

COMPREHENSIVE REVIEW ON PERFORMANCE OF NANO REFRIGERANTS USED IN REFRIGERATION SYSTEM

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Abstract

Environmental concern is the major issue faced in refrigeration and air conditioning systems. The performance of a refrigeration system can be altered through altering the system or changing the properties of working fluids such as refrigerants. Traditionally, CFC is widely used as a refrigerant in refrigeration systems. But this CFC refrigerant has high ODP and GWP value. So, other refrigerants such as HCFC and HFC is developed as an alternative to CFC refrigerant. However, this refrigerant also have high GWP values. So, the researchers are focused on designing an effective-refrigerant that reduce the emission due to usage of reduced power consumption. Recently, the use of Nanoparticles had gained attention in many engineering fields due to its excellent properties. This review article summarizes the use of different nanorefrigerant in the refrigerant system along with its performance. Initially, this article covers the use of traditional refrigerants Such as CFC. After that, the use of conventional refrigerants such as HCFC and HFC as a substituent for CFC is displayed. After that integration of Nanoparticles along with conventional refrigerant for performance-improvement is studied. Following that various Nanoparticles such as TiO₂, SiO₂ and CuO dispersed along with conventional refrigerant are also studied. The analysis is done through evaluating the performance of nanorefrigerant based on COP and Power consumption. Analysis showed that the application of Nanoparticles along with refrigerant attains better performance in comparison with conventional refrigerant. Ultimately, the difficulties and possibilities for further study are highlighted, which will be helpful for the field's newcomers and manufacturers.

Keywords: Refrigeration System, CFC, Ozone Depletion Potential, Global Warming Potential, Nanorefrigerant, Power Consumption

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Introduction

The four crucial components of a fundamental refrigeration system are the compressor, capillary tube, condenser, and evaporator. The four components of the system are advantageous for applications requiring freezers and air conditioners (Azmi *et al.*, 2017). Before sending the refrigerant to the condenser, the compressor, which is put together in the right order, will compress it into a vapour at high pressure and temperature. Before being fed into a capillary tube, high pressure and temperature refrigerant will be cooled in the condenser using free convection heat transfer. Condenser pressure is lowered to evaporator pressure using a measurement device known as a capillary tube. During this process, the refrigerant's temperature falls as well, changing its phase from sub-cooled liquid to mixture. After that, the refrigerant is fetched into the evaporator (Mota-Babiloni *et al.*, 2020).

Evaporators, which serve as heat exchangers, absorb the available heat in a cold environment. The refrigerant subsequently conducts the heat into the compressor. Every one of these procedures was ongoing (Sun *et al.*, 2016). The layout of the basic refrigeration system is given in Figure 1.

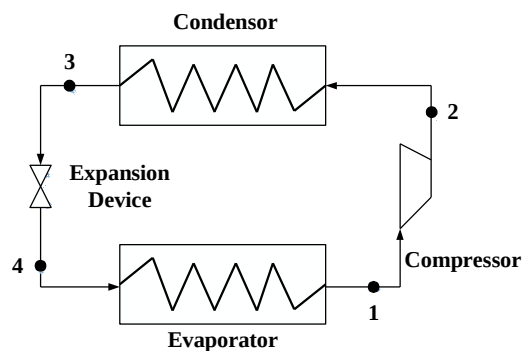


Figure 1. Schématic Representation of Basic Refrigeration System

The majority of transport refrigeration systems, on the other hand, use multi-evaporator refrigeration systems, which have more than two evaporators and enable the independent cooling of numerous compartments within a single trailer. Refrigerants are used in cooling components because they help reduce the heat generated inside the system, which is why their use is crucial (Qureshi and Zubair, 2012). The main functions of the refrigerants are heat absorption and cooling of the system. The low-pressure gas that it frequently

contains is effectively stored in the copper coils. This refrigerant, when mixed with copper, plays a significant function in the absorption of heat that travels through various copper components because copper is widely known for being a good conductor of heat transmission (Babu *et al.*, 2021).

As the cooling process progresses, the heated refrigerant gas is converted into a liquid and evacuated through a fan until it is again converted back into a gaseous condition (Dalkilic and Wongwises, 2010). The heated air is driven outside and the cool air is circulated within the house using refrigerant pipes until the desired temperature is obtained. Traditional refrigerants, which have historically been used in refrigeration, are inefficient and contribute to global warming. The effectiveness and security of refrigeration both grew over time as new techniques were created (Baakeem *et al.* 2018). The application of nanomaterials as chemicals in refrigeration systems has a variety of advantages, including improved thermal conductivity and heat transfer coefficient, which reduces the system's energy consumption.

In comparison to conventional refrigerants such as chlorofluorocarbons (CFCs), hydrofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), which have a substantial detrimental impact on ozone depletion and global warming, nano-refrigerants provide a superior option. (Saidur *et al.*, 2011). The efficiency of nanoparticles in refrigeration and air conditioning systems depends on their kind, size, shape, and volume % in the lubricant or working fluid. If a compressor's workload could be decreased or an evaporator's capacity to absorb heat could be improved in a refrigeration system, the use of nanofluid science would be expanded.

Metals like copper, nickel, and aluminium as well as oxides like Al_2O_3 , TiO_2 , CuO , and SiO_2 can be used to make nanoparticles. In a variety of heat transfer applications, base fluids such as water, propylene compounds, etc. are employed in addition to refrigerants (Sun *et al.*, 2019). By producing nanoparticles and spreading them throughout the base fluid, nano-refrigerants are produced. However, the kind, size, shape, and concentration of nanoparticles affect a refrigeration system's efficiency. As manufacturing and dispersion methods for nanoparticles advanced, the study of nanofluid would grow. Before any new nanoparticle material can be produced, all testing and experimentation processes must be finished (Krasae-In *et al.*, 2010). This article includes a study of the usage of nanorefrigerant in refrigeration systems, as well as its advantages over other conventional refrigerants such as CFC, HFC, and HCFC. Additionally, the performance of different

nanorefrigerant is also analysed using the energy destruction rate, power consumption and Coefficient of Performance (COP) (Tassou and Grace, 2005).

Outline of the Articles Considered for Analysis

The main intention of this present work is to carry out a review of the use of various nano refrigerants used in the evaporator of the refrigeration system. Around forty nine articles are taken for the study which is acquired from the online database from the past fourteen years (2008-2022). The journals from which the articles were obtained are Elsevier, springer, Wiley, taylor, ASM and mdpi. The study is carried on different stages. In the first stage, the use of conventional refrigerants such as CFC is studied. In the second stage, the usage of alternative refrigerants such as HCFC and HFC is studied. Then, the use of different nanorefrigerant in a refrigeration system is studied. Then, the performance of nanorefrigerant is studied and compared with conventional refrigerant.

