Thermal Performance of Vapour Compression Refrigeration System using Bimetallic Strontium Hexaluminate Nanorefrigerants

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ABSTRACT: Nanoparticles are added to standard compressor lubricants to improve performance and reduce the energy consumption of vapour compression refrigeration systems (VCRS). This work evaluated the compatibility, viability, and utility of a bimetallic oxide strontium hexaluminate ($SrAl_{12}O_{19}$) nano-lubricant with nominal sizes of 20–40 nm by characterising and evaluating its thermophysical properties while assessing its effect on the performance and energy consumption of existing, unmodified VCRS. Eco-friendly R600a were used as the system's refrigerant and the performance, energy consumption, and energy efficiency of VCRS were investigated by altering the concentration of $SrAl_{12}O_{19}$ (1%–20%) in the compressor lubricant. The results showed that as the temperature increases, the viscosities significantly decreased and increased as the concentration of nanoparticles is increased. In contrast, the density and acidity of the nanolubricant increased as the volume concentration of nanoparticles increased. The addition of nanoparticles into the compressor oil enhanced the performance of the VCRS performance and reduced the energy required to operate the system; however, these performance metrics decreased as the concentration of nanoparticles increased further. When the concentration of nanoparticles increased, exergy efficiency reached the maximum at 5% volume concentration

KEYWORDS: Coefficient of performance, Exergy, Nanolubricant, Strontium Hexaluminate, Vapour compression refrigeration system

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I. INTRODUCTION

Vapour compression refrigeration systems (VCRS) and air conditioning systems are frequently used in homes, workplaces, and industries. They are used for the preservation, cooling of food items and cooling of the environment. However, the United States (US) Energy Information Administration reported that these systems account for approximately 25 percent of the energy utilised in residential buildings (EIA, 2019). Consequently, it becomes imperative to lower these systems' energy consumption and their carbon footprint. Hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC) refrigerants (R113, R134a, and R12) are frequently used in VCRS, and air conditioning systems. They release greenhouse gases (fluorine and chlorine) into the atmosphere and contribute to ozone depletion and climate change (Molana and Wang 2020). Alternative refrigerants such as R290, R600a, ammonia, and propane are considered as replacement to HCFC and HFC refrigerants. These novel alternative eco-friendly refrigerants when compared with HCFC and HFC have lesser global warming potential (GWP) and ozone depletion potential. Thermophysical characteristics of the refrigerant have a direct impact on refrigeration system performance. The low thermal conductivity of eco-friendly refrigerants reduces the heat transfer rate within the VCRS and impacts the system's overall performance.

Therefore, it has become imperative to improve the thermal conductivity of eco-friendly refrigerants. The properties of these refrigerants can be enhanced by dispersing nanoparticles into them to form nanofluid (Alawi *et al*, 2014; Feroskhan *et al*, 2022). The thermal conductivity and viscosity of nanofluid increases as the concentration of nanoparticles increases (Sanukrishna *et al,* 2017). There are two techniques used in the preparation of nanorefrigerant. The first technique involves the dispersion of metallic, non-metallic, and carbon nanoparticles directly into the refrigerant that is liquid at atmospheric conditions while the second technique involves the dispersion of the nanoparticles into the compressor's lubricant. The addition of nanoparticles into the lubricant alters its property, thereby, improving its lubricity, while, increasing the solubility rate of the refrigerant in the lubricant. These enhancements lower friction and the rate at which the compressor's moving components wear out (Alawi *et al,* 2015; Kumar *et al,* 2022). Lee et al. (2009) demonstrated that substituting nanolubricant for conventional lubricant reduced the friction coefficient by up to 90% and concluded that the nano oils had superior lubricating properties. High thermal conductivity and surface area of nanoparticles increases the thermal conductivity of the refrigerant, thereby improving the rate of heat transfer between

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the system and the environment. The overall performance of the system and its energy usage are influenced by the effective heat removal within the refrigerator system.

Metals and its oxides nanoparticles such as Ti, TiO_2, SiO_2, ZnO, diamond nanoparticles, and carbon nanotubes (CNTs) are commonly used in the preparation of nanorefrigerants. The actual and theoretical coefficients of performance (COP) of 10.53% and 9.11%, respectively were obtained using Al_2O_3/R600a nanorefrigerant in a VCRS (Soliman *et al*, 2015). When nanoparticles were incorporated into the system, the heat transfer coefficient (HTC) within the evaporator improved by 50%, energy consumption decreased by 13.30%, while energy loss of 28% was observed. Sakhir and Mahmoud, (2021) studied the efficiency and energy usage of VCRS. The Al_2O_3 was mixed with R134a refrigerant at different volume concentrations (0.2%, 0.4%, and 0.6%), while varying the water temperature in the evaporator (40 to 60 degrees Celsius). The introduction of nanorefrigerants into the VCRS, improved the system's performance; at 0.6% volume concentration and 40 °C water temperature in the evaporator, the system's optimal COP, minimal energy consumption, and increased refrigeration effect were 32.219%, 22.751%, and 17.202%, respectively. The higher performance and lower energy usage was attributed to the high thermal conductivity of the nanorefrigerant, which was 0.6% higher than that of refrigerant without nanoparticles. The enhancement of particle interactions and collisions, the rise in Brownian motion of nanoparticles in the base fluid, and the chaotic movement of nanoparticles in the base fluid that results in thermal dispersion in the nanofluid were all cited as reasons for the improvement in thermal conductivity (Zawawi *et al,* 2019; Apmann *et al,* 2022). Titanium oxide (TiO_2) nanoparticles was used to improve R134a's solubility in mineral oil and the result revealed enhanced VCRS's performance and more lubricant returning to the compressor (Elcock, 2007).

