African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 3, Issue 4, October - December 2024
Page No: 200-209
Website: https://aaasjournals.com/index.php/ajapas/index
ISI 2024: 0.877 SJIFactor 2024: 6.752 معامل التأثير العربي: 1.55

Enhancing The Performance of Refrigeration Systems Using The Nanoparticles: A Comprehensive Review

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تحسين أداء ظام التبريد باستخدام الجسيمات النانوية: مراجعة شاملة

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Received: August 31, 2024	Accepted: October 14, 2024	Published: October 22, 2024

Abstract:
This review paper presents a summary of the effect of nanoparticles on refrigerants as nano-refrigerants and lubricants as nano-lubricants on the efficiency of refrigeration systems as well as the thermophysical properties of the pure fluids. The results presented in this paper confirm that addition of the nanoparticles to the pure fluids will improve the thermal properties of the pure fluids which leads to a reduction in energy consumption, and improves both of refrigeration capacity, and the coefficient of performance of refrigeration system. Improving the thermal properties of refrigerants and lubricants is related to the concentration and type of nanoparticles being mixed with them. Application of nanoparticles technology to nano-lubricants achieves a good tribology characterization such as friction reduction and wear rate as compared to pure compressor lubricants. This achieves a longer life of mechanical parts, especially a compressor. Applying the nano-refrigerants achieves good thermophysical properties due to suspended nanoparticles which have a good thermal conductivity as compared to the pure refrigerants. However, nanoparticles technologies in refrigeration systems face many obstacles such as the costs of synthesizing nanoparticles and obtaining a homogeneous mixture free of sediment and agglomeration, which means stability for these particles for the longest possible period with lubricants and refrigerants.

Keywords: Refrigeration Systems, Thermophysical properties, Nano-particles.

الملخص
تقدم ورقة المراجعة هذه ملخصًا لتأثير الجسيمات النانوية على المبردات كمبردات نانوية ومواد التشحيم كمواد تشحيم نانوية على كفاءة أنظمة التبريد وكذلك الخصائص الفيزيائية الحرارية للسوائل النقية. تؤكد النتائج المقدمة في هذا البحث أن إضافة الجسيمات النانوية إلى السوائل النقية سيحسن الخواص الحرارية للسوائل النقية مما يؤدي إلى تقليل استهلاك الطاقة وتحسين كل من قدرة التبريد ومعامل أداء نظام التبريد. يرتبط تحسين الخواص الحرارية لغازات التبريد ومواد التشحيم بتركيز ونوع الجسيمات النانوية التي يتم خلطها معها. يحقق تطبيق تقنية الجسيمات النانوية على مواد التشحيم النانوية توصيفا جيدا للترايبولوجيا مثل تقليل الاحتكاك ومعدل التآكل مقارنة بمواد تشحيم الضاغط النقي. هذا يحقق عمرا أطول للأجزاء الميكانيكية، وخاصة الضاغط. أثناء تطبيق المبردات النانوية يحقق حالة حرارية جيدة

الكلمات المفتاحية: أنظمة التبريد، الخواص الفيزيائية الحرارية، جزيئات النانو.

Introduction

The biggest challenge facing the world in the energy sector is the shortage of energy sources and their excessive consumption, especially in both refrigeration and conditioning systems, and heat pumps. Recently, many researches have emerged to improve the efficiency of thermal systems in many ways, including: (I)

