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A Review on Effects of Different Nano Lubricants with Sustainable Refrigerants Blend on the Performance of Domestic Air Conditioners

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Abstract

This review paper outlines the potential applications of sustainable hydrocarbon-based refrigerants and nano lubricants in domestic air conditioning systems, as well as the justification of their effectiveness through energy and exergy analysis. HCFC-based refrigerants, such as R22, offer both great thermal performance and cost-effectiveness. These refrigerants are usually used in domestic air conditioning systems although these have a detrimental effect on the environment, as outlined by the Montreal Protocol and the Kyoto Protocol, due to their contribution to ozone layer depletion and greenhouse gas emissions. For these reasons, developed nations are pursuing alternatives to these refrigerants, and ongoing research is being conducted. The research highlighted in this review paper pertains to sustainable refrigerants, which are a blend of HC and HFCs, due to their environmental friendliness, low GWP, and low ozone depletion potential (ODP). This study also examines the research on nano lubricants, which have the potential to enhance the thermal properties such as viscosity, conductivity, and thermal diffusivity in heat transfer devices compared to base fluids. Through the help of these studies, it has been observed that HCs blend with R22, as well as the mixture of nano lubricants, exhibit better exergy efficiency compared to R22 alone in refrigeration systems.

Keywords: Nanolubricant, Refrigerants blend, Exergy, Global warming potential (GWP), Air conditioner.

1. Introduction

The development of refrigerants in air conditioning systems has progressed through four generations, each addressing environmental and efficiency issues. The initial-generation refrigerants employed natural chemicals such as air, water, CO_2, NH_3, SO_2, and hydrocarbons (HCs), which had negligible effects on the environment[1]. Despite their effectiveness, they faced limitations in low-temperature applications. The subsequent generation of refrigerants introduced CFCs and HCFCs, which offered improved thermodynamic characteristics but also led to ozone depletion[1]. Common examples include R12 and R22, which were widely used until their phase-out began due to environmental regulations[2]. Third-generation refrigerants, such as hydrofluorocarbons (HFCs) R404A and R410A, were introduced, presenting reduced ODP yet maintaining a significant GWP [3]. These refrigerants enhanced energy efficiency but drew worries regarding their climatic influence. Fourth generation refrigerants prioritize low GWP alternatives, including hydrofluoroolefins (HFOs) such as R1234yf and R1234ze, engineered to reduce environmental impact while preserving efficiency [4], [5]. Investigation indicates that R1234yf offers enhanced performance characteristics, including reduced power consumption and exergy loss relative to traditional refrigerants[3]. Considering significant gains in energy efficiency and reductions in ozone depletion due to breakthroughs in refrigerants, the difficulty persists in balancing performance with sustainability concerns, especially as the industry shifts towards fourth-generation refrigerants.

Choi initially invented nanofluids, or nanoparticles dispersed in base fluids like water, ethylene glycol, and oil[6]. Nanofluids possess a promising application in renewable energy. They have remarkable characteristics, including thermal properties and stability. Numerous studies show that they exhibit superior convective heat transfer properties compared to base fluids[7]. There are two broad categories of nanofluid uses: coolants and lubricants. Refrigerant-based systems directly incorporate nanoparticles into the refrigerant, while lubricant-based systems first blend the nanoparticles with the lubricant before adding them to the refrigerant[8]. The integration of nano lubricants with sustainable refrigerant blends presents a promising avenue for enhancing the performance of domestic air conditioners. This review explores the thermodynamic characteristics and efficiency improvements achieved through the use of various nanoparticles, such as CuO, TiO_2, and SiO_2, in conjunction with alternative refrigerants. The findings indicate that these nano-enhanced lubricants not only improve heat transfer and reduce energy consumption but also contribute to lower environmental impacts by utilizing

refrigerants with reduced GWP. Studies show that nano-refrigerants like TiO_2-R152a and CuO-R152a significantly enhance the COP, achieving values up to 10.8 [9]. The incorporation of nano-oxides can lead to a COP increase of 23-29% in air conditioning systems [10]. The use of SiO_2-TiO_2 nanolubricants has demonstrated a 25% reduction in friction, enhancing overall system efficiency [11]. The shift from traditional refrigerants to eco-friendly options, combined with nanotechnology, addresses both energy efficiency and environmental concerns [12], [13]. The application of nanoparticles in refrigerants helps mitigate the high GWP associated with conventional refrigerants, promoting a more sustainable approach to cooling systems[13]. There are three basic types of nanolubricant additives: nanometal-based additives, nanocarbon-based additives, and nanocomposite-based additives, as shown in Table 1.

