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Review Article

Review on performance enhancement of nano-refrigerant

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ABSTRACT
Nano refrigerants, which involve the combination of refrigerants with nanoparticles, serve to enhance the refrigeration process. Studies have demonstrated that when compared to conventional refrigerants, the introduction of nanoparticles significantly enhances heat transfer capabilities. The convergence of nano-particles and R-134a represents an innovative concept, leading to the creation of nano-refrigerants that effectively enhance the thermo-physical properties of traditional refrigerants. The integration of nano-particles with refrigerants can be seamlessly achieved. The present paper offers an exhaustive review of the literature, focusing on the performance augmentation of Nano-Refrigerant (R-134a/Al_2O_3) within Vapor Compression Refrigeration systems (VCRs) under steady-state conditions. This involves the dispersion of 50 nm alumina (Al_2O_3) nanoparticles within the R-134a refrigerant to elevate its heat transfer efficiency and enhance its thermo-physical characteristics beyond those of conventional refrigerants. Ultimately, the study reveals a substantial upsurge in both cooling capacity and thermal efficiency of the system when employing the nano-refrigerant (R-134a/Al_2O_3). Consequently, the article's objective is to appraise the enhancement of VCR systems through the utilization of nano refrigerants, along with a consideration of natural convection and entropy generation.

1. Introduction

To improve heat transfer, nanofluids play major applications such as HVAC/R systems, nuclear reactors, and electronics. A class of heat transfer fluid based on nanotechnology called nanofluid contains nanoparticles. These nanoparticles typically span a size spectrum of 1 to 100 nm and are uniformly and consistently distributed throughout a foundational fluid, which serves as a prevalent medium for heat transfer processes [1]. Furthermore, the high specific surface area of nanofluids increases the surface area accessible to heat transfer between fluids and particles. When compared to micrometer-sized particles, nanofluid has further advantages such as lower reduction (pumping, power and particle clogging) [2]. Moreover, when the nanoparticle is properly dispersed in the base refrigerant fluid mixture, nano refrigerant is a type of nanofluid that is developed. Due to its high characteristics compared to the base refrigerant, it has the potential to increase heat transfer rates. Hence, incorporating nano refrigerants into refrigeration systems tends to yield more compact and lightweight systems, amplifying the thermal conductivity of the working fluid, thereby enhancing heat transfer capabilities. Moreover, the 1, 1, 1, 2-tetrafluoromethane, can be utilized as an alternative refrigerant. It is often employed in cooling systems, especially among underdeveloped nations, and has low ozone depletion potential and medium potential for global warming working fluid with conventional mineral oil because of its high chemical polarity; instead, polyester (POE oil). This raises the possibility that adding nanoparticles to lubricants may help to overcome the limitation.

The refrigerant most frequently utilized in modern refrigeration systems is R134a, such as vapor compression refrigeration (VCR) systems, household refrigerators, and air conditioners. The R-134a requires large amounts of electricity. To make the cooling process more effective and efficient and provide the opportunity to protect the environment, there is a need for new alternative refrigerants that can be replaced with advanced thermal physical properties such as high heat transfer and low power consumption. Nanotechnology is a new technology currently being developed. Nano-refrigerants are formed with the help of technology. Recently, there have been a few studies under VCR structures in nanomaterials to improve the cooling system Bi and Shi [3]. Thus the system strength intake was experimentally the use of R134a/ Al_2O_3 combination as the operating fluid. The results confirmed that the gadget strength intake decreased with the aid of 7% Nano-refrigerant. Jwo et al. [4]. Introducing POE/PAG refrigerant oil into R134a along with polyester, and incorporating nanoparticles (Al_2O_3) at varying concentrations (0.05%, 0.1%, and 0.2% by weight) into mineral oil, aiming to enhance both the lubrication process and heat transfer capabilities. Their consequences confirmed that the most useful combination changed into 60% R134a and 0.1 wt % Al_2O_3. The intake of electricity decreased with the aid of using approximately 2.4%, and there has been growing in the (COP) with the aid of using

4.4%. Bi et al. [5]. Researchers have demonstrated that utilizing several nanoparticles may be effective in improving heat conductivity even further. Hybrid nanofluids are fluids that contain several nanoparticles.

