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ORIGINAL ARTICLE

Enhancing the thermal performance of VCR systems using nano refrigerants

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Abstract

Refrigerants and nanoparticles are combined to create nano refrigerants, a novel family of nanofluids. They have many possible uses in several industries, including heat pumps, air conditioning, and refrigeration. Consequently, the thermophysical parameters and heat transfer characteristics of conventional refrigerants exhibit anomalous improvements upon adding nanoparticles, thereby augmenting the efficiency of refrigeration systems. The current work dispersed copper oxide nanoparticles throughout a glycol-based fluid to create an HFO-blended HFC nano refrigerant containing CuO, Al_2O_3, and TiO_2. The impact of incorporating nanoparticles concerning the thermal performance attributes of nano refrigerant was examined. The enhanced evaporator heat transfer rate, coefficient of performance, and energy destruction ratio for the refrigeration system for three HFO blended HFC refrigerants were used to assess the overall performance of VCR systems. The glycol-based fluid with CuO nanoparticles was shown to have the best thermal performance. The fluid based on TiO_2 and glycol showed the lowest thermal performance.

1. Introduction

With many governments enacting energy laws on the use of energy to lower energy consumption levels for long-term sustainability, the world is currently faced with the challenge of energy security. The issue of rising energy consumption has been studied because the current energy-producing process involves burning fossil fuels, which is one of the causes of global warming. Commercial buildings' heating, ventilation, and air conditioning systems consume over 50% of the energy used in those structures. Researchers are currently concentrating on the energy consumption by air conditioning and refrigeration systems. Air conditioning and refrigeration are essential for home and business comfort and preservation. Appliances operating on refrigeration, air conditioning, and heat pumps need a lot of energy. Scientists are developing several strategies to boost air conditioning and refrigeration systems' functionality and energy efficiency in response to this energy crisis. Nonetheless, some researchers have attempted to alter the design elements to enhance the refrigeration system's performance. The application of nano refrigerants improves the refrigeration system's overall thermal performance. Nano refrigerants have better heat transfer ability than those without nano-mixed particles in the refrigeration systems.

1.1 Use of Nano-based fluid in VCRS

Nanoparticles are considered nano refrigerants or nano lubricants when dissolved in a base fluid for one. One benefit of utilizing nanoparticles in air conditioning and refrigeration systems is enhancing thermal conductivity, which lowers energy usage. The 10–100 nm range is the minimal size of commercially available nanoparticles. However, the kind, concentration, size, and shape of the nanoparticles in the base