Table 1. Types of nanolubricant additives

Types of nanolubricant additives		Examples
Nanometal-based lubricant additives	Pure metal	Cu[14], Ag[14], Fe[15]
	Metal Oxide	CuO[16], Al_2O_3[17], TiO_2[18]
Nanocarbon-based lubricant additives	Pure Carbon	Nano Diamond[19], CNTs[20], Graphene[21]
Nanocomposite-based lubricant additives		Al_2O_3/MWCNT[22], Al_2O_3/TiO_2[23]

2. Research methodology

2.1 Nano-lubricants preparation

Researchers have thoroughly investigated various methods for the preparation of nano lubricants. Ahmed et al. [24] synthesized a nanolubricant by combining TiO_2 nanoparticles with MO. More stability of the nanolubricant was achieved by adding a CTAB surfactant to the mixer. Kumar et al. [25] employed CuO_2 nanoparticles with an average particle size of 20nm along with compressor lubricating oil. The nanolubricant was produced utilizing an ultrasonic processing approach. Razzaq et al. [26] synthesized nanolubricants for compressors by incorporating TiO_2 into pure mineral oil as a substitute for POE. Additionally, to achieve stability of the created nanolubricants blend, the sonication procedure was conducted and a surfactant was introduced to the blend. Subramani and Prakash employed nano lubricant by employing a two-step process with Al_2O_3, which has an average particle size of less than 50 nm and a density of 0.26 g/cc [27]. Sharif et al. [28] implemented SiO_2 nanoparticles with an average particle size of 30 nm to create a nanolubricant for an automobile AC compressor using a two-step method, without the use of any surfactant. Wang et al. [29] developed a novel mineral oil-based nanolubricating oil consisting of a combined mixture of nanoparticles ($NiFe_2O_4$) to substitute POE-based lubricants in refrigeration oil. The prepared nanolubricant shows stability and solubility. Narayanasarma and Kuzhiveli conducted a study on a nanolubricant for a refrigeration compressor using POE oil saturated with SiO_2 nanoparticles (with an average particle size of 5-20 nm as observed by TEM). Integrating SiO_2 nanoparticles into the synthesised nanolubricant results in improved Flashpoint, Firepoint, and Viscosity Index [30]. Senthilkumar and Anderson investigate the use of POE-based SiO_2 nanolubricants in vapour compression refrigeration systems. The nanolubricant was prepared by two-step method, and the average size of the nanoparticle was 2-5 nm[31]. Table 2 represents the summary of all previous studies regarding the preparation of nanolubricant.

Table 2. Summary of previous studies for nanolubricant preparation

Author	**Refrigerant**	**Nano particles**	**Stability**	**Lubricants**	**Preparation Method**
Ahmed et al. [24]	Blend of R32 and R22, Blend of R32/R-600a & R22	TiO_2	CTAB surfactant was used for providing stability	Mineral oil (MO)	Prepared by mixing the CTAB surfactant and mineral oil with nanoparticles
Kumar et al. [25]	LPG	CuO	–	Mineral oil (MO)	Ultrasonic processing technique
Razzaq et al. [26]	Blend of R22/R600a	TiO_2	Stable for 2 months	Mineral oil (MO)	After mixing mineral oil and nanoparticles, sonication and surfactant were added
Subramani and Prakash[27]	R134a	Al_2O_3	Stable for more than 3 days	Mineral oil (MO)	Two-step process
Sharif et al. [28]	R134a	SiO_2	More than 1 month	PAG	Two-step method

Wang et al. [29]	R134a, R407C, R410a and R425a	$NiFe_2O_4$	For 1 year	Naphthene based MO B32	Formed by blending of nanoparticle into naphthene based oil B32
Narayanasarma and Kuzhiveli [30]	R134a	SiO_2	Oxidative stability affected slightly	Polyolester (POE)	Two-step method
Senthilkumar and Anderson [31]	R410A	SiO_2	–	Polyolester (POE)	Two-step method