Advanced hybrid nanofluids have higher thermal conductivity coefficients. Hybrid nanofluid is still a new step as only a limited amount of research has been done on it. In one of the recent researches, in this paper, Al_2O_3/R134a hybrid for performance enhancement in the refrigeration system. Currently, 2-methods are used for preparing nanofluids that could be run in a refrigeration system: The first method is vapor phase nanopowders mixed into a liquid. It is a one-step method. This method involves condensing the vapor phase nanopowders with a liquid with pressure at low vapor and then simultaneously dissolving it in liquid. In domestic refrigeration and air conditioning systems throughout the world, HFC-134a, also known as 1, 1, 1, 2-tetrafluoromethane, is commonly employed as an alternative refrigerant. It is often used in refrigeration systems, and has a low ODP and a medium GWP [7]. Additionally, POE's high friction coefficient and flow choking in the compressor are issues with POE as a lubricant. This increases the possibility that incorporating nanoparticles into lubricants helps overcome the restriction. It can improve working fluid characteristics and energy efficiency [8].

1.1 Refrigerants

The term "refrigerant" pertains to the operational fluid employed in refrigeration systems. The prevalent refrigerant is a blend of hydrocarbons and halogens, available under various brand names like Freon, Genetron, Arcton, Isotron, Frigen, and more. These compounds often based on methane or ethane, substitute hydrogen and carbon atoms with chlorine or fluorine atoms. In the mid-1970s, researchers uncovered that chlorofluorocarbons (CFCs) escalate the influx of UV radiation into the Earth's atmosphere. Additionally, they impede the egress of infrared radiation from the planet into space, amplifying the greenhouse effect and consequently contributing to global warming [6].

1.2 Nano refrigerants

Nano-refrigerant stands as an innovative form of nanofluid, recognized as an advanced refrigerant that augments the speed of heat exchange within refrigeration systems. Various materials possess the potential to serve as nano-sized particles, typically falling within the range of 1nm to 100nm, and are dispersed within traditional refrigerants [7].

Table 1: Properties of refrigerants

S. No	Properties	R_134a	LPG
1.	Boiling point	-26.7℃	42℃
2.	Ozone depletion level	0	0
3.	Critical Temperature	122℃	104℃
4.	Global Warming Potential (GWP)	1200	0

1.3 R134a

R134a, classified within the HFC group of refrigerants, is alternatively named tetrafluoromethane (CF_3CH_2F). This substitution arises from the adverse impact of HCFC refrigerants on the ozone layer [8]. Presently, R134a serves as a substitute for the CFC refrigerant R12 in centrifugal compressors, screw compressors, scroll compressors, and piston compressors. Noteworthy is its non-toxic, non-flammable, and non-corrosive nature, rendering it innocuous during regular handling.

2. Nano fluids

2.1 Historical background

Traditional fluids like water, ethylene glycol (EG), and engine oils are recognized for their limited thermal conductivity, which hampers the effectiveness of heat transfer, particularly under slight temperature deviations. To enhance the performance of energy conversion systems, there's a demand for working fluids that exhibit elevated energy efficiency [9]. To determine the high dispersion stability with superior Brownian motion of nanoparticles are mixed with PAG oil. This concedes VCRs enhance heat transfer under Brownian motion flight of nanoparticles. This ensures that Due to the presence of these solid nanoparticles conduction or convection coefficient of heat transfer increases [10]. This nano-refrigerant shows various advantages. Improved dispersion stability for similar heat transfer with an increase of Brownian motion and less pumping power. Furthermore, nanofluids are low-concentration colloidal suspensions of nanoparticles in base fluids that drastically improve their characteristics. Nanofluids have

- better HT between particles and fluids because of excessive NPs floor place;
- higher dispersion balance with the main Brownian movement;
- decreased particle clogging, and
- decreased pumping power in comparison to the base fluid.

Analogously, nanoparticles can be added to the refrigerant, and the resulting mixture of the nanoparticle mixture is called nano refrigerant [11]. By combining natural refrigerant and nano lubricant, a nano lubricant-refrigerant may be created. Nanofluids consist of nano lubricant, nano refrigerant, and nano lubricant-refrigerant. Nanolubricant improves tribological houses in refrigeration systems, improving compressor performance and solubility of oil and refrigerant [12].

2.2 Procedure for mixing nano lubricants

Distinct techniques are utilized to create nanofluids, ensuring their uniformity, enhanced stability, and prevention of aggregation and settling. The fabrication of nanofluids can be accomplished through chemical or mechanical means [13]. The one-step and 2-step method are both used to prepare the nanofluids. The one-step process simultaneously prepares and disperses nanoparticles in a liquid. The two-step process involves creating nanoparticles separately, then dispersing them while preserving the stability of the nanofluid. The following are suggestions for the preparation of nanofluids [9]. Such as the stability of nanoparticles, dispensability, ability to coexist chemically, and thermal stability of nanofluids.