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refrigerant all significantly impact how well they function in refrigeration systems. Dispersing nanoparticles in refrigeration and air conditioning applications is commonly accomplished using various technological techniques, including homogenizing, high-shear mixing, ultrasonic agitation, and magnetic force agitation. Nanoparticles are considered nano refrigerants or nano lubricants when dissolved in a base fluid for one. According to Choi et al. [1], Adding nanoparticles to the refrigerant can improve its thermal performance by enhancing its thermal conductivity, which lowers the system's energy usage. This is one benefit of utilizing nanoparticles in air conditioning and refrigeration systems. The 10–100 nm range is the minimal size of commercially available nanoparticles. However, the kind, concentration, size, and shape of the nanoparticles in the base refrigerant all significantly impact how well they function in refrigeration systems. Dispersing nanoparticles in refrigeration and air conditioning applications is most commonly accomplished by the use of various technological techniques, including homogenizing, high-shear mixing, ultrasonic agitation, and magnetic force agitation, by employing 0.05–0.015 vol% TiO_2 nanoparticles in compressor lubricant. Sabareesh et al. [2] showed that 0.01 vol% is the ideal fraction value for improved tribological properties. They also found that employing nanoparticles with R12 led to 11% reduction in compressor energy consumption and 17% improvement in COP. Peng et al. [3] used CNTs distributed in an R113/oil blend to improve the heat transfer coefficient by 61%. Mahbubul et al. [4-5] Al2O3 was circulated in R141b refrigerant in order to examine the viscosity and thermal conductivity at 2% volume fraction, the viscosity and thermal conductivity of the R141b/Al2O3 nano refrigerant are 1.626 and 179 times higher than those of pure refrigerant. Using Al2O3 nano refrigerant, Subramani and Prakash [6,7] found a 33% overall COP increase and a 25% reduction in energy usage in the VCR cycle. The cycle's freezing capacity was additionally enhanced. Jwo et al. [8] used R134a and R12 with a weight percentage of 0.05–2% of Al2O3 particles and found that R134a refrigerant replaces R12 like polyester oil replaces minerals. Jwo et al. [9] observed a 2.4% decrease in compressor work. Al2O3 nanoparticles distributed in R141b significantly increased the thermal conductivity and viscosity. Multiple investigators investigated the effects of refrigerant-based nanofluids' thermophysical characteristics and performance characteristics on refrigeration systems through a horizontal circular tube study [9]. The refrigeration system's efficiency and coefficient of performance are then determined by heat transfer. The qualities of the refrigerant are reported to enhance when nanoparticles are added. This enhancement is contingent upon the nanoparticle concentration, size, and material characteristics [10,11]. Diamond nanoparticles were scattered in an R113/VG68 blend by Peng et al. [12] in order to investigate the nucleate boiling heat transfer coefficient. The author found that using fractions of 0.05–0.5 weight percent of nanoparticles enhanced HTC by 63.4%. Additionally, the study indicated that diamond nanoparticles have a more significant impact on heat transfer properties when compared to a CuO/oil blend, when 0.1% mass fraction of Al2O3 particles were mixed in polyester oil, according to Mahbubul et al. [14]. Appropriate particle dispersion in the fluid to prevent rapid settling in the fluid medium (refrigerant) is one of the challenges in designing nanoparticles for refrigerants. However, according to, this obstacle has mostly been removed. Efficient work output delivery, as demanded by several industries worldwide, depends on the effective heat transfer enhancement provided by the nano-based fluid. Because metallic fluids have a far higher heat conductivity than normal fluids, a particle size of roughly 10 nm is advised. Depending on the nano based particle of the conventional fluid, clogging and abrasion are problems specific to nanofluid. It is anticipated that the issue of clogging and abrasions will be lessened by using nano-sized suspensions instead of micro-sized suspensions. The size of this nanoparticle is 1000 times greater than that of the microparticle. The fluid's stability, corrosion resistance, and thermal conductivity all dramatically rise with surface area. When nanoparticles are made in powder form, there is a problem with the particles clustering, which frequently causes the particles to settle in the liquid. The same shape and input requirements were used in tests for four baseline refrigerants [15-19]. For the same input parameter, the refrigeration system's coefficient of performance (COP) varies. Even though studies on selecting environmentally friendly refrigerants have been conducted recently. Greenhouse gases affect biodiversity in today's present situation of high GWP refrigerants. According to Mishra [20-22], adding nano refrigerants enhanced the VCR system's heat transfer performance, particularly in nucleate and pool boiling heat transfer. When it comes to improving the heat transfer of base refrigerants, carbon nanotubes are a superior option to other nanoparticles [16]. As the dimension of the nanoparticles lowers, the pressure drop also drops, but the rate of heat transfer increases. Another issue related to the usage of hydrocarbon-based nano refrigerants is flammability. Mishra [23, 24] evaluated the performances using Al2O3 at a 5% volume fraction in four different refrigerants, R600a, R290, R404a, and R134a, and found the same (20%) and 18% using R134a and 16% using R404aimprovement in COP in hydrocarbons; however, are lagging behind the other refrigerant when it comes to increases in the refrigeration system's coefficient of performance [25-26].

1.2 Hydrofluoroolefin (HFO) blended HFC refrigerants.

HFO blended HFC refrigerants were commonly used to replace high GWP and zero ODP refrigerants in low- and medium-temperature commercial refrigeration systems. The details of HFO blended HFC refrigerants in composition and environmental considerations regarding global warming and ozone depletion are below.