2.2 Preparation of refrigeration blend

Several studies have been conducted on HC, HFC, and their mixtures in order to uncover alternative refrigerants to supplant the existing refrigerant. Tashtoush et al. [32] conducted a study to replace R12 by preparing a blend of propane and butane with R-134. Several blends have been generated in the lower explosive limits of propane and butane, which is a mixture of 50% butane and 50% propane. Wongwises and Chimres investigate the potential of hydrocarbon mixtures, including propane (R290), butane (R600), and isobutane (R600a), to replace HFC-134a in domestic refrigerators [33]. Their results indicate that the optimal outcome is achieved by mixing propane and butane in a 60:40 ratio. Akash and Said [34] investigated the potential of a commercial LPG composition consisting of 30% propane, 55% n-butane, and 15% iso-butane by mass fraction as a substitute for R-12 refrigerant. In an effort to replace R-12 refrigerant, Hammad and Alsaad conducted tests on four hydrocarbon mixtures: 100% propane, 75% propane-19.1% butane-5.9% isobutane, 50% propane to 38.3% butane-11.7% isobutane, and 25% propane-57.5% butane-17.5% isobutane. Best results were achieved with a hydrocarbon combination consisting of 50% propane, 38.3% butane, and 11.7% isobutane[35]. Sekhar and Lal conducted an experiment to substitute CFC12 refrigerant with hydrocarbon blends composed of HC600a and HC290 at weight percentages of 7%, 9%, and 11% in HFC134a [36]. Jung et al. [37] examine the performance of a propane/isobutane (R290/R600a) blend as a potential substitute for CFC12 in household refrigerators. The simulation findings indicated that including 0.2 to 0.6 mass fraction of propane/isobutane (R290/R600a) blend improved performance in comparison to CFC12. Fatouh and Kafafy explored the feasibility of substituting R-134a with a hydrocarbon blend consisting of propane and commercial butane. A performance comparison is made between hydrocarbon mixtures with propane mass fractions ranging from 0.5 to 0.7 and R-134a [38]. Table 3 represents the summary of all previous studies regarding the preparation of refrigerant blend.

Table 3. Summary of previous studies for refrigerant blend preparation

Author	Refrigerant blend	Previous Refrigerant	Mass fraction/Weight percentage used
Tashtoush et al. [32]	Blend of butane, propane and R134a	R12	Made on lower in lower explosive limit at a mixture of 50% butane and 50% propane
Wongwises and Chimres [33]	Blend of propane (R290), butane (R600) and isobutane (R600a)	HFC-134a	Mixing propane and butane 60:40 ratio gives best performance.
Akash and Said [39]	Blend of propane, n-butane and iso-butane	R-12	30% propane, 55% n-butane, and 15% iso-butane by mass fraction.
Hammad and Alsaad [35]	Blend of propane, butane and isobutane.	R-12	Mixture contains of 100% propane, 75% propane-19.1% butane-5.9% isobutane, 50% propane to 38.3% butane-11.7% isobutane, and 25% propane-57.5% butane-17.5% isobutane
Sekhar and Lal [36]	Blend of HFC134a,HC600a and HC290	CFC12	HC600a and HC290 at weight percentages of 7%, 9%, and 11% in HFC134a.
Jung et al. [37]	Blend of R290/R600a	CFC12	0.2 to 0.6 mass fraction of R290 and R600a
Fatouh and Kafafy [38]	Blend of propane and commercial butane	R-134a	Tested with propane mass fractions ranging from 0.5 to 0.7

3. Performance analysis

The performance analysis of a vapor compressor refrigeration system involves assessing exergy and energy efficiency, COP, and evaluating environmental aspects. Researchers have undertaken several studies on nano lubricants and sustainable refrigerants to enhance performance, energy efficiency, and reduce environmental