As the most efficient refrigerants are readily available in liquid form under standard atmospheric pressure, preparing nano lubricants proves notably simpler than crafting nano-refrigerants directly. The foundational fluid is infused with carefully measured nanoparticles of the appropriate composition and dimensions. To generate a stable nanofluid, stirring is first done with a mechanical stirrer and then with a magnetic stirrer [14]. The creation of nanofluids and nanoparticles is separated using this detailed process. As a result, these stages may result in the agglomeration of nanoparticles, particularly during the drying, storing, and transportation of nanoparticles. Aggregation not only diminishes thermal conductivity but also leads to sedimentation and blockage within microchannels. To mitigate particle agglomeration and improve dispersion characteristics, uncomplicated techniques such as ultrasonic agitation or the introduction of surfactants into the fluids can be employed [15]. In the present overview, R134a is used as the refrigerant, and Al_2O_3 nanoparticles concentrations and sizes are mixed with PAG oil as a lubricant, R134a as a refrigerant, and additional aspects, a new VCRs. It was developed to suit the requirements of this experiment. According to the results of the study, lubricating nanoparticles with oil may increase heat transfer while reducing power consumption.

2.3 Method to enhance the stability of nanofluids

Various researchers explored various approaches to achieving stability. These techniques include the addition of surfactants, high-pressure homogenization, and sonication (ultrasonic vibration) [12].

(a) Ultrasonication: Supersonic waves are produced during ultrasonication, splitting up larger particles into smaller fragments. The bath and probe types of ultrasonicators are the most common types. Regarding improved performance, research suggests the probe sonicator be preferable. Various researchers to stabilize nanofluid have applied this method [13].

(b) Surfactants in nanofluids: Dispersants, also known as surfactants, find application in nanofluids. Elevating nanofluid stability is a straightforward and cost-effective procedure, achieved by introducing dispersants into two-phase systems.

(c) Thermophysical properties: Within the domain of nano refrigerants, key thermophysical attributes encompass thermal conductivity, viscosity, and density. These properties hold particular importance for forecasting heat transfer and pressure variations in thermal engineering systems. Optimizing these characteristics is imperative to amplify the efficacy of nano refrigerants [16].

(d) Thermal conductivity: A comprehensive exploration was conducted into the thermophysical traits and operational parameters of a refrigeration system employing nanofluids centered around R134a. Their findings indicated, among various insights, the influential role of nanoparticles and refrigerant thermal conductivities in heat transfer applications, thereby shedding light on the effectiveness of the refrigeration system [15].

2.4 Vapor compression refrigeration system

Refrigeration is commonly used with VCRs. As the refrigerant evaporates at very low temperatures, refrigeration is achieved in VCRs. The compressor needs to be started mechanically. The Evans-Perkins cycle, commonly referred to as the Reverse Rankine cycle, is a necessary component of the actual vapor pressure cycle [10].

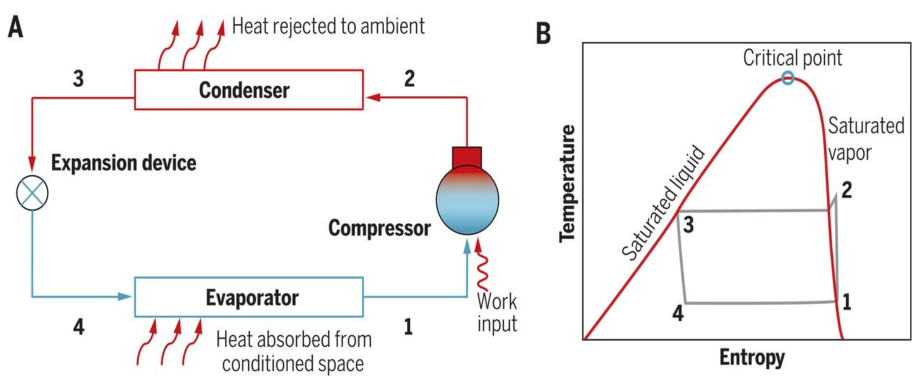

Figure 1: Simple vapour compression cycle

Components of VCR system [17]:

(a) Compressor: A compressor functions by drawing in air through an inlet or suction valve and subsequently compressing it. The low-pressure and low-temperature vapor refrigerant extracted from the evaporator is pulled into the compressor. Here, it undergoes an isentropic compression, resulting in elevated pressure and temperature. Subsequently, the compressed refrigerant is discharged through a delivery or discharge valve, eventually entering the condenser.