Modifications to heat exchangers and all their parts and (II) Optimization of operating fluids [1]. The first attempt to enhance the thermophysical properties of operating fluids was from Maxwell in 1873 where he mixed particles ranging in diameter from millimeter to micrometer into a pure fluid; however, this attempt faced many problems such as stability, clogging, and erosion. To improve heat transfer properties Choi in 1995 mixed the nanoparticles with working fluids to create a new concept which is nanotechnology. [2]. There are three types of nanofluids as follows (I) mono-nanofluids which contain identical nanoparticles, (II) hybrid nanofluids which contain different nanoparticles, (III) hybrid nanofluids which contain composite nanoparticles [1]. To successfully prepare nanofluids, the following conditions must be met: dispersibility, stability, chemical compatibility of nanoparticle, and thermal stability of nanofluids. Under these conditions, the thermal properties between nanoparticles and fluid will improve. [3]. There are two ways to prepare nanofluid, the first is called a one-step method, in this method, nanoparticle is prepared in powder form and mixed with pure fluids followed by processes such as ultrasonic, magnetic force, homogenizing, and high shear mixing for the diffusion of nanoparticles into the pure fluid. The one-step method, in this method, the nano-vapor powders are condensed into a liquid by reducing the pressure and dissolving them immediately in the pure fluid. [4, 5].

Literature review

The literature review was divided into three groups

The effect of nano-lubricants on the performance of refrigeration systems

Jatinder Gill et al (2019) studied the effect of different concentrations of TiO_2 mixed with MO in a household refrigerator as an alternative to R134a also used LPG as a refrigerant. A result showed an increase in the cooling loads and the efficiency of the system by 18.74-32.72 and 10.15-61.49%, respectively as the energy consumed by the compressor was less compared to the work of the system by R134a [6]. Munuswamy Karthick et al (2020) studied the performance of household refrigerator using different samples of nano-lubricants, R600a was a refrigerant. A result confirmed that COP increased by 14.61% and the nano-lubricants achieved higher COP which reduced the power consumption [7]. Damola S. Adelekan et al (2019) studied the household refrigerator using nano-lubricants which contain different concentrations TiO_2, LPG was a refrigerant. A result confirmed that the nano-lubricants achieved a reduction of power consumption by 14%, 9 %, and 8% respectively as compared to (pure MO) [8]. Dattatraya G. Subhedar et al (2020) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of Al_2O_3 added to MO, and R134a was a refrigerant. A result confirmed that 0.075vol % achieved the highest value of COP by 85%, and the use of nano-lubricants saved 27% compressor power [9]. T. O. Babarinde et al (2019) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of TiO_2 added to MO, and R600a was an alternative to R134a. A result confirmed that 0.4 g/L of TiO_2 achieved the highest COP and the lowest energy consumption as compared to R134a [10]. F. Selimefendigil (2019) studied the performance of household refrigerator using nano-lubricants which contains of TiO_2 added to PAG oil, and R134a was a refrigerant. A result confirmed that 0.5vol.%, 0.8vol.%, and 1vol.% achieved an improvement of COP around 1.43%, 15.72%, and 21.42%, respectively; and 1vol.% achieved the reduction in power consumption by 15% [11]. S. Sundararaj et al (2020) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of hybrid nanoparticles such as Au, HAuCl4, and CNT, mixed with PAG oil, and R134a was a refrigerant. A result confirmed that 0.2vol.% Au and 0.02vol. % CNT achieved the lowest power consumption as compare to another compositions of nanoparticles, greatest refrigeration effects, and maximum value of COP [12]. Anusha Peyyala et al (2020) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of Al_2O_3 nanopowder added to MO, and R410a was a refrigerant. A result confirmed that the highest value of COP was observed at 0.2vol% of Al_2O_3 [13]. T.O. Babarinde et al (2019) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of graphene mixed with MO, R600a were a refrigerant. A result confirmed that nano-lubricants based on 60 g of R600a and 0.2 g/L graphene exhibited the lowest value of power consumption and the highest value of COP [14]. D. S Adelekan et al (2019) studied the performance of household refrigerator using nano-lubricants which contain of TiO_2, mixed with MO, and R600a was a refrigerant. A result confirmed that the highest values of COP and refrigerating capacity were 4.99 and 290.83kJ/kg based on 40g-0.1g/L nano-lubricants [15]. Oluseyi O. Ajayi et al (2019) studied the performance of household refrigerator using Al_2O_3 added to OM, and R134a was a refrigerant. A result confirmed that nano-lubricants achieved the highest value of refrigeration capacity, the best efficiency, and lowest power consumption [16]. A. Senthil kumar et al (2020) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of Sio_2, mixed with POE oil, and R410A was a refrigerant. A result confirmed that 40 g of R410A and 0.4 g/L of Sio_2 achieved the best refrigerating capacity and the lowest value of power consumption, this led to enhancing COP as compare to pure lubricant [17]. A. Senthilkumar et al (2020) studied the performance of household refrigerator using nano-lubricants which contain different concentrations of Al_2o_3/Sio_2 hybrid nanoparticles, and R600a was a refrigerant. A result confirmed that 0.6 g./L of Al_2o_3/Sio_2 achieved the highest refrigeration capacity and COP, while the lowest compressor work, as compared to pure lubricants [18]. *Table.1and* figure.1 display some important results obtained from recent studies based on nano-lubricants.

