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Enhancing the Performance of Vapour Compression Refrigeration System using Nano Refrigerants: A review

T. O. Babarinde[1, 3*], S. A. Akinlabi[2], D. M. Madyira[1]

[1]Department of Mechanical Engineering Science, University of Johannesburg, South Africa
[2]Department of Mechanical & Industrial Engineering Technology, University of Johannesburg, South Africa
[3]Mechanical Engineering Department, Covenant University Ota, Nigeria
E-mail address: taiwo.babarinde79@gmail.com, stephenakinlabi@gmail.com, dmadyira@uj.ac.za

Abstract. Application of Nano particles as additives in refrigerants has been identified as a way of enhancing the performance of the vapour compression refrigeration system (VCRS) without modifying the system components. When Nano particles are dispersed in a refrigerant or lubricant, they are regarded as Nano refrigerants or lubricants. The improvement in heat transfer and tribology are responsible for the enhancement of VCRS performance. In this review paper, the effect of Nano particles on the coefficient of performance, power consumption, thermal conductivity, viscosity and heat transfer of refrigerants are discussed. It is shown that the application of Nano particles as additives in refrigerant and lubricant in VCRS is favourable and promising. Therefore, Nano refrigerants are expected to be the future refrigerants to be adopted by VCRS manufacturers.
Keywords: Nanofluids, COP, Power consumption, Thermal conductivity

1. Introduction

Today the world is confronted with the challenge of energy security with the governments of many nations implementing energy policies on the use of energy to decrease energy consumption levels for long term sustainability [1]. Government leaders and researchers have deliberated the problem of growth in energy consumption because the current generation of energy accompanies the burning of fossil fuels, which contributes to global warming. It is estimated that about 50% of energy consumption in commercial buildings goes to heating, ventilation and air-conditioning (HVAC) systems. Therefore, researchers are now focused on energy consumed by refrigeration and air-conditioning system [2]. Refrigeration and air-conditioning are needed for domestic and industrial comfort and preservation purposes. Refrigeration, air conditioning and heat pump appliances require significant amounts of energy for their operation. Due to this energy challenge, researchers are finding various means to improve performance and energy efficiency of refrigeration and air conditioning system. Although, some researchers have tried to improve the performance of refrigeration system [3]–[12], this has focused on the modification of the design components of the system. Choi et al. found that application of Nano particles to the refrigerant is capable of enhancing the thermal properties [13]. When Nano particles are dispersed in a refrigerant or lubricant base fluid, they are regarded as Nano refrigerant or Nano lubricant. The advantages of using Nano particles as additives in refrigeration and air conditioning system include enhancement of thermal conductivity and viscosity leading to the reduction in energy consumption of the system. The minimum widely available size of Nano particles ranges from 10–100 nm. However, the performance of Nano particles in refrigeration and air conditioning systems largely depends on the type and concentration of Nano particles in the base refrigerant or lubricant, Nano particles size and shape of the Nano Particles. The most common method of dispersing Nano particles in refrigeration and air conditioning applications is by using different technical methods such as homogenizing, ultrasonic agitation, high-shear mixing and magnetic force agitation [14]

2. Advancement of Nano Particles as Additives in Refrigeration and Air-Conditioning Systems

Thermal conductivity is a significant property by which Nano particles are being selected for application in Nano refrigerant applications. The heat transfer coefficient and heat transfer in the VCRS system are dependent on thermal conductivity and properties such as Nano concentration, particle size and flow rate. In addition, the viscosity of Nano particles imbedded fluid affects the pressure drop and hence the heat transfer of Nano fluid. Addition of Nano particles reduces the specific heat and increases density. Also, an increase in dynamic viscosity brings about decrease in convective heat transfer coefficient and frictional pressure drop therefore compressor pumping power increases (Bhattad et al, 2018). As a result of frictional drops in the compressor, the compressor work input reduces, which in turns increases the COP of the system. In this section, past and present works on the effect of Nano refrigerant, Nano lubricant and other Nano fluids on refrigeration and air-conditioning system are presented.

2.1 Effect of Nano particles additives on the thermal conductivity and viscosity of refrigerants in refrigeration system.