Use of Conventional Refrigerants In Refrigeration System

Initially, Chlorofluorocarbon (CFC) is a widely used refrigerant in refrigeration systems prevailing all over the globe. CFC is generally referred to as conventional refrigerants. However, the release of chlorine from CFC into the atmosphere creates the destruction of ozone molecules leading to health hazards. Because this ozone layer restricts the entry of very dangerous ultraviolet radiation. As this hazard is considered a global problem the production of different variants of CFC is banned in early 1980. Therefore, developing environmentally friendly refrigerants is a priority in order to lessen ozone layer depletion and global warming. The use of HCFC and HFC refrigerant as alternatives to CFC is focused as they offer reduced ODP and GWP. The evolution of conventional and alternative refrigerants is given in Figure 2.

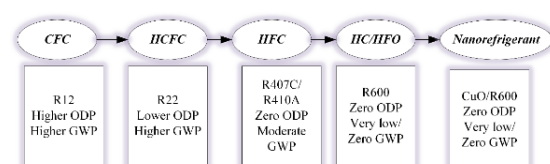


Figure 2. Evolution of various refrigerants used in the Refrigeration System

Selection of effective and eco-friendly refrigerants is considered to be a challenging task in the refrigeration system. In addition to pure refrigerants, a mixture of refrigerants is used in various refrigeration systems. Some of the articles that utilized conventional refrigerants such as CFC are reviewed below.

Arcaklioğlu *et al.* (2004) studied the Coefficient of Performance (COP) and Total Irreversibility (TI) Parameters for different variants of CFC such as pure and mixed refrigerants. Artificial Neural Network (ANN) was used for finding COP and TI of various CFC based refrigerants. Zhang *et al.* (2017) conducted an experimental Developed model attained R^2 value of 0.99 and error in the range of 2-3%. Study to analyse the emission rate of CFC-12 refrigerants and further compared it with some of the alternative refrigerants such as HCFC and HFC. The analysis concluded that the emission factor was maximum for CFC-12 refrigerants compared to other refrigerants. Kumar and Rajagopal (2007) focused on conducting an experimental analysis to find an alternative refrigerant to CFC-12 that produces low global warming potential (GWP) and ozone depletion potential (ODP). Various research work conducted on refrigeration systems reported that there was no refrigerant that focused on achieving both GWP and ODP.

Mani *et al.* (2008) designed a new refrigerant mixture through combining R290 and R600a for application in a vapour compression enabled refrigeration system. The suggested refrigerant's performance was also contrasted with that of the CFC-12 standard refrigerant. Analysis revealed that employing the intended refrigerant resulted in a performance that was closer to CFC-12. Finding an environmentally safe refrigerant alternative to CFC-12 with comparable performance served as the motivation for Agrawal and Shrivastava (2010). Moreover, the use of CFC-12 causes environmental hazards by depleting ozone later still they were used in various refrigeration applications for its efficient performance. So, the researcher in this present study focused on finding an eco-friendly refrigerant whose performance was similar to CFC-12.

Yıldırım *et al.* (2018) conducted a theoretical study on R32 to use as an alternative to various chlorofluorocarbon and hydrofluorocarbon refrigerants used in air conditioning and vapour compression system. Analysis showed that R32 produced low GWP and a higher coefficient of performance when compared to CFC. Prior articles

explained various alternative refrigerants as a pure form or mixture designed for substituting CFC-12. Most of the articles reported in this section made a comparison study between the designed refrigerant and CFC-12. However, the designed refrigerant attained lower GWP and ODP but the performance is slightly closer to CFC-12. Presently, the use of CFC-12 refrigerants in various refrigeration, heat pumps and air conditioning applications had been banned due to the release of harmful substance into the atmosphere that causes ozone layer depletion. Nowadays most scholars are focusing on designing eco-friendly refrigerants with similar performance as that of CFC-12.

Use of Alternative Refrigerants in Refrigeration System

The banning of CFC refrigerant due to the emission of a large amount of greenhouse gases led to the development of alternative refrigerants that are found to be environmentally friendly and produces lower GWP and ODP. HCFC based refrigerant is designed as an alternative to CFC in the early years 1970 when the production of CFC is banned. However this HCFC refrigerant reduces only ODP and it does not possess any impact on GWP. Further to reduce both GWP and ODP, HCF is developed to substitute HCFC. Though the design of HCF refrigerant helps in reducing both ODP and GWP it achieved reduction only in a moderate amount. Next, natural refrigerants are developed to reduce both GWP and ODP to act as eco-friendly. Some of the article reported on designing alternative refrigerant to reduce carbon dioxide emission and the greenhouse effect is reviewed below.

HCFC based refrigerant

Refrigerants made up of HCFC are generally composed of chlorine, fluorine, hydrogen and fluorine. However, this refrigerant is found to be less stable in comparison with CFC. It also causes lesser destruction of the ozone layer when compared to CFC. Substances that are used in HCFC are also called *transitional substances*. Some of the articles reported on the usage and drawback of HCFC refrigerant are reviewed below.

Yang and Wu (2013) planned on developing an alternative refrigerant to HCFC-22 as they create moreover equal impact on the environment as that of CFC-12. This article stated that HCFC was commercially used as a working fluid till 2010. It achieved 0.004 ODP and higher GWP. Due to higher GWP the use of HCFC was reduced.

Xiang *et al.* (2014) contributed to improving the design of HCFC-22 refrigerants for mitigating the impact of global warming caused by these

refrigerants in different seasons. HCFC based refrigerants was presently used as refrigerants in air conditioning and refrigeration system. The emission of global effects varied with respect to seasons. Analysis showed that global impact was three times greater in summer than in winter. Cleland *et al.* (2009) performed an experiment to find alternative refrigerant to substitute HCFC-22 in dairy farms. HCFC-22 was used as a refrigerant in dairy refrigeration systems. Based on the analysis it was found that hydrocarbon based refrigerants such as a mixture of propane and ethane can be used in dairy farms as their performance was similar to that of HCFC-22.

Cardoso *et al.* (2017) conducted an analysis to find the variant of refrigerant which was commonly used in the food industry of Portuguese country. The analysis found R22 a variant of HCFC was commonly used in the food industry. But this refrigerant has a high GWP. So, the researchers were finding alternative refrigerants to R22 that possess low GWP. Zhao *et al.* (2015) calculated life cycle carbon footprints for fluorinated refrigerants used in refrigeration and air conditioning systems. Through calculating the carbon footprint, the potential for emission of greenhouse gas can be reduced effectively. This reduction of greenhouse emissions was achieved through improving the recycling rate of refrigerants.

The articles mentioned here is related to the use of HCFC based refrigerants for cooling purpose in various refrigeration and air conditioning system. However, these refrigerants are largely used in the early years their usage is banned presently due to high GWP. But still, the variants of HCFC are used in most of the food and dairy industries. HCFC helps in achieving higher cooling capacity but due to high greenhouse gas emissions, the production of HCFC is banned all over the world. So, researchers in almost all parts of the world are focusing to design an alternative refrigerants whose performance is similar to that of HCFC based refrigerants.

HFC based refrigerant

The refrigerant gases most often used nowadays are hydrofluorocarbons (HFC). They have taken the place of the ozone-depleting hydrochlorofluorocarbons (HCFC) and chlorofluorocarbons (CFC), respectively. Some HFC refrigerant blends or combinations have the undesired trait of temperature slide. There is a small variation in evaporating and condensing temperature at constant pressure during a phase change because the composition changes. Some of the articles reported on the usage and drawback of HFC refrigerant are reviewed below.