The effect of nano-refrigerants on the performance of refrigeration systems

K. T. Pawale et al (2017) studied the performance of household refrigerators using nano-refrigerants which contain different concentrations of Al_2O_3, 50nm was scattered inside R134a. A result confirmed that 0.5wt.% of nanoparticles enhanced the efficiency of the refrigeration system, however, high concentrations of nanoparticles reduce the efficiency of the system. [24]. G. Sathesh Kumar et al (2018) studied the performance household refrigerator using nano-refrigerants which contain different concentrations of ZnO / SiO_2 hybrid nanoparticles, mixed with 0.5 kg of R134a.A result confirmed that COP increased around 26 %. [25] V.S. Manikanden et al (2019) studied the performance of household refrigerator using nano-refrigerants which contain of CuO, pure nano-Cuo, and Ag -doped nano-CuO were dispersed into R290. A result confirmed that COP of Ag-doped nano-CuO increased up to 29%, while the power consumption of a system reduced up to 28% [26]. Lal Kundan et al (2019) studied the performance of household refrigerator using nano-refrigerants which contain different concentrations of Al_2O_3 scattered inside R134a, particle size diameter 20nm. A result based on volume flow rates of refrigerants confirmed that 6.5 L/h and 11 L/h achieved improvements of COP from7.20 % to 16.34% respectively at 0.5 wt. % of Al_2O_3, however, the use 1 wt.% of Al_2O_3 caused reduction of COP at the same volume flow rates [27]. M Nagaraju et al (2018) studied the performance of household refrigerator using nano-refrigerants which contain different concentration of CuO particle size range 10 to 70 nm was scattered inside R134a. A result confirmed that 0.8wt. % of Cuo was the optimal concentration which achieved the highest heat transfer, COP, and reduction of power consumption [28]. Satyam Kumar et al (2019) studied the performance of household refrigerator using R134a / PAG oil, R600a / PAG oil, and Cu nanoparticles was scattered inside R600a. A result confirmed that R600a achieved the highest values of COP and refrigeration capacity around 27.12% and 25% respectively as compared to R134a, while the reduction of power consumption was 1.69% which was less than that of R134a [29]. V.P. Suresh Kumar et al (2016) studied the performance household refrigerator using different concentrations of ZrO_2, particle size diameter 20 nm was scattered inside both R134a and R152a. A result confirmed that the maximum of COP was 33.45% based on (0.06 vol % of ZrO_2/ R152a). The use of R152a as a refrigerant was environmentally beneficial due to its properties such as zero ozone depletion potential and very low global worming potential [30]. Qasim S. Mahdi et al (2017) studied the performance of household refrigerator using nano-refrigerants which contain different concentrations of Al_2O_3, diameter size of 20-30 nm was scattered inside R134a. A result confirmed that increase the nanoparticle concentration improve the COP by 3.33% to 12%, respectively, and the energy consumption reduced nearly 1.6% and 3.3%, respectively [31]. Pallav Pandey et al (2017) studied the performance of household refrigerator using different concentrations of TiO_2, particle size diameter 30-50 nm was scattered inside R134a.A result confirmed 0.4 vol. % of TiO_2 improved the COP around 11.1% at 20°C, 25°C, and 30°C evaporator temperatures. Also, it has not been observed an increase or decrease in power consumption, which confirmed that the nanoparticle was completely dissolved into the refrigerant [32]. *Table2 and figure 2* display some important results obtained from recent studies based on nano-refrigerants.