Thermal conductivity and viscosity are important properties of Nano refrigerants compared to the convectional working fluids in refrigeration and air-conditioning system application. Also, Nano particles additives have been proven by various researchers to improve the tribological performance of the compressor in refrigeration and air-conditioning systems. Some researchers have recently carried out investigations on Nano refrigerants as a drop-in replacement for conventional refrigerants in refrigeration systems. Selvam et al. [15] carried out an investigation using silver Nano fluids in ethylene glycol and water mixture. Thermal properties analyzer (KD2 Pro) was used to measure the thermo-physical properties such as, viscosity, thermal conductivity, density and specific heat. The thermal conductivity improved with an increase in Nano particle concentration and temperature. The enhancement of thermal conductivity observed was within the range 0.15%vol to 12 vol% at 50°C. The viscosity and density also increased with increase in Nano particle concentration and decreased with an increase in temperature. The specific heat decreased with increase in Nano particle concentration and increased with temperature increase. This decrease in specific heat is credited to the lower specific heat of added Nano particles. Akilu et al. [16] examined TiO_2-CuO Nano composite in ethylene glycol. The viscosity and thermal conductivity were measured regarding nanoparticles volume concentration and temperature. The result observed showed that thermal conductivity and viscosity largely depend on the Nano particles volume concentration and temperature. An enhancement of 16.7% and 80% was gained at 2.0% volume concentration compared to base ethylene glycol at 40.4^o C. Akel et al. [17] evaluated a Single Wall Carbon Nano tube(SWCNT) water Nano fluid as a secondary fluid in a refrigeration system. The SWCNT-water Nano fluid was tested as a secondary fluid with the range of 4 - 9 kW cooling power. An R22 VCRS made up of electronic expansion valve and air-cooled condenser type was used as the test rig. Different volumetric concentrations of Nano fluid were used for the experiment. The resulting output showed that the thermal conductivity and refrigerating capacity of Nano fluid as secondary refrigerant were improved. Akhavan-behabadi et al. [18] carried out research on pure R600a refrigerant using CuO nanoparticles of different mass fraction (0.5, 1.0 and 1.5%) and compared it with baseline refrigerant (R600a). The result obtained revealed that the heat transfer of the system increased by 83% compared to the pure refrigerant. Ghorbani et al. [19] studied the performance of R600a/POE/CuO Nano refrigerant by comparing it to the base fluid (R600a/POE) in a refrigeration system. Separate fluids with pure R600a, R600a-oil with POE mass percentage of 1%, three different R600a-oil-Nano particle mixtures with mass percentages of 0.5, 1, and 1.5% were considered experimentally. The outcome revealed that addition of Nano particles resulted in 4.1%, 8.11%, and 13.7% average rise in condensing heat transfer coefficient when compared with the R600a-oil mixture. Also, the maximum amount of increase in heat transfer coefficient was recorded for 1.5% mass percentage. Nabil et al. [20] investigated heat transfer performance of TiO_2 Nano particles in water-ethylene glycol (EG) mixture. The study was carried out at different operating temperature conditions. The viscosity and thermal conductivity were considered under the temperature range of 30^{o}C-80^{o}C. The result showed an increment in thermal conductivity of 15.4% at 1.5vol % Nano concentration at 60ºC. The Nusselt number also showed an improvement of 22.8% and 28.95% at 50ºC and 70ºc respectively. Maheshwary et al. [21] examined