Table 1: composition and environmental considerations of HFO Blends

S. N	HFO Blends	Composition	GWP	ODP	Safety Code	Utility
1	R448A	7%HFO-1234ze+20% HFO-1234yf+21% HFC-134a+26% HFC-125 +26%HFC-32	1387	0	A1	In low- and medium-temperature refrigeration systems, R448A is a non-flammable HFO blend that is used to replace R22, R404a, and R507a in the current systems.It doesn't harm the ozone layer in any way.
2	R449A	25% HFO-1234yf+ 26%HFC R134a+ 25% HFC-125+ 24% HFC-32	1397	0	A1	Superior to R507, R449A refrigerant has a lower potential for global warming and is non-ozone depleting and environmentally friendly. Additionally, it successfully replaces R404a, R410a, HCFC-22, and R407c in a variety of commercial and industrial refrigeration applications for low- to medium-level consumption.
3	R452A	30% HFO1234yf +11% HFC32+59% HFC125	2141	0	A1	The hydro fluoroolefin (HFO)-based R452a refrigerant is a low-GWP, non-depleting substitute for R-404a and R507 refrigerants. The capacity of R452a refrigerant is higher than that of R449A at low condensing temperatures. It can also be utilised for adapting old systems into new ones that are commercial refrigeration systems.

2. Results and Discussion

Table 2 (a-c) showed the evaluation of thermal design performance parameters of VCR systems using R- 452A refrigerants in the primary circuit and glycol-based three nanofluids in the secondary fluid circuit of the evaporator. It has been observed that TiO_2 nano mixed glycol-based fluid is mainly utilized in the evaporator's secondary circuit, giving lower thermal performances than copper oxide mixed glycol-based fluid flow in the secondary circuit of the evaporator. Similarly, first law energy performance in terms of COP and second law thermal performance (Exergy efficiency) using copper oxide is better than Al_2O_3. The performance improvement using copper oxide is maximum (up to 10.96%) and lowest (4.3%) using TiO_2. However, using Al_2O_3, the percentage improvement was 7.88%, which is higher than using TiO_2 mixed glycol-based fluid. Similarly, the heat transfer coefficient improvement by using copper oxide mixed glycol-based fluid is 51.8%, 41.9% by using Al_2O_3 mixed glycol-based fluid, and 38.09% using TiO_2 mixed glycol-based fluid.

Table 2: Process parameters

S. No.	Parameter	Value
1	Length of evaporator tube	11.1m
2	Length of condenser tube	16.6m
3	Mass flow rate of brine (Actually varying from 0.06 to 0.12kg/sec)	0.08kg/sec
4	Mass flow rate of water (Actually varying from 0.06 to 0.12kg/sec)	0.10 kg/sec
5	Inlet temperature of glycol-based fluid	300K
6	Inlet temperature of glycol-based fluid	300K

The improvement in the exergy efficiency by using copper oxide mixed with glycol-based fluid is 9.05%, and the lowest (4.45%) by using glycol-based TiO_2 nanofluid in the secondary fluid circuit of the evaporator. Following input values have been taken for numerical investigation. Table-3(a-c) showed the evaluation of thermal design performance parameters of VCR systems using R-449A refrigerants in the primary circuit and glycol-based three nano fluids in the secondary fluid circuit of the evaporator. It has been observed that TiO_2 nano mixed glycol-based fluid is mainly utilized in the evaporator's secondary circuit, giving lower thermal performances than copper oxide mixed glycol-based fluid flow in the secondary circuit of the evaporator. Similarly, first law energy performance in terms of COP and second law thermal performance (Exergy efficiency) using copper oxide is better than Al2O3. The performance improvement using copper oxide is maximum (up to 11.20%) and lowest (3.8%) using TiO_2. However, by using Al_2O_3, the percentage improvement was 7.85%, which is higher than when using TiO_2 mixed glycol-based fluid. Similarly, improvement in the heat transfer coefficient using copper oxide mixed glycol-based fluid is 47.92%, 43.562% using Al2O3 mixed glycol-based fluid, and 41.94% using TiO_2 mixed glycol-based fluid. The improvement in the exergy efficiency by using copper oxide mixed with glycol-based fluid is 9.05%, and the lowest (4.45%) by using glycol-based TiO_2 nanofluid in the secondary fluid circuit of the evaporator.