Thermophysical Properties of Nano-refrigerants and Nano-lubricants

The thermal conductivity is one of the most important physical properties because of its effect on boiling and convective heat transfer coefficients, and this reflects the reason for the increasing research on the study of this property and with the remarkable progress, especially in recent years and the demand by researchers to study nanoparticles, studies have begun to increase, which include the effect of these particles on the thermophysical properties of others such as viscosity, density and specific heat [2]. The thermophysical properties of nano-lubricants using Al_2O_3 and ZnO respectively mixed with POE oil at temperature ranging from 288 to 318 K was studied by M.A. Kedzierski et al (2017). A result confirmed that the increase of the nanoparticle concentrations led to the increase of viscosity, density, and thermal conductivity but viscosity and density decreased with increasing of temperature [38]. thermal conductivity and viscosity of nano-lubricants using different concentrations of TiO_2 added to PAG at temperatures ranging from 20°C to 90°C.were studied by S.S. Sanukrishna et al (2018). A result confirmed that the increase of nanoparticle concentrations led to increasing these parameters, but these parameters decreased with increasing a temperature [39]. The thermal conductivity and dynamic viscosity of nano-lubricants using different concentrations of Al_2O_3/SiO_2, Al_2O_3/TiO_2, and TiO_2/SiO_2 added to PAG oil at temperatures ranging from 303 to 353 were studied by K N.N.M. Zawawi et al (2018). A result confirmed that nano-lubricants based on 0.1vol. % of Al_2O_3/TiO_2/PAG improved the viscosity by20.50 % at the temperature of 303 K. While nano-lubricants based on 0.1vol % of Al_2O_3/SiO_2/PAG improved the thermal conductivity by 2.41% at the same temperature [40]. The density and the kinematic viscosity of nano-lubricants using different concentrations of h-BN nanoparticle were measured by R. Harichandran et al (2019). A result confirmed that the increase nanoparticle concentration led to increasing density, related to a kinematic viscosity of pure POE and nano-lubricants at various temperatures decreased these values with increasing of temperatures [20]. Thermal conductivity of four samples of nanolubricants which contain different concentrations of Al_2O_3 and TiO_2 was studied by Munuswamy Karthick et al (2020). A result confirmed that MO based on 0.05 vol.% of Al_2O_3 achieved the highest value of thermal conductivity, while MO based on 0.01 vol. % Al_2O_3 and 0.005 vol.% of TiO_2 achieved the lowest value of thermal conductivity [7]. The viscosity of nano-lubricants using different concentrations of CuO was studied by Ravinder Kumar et al (2018). A result confirmed that 0.2–1.0 wt.% of CuO led to an increase of the viscosity by 17%. In addition, viscosity decreased with increasing temperature [41] The thermal conductivity and viscosity of nano-lubricants using different concentrations of TiO_2 was studied by Gill Jatinder et al (2019). A result confirmed that the thermal conductivities were higher than pure oil by 14.37-41.25%, while the viscosities of nano-lubricants were lower than pure lubricant by 2– 6%. As well as, the viscosity decreased with increasing concentrations until 0.2g/L and then increased with increasing concentrations to reach the peak value at 0.6g/L of TiO_2 [42]. *Table 3* displays some important results obtained from recent studies based on nano-particles.

Table1. Summarized Literature Review Based on VCRs With Varieties of Nanoparticles.