After the Kyoto Protocol, HFC refrigerants including R134a, R407C, R404A and R410A have been widely utilised in heating, air conditioning, and refrigeration (HACR) systems. The drawbacks of these HFC refrigerants were demonstrated by Pabon *et al.* (2020). Nevertheless, they are being phased out due to their enormous capacity to contribute to global warming (GWP). High GWP refrigerants have a number of alternatives, but R1234yf, a hydrofluorolefin (HFO) fluid, stands out as a leading competitor. Hydrofluorocarbons (HFCs), hydrofluoroolefins (HFOs), and a number of mixes have been shown to replace chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs), according to Venkatarathnam and Srinivasa (2012). The current trend is to return to the naturally occurring fluids that were first employed, such as ammonia, carbon dioxide, hydrocarbons, water vapour, etc., due to the potential for global warming that these newly produced refrigerants possess.

The refrigerants R134a, R404A, and R410A have been replaced by environmentally friendly alternatives such as hydrofluoroolefin (HFO) refrigerants and their combinations with hydrofluorocarbons (HFC), which can be made to exhibit intermediate characteristics and become the ideal candidate for many RAC applications, with GWP values of 1300, 3943, and 2088. Daviran *et al.* (2017) examined the efficacy of HFO-1234yf and HFC-134a as alternatives in refrigeration and automobile air conditioning systems. The findings reveal that HFO-1234yf has an 18-21% lower refrigerant-side total heat transfer coefficient than HFC-134a and a pressure drop that is 24% and 20% smaller than HFC-134a during the condensing and evaporating processes, respectively.

In a small brazed plate heat exchanger, the HFC refrigerants 134a, 410A, and 236fa were vaporised. Longo and Gasparella (2007) described the experimental pressure drop and heat transfer coefficients. Also tested were heat flux, refrigerant mass flux, saturation temperature, outlet conditions, and fluid characteristics. The experimental results are summarized in terms of refrigerant heat transfer coefficients and frictional pressure decrease. Strong sensitivity to heat flux and outlet conditions and weak sensitivity to saturation temperature is demonstrated by the heat transfer coefficients. According to research by Deymi-Dashtebayaz *et al.* (2020) the effect of different refrigerants on the effectiveness of geothermal heat pump operation is examined. Five HFC refrigerants, including R125, R134A, R404A, R407C, and R507A, have appropriate operating ranges that are investigated for use with geothermal heat pumps, refrigeration and air conditioning systems.

Rasti *et al.* (2013) developed two domestic refrigerants such as R600a and R436A that can be used as an alternative to R134a which was a common variant of HFC. This R134a was utilized as domestic refrigerants and found to be environmentally safe and non-toxic however the effect of GWP was high. Analysis showed lesser energy consumption was achieved using the developed refrigerant when compared to HFC and it can be well suited for domestic applications. Designed refrigerants also possess lesser global impact when compared with alternative refrigerants.

HC and HFO based refrigerants

As low GWP refrigerants, HFO and HC have been investigated for application in freezers and air conditioning systems. The lubricating effectiveness of the sliding components of the compressor is established by these refrigerants.

Yan *et al.* (2021) conducted a theoretical study to analyse the use of R1224yd(Z) and R1336mzz(Z) which was HC and HFO based refrigerant developed as an alternative to R134a refrigerant. Analysis showed that R1224yd(Z) and R1336mzz(Z) can be well suited for heat pump and through optimizing the process better performance can be achieved.

He *et al.* (2022) analysed the theoretical performance of auto-cascade system made up of HC refrigerants. Five different HC based refrigerants such as R1150/R600a, R170/R600, R170/R600a and R23/R134a was designed and compared. Analyses showed that improved heat transfer rate and COP was achieved using R170/R600.

Thavamani and Senthil (2022) developed hydrocarbon refrigerant based vapour compression refrigeration system and analysed its performance. Lesser power consumption of about 17.86% was achieved using HC refrigerant system and more than 40% cooling capacity was attained.

Kumma and Kruthiventi (2022) developed domestic refrigerators mixed with eco-friendly hydrocarbon and hydrofluorocarbon. R600a, R600 and R290 (HC refrigerant) and R161, R152a (HFC refrigerant). From the analysis it was concluded that HFC refrigerant based refrigeration system attained better COP.

Liu *et al.* (2020) predicted heat capacity of different refrigerants such as HCFO, HFO, HFC and HC in case of liquid case. Around 17 refrigerants was developed and analysed which showed that better extrapolation ability was achieved at low temperature region.

Ayyamperumal Lalitha Saravanan *et al.* (2020) analysed the performance of HC-290 refrigerant used in split air conditioner. Analysis showed that better power consumption, COP and cooling capacity was achieved using HC-290.

Integration of Nanoparticles Along with Refrigerants

In order to improve system efficiency, nanoparticles are added to the refrigerant in refrigeration systems (nanorefrigerant). Nanorefrigerants are specialised subtypes of nanofluids. The mechanical and thermodynamic effectiveness of refrigeration systems could be greatly increased by the use of nanofluids. The efficacy of the system can be increased by adding nanoparticles to the base liquids, even if the impact on pressure must be carefully examined. In the refrigeration system, the nanorefrigerant serves as a heat absorber, a cooling agent, and also helps to improve heat transfer. Therefore, by incorporating nanoparticles into the refrigerant, the refrigeration system's capacity to conserve energy can be increased. Due to their superior heat transfer characteristics, nano refrigerants are discovered to be a fantastic alternative to improve the performance of refrigeration systems. Various articles reported on the design and use of Nano refrigerant in a refrigeration system are reviewed below.

Baskar *et al.* (2018) conducted an experimental investigation on adding nanoparticles namely zirconium oxide along with the refrigerants for application in vapour compression refrigeration system. Analysis showed that an improved coefficient of performance was achieved on using Nano refrigerant in the refrigeration system. Singh *et al.* (2021) analysed the performance and energy consumption attained by nanorefrigerant designed through merging R134a with Multi-Wall Carbon

NanoTubes (MWCNT) particles for utilization in various domestic refrigeration applications. Analysis showed that effective cooling capacity was achieved using the designed Nano refrigerant.

Rezaeianjouybari *et al.* (2020) designed a nanorefrigerant through dispersing CuO Nanoparticles on R600 pure refrigerants. The optimal concentration of nanomaterial was selected using Bayesian optimization. Through dispersing Nanoparticles in pure refrigerants, the rate of heat transfer can be improved. Analysis showed that an improved heat transfer rate was achieved when the concentration of nanoparticles was 1.5-2.2%. Ahmed *et al.* (2022) studied the performance of the refrigerator integrated with two types of nanofluid such as alumina and copper nanofluid that was prepared with a concentration range of 1-5%. Analysis showed that nano refrigerants had attained improved heat transmission across the condenser in the refrigeration system.