(b) Condenser: The condenser comprises coils made from thin copper pipes. These coils are responsible for cooling and condensing the vapor refrigerant, which arrives at the condenser with high pressure and temperature. During its passage through the condenser, the refrigerant releases its latent heat to the adjacent condensing medium. This medium, commonly air or water, serves to facilitate the cooling process.

(c) Receiver: The role of the receiver vessel is twofold. Firstly, it serves as a storage unit for the vapor-liquid mixture that has been condensed. This mixture exists at elevated temperatures and pressures. Secondly, the receiver vessel plays a crucial part in supplying pure liquid refrigerant to the expansion valve. This action aids in achieving more precise throttling and control of the refrigeration system.

(d) Expansion valve: The expansion valve, also referred to as a throttle valve, serves the purpose of permitting controlled passage for liquid refrigerant under high pressure and temperature. This occurs subsequent to the reduction in both pressure and temperature [6].

(e) Evaporator: In the evaporator, which generally consists of coils made from copper pipes, the liquid-vapor refrigerant undergoes a transformation. It shifts from a liquid state to vapor refrigerant under conditions of low pressure and temperature. This transition happens by absorbing the latent heat of vaporization from the cooling medium, which could be air, water, or brine.

3. Materials and methods

Vapor-compression refrigeration constitutes one category of refrigeration methods. The vapor-compression refrigeration (VCR) system, as illustrated in Figure 1, consists of four primary components: compressor, evaporator, condenser, and expansion valve. The VCR cycle comprises four distinct stages:

Compressor (1-2): This step involves the isentropic compression of the refrigerant within the compressor. The refrigerant, initially in a saturated vapor state at low pressure, undergoes compression, raising both its pressure and temperature.

Condensation (2-3): In this phase, the refrigerant undergoes condensation while maintaining a constant pressure. At the temperature of the evaporator, the refrigerant exists as saturated vapor, while at the temperature of the condenser, it transforms into saturated liquid.

Expansion valve (3-4): The expansion valve facilitates adiabatic expansion of the refrigerant, leading to a decrease in pressure.

Evaporation (4-1): During this stage, occurring at a constant pressure, the refrigerant within the evaporator evaporates. This process involves the absorption of heat from the region to be cooled. The refrigerant transitions from a saturated liquid-vapor mixture to fully vaporized refrigerant. Throughout the process, the compressor receives vaporized refrigerant, which is then compressed, resulting in elevated pressure and temperature. The refrigerant's journey continues as it enters the condenser, condensing into a saturated liquid state. Eventually, the refrigerant, now in the form of saturated liquid, proceeds through the expansion valve, restarting the cycle [18].

$$q_e = h_1 - h_4 \tag{1}$$

The work done by the compressor

$$q_{work} = h_2 - h_1 \tag{2}$$

$$\frac{h_{2z}-h_1}{h_{2a}-h_1} \text{(Isentropic efficiency)} \tag{3}$$

Condenser's rate of heat transfer

$$q_c = h_2 - h_3 \tag{4}$$

$$\text{C.O.P} = \frac{q_e}{q_{work}} \tag{5}$$

(1) Compressor

$$W_{comp} = \dot{m}_1 c_{p,nf}(T_2 - T_1) \tag{6}$$

$\dot{m}_1 - \dot{m}_2$

where W_{comp} = power input into the compressor,
$c_{p,nf}$ = specific heat of Nanofluid at constant pressure
$\dot{m}_1$ and $\dot{m}_2$ are mass of flow rate
$\dot{T}_1$ and T_2 are temperature at the compressor inlet and exit respectively.

(2) Condenser

$$\dot{Q}_c = \dot{m}_2 c_{p,nf}(T_3 - T_2) \tag{7}$$

$\dot{m}_1 - \dot{m}_2$

where $\dot{Q}_c$ = the rate of heat removal at the condensor
$c_{p,nf}$ = specific heat of Nanofluid at constant pressure
$\dot{m}_1$ and $\dot{m}_2$ are mass of flow rate
$\dot{T}_2$ and T_3 are temperature at the condensor inlet and exit respectively.

(3) Capillary tube

$T_4 = T_3$

$m_4 = m_3$

where
T_3 and T_4 are temperature at the capilary tube inlet and exit respectively.
$\dot{m}_3$ and $\dot{m}_4$ are mass of flow rate.