Authors	Refrigerants	Lubricants	Nanoparticle	Nanoparticle concentrations	Findings
Ali CanYilmaz (2020)	R134a	POE	CuO 55 nm and Cu/Ag 30 nm alloy	0.5 %, 1 %, and 1.5 vol %	The experimental results indicated that 0.5 vol % of both CuO and Cu /Ag alloy nano-lubricant improved the COP nearly 20.88% and 14.55%, respectively as compared to pure lubricant [19].
R. Harichandran et al (2019)	R134a	POE	h-BN 70 nm	0.1 to 0.4 vol%	The experimental results indicated that COP increases up to 0.3vol% after that decreases. A maximum COP improvement was 60 % which is obtained at 0.3vol%. The use of h-BN with lubricant was not harming the system and it may be used in the future if its properties are specified [20]
David Fernando Marcucci Pico et al (2020)	R32	POE	Diamond average size 3 and 6 nm.	0.1% and 0.5wt %	The experimental results confirmed that COP and refrigerating capacity enhanced by 0.5 and 5.0%, respectively using diamond nanoparticle as compared to pure oil [21]
Vipin Nair et al (2020)	R134a	PAG	Al2O3 30 nm	0.5wt%.	The experimental results at evaporator temperatures ranging from -11 °C to 1 °C and at two various temperatures condenser 30 °C and 34 °C indicated that COP increased around 6.5 % as compared to pure lubricant [22]
K. Mohan et al (2020)	R134a	PAG	CNT, gold, and HAuCl	0.1% gold, 0.2% gold, 0.1% HAuCl4, 0.2% HAuCl4, 0.1% gold with 0.005% CNT, and 0.2% gold with 0.005 vol % CNT	The experimental results showed that nano-lubricant based on 0.1% gold with 0.005% CNT enhanced COP by 31.7% and consumed the lowest power consumption as compare to base lubricant [23]

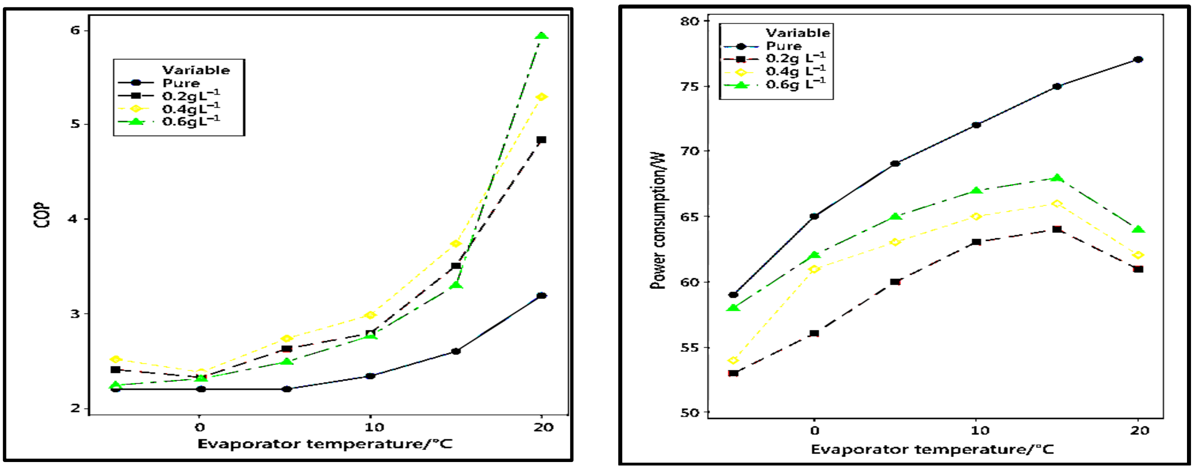
Table 2. Summarized Literature Review based on VCRs with varieties of nanoparticles.