Elsaid *et al.* (2020) integrated two types of nanofluids such as titanium oxide and magnesium oxide along with conventional refrigerants to improve the rate of mass and energy transfer characteristic in refrigeration system used in cooling towers. 0.1% and 0.5% was the concentration of nanomaterial used in enhancing the performance of the designed nano refrigerants. Joshi *et al.* (2022) performed an experimental analysis on integrating Al_2O_3 along with conventional refrigerants such as isobutane (R600a) and tetrafluoroethane (R134a). R600a possessed a higher GWP value and on the other hand, R600a had low GWP. Varying concentrations of aluminium oxide such as 0.02%, 0.04% and 0.07% was integrated along with pure refrigerants. Analysis showed that improved COP and reduced power consumption and energy destruction rate were achieved using the designed nano refrigerants. Table 1 illustrates the use of different nanorefrigerant in the refrigeration system.

Table 1. Use of Different Nanorefrigerant in Refrigeration System

Author Name	Type of refrigerant	Nanoparticle used	Description	Performance
Sarrafzadeh Javadi and Saidur (2021)	R134a	Al_2O_3	Experimental investigation had been conducted to analysis the performance of nanorefrigerant based domestic refrigerators.	Energy consumption of 2.69% is achieved at 0.1% Al_2O_3
Alawi <i>et al.</i> (2019)	R141b	Al_2O_3	The effect of thermos-physical property on COP of nano refrigerant is studied.	An improved COP of about 2.69 is achieved.
Senthilkumar and Praveen (2015)	R600a	CuO	The performance of the designed nanorefrigerant is studied.	10-20% increased cooling capacity is achieved.
Aktemur and Öztürk (2022)	R1270	CuO	The performance of the designed nanorefrigerant is studied.	94.7% of energy efficiency is achieved.
kumar <i>et al.</i> (2016)	R134a and R152a	ZrO_2	The performance of designed nanorefrigerant in a refrigeration system is studied.	Zero ODP and low GWP is attained.

Review on Various Nano Refrigerants Used in the Refrigeration System

To increase performance and cut power usage, nano refrigerants are used in a variety of refrigeration systems. In general, the two important factors that determine the choice of refrigerants are the global warming potential (GWP) and the ozone depletion potential (ODP). 4 By combining a base fluid with nanoparticles that range in size from 1 nm to 100 nm, a nanofluid can be created. 5 When a standard refrigerant serves as the base fluid, it is referred to as a nanorefrigerant, which has the potential to increase the efficiency of refrigeration systems. Metal oxides like zirconia, alumina, titania, and silica; metal carbides like SiC; carbon in a variety of forms like fullerene, graphite, carbon nanotubes, and diamond; stable metals like copper and gold; and metal nitrides like SiN and AlN are among the most widely utilised nanoparticles. The field of nanofluid science would expand as nanoparticle manufacturing and dispersion techniques improved. All stages of production, testing, and experimentation must be completed before any new nanoparticle material may be created. Two approaches were used in the preparation of nanofluid such as single step and two-step processes. Figure 3 illustrates the approaches used in nanofluid preparation.

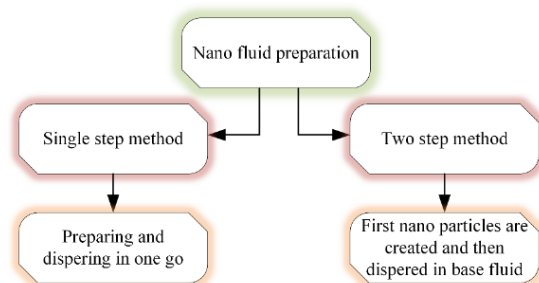


Figure 3. Approaches Used In Nanofluid Preparation

The performance of the designed nano refrigerant is determined based on the size, type, concentration of nanoparticles and method of preparation. When compared with other factor the concentration of nanoparticles greatly influences the performance of nanorefrigerant. However various nanorefrigerant had been designed through dispersing nanoparticles on lubricating and further integrating them with pure refrigerant. Various articles related to the design of nanorefrigerant for utilization in a refrigeration system are reviewed below.

TiO₂ and SiO₂ based Nano refrigerant

TiO₂ is the most prevalent nanoparticle discovered in refrigerants. When utilised in the base fluid, it improves the VCRs' overall performance. Even at low nanoparticle concentrations in the lubricant, adding TiO₂ considerably raises the COP. Adding 0.01% of titanium dioxide-based nanoparticles to raw mineral oil increased the rate of heat transfer while lowering work consumption, boosting the system's coefficient of performance, according to a general examination of the nanoparticles (COP). As the concentration rises, the viscosity rises and the friction coefficient falls. Nevertheless, SiO₂ is also used to make Nano-refrigerants. Its performance is very similar to TiO₂. Some of the articles related to the use of TiO₂ and SiO₂ based nano refrigerant for various refrigerant system is reviewed below.

Manoj Babu *et al.* (2016) examined the efficiency and dependability of nanorefrigerant-based refrigeration systems. In this research the Nanoparticles namely titanium dioxide and aluminium oxide were integrated along with conventional refrigerants like HFC-134a. 0.1% and 0.2% Concentration of TiO₂ and Al₂O₃ were integrated along with R134a. Analysis showed that improved COP and reduced energy consumption were attained using designed Nano refrigerants. An experimental investigation on the heat transfer properties of R134a refrigerants coated with Nanoparticles like TiO₂ was carried out by Ray and Bhaumik (2019). Fabrication of these nano refrigerants was achieved using the electron beam evaporation method. Analysis showed that a higher heat transfer rate was achieved on coating R134a with Nanoparticles such as TiO₂ when compared to the copper surface.

Senthilkumar *et al.* (2021) studied the performance of nano refrigerants designed using hybrid nanoparticles such as ZnO and SiO₂ in R600a. Performance analysis of the designed Nano refrigerants was conducted through varying the concentration of Nanoparticles such as 0.4g and 0.6g. Analysis showed that improved coefficient of performance, cooling capacity and reduced power consumption were achieved using the designed Nano refrigerants. Sabareesh *et al.* (2012) designed nano refrigerants through dispersing TiO₂ in conventional refrigerants such as R12 to reduce the emission of greenhouse gases. Analysis showed that an improved coefficient of performance was attained using the designed nano refrigerants. Additionally, the dispersion of low concentration Nanoparticles in R12 refrigerants helped to achieve improved performance.

Senthilkumar and Anderson (2021) designed a nanorefrigerant through dispersing SiO₂

Nanoparticles into the lubricating oil of R410A refrigerant. Analysis was conducted through varying concentrations of silicon dioxide and mass of refrigerant as 0.2%, 0.4%, 0.6% and 30, 40, 50, 60, and 70g. An experimental study showed that a higher refrigerating effect of 160W was attained when the concentration of SiO_2 is 0.4% and the refrigerant mass is 40g. Along with refrigerating effect higher coefficient of performance, nearly 1.7 was achieved. Sandipan Deb *et al.* (2020) conducted an experimental investigation for analysing the effect of surface wettability upon thin film coated with silicon dioxide Nanoparticles with the help of saturated refrigerant R-141b. Analysis showed that improved heat transfer rate and surface wettability was attained using the designed silicon dioxide based Nano coated surface.