Table-2(a) Evaluation of thermal design performance parameters of VCR systems using R 452A refrigerants in primary circuit and glycol based CuO nano fluid in secondary fluid circuit of evaporator

S.No.	Performance Parameters for *R 452A*	COP with CuO Nano	COP without Nano	% improve-ment
1	COP	2.957	2.665	10.957
2	Exergy Efficiency	0.3015	0.2765	09.046
3	$U_{\_Eva}$ ($W/m^{2o}C$)	995.5	655.7	51.82
4	$U_{\_Cond}$ ($W/m^{2o}C$)	650.7	620.6	4.85

Table-2(b) Evaluation of thermal design performance parameters of VCR systems using R 452A refrigerants in primary circuit and glycol based Al_2O_3 nano fluid in secondary fluid circuit of evaporator

S.No.	Performance Parameters for *R 452A*	COP with Al_2O_3 Nano	COP without Nano	% improve-ment
1	COP	2.875	2.665	7.88
2	Exergy Efficiency	0.2978	0.2765	7.698
3	$U_{\_Eva}$ ($W/m^{2o}C$)	930.7	655.7	41.94
4	$U_{\_Cond}$ ($W/m^{2o}C$)	645.7	620.6	4.044

Table-2(c)Evaluation of thermal design performance parameters of VCR systems using R452A refrigerants in primary circuit and glycol based TiO_2 nano fluid in secondary fluid circuit of evaporator

S.N	Performance Parameters for -R452A	COP with TiO_2 Nano	COP without Nano	% improve-ment
1	COP	2.78	2.665	4.312
2	Exergy Efficiency	0.2880	0.2765	4.448
3	$U_{\_Eva}$ ($W/m^{2o}C$)	905.3	655.6	38.087
4	$U_{\_Cond}$ $W/m^{2o}C$)	630.90	620.6	1.570

Table-3(a) Evaluation of thermal design performance parameters of VCR systems using R-449A *refrigerants in primary circuit and glycol based CuO nano fluid in secondary fluid circuit of evaporator*

S.N	Performance Parameters for HCFO- R-449A	COP with CuO Nano	COP without Nano	% improve-ment
1	COP	2.977	2.675	11.20
2	Exergy Efficiency	0.3021	0.2768	9.14
3	$U_{\_Eva}$ ($W/m^{2o}C$)	950.1	642.3	47.92
4	$U_{\_Cond}$ ($W/m^{2o}C$)	624.6	614.3	1.6767
1	COP	2.977	2.675	11.20

Table-3(b)Evaluation of thermal design performance parameters of VCR systems using R-449A *refrigerants in primary circuit and glycol based Al_2O_3 nano fluid in secondary evaporator fluid circuit*

S.No	Performance Parameters for R-449A	COP with Al_2O_3 Nano	COP without Nano	% improve-ment
1	COP	2.885	2.88	7.85
2	Exergy Efficiency	0.328	0.288	7.695
3	$U_{\_Eva}$ ($W/m^{2o}C$)	922.4	642.8	43.562
4	$U_{\_Cond}$ $W/m^{2o}C$)	626.3	614.24	01.963

Table-4(a) to table-4(c) showed the evaluation of thermal design performance parameters of VCR systems using R-448A refrigerants in primary circuit and glycol based three nano fluids in secondary fluid circuit of evaporator and It has been observed that glycol based TiO_2 nano fluid is mainly utilized in the secondary circuit of the evaporator gives lower thermal performances than using Al_2O_3 and TiO_2 nano fluid.