Authors	Refrigerants	Nanoparticles	Nanoparticle concentrations	Finding
Shailendra Kumar et al (2016)	R134a	Al_2O_3 20nm	0.4 and 0.8 wt. %	The experimental results based on VCRs. showed that COP of R134a + 0.4%Al_2O_3 and R134a + 0.8% Al_2O_3 improved by 2.45% and 5.37% respectively as compared to pure refrigerant [33].
K. Veera Raghavalu et al (2016)	R134a	Al_2O_3 and TiO_2 20 nm	0.15 to 0.2 wt.%	The experimental results of performance of VCRs indicated that the addition of Al_2O_3 and TiO_2 enhanced COP by 12.08% by 21.18% respectively as compared to R134a [34].
G Senthilkumar et al (2017)	R22	CuO	0.05 vol%	The experimental results of vapor compression refrigeration system showed that addition 0.05vol % nano particles enhanced the heat transfer properties of refrigerant and deceased power consumption and increased COP from 0.58 to 0.62 [35]

Pravesh Kumar Kushwaha et al (2016)	R134a	Al_2O_3	0.25 % and 0.50 wt.%	The experimental results based on VCRS showed that COP of R134a + 0.25 % Al_2O_3 and R134a + 0.50 % Al_2O_3 improved up to 11.76% as compared to base refrigerant R134a [36].
A. Senthilkumar et al (2015)	R600a	CuO 50 nm	0.1 and 0.5 g/L	The experiment results showed that dispersing 0.1 and 0.5g/L of CuO into R600a in the domestic refrigerators saved 11.83% and 17.88% of power consumption respectively and improved a performance of a system [37].

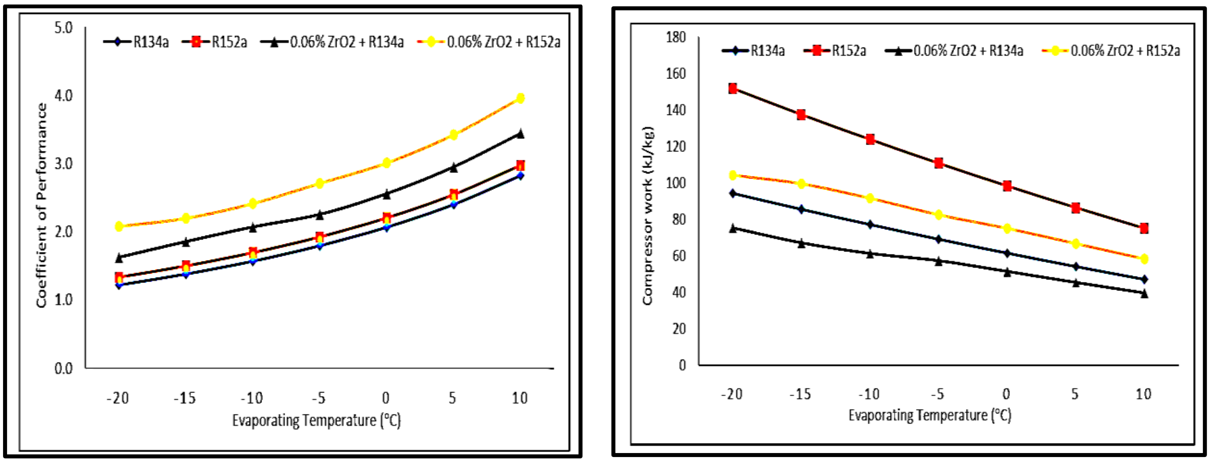
Table 3. Summary of Thermophysical Properties of Nano-refrigerants and Nano-lubricants**.**