pollution in vapor compression refrigeration systems. Gill et al. [40] studied a household refrigerator that ran on LPG and compared its performance with that of a variety of mass charges (40, 60, and 80 g) of R600a refrigerant and nano-lubricant concentrations (0, 0.2, 0.4, and 0.6 g/L) of TiO_2. The best performance is achieved with a 40 g charge of refrigerant and a TiO_2 concentration of 0.2 g/L in an R-600a based refrigerator. Razzaq et al. [41] conducted an experiment to substitute R22 refrigerant and POE base lubricant with a blend of increasingly sustainable R22 and R600a refrigerants in an 80:20 mass charge ratio. They also used a mixture of TiO_2 and MO as a lubricant, with TiO_2 content ranging from 0.1% to 0.4%. The best outcome is achieved with a blend of R22 and R600a containing 0.4% nano-lubricant, above that of R22 with POE. Ahmed et al. [42] investigated a potential replacement for R22-based refrigerant using a mixture of R32 and R600a (50:50 mass charge) and TiO_2 nanolubricant (0.01-0.02% v/v). Their investigation concluded that a blend of R32 and R600a is not an adequate substitute for R22. DILAWAR and QAYOUM [43] conducted a performance analysis of the R290 and R-600a blend in a mass fraction of 80:20, as well as the impact of Al_2O_3 nano-additives (0.05-0.2% v/v) in POE compressor oil, with the objective of replacing R-134a in the household refrigerator. Compared to R-134a and R290 and R600a alone, the data indicate that a blend of R290 and R600a provides superior overall performance. Optimal performance is achieved at a concentration of 0.15 vol% of Al_2O_3 nanoparticles. Further verification of the experimental data was achieved by the utilization of MATLAB Simulink results. Babarinde and Madyira [44] initiated a study to replace R134a in a vapor compression refrigerator system with renewable R600a refrigerant including TiO_2, Al_2O_3, and SiO_2 nano lubricants. The R-600a with nano-mixture exhibited enhanced performance through the improvement of COP, reduction of evaporation temperature, pull-down times, and power consumption. Accordingly, their study indicates that R-600a containing nanolubricants has the capability to substitute R-134a and R-600a in cases when R-600a is used without these nanolubricants. Dilawar and Qayoum [45] evaluate the impact of Al_2O_3 nanoparticles added at concentrations of 0.045, 0.09, 0.135, and 0.18 vol% in POE oil for compressor lubrication. They also analyse the performance of sustainable refrigerant blends of R32, R161, and R13I1. The results indicate that the refrigerant mixtures containing alumina nanolubricant exhibited superior results compared to the POE oil-based lubricant. Optimal performance of nanolubricants is achieved at a concentration of 0.135 vol% of Al_2O_3 nano particles. Sharif et al. [46] investigate the potential to replace R-134a in automobile air conditioning systems with a more sustainable and environmentally friendly refrigerant, R1234yf, using an Al_2O_3–SiO_2 based hybrid nanolubricant at volume concentrations of up to 0.05%. The optimum performance of the hybrid nanolubricant is achieved at a volume concentration of 0.03% Al_2O_3–SiO_2. This is evidenced by a 2.8% increase in the heat absorption value of the evaporator and an average decrease of 7.7% in the compressor work at that concentration. Table 4 provides a summary of several previous studies conducted by researchers to improve the performance of vapor compression refrigeration systems by utilising sustainable refrigerants or refrigerant mixtures and nano lubricants.

Table 4. Summary of previous studies based on sustainable refrigerants and nanolubricants

Author	**Previous Refrigerant**	**Substitute Refrigerant**	**Nano particle for lubricant**	**Outcomes**
Gill et al. [40]	LPG	R-600a	TiO_2	R-600a performs superior than LPG.
Razzaq et al. [41]	R-22	Blend of R22 and R-600a	TiO_2	Blend of R-22 and R-600a with nanolubricants exhibited superior performance compared to R-22 alone
Ahmed et al. [42]	R-22	Blend of R-32 and R-600a	TiO_2	Blend of R-32 and R-600a is not an adequate substitute for R-22
DILAWAR and QAYOUM [43]	R-134a	Blend of R-290 and R-600a	Al_2O_3	Blend of R-290 and R-600a provides superior overall performance than R-134a,R-290 and R-600a alone
Babarinde and Madyira [44]	R-134a	R-600a	TiO_2, Al_2O_3, and SiO_2	R-600a with nano-mixture exhibited enhanced performance and has capability to to substitute R-134a and R-600a with use of nano lubricants
Dilawar and Qayoum [45]	–	Blends of R32, R161, and R13I1	Al_2O_3	The refrigerant blends containing alumina nanolubricant exhibited superior results compared to the POE oil-based lubricant
Sharif et al. [46]	R-134a	R1234yf	Al_2O_3–SiO_2	Al_2O_3–SiO_2 based hybrid nanolubricant exhibits excellent stability and performance

4. Conclusion

The present review focuses on the utilization of environmentally friendly sustainable refrigerant blends and various nanolubricants to improve the efficiency of domestic refrigeration systems. The synthesis of nanoparticles for nanolubricants using different techniques is being highlighted, along with its impact on vapor compression refrigeration systems, particularly in terms of enhancing exergy and energy efficiency, thereby reducing power consumption. The effect on performance and the techniques for preparing blends of ecologically friendly sustainable refrigerants are being examined by the analysis of studies conducted by numerous researchers. Several studies have shown that nanoparticles in nanolubricants and blends of sustainable refrigerants can replace compressor lubricants and non-environment-friendly refrigerants. Additionally, the use of nanolubricants and sustainable refrigerants improves various environmental aspects of vapor compression refrigeration systems, including GWP and ODP. The future study should prioritize the development of cost-effective methods to enhance performance and efficiency, as well as minimize environmental impact aspects, in refrigeration systems through the utilization of various renewable resources.

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