Sarrafzadeh Javadi and Saidur *et al.*, (2021) performed energy efficiency and thermodynamic analysis on nano refrigerator designed using aluminium oxide. Energy efficiency was reduced to 2.69% on using aluminium oxide Nano particles in the refrigeration system.

Farahani *et al.* (2021) analysed the characteristic of refrigeration cycle substituted with Nano refrigerant and spiral star fins. SiO_2 and TiO_2 Nano particles were combined and used in the concentration of 0.025-0.3% and achieved 8% improved Coefficient of Performance (COP).

Cuo based Nano refrigerant

The CuO-PAG nano-lubricant is created by dispersing CuO nanoparticles in a lubricant made of PAG oil. This was done to improve the lubricant's tri-biological properties and thermal conductivity. For a higher COP and a lower potential for global warming, the R134a-based refrigerant was added to the CuO-PAG oil Nano lubricant. Some of the articles reported on the utilization of CuO based nanorefrigerant for various refrigeration purpose is reviewed below. Senthilkumar *et al.* (2023) analysed the functioning of R600a Nano refrigerants designed through integrating hybrid Nanoparticles such as CuO and Al_2O_3 along with R600a refrigerants. Analysis showed that enhanced performance with improved cooling capacity and reduced power consumption was achieved using the designed Nano refrigerant R600a. It was found to be a better replacement for conventional pure refrigerants.

Manikanden and Avinash (2019) conducted an experimental investigation and compared the performance of nano refrigerants made using pure

CuO and silver doped CuO. CuO based Nanoparticles were dispersed within R290 pure refrigerants in the ratio of 1:100. A comparison research performed on this constructed model revealed that using silver doped CuO nano refrigerants in the refrigeration system resulted in increased coefficient of performance and lower power consumption. Sanukrishna SS and AS (2017) developed a nano refrigerant by dispersing nanoparticle namely copper oxide in Polyalkylene glycol (PAG) oil which was a Nano lubricant and further infusing it with conventional refrigerant R-134. Performance investigation revealed that using Nanoparticles with refrigerant improved heat transfer rate, coefficient of performance, and power consumption.

Ghorbani *et al.* (2017) designed a nano refrigerant through dispersing CuO Nanoparticles in polyester oil and further infused in conventional refrigerants such as R600a. Performance of the designed nanorefrigerant was evaluated through varying concentrations of Nanoparticles as 0.5%, 1% and 1.5%. Analysis showed that an increased heat transfer rate was achieved using the designed nano refrigerant at 1.5%. Sheikholeslami *et al.* (2018b) designed a nanorefrigerant through integrating CuO along with conventional R600a refrigerant. Then, the author conducted an experimental study to determine a hydrothermal characteristic of nano refrigerant. Analysis revealed that due to the presence of Nanoparticles, the pressure drop created due to friction was improved.

Sheikholeslami *et al.* (2018a) evaluated the exergy loss and entropy generation of the Nano refrigerant condensation process. In this study effect of some of the parameters such as concentration of Nanoparticles, mass flux and vapour quality upon exergy loss and entropy generation were studied. Analysis showed that entropy generation increases with an increase in Nanoparticle concentration. On the other hand, with an increase in mass flux and vapour quality, the exergy loss got decreased. Tashtoush *et al.* (2017) analysed the functioning of an ejector refrigeration system designed using nanorefrigerant. This nanorefrigerant was designed through dispersing CuO in R134a pure refrigerant. Analysis was performed to determine the effect of Nanoparticle size, type and mass fraction on the heat transfer coefficient. Additionally, the COP achieved using the ejector refrigeration system utilizing Nanoparticles was also studied. The result showed that a higher COP of about 24.7% was achieved using nanorefrigerant in comparison with pure refrigerant.

Jeyakumar *et al.* (2022) developed nano fluid based refrigerants using CuO and Al₂O₃ to analyse coefficient of performance and power consumption. In contrast to normal refrigerant nano refrigerants such as Al₂O₃ and CuO attained 0.6% and 1.39% of power consumption.

Arumuganainar *et al.* (2023) developed three types of nano refrigerant using MgO and ZrO₂ and further performed thermodynamic analysis. Three combination of nano refrigerants used in R134a was R134a/ZrO₂, R134a/MgO and R134a/MgO/ZrO₂. Results confirmed that high rate of thermal conductivity and COP Of about 0.0196 W/mK and 3.5 was achieved using R134a/MgO Nano refrigerants.

Khetib *et al.* (2022) analysed the performance of ejector refrigeration system made of nano refrigerants which was used for cooling purpose in lithium ion battery used in solar system. Using nanorefrigerants in ejector system COP was improved to around 22.83%.

Aktemur and Ozturk (2023) designed a nano refrigerant combining R152a with Cu which was used in booster enabled ejector vapour compression refrigeration system. Analysis showed that energy destruction rate was reduced from 18.46%-34.48% and energy efficiency was enhanced of about 1.96%.

Anish *et al.* (2020) developed a nano refrigerant CuO/Al₂O₃-R22 used as working fluid. Improved heat transfer rate and reduced energy consumption was achieved using the developed nano-refrigerant.

CNT based Nano refrigerant

CNT is widely used in various applications because of its improved electrical, mechanical and thermal properties. Because of its improved properties CNT based nanoparticles are mixed with lubricating oil and used as nano refrigerant in the refrigeration system. Through varying the concentration of nanoparticles the performance of the refrigerant is greatly influenced. Some of the articles reported on the design of nano refrigerants using CNT nanoparticles are reviewed below.

Ahmadpour and Akhavan (2019) conducted an experimental investigation to study the effect of heat transfer on integrating MWCNT (multi-walled carbon nanotube) based Nanoparticles along with R600 refrigerants. Analysis was conducted through varying the concentration of Nanoparticles such as 0.1, 0.2 and 0.3%. The results showed that a nanoparticle concentration of 0.3% resulted in the greatest rate of heat transmission. Eshgarf and Afrand (2016) conducted an analysis to determine the rheological characteristic of hybrid Nano

refrigerant functionalized with acid. The hybrid Nanoparticles were designed through dispersing MWCNT with SiO₂ in a polyester oil. Then, the designed Nano refrigerant was dispersed in conventional refrigerant R600a. Analysis showed that the designed Nano refrigerant exhibited pseudoplastic rheological characteristics with the value of power law index less than unity.

Kumaresan *et al.* (2012) conducted experimental study on the convective heat transfer capabilities of a secondary refrigerant-based CNT nanofluid in a tubular heat exchanger. To make the nanofluid, multiwalled carbon nanotubes (MWCNT) are disseminated in a water-ethylene glycol mixture. The results show that the convective heat transfer coefficient increases to a maximum of 160% for nanofluids containing 0.45 vol. Ahmadpour *et al.* (2020) developed a nano refrigerant through incorporating a multi-walled carbon nanotube (MWCNT) in a conventional R600 refrigerant which was used within a horizontal micro fin tube. In that designed nano refrigerant an experimental investigation was conducted to analysis heat transfer characteristics. Simulation analysis revealed that by utilizing MWCNT nanoparticles the heat transfer rate was increased up to 74.8%.