Authors	Refrigerant	Lubricant	Nanoparticle	Nanoparticle concentrations	Finding
S.S. Sanukrishna et al (2018)	-	PAG	Al_2O_3	0.07 to 0.6 vol%	The experimental results of nano-lubricants within temperature ranging from 20 to 90°C indicated that a maximum thermal conductivity ratio and a maximum viscosity ratio were 1.48 and 18.42 at 0.6vol% and temperature 20 °C. respectively [43]
Subramani Narayanasarma et al (2019)	-	POE	SiO_2	0.01% to 0.2wt%	The experimental results of nano-lubricants within temperatures ranging from 25 to 85 °C, indicated that a thermal conductivity and a viscosity enhanced by increasing nanoparticles concentration. A maximum value of thermal conductivity ratio was 1.109, at 0.2wt% and 85 °C. The viscosity reduces with temperature while thermal conductivity increases with increasing of temperature [44].
Dattatraya G. Subhedar et al (2020)	-	MO	Al_2O_3	0.05%,0.075%, 0.1%, and 0.2 vol%,	The experimental results of nano-lubricants showed that increasing volume fraction of nanoparticle, leads to increase a viscosity compared to a pure lubricant [9]
Mohammad Hemmat Esfe et al (2020)	--	SAE 50 oil	20% MWCNT/ 80 % ZnO hybrid	0.0625%, 0.125 %, 0.25%, 0.5 %, 0.75 % and 1vol %	The experimental results of nano-lubricants within temperature ranging from 25–50 °C, showed that viscosity based on hybrid nanoparticles improved with increasing nanoparticles concentration at a constant temperature, while decreasing with increasing of temperature [45].
N. N. M. Zawawi et al (2019)	-	PAG	Al_2O_3 /SiO_2 hybrid	20:80, 40:60, 50:50, 60:40 and 80:20 for 0.1vol%	The experimental results of nano-lubricants at temperatures ranging from 30 to 80 °C., showed that thermal conductivity improved by 2.41% at temperature of 80 °C, while the highest improvement of dynamic viscosity, was 9.34% at 70 °C. Improvements in both parameters were observed for 50:50 nanoparticle ratios [46].
Songyuan Zhang et al (2020)	R141b	-	Al_2O_3, TiO_2 and SiO_2	0.02 to 0.1vol %	The experimental results of nano-refrigerants within the temperature ranging from 278 to 298 K. showed that thermal conductivity increases with increasing temperatures and concentrations, whereas decreases with increasing diameter size. Reduce diameter size in all cases caused increasing of thermal conductivity [47].
P.B. Maheshwary et al (2018)	R134a	-	ZnO	0.1 vol %	The experimental results of nano-refrigerants within temperature ranging from 283 to 307 K. showed that nano-refrigerant based on ZnO spheral and cubic shape has higher values of viscosity and density but lower a specific heat compared to pure refrigerant. The improvements of thermal conductivity of spheral and cubic shape of ZnO were of 25.26% and 42.5 %, respectively [48].
M.R.M. Nawi et al (2018)	HFE7000	-	SiO_2	0.005–0.02 vol%	The experimental results based on SiO_2/HFE7000 nano-refrigerant within temperature ranging from 283 to 303 K, showed that nano--refrigerants exhibited high stability with SiO_2 more than 90 days. A thermal conductivity increases with increasing concentration, but decreasing with temperatures. The highest improvement of thermal conductivity was 27% at 0.02vol%. Also, a viscosity of nano-refrigerants increases with increasing volume fractions but decreasing with temperatures [49]



(a) (b)

Figure 1 a) Variation in COP b) Variation in power consumption Damola S. Adelekan et al [8]



(a) (b)

Figure 2 a) Variation of COP with evaporating temperature b) Variation of Compressor work with evaporating temperature V.P. Suresh Kumar et al [30]