the effect of the shape of Nano particles on heat transfer properties and thermo physical properties of ZnO/R-134a Nano refrigerant in VCRS. A cubic and spherical shape of ZnO nanoparticles were considered for the test. The results revealed that cubic ZnO Nano particles in R134a had 42.5% increment thermal conductivity compared to pure R134a refrigerant. The author recommended the use of ZnO nanoparticles of cubic shape in R134a in VCRS. Zawawi et al. [22] investigated three different Nano composite (Al_2O_3-SiO_2, Al2O_3-SiO_2, TiO_2-SiO_2) in a polyakylene glycol (PAG) lubricant. The thermal conductivity was measured using KD2Pro. The results obtained reveal an enhancement of 20.5% increase in viscosity for Al_2O_3-TiO_2/PAG Nano lubricant in 1% Nano volume concentration at 34ºC. Thermal conductivity increases of 2.4% was recorded for Al_2O_3-SiO_2/PAG for 0.1% Nano lubricant at 30ºC. Sanukrishna et al. [23] studied the thermal and rheological behavior of TiO_2-PAG oil in VCRS. TiO_2-PAG Nano lubricant of 0.7% to 0.8% volume fractions were used in a temperature range of 20ºC to`90ºC. The result showed that thermal conductivity and viscosity were 10 and 1.38 times higher than pure lubricant for 0.6% and 0.8% volume fraction respectively with the optimal volume of 0.4%. Zawawi et al. [24] conducted an experiment on Al_2O_3 Nano lubricant in automotive air-conditioning system. The thermal conductivity and viscosity were measure using KD2Pro, thermal analyzer and LVDV-III Rheometer. The findings showed that Nano lubricant has higher thermal conductivity and viscosity of 1.45% and 7.8% respectively compared to pure PAG lubricant for 1.0% and 0.4%wt Nano concentration. Wang et al. [25] experimented to improve the coefficient of performance of air-conditioning system using a mixture of fullerenes (C70) and $NiFe_2O_4$ dispersed in compressor lubricant oil after solid grinding. The result showed that the coefficient of friction reduced from 0.13 to 0.06 which translate to a reduction in wear. The coefficient of performance of the air-conditioning system also increased by1.23 %. In another research, Wang et al. [26] investigated tribological properties of $NiFe_2O_4$ and onion alike fullerenes as a Nano composite in reciprocating compressor to enhance the coefficient of performance and reliability of a refrigeration system. $NiFe_2O$ and Onion like fullerenes (OLFs) were modified to form a Nano composite using KFR22 solid grinding (SG) and dispersed in compressor lubricant oil. The morphologies of $NiFe_2O_4$ were also characterized using transmission electron microscopy (TEM). Furthermore, the tribological properties of the refrigerator Nano lubricant were considered using a multi-functional reciprocating frictional wear tester. The results revealed that the frictional coefficient of the compressor was reduced from 0.15 to 0.04. Melnyk [27] presented experimental data for the solubility, viscosity and density of working fluid (R600a) in a refrigeration system with a constant capillary tube length. Al_2O_3 and TiO_2 nanoparticles were tested in R600a refrigerant using a mineral oil as the compressor lubricant and compared with pure R600a refrigerant under a varied range of concentrations and temperature. The result showed that the R600a/TiO_2 and R600a/Al2O_3 Nano refrigerant increased in viscosity with a reduction in surface tension**.** Sun et al**.** [28] examined heat transfer of multi-walled CNT of MWCNT-COOH/R141b and MWCNT-OH/R141b. The volume concentration of the Nano refrigerants was 0.059, 0.117 and 0.1765% and a vapor quality rang of 0.2-0.7 with a mass flow rate of 100-350 kgm^2s^1. The findings showed that the heat transfer rate of MWCNT-COOH/R141b Nano refrigerant performed better than that of MWCNT-OH/R141b Nano refrigerant.