Table-3(c) Evaluation of thermal design performance parameters of VCR systems using R-449A) refrigerants in primary circuit and glycol based TiO_2 nano fluid in secondary fluid circuit of evaporator

S.N	Performance Parameters for R-449A	COP with TiO_2 Nano	COP withou t Nano	% improvement
1	COP	2.776	2.675	3.776
2	Exergy Efficiency	0.289	0.2768	4.4075
3	$U_{\_Eva}$ ($W/m^{2o}C$)	910.2	645.3	41.05
4	$U_{\_Cond}$ ($W/m^{2o}C$)	625.9	615.4	1.706

Similarly, first law energy performance in terms of COP and second law thermal performance (Exergy efficiency) using copper oxide is better than using Al_2O_3. The performance improvement using copper oxide is maximum (up to 11.20%) and lowest (3.26%) using TiO_2. However, by using Al_2O_3 the percentage improvement was 7.865% which is higher than using TiO_2 mixed glycol-based fluid. Similarly, improvement in the heat transfer coefficient by using copper oxide mixed glycol-based fluid is 43.27%, 42.37% by using Al_2O_3 mixed glycol-based fluid and 40.3% using TiO_2 mixed glycol-based fluid. The improvement in the exergy efficiency by using copper oxide mixed glycol-based fluid is 9.14% and lowest (4.2645%) by using glycol based TiO_2 nano fluid in secondary fluid circuit of evaporator.

Table-4(a) Evaluation of thermal design performance parameters of VCR systems using R-448A *refrigerants in primary circuit and glycol based CuO nano fluid in secondary fluid circuit of evaporator*

S.N	Performance Parameters for R-448A	COP with CuO Nano	COP without Nano	% improvement
1	COP	2.790	2.670	11.236
2	Exergy Efficiency	0.3092	0.2670	9.14
3	$U_{\_Eva}$ ($W/m^{2o}C$)	907.2	641.7	43.27
4	$U_{\_Cond}$ ($W/m^{2o}C$)	624.7	613.6	1.809

Table-4(b)Evaluation of thermal design performance parameters of VCR systems using R448A refrigerants in primary circuit and glycol based Al_2O_3 nano fluid in secondary fluid circuit of evaporator

S.No.	Performance Parameters for R-448A	COP with Al_2O_3 Nano	COP without Nano	% improve-ment
1	COP	2.880	2.670	7.865
2	Exergy Efficiency	0.333	0.267	7.653
3	$U_{\_Eva}$ ($W/m^{2o}C$)	901.7	641.7	42.37
4	$U_{\_Cond}$ ($W/m^{2o}C$)	624.5	613.6	1.776

Table-4(c) Evaluation of thermal design performance parameters of VCR systems using R-448A *refrigerants in primary circuit and glycol based TiO_2 nano fluid in secondary fluid circuit of evaporator*

S.N	Performance Parameters for R-448A	COP with TiO_2Nano	COP without Nano	% improve-ment
1	COP	2.757	2.670	3.258
2	Exergy Efficiency	0.2885	0.2767	4.2645
3	$U_{\_Eva}$ ($W/m^{2o}C$)	900.3	641.7	40.299
4	$U_{\_Cond}$ ($W/m^{2o}C$)	622.90	613.6	1.5156

3. Conclusions

The numerous investigations on nano-based refrigerants to improve refrigeration system performance and heat transmission were presented in this study. The benefits of lower costs, longer system life, and higher heat transfer rates collectively enhance the effectiveness of the refrigeration system. The first and second law efficiency analysis was done for HFO blended nano refrigerant performance evaluation employing nano mixed-based fluid—properties of thermodynamics and energy consumption.

The refrigeration system's thermal conductivity and heat transfer coefficient are enhanced by adding nanoparticles to refrigerants; when nanoparticles are used in refrigerants, the amount of energy used decreases. The following conclusions were drawn from this work.

- Using nanomaterials in refrigerant offers a potential boost to refrigeration systems' coefficient of performance.

- The fluid improves the refrigeration systems' first and second law performances based on a mixture of nanoparticles.
- Compared to other nano mixed-based fluids, copper oxide-based nano fluid provides the best thermal performance, and TiO_2 gives the lowest thermal performance.
- Nano-based fluids make the refrigeration system more efficient than without nano-based fluid because nanoparticles mixed in brine water and glycol enhance COP and evaporator heat transfer coefficient.
- Nanoparticles influenced the heat transfer enhancement in the condenser of conventional refrigeration system influence of the nanoparticles on the thermal performance of the nano-refrigerant.
- The nanofluid can achieve cooling considerably faster and more effectively than conventional refrigerants due to its higher capacity to improve first and second-law efficiencies, as determined by its thermal conductivity.

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