Lin *et al.* (2015) designed nano refrigerant through dispersing MWCNT in R141b pure refrigerant and further studied the dispersion stability of MWCNT based nanorefrigerant used in the refrigeration system. On the other hand the dispersion stability of nanorefrigerant was studied with the addition of surfactant. Normally, the concentration and type of surfactant had a greater impact on the dispersion stability. Analysis showed that with the addition of surfactant namely dodecyl benzene sulfonate (SDBS) and increasing ultrasonication time, the dispersion stability was improved. Babarinde *et al.* (2020) evaluated the energy consumption achieved using R600a/MWCNT based nano refrigerant and then compared it with conventional refrigerant R134a utilized in a household refrigeration system. Analysis showed that the designed R600a/MWCNT based nano refrigerant achieved reduced power consumption of about 0.0639 kW and improved COP in comparison with R134a.

Akhtar and Rajput (2023) analysed the performance of MWCNT-R134a based nano refrigerant used in ice plant. MWCNT with varying concentration of 0.05g, 0.20g 0.10g and 0.25g was dispersed in polyolester oil and mixed with tetrafluoro ethane refrigerants. Cooling capacity and COP was improved to about 11.29% and 40.09%.

Performance Analysis

The performance of the designed nano refrigerant is evaluated and further compared with conventional or pure refrigerant. The major parameter used for finding the performance of the designed refrigerant is the coefficient of performance and power consumption. In addition to it, Ozone depletion potential and global warming potential is also used to determine the functioning of the designed refrigerant. The concentration of nanoparticles in a specially developed nanorefrigerant has a significant impact on its performance. Initially, the COP is validated for the designed nano refrigerant through varying the concentration of nanoparticles and further comparing the designed nano refrigerant with that of conventional refrigerant.

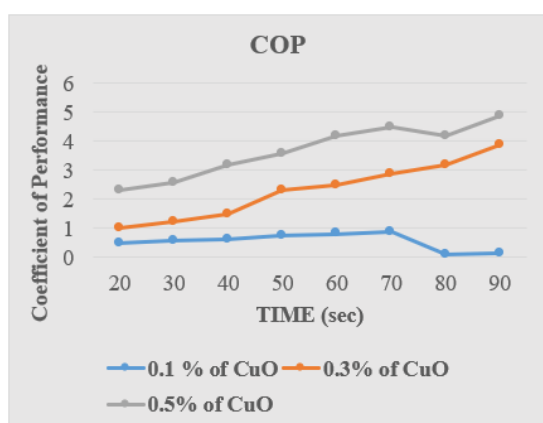


Figure 4. Evaluation of COP With Respect To Nano Particle Concentration

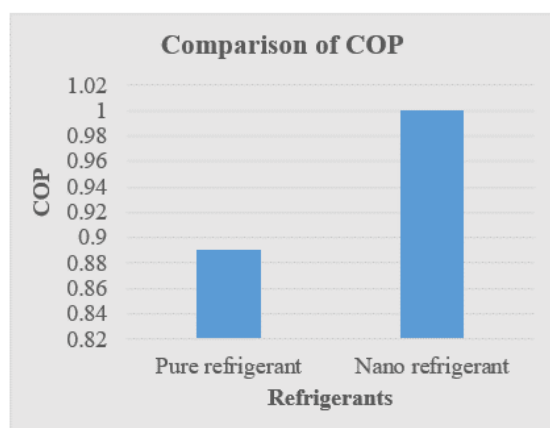


Figure 5. Comparison of COP between Conventional and Nanorefrigerant

Evaluation of COP

The proportion of electrical power consumption to heat dissipation is known as the Coefficient of Performance (COP). It is the criterion used to assess the performance of the refrigeration unit. It demonstrates the efficiency of the heating and cooling systems. A rising coefficient of performance (COP) indicates that the cooling output will increase proportionately to the input of electricity. Efficiency is directly correlated with increased COP. Figures 4 and 5 illustrate the evaluation of COP.

COP calculated with respect to the concentration of Nanoparticles is illustrated in Figure 4. The concentration of Nano particles greatly influences the performance of any nanorefrigerant. However with respect to the increase in Nanoparticle concentration, COP value gets increased. COP value greater than 1 illustrates the greater efficiency of the designed refrigeration system. At 0.1 concentration of CuO (Tashtoush *et al.*, 2017; Ghorbani *et al.* 2017, Sheikholeslami *et al.* (2018b) the COP value is 0.74 when the time is 50 sec. For a similar value of time, the COP value is 2.3 when the concentration of CuO increased to 0.3%. On the other hand at a higher Nanoparticle concentration of about 0.5 %, the value of COP is 3.6. Through this plot, we can conclude that COP gets increased with respect to the increase in the concentration of Nanoparticles.

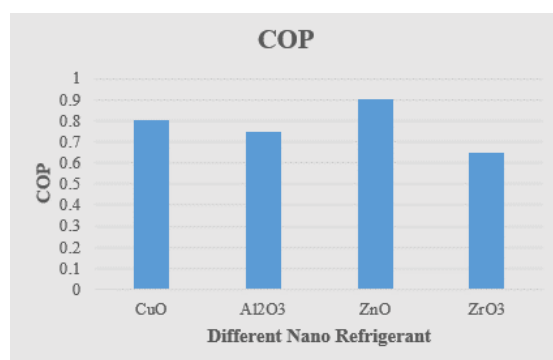


Figure 6. Comparison of COP between Different Nanorefrigerant

The value of COP is compared between the pure refrigerant and designed nanorefrigerant and illustrated in Figure 5. Normally, COP value determines the performance of the refrigeration system. Dispersion of Nanoparticles within conventional refrigerant is introduced to improve the performance. From the graph, it is found that the value of COP calculated for pure refrigerant is 0.89 whereas the value of COP calculated for nanorefrigerant is 1. Figure 6 illustrates the comparison of COP using different nano refrigerant. COP of different nano refrigerant such as CuO (Ghorbani *et al.* (2017); Sanukrishna SS and AS (2017); Tashtoush *et al.*, (2017); Sheikholeslami *et al.* (2018a); Sheikholeslami *et al.*, (2018b); Manikanden and Avinash (2019); Anish *et al.* (2020); Jeyakumar *et al.* (2022), Aktemur and Ozturk (2023)), Al_2O_3 , (Manoj Babu *et al.*, (2016); Senthilkumar *et al.*, (2023)) ZnO (Senthilkumar *et al.*, (2021), Sendil Kumar *et al.* (2014)) and ZrO_3 (kumar *et al.*, (2016); Arumuganainar *et al.*, (2023)) is 0.8, 0.75, 0.9 and 0.65. Based on this comparison it is found that on introducing Nanoparticles into conventional refrigerant the performance of the refrigeration system gets increased.