2.2 Effect of nanoparticles on the COP, cooling capacity and power consumption of refrigeration system

Power consumption has been one of the major criteria always considered for purchasing refrigeration and air-conditioning units due to the high cost of energy consumption attached to it. Refrigerators and air-conditioners manufactures also consider the cooling capacity and coefficient of performance of a refrigeration unit. Some recent works were done on Nano refrigerants to substitute convectional refrigerants in VCRS. Balaji et al. [29] conducted research in order to reduce the air conditioning compressor load. A shell-and-coil heat exchanger was introduced as an intercooler using water and ethylene glycol of 70:30 mixture ratio as the base fluid. Al_2O_3 Nano particles of different Nano concentration by volume were used for the experiment. The result revealed that the coefficient of performance (COP) of the system increased with decrease in temperature as a result of decrease in the compressor work input. An increase in COP of 49.32% was achieved for the 0.75% of Nano fluid compared with the base fluid without intercooler. A significant drop in power consumption of 12.24% was also recorded. Nabil et al. [30] conducted a comparative study on thermo-physical properties of Al_2O_3 and SiO_2 Nano particles dispersed in polyalkyene glycol (PAG) lubricant oil to improve the performance of an automobile air conditioning system. The Nano particles were dispersed in the lubricant oil of the automobile air conditioning compressor to enhance the thermal conductivity and viscosity of the system. The SiO_2 Nano particles were dispersed in PAG lubricants oil of 0.2–1.5% volume concentrations at 30–80°C working temperature conditions and compared with performance of Al_2O_3 Nano lubricant. The result showed that thermal conductivity and viscosity increased with increase in Nano concentration of the lubricant oil but decreased with temperature. However, SiO_2 Nano lubricants with concentration of less than 1.0% by volume were the most suitable in the system. Ohunakin et al. [31] worked on performance of SiO_2, TiO_2, and Al_2O_3 Nano lubricants in household refrigerator system using liquefied Petroleum Gas (LPG) as working fluid. TiO_2, SiO_2 and Al_2O_3 nanoparticles were dispersed in a mineral oil in the LPG as the working fluid. The performances such as power consumption, viscosity and thermal conductivity at the compressor discharge and suction, the pull-down time was also considered. The result revealed that Nano lubricant-based LPG had a lower temperature with a pull-down time of 180 min. Moreover, SiO_2 and TiO_2 led to 12% and 13% reduction in power consumption respectively in comparison with the base LPG refrigerant. Also, there were improvement in the cooling COP, the COP of SiO_2 and TiO_2 Nano particles in LPG are higher than of pure LPG with 2.06% and 2.97% respectively, while a drop in COP of 2.91% was experienced with $Al2O_3$ Nano particles in LPG at steady state. In the experiment, Al_2O_3 Nano lubricant was not suitable for LPG due to an increase in power consumption compared to the base LPG refrigerant. In a related study by Adelekan et al. [32], the author investigated TiO_2 Nano particles in 40, 50, 60 and 70 g of liquefied petroleum gas with varied Nano concentration of 0.2, 0.4 and 0.6g/L in domestic refrigerator designed to work with R134a refrigerant. The system pull down time, compressor power input, cooling capacity, coefficient of performance (COP) and power consumption were analyzed. The outcome of results obtained indicated equivalent evaporator air temperatures with decline in power consumption for 40, 50, 60g Nano lubricant concentration but an increased in 70g charge of LPG in all Nano-lubricant concentration. Bhattacharyya et al. [33], [34] studied an energy saving of a geothermal Nano technology in an air-conditioning system. A Nano fluid of Al_2O_3/R134a was used as the working fluid. The findings showed that a geothermal air-conditioning system using Nano fluid of Al_2O_3/R134a had better energy savings and COP compared with conventional air conditioning refrigerant using R134a refrigerant. Ajayi et al. [35] investigated the fluid flow of Cu Nano particles in R134a and R600a in adiabatic capillary tube of a VCRS. The result showed that pure R134a and R600a have more isothermal regions which mean that the heat transfer is not fast enough to increase the temperature of the connecting region compared to the Cu/R134a and CU/R600a Nano refrigerants. Also, the base refrigerant had higher work input than Cu/R134a and CU/R600a, which implies a decrease in coefficient of performance of the system. Hady et al. [36] performed an experiment to replace water in chilled water air-conditioning unit with Al_2O_3-water Nano fluid using an Al_2O_3 Nano-concentration of 0.1, 0.2, 0.3 and 1% wt. The result showed that Al_2O_3-water Nano fluid has higher COP of 5% and 7% for 0.1%wt and 1%wt respectively in the system. Also, there was an increase in cooling capacity and decrease in power consumption of Al_2O_3-water in the chilled water air-conditioning unit. Kumar and Singh [37] worked on ZnO Nano particles effect on a mixture of hydrocarbon made up of 50% R290 and 50% R600a in a vapour compression system. The nanoparticles were introduced via the lubricant oil in the compressor using different percentage by weight of ZnO/R290/R600a Nano refrigerant. The outcome showed that energy consumption of the system was reduced by 7.8% using ZnO/R290/R600a Nano refrigerant of 0.2 -1.0 wt% range of Nano concentration. The COP of the system also increased by 46% compared to base refrigerant (R290/R600a).

3. Present state of Nano refrigerant in refrigeration and air conditioning system.

The application of Nano particles in refrigeration systems has shown significant improvement in terms of COP, power input, cooling capacity, power consumption, thermal conductivity and viscosity Nano refrigerants in VCRS compared to the conventional refrigerants.

Table 1 Summary of the previous work on enhancing the performance of VCRS using Nano refrigerants

