefficient (COP) of vapour compression refrigeration using nano mixed glycol water

Performance Parameters	With Nano	% enhancement	With Nano Al_2O_3	% enhancement	With Nano TiO_2	% enhancement	Without Nano
R1233zd(E)	669.7	7.880	653.09	5.1643	640.6	3.122	621.5
R1224yd(Z)	663.4	6.914	648.65	4.5366	636.9	2.643	620.5
R1336mzz(Z)	662.2	6.858	647.6	4.5021	635.9	2.614	619.5
R1225ye(Z)	657.6	6.529	640.8	3.807	629.7	2.008	617.3
R-1243zf	658.9	6.584	644.7	4.287	632.6	2.330	618.2
R-1234ze(E)	660.6	6.841	645.6	4.415	633.3	2.426	618.3
R-1234yf	645.3	5.605	634.3	3.796	623.5	1.964	611.1

5. Conclusions & Recommendations

The thermal performances of the VCR system with different HFO & HCFO refrigerants in the primary circuit and Glycol based fluid in the secondary circuit of the evaporator with suspended nanoparticles in the circuit have been evaluated and it was found that three factors (mass flow rate of brine, compressor speed and water flow rate in the condenser strongly affecting system thermal performance enhancement (COP), heat transfer characteristics, and solubility of nano refrigerants into the base refrigerant. The following conclusions were drawn

- Use of nano refrigerants required lower power consumption however by using nano refrigerants in secondary circuit increases the evaporator and condenser heat transfer rates in VCR systems.
- Using CuO nano refrigerants maximizing the improvement in the heat transfer coefficient of thermal evaporators.
- The system's overall coefficient of performance (COP) can be improved by including nano refrigerants CuO and HCFO-1233zd(E) refrigerants is higher than HCFO-1224yd(Z) is used in this combination.
- When nano refrigerants are used in the system with the same input parameters as HFO refrigerants, heat transfer rates and system efficiency (first and second law) can be significantly increased utilizing R1233zd(E). while HFO-1234yf yields the lowest performances.

- When comparing the thermal system performances under identical input settings, the brine flow nano fluid significantly higher than gycol-based nano fluid.

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