Conclusion

Most research has shown that the use of nanoparticles improves both the efficiency of refrigeration systems and of freezing capacity and reduces electrical energy consumption. Nanoparticle concentration affects improving the efficiency of refrigeration systems, as studies have shown that the higher concentration of nanoparticles, the better the efficiency of refrigeration systems, but some studies have shown that the efficiency of refrigeration systems increases at a specific concentration and then decreases , all research has confirmed that the use of nanoparticles with lubricants or refrigerants works safely in refrigeration systems, adding nanoparticles to lubricants reduces friction between rotating parts and wear rates when compared to base lubricants, which maintains a longer compressor life .Thermal conductivity is affected by several variables, including temperatures; particle size, dispersion, and stability. When increasing both the concentration of nanoparticles and temperature, thermal conductivity increases, thermal conductivity increases as the size of the diameter of nanoparticles decreases, improvement thermal conductivity of nanofluid was related to increase of thermal conductivity of nanoparticle. Surface layer between fluid particles and nanoparticles could act as a thermal bridge which leads to enhance heat conduction. One of the most important physical properties of lubricants is viscosity, so high viscosity leads to loss of energy and high operating temperatures, while low viscosity causes excessive wear between the moving parts. Viscosity increases with increasing of nanoparticle concentrations due to increase in their intermolecular force, while decreases with increasing of temperature due to increase a distance between nanoparticles which leads to reduce intermolecular force between the particles, which makes the layers less resistant to movement on top of each other, specific heat increases with increase temperatures whereas decreases with increase nanoparticle concentrations , density increases with increasing nanoparticle concentrations while decreases with increasing of temperature and the appropriate choice of nanoparticles type and concentration is an important role in improving the efficiency of refrigeration systems.

Some suggestions can be considered in future works

1. The previous studies reported that there is a lack of research done based on HC as a refrigerant. This refrigerant has environmentally friendly properties as well as flammability problems, therefore, much research must be carried out to overcome the flammability problems to use HC-based nano-refrigerants to reduce the environmental problems;
2. No enough researches on the application of nanoparticles into natural refrigerants for example carbon dioxide and ammonia;
3. Many kinds of research have been done on using metals and metal oxides of nanoparticles but still a need of comparative studies on this topic;
4. Examine various kinds of nanoparticles and refrigerants to determine an optimum nano refrigerant, the optimal concentration of nanoparticles dispersed in base refrigerant, size, and shape, to obtain the best performance improvement;
5. A comparative study must be carried out to clarify which gives system life cycle cost and the best performance, mixing the nanoparticles with compressor oil or with refrigerant;
6. Not enough studies about blending of nanoparticles with new refrigerants;
7. Several experiments must be carried out to obtain the suitable lubricant oils, refrigerants, and nanoparticles to enhance the performance of VCRs; and
8. One of the biggest challenges of the use of nano-refrigerant in VCRs is the process of preparing a uniform, homogeneous and stable mixture of nanoparticles with lubricant oils or refrigerants and its production cost by overcoming these challenges, it is expected that nanofluid will do a significant impact as a refrigerant in refrigeration system.

Abbreviations

PAG: Poly Alkylene Glycol
COP: Coefficient of Performance
VCRs: Vapor Compression Refrigeration System
MO: Mineral Oil
POE: Polyol ester oil
LPG: Liquefied Petroleum Gas
GWP: Global Warming Potential
ODP: Ozone Depleting Potential
Wt.: Mass fraction
Vol: Volume fraction
CuO: Copper Oxide
TiO_2: Tanium Dioxide
Al_2O_3: Aluminum Oxide
ZnO: Zinc Oxide
R134a: 1,1,1,2 –Tetrafluoroethane
SiO_2: Silicon Dioxide
Ag: Silver
R152a:1,1 Difluoroethane
R600a: Isobutane
h-BN: Hexagonal Boron Nitride
Cu: Copper
ZrO_2: Zirconium Dioxide or Zirconia
HAuCL4: Tetrachloro (hydrido) gold
Au: Gold
CNT: Carbon NanoTubes
R290: Propane
R22: Chlorodifluoromethane
Al: Alumina
R410a: Difluoromethane HFC32/Pentafluoro ethane HFC125
R32: Difluoromethane
HFE7000: 1-methoxyheptafluoropropane
R141b: Dichlorofluoroethane
MWCNT: Multi walled Carbon Nanotubes
HCs: Hydrocarbons

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