Author	Type of experiment	Nano refrigerant/ Nano lubricant	Performance evaluation
Maheshwarry et al., 2018	Effect of shape of nanoparticles on heat transfer performance	ZnO/R134a	The experiment revealed that cubic shape ZnO/R134a Nano refrigerant has higher transfer of 42. % in the system.
N.N Zawawi et al., 2018	Thermal conductivity performance of Nano hybrid in PAG lubricant oil.	Al2O3-SiO2, Al2O3-TiO2, TiO2-SiO2, PAG	The result showed an increase in thermal conductivity of 20.5% and 2.4% for Al2O3-TiO2 and Al2O3-SiO2 respectively.
Sanukrishna et al., 2018	Experimental study of thermal conductivity of Nano lubricant in VCRS	TiO_2- PAG	The study showed 1.3% increase in thermal conductivity
Nabil et al., 2017	Comparative study of Al_2O_3 and SiO_2 in PAG in automobile air-conditioning system	Al_2O_3 and SiO_2 in PAG	The experimental analysis showed that Nano lubricant has higher thermal conduction and viscosity than pure PAG with SiO2/PAG having highest
Ohunakin et al., 2017	Performance of Nano lubricant in VCRS	TiO2 Al_2O_3 and SiO2 in LPG	The study showed 12% and 13% reduction in power consumption for SiO2/LPG and TiO2/LPG respectively
Adelakn et al., 2017	Investigation of Nano lubricant in VCRS working with LPG	LPG/TiO_2	The investigation revealed that 40. 50. 60g mass charge of LPG/TiO_2 perform better in terms of COP and power consumption
Bhattacharya et al., 2017	Energy saving using Nano technology in geothermal air-conditioning system	Al_2O_3/R134a	The research showed a better energy savings with Al_2O_3/R134a compare to pure R134a
Oluseyi et al., 2017	Investigation of nanoparticles in VCRS	Cu/R600a, Cu/R134a	The outcome of the result showed Cu/R600a and Cu/R134 have higher than pure R134a
Hady et al., 2017	Replacement of chilled water-air conditioning unit	Al_2O_3-water	The result revealed a higher COP of 5% and 7% for Al2O3-water0.1% and 1% wt Nano concentration respectively.
Akilu et al., 2017	Experimental investigation of Nano composites in ethylene glycol	TiO2-CuO/ ethylene glycol	Performance evaluation of the Nano refrigerant showed that an increase in thermal conductivity and viscosity of 16.7% and 80% respectively.
Akel at al., 2017	Investigation of a single wall carbon nanotube in VCRS	SWCNT/R22	The experimental outcome revealed an improvement in thermal conductivity of the VCRS.
Ghorbani etal., 2017	Analysis of Nano refrigerant in vapour compression system.	R600a/POE/CuO	The experimental analysis showed an increase in 4.1%, 8.11% and 13.7% for 0.5, i% and 1.5% mass percentage of Nano refrigerant.
Nabil et al., 2017	Performance of Nano particle in water-ethyl glycol	TiO_2/water-ethyl glycol	The study showed an increase in thermal conductivity by 15.4% and increase in nusselt number by 22.8% and 28.95% at 50°C and 70°C respectively.
Akilu et al., 2017	Experimental investigation of Nano composites in ethylene glycol	TiO_2-CuO/ ethylene glycol	Performance evaluation of the Nano refrigerant showed that an increase in thermal conductivity and viscosity of 16.7% and 80% respectively.

Akel at al., 2017	Investigation of a single wall carbon nanotube in VCRS	SWCNT/R22	The experimental outcome revealed an improvement in thermal conductivity of the VCRS.
Ghorbani etal., 2017	Analysis of Nano refrigerant in vapour compression system.	R600a/POE/CuO	The experimental analysis showed an increase in 4.1%, 8.11% and 13.7% for 0.5, i% and 1.5% mass percentage of Nano refrigerant.
Nabil et al., 2017	Performance of Nano particle in water-ethyl glycol	TiO_2/water-ethyl glycol	The study showed an increase in thermal conductivity by 15.4% and increase in nusselt number by 22.8% and 28.95% at 50°C and 70°C respectively.
Zawawi et al., 2017	Performance of nano particle in PAG lubricant oil.	TiO_2/PAG	The investigation showed higher thermal conductivity and viscosity of 1.45% and 7.8% respectively
Selvan et al., 2016	Enhancement of thermal conductivity and viscosity of ethylene –water.	Ag/ethylene-water	The finding showed an enhancement in thermal conductivity within the range of 12% to 0.15% for 50°C.
Balaja et al., 2015	Experimental research on air-conditioning compressor load.	Al_2O_3/ water ethylene glycol	The COP of the system and thermal conductivity increased by 49.32% and 12.24 % respectively

But currently, apart from R600a refrigerant, only few and scanty researches have been done on eco-friendly Nano refrigerants such as LPG and other hydrocarbon mixture refrigerants. Moreover, more researches need to be carried out on thermodynamics and heat transfer properties of hybrid nanoparticles in hydrocarbon mixtures and R152a refrigerants in vapor compression refrigeration systems.

4. Conclusion

Application of Nano particles as additives in refrigerant, lubricant and other fluids for refrigeration and air-conditioning systems has been proved to be successful according to the literature review without modification to the physical design components of the VCRS as a result of the significant improvement, especially in energy enhancement. It is believed that VCRS manufacturers will adopt Nano refrigerants as working fluids in refrigeration and air-conditioning system.

The following conclusions can be drawn from this current study:

- A significant reduction in energy consumption is achieved
- Work input of Nano refrigerant reduces compared to the base refrigerant thereby promotes increase in COP of the system.
- A shorter pull-down time in refrigeration system is possible
- The thermal conductivity increases with temperature increase up to the optimal concentration
- The viscosity increases with increase in temperature up to the optimal concentration
- Nano refrigerants specific heat increases with increase in temperature and concentration
- A reduction in compressor friction and wear can be achieved.

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