(4) Evaporator

$$Q_e = \dot{m}_4 c_{p,nf}(T_1 - T_4) \tag{8}$$

$\dot{m}_4 - \dot{m}_3$

where Q_e = rate of heat removal at the evaporator
$c_{p,nf}$ = specific heat of Nanofluid at constant pressure
$\dot{m}_4$ and $\dot{m}_3$ are mass of flow rate
$\dot{T}_4$ = inlet temperature of refrigerant, and
$\dot{T}_1$ = outlet temperature of refrigerant, and
while the nano refrigerant's thermo physical properties.

$$\text{Density: } \rho_{NP} = \omega_n \rho_p + (1 - \omega_n)\rho_{PR} \tag{9}$$

Table 2: Technical conditions of setup

Capacity	VCR system
Condenser	Air-cooled
Compressor	Hermetically Sealed
Refrigerant	R_134a
Drier/filter	Dry all Make
Expansion device	Capillary Tube
Refrigerant flow	Rotameter
Measurement	
Pressure indication	Pressure Gauges,
Temperature indicator	Digital LED
Supply	230 Volts, 50Hz,

3.1 Charging of set-up

To detect the leakage in the refrigeration test ring, a pressure range of 4-6 bar is used to fill R-134a gas. It must be kept for minutes and supplied for 10 to 15 minutes. As a consequence, leakage is detected. After that, the ex-valve is connected to the vacuum pump, and R134a gas is evacuated by creating a vacuum. This procedure has been carried out as a precaution. The prepared nano lubricant was transported to the compressor by the service ports. The allowed weight is about 130 – 160 ml or 120 grams. The stabilization time of the system is 20 min.

3.2 Performance test

A pure R-134a refrigerant is used for the performance test, which provides a basis for test comparison. R-134a with nano-lubricant was added to the testing apparatus in varying concentrations and the test was conducted. Each sample has to be done in the same setup 2-3 times for accuracy and stability [19]. The incremental masses of 120 grams and 160 grams can be performed.

The performance of the test rig has been affected by the following factors: Refrigeration effect q = heat removal\mass flow rate, and C_{op} = heat removal\work input.

Energy factor = cooling capacity\power consumption.

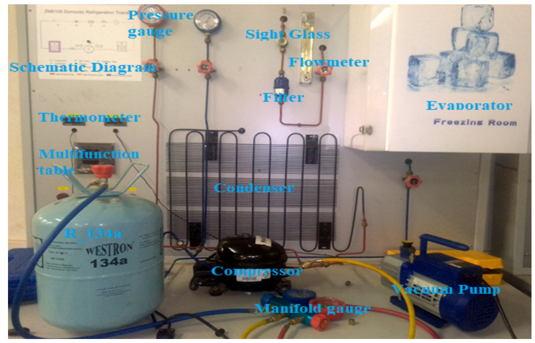

Figure 2: Experimental setup

The VCR system can be seen in the experimental setup in Figure 2. Compressor, condenser, expansion device, evaporator, measuring device, and control gadget comprise this set of components [18]. In the above figure, the experimental setup reveal under the VCR system.

4. Conclusions

The study outcomes demonstrate an upward trend in both nanoparticles and the subsequent cooling effectiveness of the system. Additionally, the Coefficient of Performance (COP) of the system sees an improvement. Conversely, the workload of the compressor experiences a reduction. On the whole, these results underscore the necessity for further exploration to ascertain the impact of diverse nanoparticle characteristics on VCR systems.Moreover, the incorporation of nano-Al_2O_3 into the refrigerant leads to a noteworthy escalation in both the cooling capacity and thermal efficiency of the system. Notably, the introduction of 0.5 percent Al_2O_3 nanoparticles into the base refrigerant results in an enhanced overall performance compared to the pure base refrigerant. It should be noted, however, that elevating the nanoparticle content beyond a certain percentage in the base refrigerant could lead to a decline in system performance.

Table 2: Nomenclatures

R134a	1,1,1,2 Tetraflouroethane	HCFC	Hydro Chlorofluorocarbons
R22	Chlorodifluoromethane	VCR	Vapour Compression Refrigeration
R-12	Dichlorofluoromethane	HVAC	Heating Ventilating and Air-Conditioning
LPG	Liquefied Petroleum Gas	CFCs	chloro-fluoro carbons
HT	Heat Transfer	EG	Ethylene Glycol
ODP	Ozone Depletion Potential	POE	Poly Ester Oil

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