Energy destruction rate analysis

Resource damage is normally quantified by exergy destruction. The exergy destruction ratio evaluates the degraded resources and identifies the system components where destruction is taking place, whereas exergy efficiency analyses the quality of the exergy the system is harnessing. By identifying the cause of the degradation, it can be completely eradicated, increasing the refrigeration system's effectiveness. However, the rate of energy destruction is inversely proportional to energy efficiency of the system.

EDR comparison done between conventional and nano refrigerant is displayed in Figure 7. The energy destruction rate is normally calculated in terms of percentage. Introducing of various Nanoparticles into conventional refrigerant is done in order to reduce energy destruction and to achieve better energy efficiency. The energy destruction rate attained for conventional refrigerants such as CFC (Arcaklioğlu *et al.*, (2004); Kumar and Rajagopal (2007); Mani *et al.*, (2008); Agrawal and Shrivastava, (2010); Zhang *et al.*, (2020); Yıldırım *et al.*, (2018)), HCFC (Yang and Wu, (2013), Xiang *et al.*, (2014), Cleland *et al.*, (2009), Cardoso *et al.*, (2017), Zhao *et al.*, (2015)), and HFC (Longo and Gasparella, (2007); Rasti *et al.*, (2013); Daviran *et al.*, (2017); Deymi-Dashtebayaz *et al.*, (2020)), is 80%, 65% and 40% respectively. Following that energy destruction rate achieved using the designed nano refrigerant is determined to be 15%. Through

this comparison study it is revealed that a reduced energy destruction rate is achieved using nanorefrigerant in comparison with conventional refrigerant. Figure 8 illustrates the comparison between different nano refrigerant based on Total Equivalent Warming Impact (TEWI). TEWI is normally defined as the total of direct as well as indirect emission of greenhouse effect. TEWI Calculated for CuO, Al_2O_3 , ZnO and ZrO_3 is 800, 1500, 500 and 1000.

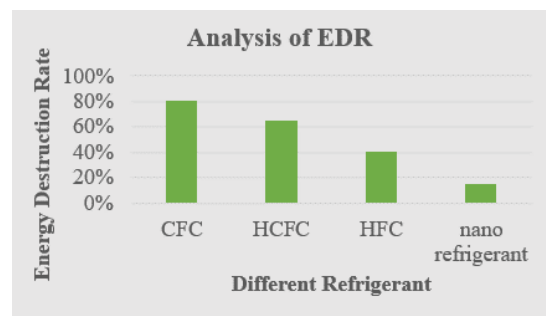


Figure 7. Comparison of EDR Achieved Using Different Refrigerant

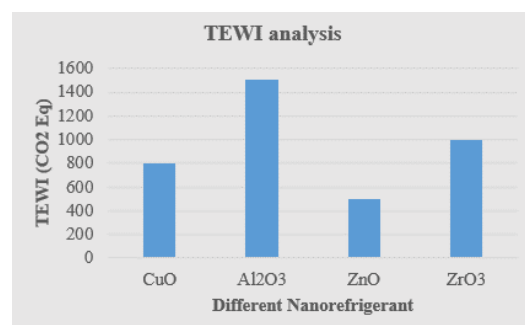


Figure 8. Comparison of Destruction Rate Achieved Using Different Nano Refrigerant

Analysis of Power Consumption

Power consumption is the term used to describe how much electrical energy is consumed to operate anything, such a home appliance, for a given amount of time. Typically, watts (W) or kilowatts (kW) are used to express power consumption. Equipment consistently uses more energy than is necessary. This is so because all machinery has some degree of inefficiency. Power loss is caused by heat, vibrations, and electromagnetic radiation. However, in case of refrigeration system higher amount of electrical energy is used. So, to minimize power consumption integration of Nano particles along with conventional refrigerant is focused.

A comparison of power consumption with respect to the concentration of Nanoparticles is given in Figure 9. On increasing the concentration of Nanoparticles the power consumption is found to be reduced. When the concentration of CuO (Tashtoush *et al.*, 2017) is 0.1%, the achieved power consumption is found to be 42 W at 40 sec. Following that, at 0.3% of CuO the power consumption is 69 w at 40 sec. Finally, at a higher concentration of about 0.5% of CuO the power consumption is 62 w at a similar 40 sec. Based on this study it is found that reduced power consumption is attained at higher concentrations of CuO Nanoparticles.

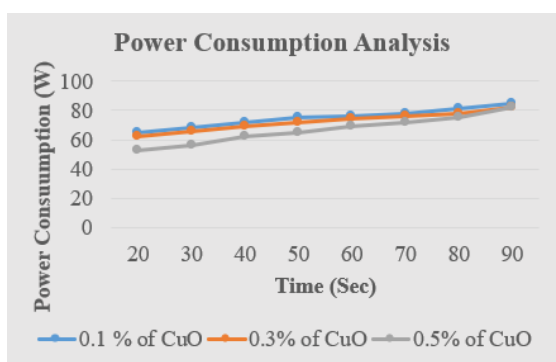


Figure 9. Power Consumption Achieved with respect to Nano Particles Concentration

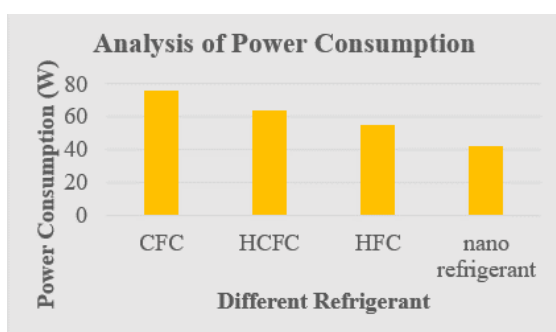


Figure 10. Comparison of Power Consumption between Conventional and Nanorefrigerant

A comparison of power consumption between conventional and nano refrigerants is displayed in Figure 10. Power consumption is normally calculated in terms of watts. Introducing various Nanoparticles into conventional refrigerant is done in order to attain reduced power consumption and to improve system efficiency. The value of power

consumption attained for conventional refrigerants such as CFC, HCFC and HFC is 76 W, 64 W and 55 W respectively. Following that power consumption achieved using the designed nano refrigerant is determined to be 42W. Through this comparison study it is revealed that reduced power consumption is achieved using Nano refrigerant in comparison with conventional refrigerant.

Evaluation of ODP and GWP

The global warming potential (GWP) of a substance is a measure of its potential for harm. With a GWP value of 1, carbon dioxide (CO₂) is used as a benchmark for comparing the values of other chemicals. The global warming potential (GWP) is estimated over a set time frame, often 100 years. The scale is at zero. The number of F-gases is expressed in tonnes of carbon dioxide equivalent.

Following that ODP value describes how hazardous a material is to the ozone layer on a relative basis. The ozone layer is negatively affected by CFC and HCFC refrigerants because chlorine reacts with ozone and catalyses the conversion of ozone molecules into oxygen. More than 100,000 ozone molecules might be destroyed by a single chlorine atom. The ozone layer has already suffered evident harm as a result of this process.

A comparison of ODP values for different refrigerants is displayed in Figure 11. The value of ODP equal or closer to one displays higher cause of ozone depletion by the refrigerant. So, the introduction of Nanoparticles into conventional refrigerant helps to reduce ODP value to zero. The value of ODP attained for conventional refrigerants such as CFC, HCFC and HFC is 1, 0.88 and 0.05 respectively. From this analysis it is found that traditional refrigerant such as CFC has higher ODP than alternative refrigerants such as HCFC and HFC has moderate ODP.

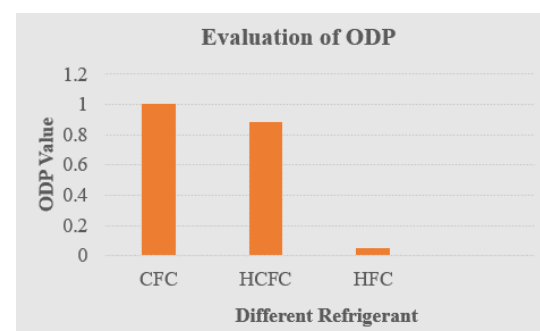


Figure 11. Evaluation of ODP for Different Refrigerant

A comparison of GWP values for different refrigerants is displayed in Figure 12. A higher GWP value is obtained on using traditional refrigerant. So, the introduction of Nanoparticles into conventional refrigerants helps to reduce the GWP value to zero. The value of GWP attained for conventional refrigerants such as CFC, HCFC and HFC is 3800, 1400 and 500 respectively. From this analysis it is found that traditional refrigerant such as CFC has higher GWP than alternative refrigerants such as HCFC and HFC has moderate GWP. Table 2 illustrates the case studies of different nano refrigerant used in practical insights.

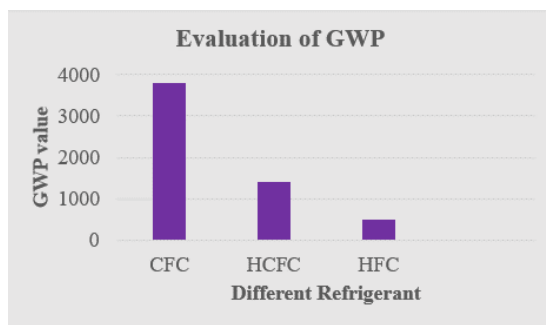


Figure 11. Evaluation of ODP for Different Refrigerant

Table 2. Case Studies of Different Nano refrigerants

Nano refrigerant	properties	Application
R134a-Al ₂ O ₃	High corrosion resistance and wear resistance	Heat ventilation and air conditioning system
R141b-Al ₂ O ₃	High corrosion resistance and wear resistance	Vapour compression system
R600a-CuO	High stability and thermal conductivity	Vapour compression refrigeration system and heat pump.
R134a-ZrO ₂	Energy conservation and high stability	Domestic refrigerator and freezer.
R152a-ZnO	Chemical and thermal stability	Vapour compression refrigeration

Practical Application of Different Nano refrigerant

The filling ratio of the working fluids primarily determines the performance of the heat pump, air conditioning system, vapour compression system, freezer, and household refrigerator. The model

forecasts the fluids output temperatures, operating pressures, compressor power consumption, and the overall energy performance of the system based on data about the fluid input conditions, geometric features of the system, size of nanoparticles, and compressor speed. It is convenient to compare the thermal performance of several nanoparticles using such an approach. The nonlinear equations of the system model were investigated and created using nanofluids as a fluid in various systems. Higher heat conductivity than that predicted by the macroscopic models that are now available, great stability, and minimal penalty from an enhancement in pressure drop and pipe wall erosion caused by suspensions of micrometer or millimeter particles are the benefits of nanofluids.

Suggestion

Refrigerants are mainly used as working fluid in the case of refrigerant systems. They constantly keep changing from liquid to gaseous state and vice versa. Initially, in the olden days, variants of CFC is commonly used as refrigerants in refrigeration systems. Although it possess better performance it causes harmful to the environment due to the release harmful substances into the atmosphere. CFC has higher value of GWP and ODP and increased power consumption due to which its production is banned all over the world. To reduce the release of harmful substances into atmosphere alternative refrigerants such as HCFC and HFC refrigerant is developed as a substituent to CFC. These alternative refrigerant such as HCFC and HFC has moderate GWP and ODP. To attain lower power consumption, different Nanoparticles are dispersed directly integration of Nanoparticles along with conventional refrigerant is done. Integration of nanoparticles reduces power consumption which ultimately results in reduction of emission generated from electric power supply based on total equivalent warming impact (TEWI) study. Pure refrigerant or mixed with lubricant oil and then introduced along with the refrigerant. The size, type and concentration of Nanoparticles have a greater impact on refrigeration performance. However, based on this review it is suggested that the use of Nano refrigerant achieved better refrigeration performance with reduced power consumption, ODP, GWP and increased COP.

Conclusion

The use of different Nano refrigerants in the refrigeration system is reviewed in this study. Initially, CFC refrigerants is commonly used in a refrigeration system as the working fluid. Due to the release of increased hazardous substances from

CFC, these refrigerants are banned from usage. So, an alternative refrigerant using hydro components such as HCFC and HFC was developed as a substituent for CFC. In spite of improved refrigeration performance, these refrigerants possess moderate ODP and GWP as well as increased power consumption. To meet all these requirements a better refrigerant must be designed. Recently, nanotechnology is at scope and widely used in various applications. Numerous challenges arise in the preparation of nanoparticles yet their usage is widespread. The concept of nanotechnology is introduced in the design of refrigerants for refrigeration systems. Various types of Nanoparticles such as TiO_2 , SiO_2 , CuO , and CNT and so on are integrated along with conventional refrigerant to obtain a Nano refrigerant. Performance attained using the designed Nano refrigerant is studied using some of the parameters such as power consumption, COP, ODP and GWP. The evaluation of these parameters revealed that reduced power consumption, and increased COP is achieved using nano refrigerant. So, the use of nanorefrigerant is suggested to be an effective alternative to conventional refrigerant in the refrigeration system.

Future scope

The application of nanotechnology offers greater opportunities to dispel these uncertainties. Numerous simulations, analyses, investigations, and correlations are required for substantially better equipment performance. More study is required because the synthesis of low boiling point refrigerant-based Nano fluid is a difficult problem. It is still necessary to research the physics underlying the fluctuation of Nano fluid thermophysical characteristics. A thorough investigation is required for some characteristics of nanofluid, such as surface tension and dielectric properties, as well as for the field of a newly developing fluid called a hybrid nanofluid, which is a blend or composite of two different nanoparticles in a base fluid. The refrigeration industry is moving toward natural refrigerants due to environmental concerns. However, no research on naturally based nano refrigerants (apart from R600a) has been done.

Déclarations

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Conflict of Interest

The authors declared that they have no conflicts of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

Availability of data and material

Not applicable

Code availability

Not applicable

Author contributions

The corresponding author claims the major contribution of the paper including formulation, analysis and editing. The co-author provides guidance to verify the analysis result and manuscript editing.

Compliance with ethical standards

This article is a completely original work of its authors; it has not been published before and will not be sent to other publications until the journal's editorial board decides not to accept it for publication.

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