In the experiments conducted by Mahdi *et al* (2017), employing Al_2O_3 (20–30 nm) nanoparticles dispersed in R134a refrigerant, the HTC increased with the increase in the nanoparticle concentration (0.01 and 0.02). When compared to pure refrigerant, the rate of heat transfer increased from 6.7% to 21.4%, although power consumption decreased by 1.6% and 3.3% for 0.01% and 0.02% volume concentrations, respectively. Given that the thermal conductivity of metallic nanoparticles is higher than that of metallic oxide, the nanorefrigerant made with them has a higher thermal conductivity than its oxide equivalent (Zhang *et al,* 2020). Raghavulu and Rasu, (2021) dispersed graphene oil nanoparticles with varying volume concentrations (0.025–0.15) into polyester oil (POE). The optimum COP was recorded at 0.10% after which it decreased as the graphene oil nanoparticles concentration increased. In another study conducted by Ogbonnaya *et al* (2023), the COP of the VCRS decreased as the concentration of the nanoparticle increased. This trend was attributed to the nanolubricant's increased viscosity, which increased compressor work and decreased the rate of heat removal. However, the energy destruction caused by friction in the compressor was significantly reduced, even though the compressor's destruction was higher than that of the other VCRS components.

Numerous investigations have examined the impact of both single and hybrid metals and their oxides on the performance of VCRSs. Based on published works, it is evident that the dispersion of metal and oxide nanoparticles in refrigerant or lubricant improved the properties of the refrigerant, which in turn improved performance and reduced energy consumption of the VCRS. The current study focuses on the usage of nominally 20–40 nm-sized strontium hexaluminate ($SrAl_{12}O_{19}$) nanoparticles dispersed as an additive to mineral oil at different mass concentrations of 1%, 3%, 5%, 10%, and 20%. Additionally, while the long-term performance stability of the nanorefrigerant in the VCRS was examined by running the nanolubricant in the compressor for an extended period (24 hours), bimetallic oxides like $SrAl_{12}O_{19}$ have not been thoroughly studied as nanolubricant additives to understand how it alters thermophysical performance which affects the performance, energy consumption and efficiency, and the mechanism behind the heat transfer enhancement

II. METHODOLOGY

A. *Materials*

Eco-friendly isobutane (C_4H_{10}) (R600a) and pure Capella D-lubricant were utilised as a refrigerant and compressor lubricant, respectively. Nanostructured and Amorphous Materials Inc., USA supplied the 20–40 nm-sized strontium hexaluminate nanoparticles ($SrAl_{12}O_{19}$). Tables 1 and 2 display the properties of the $SrAl_{12}O_{19}$ nanoparticles and the Capella D lubricant, respectively.

Table 1: Specification of $SrAl_{12}O_{19}$ (nanoamor)

Property	Value
Particle size	20-40nm
Purity	99.5%
Morphology	Flaky
Specific surface area (m^2/g)	30
Molecular weight	205.58
Density at 20 °C (g/cm^3)	4.0
Thermal Conductivity ($Wm^{-1}K^{-1}$)	6.63
Colour	Light grey
Lattice energy	-987.62

Table 2: Properties of the Capella D compressor oil (Ajayi et al. 2019).

Properties	Value
Density at 30 °C (kg/m^3)	0.76
Kinematics viscosity at 40 °C (cSt)	42.54
Kinematics viscosity at 100 °C (cSt)	6.45
Flashpoint (K)	238
Pour Point (K)	-45
Acid number	0.02

B. Materials Characterisation of Nanoparticles Samples

A material's structure and properties are measured and assessed as part of the characterisation process to understand why varied materials exhibit different properties and behaviours. The Department of Chemical, Metallurgical and Materials Engineering, Faculty of Engineering and Built Environment, Tshwane University of Technology, South Africa, conducted the nanoparticle characterisation.

C. Preparation of Nanolubricant

The nanolubricants were prepared using the two-step method. The volume concentration of $SrAl_{12}O_{19}$ nanoparticles in the lubricant was obtained using eqn (1) (Das *et al,* 2003).

$$\phi = \frac{m_p/\rho_p}{m_p/\rho_p + m_l/\rho_l} \tag{1}$$

where ϕ is the nanoparticle volume concentration (v/v), ρ_p and ρ_l are the liquid phase density of the lubricant and nanoparticle respectively while m_l and m_p are the masses of the lubricant and nanoparticle, respectively. The samples were prepared with strontium hexaluminate nanoparticles ($SrAl_{12}O_{19}$) with nominal diameters ranging from 20 to 40 nm, and at various volume concentrations (v/v) of 1%, 3%, 5%, 10%, and 20%. After weighing the appropriate quantity of dry $SrAl_{12}O_{19}$ on the digital electronic balance, it was poured into the lubricant. To improve the stability of the $SrAl_{12}O_{19}$ nanoparticles in the lubricant, the solution was rapidly mixed for 120 minutes using a magnetic stirrer after being agitated for 180 minutes in an ultrasonic bath to break up any nanoparticle agglomerates. Since surfactant alters the thermophysical characteristics of the nanolubricant and hence impacts the efficiency of the vapour compression refrigeration system, as such, was not introduced (Khairul *et al*, 2016). Figure 1 shows the samples of nanolubricant prepared at different nanoparticle concentrations.

Figure 1: Samples of $SrAl_{12}O_{19}$ nanolubricants

D. Determination of Nanolubricant Thermophysical Properties

The ASTM standards were used to determine the thermophysical parameters (density, dynamic viscosity, conductivity, and pH values) of nanolubricants. The Brookfield DV-II Viscometer (DV2T) was used to evaluate the dynamic viscosity while adjusting the nanolubricant's temperature (278 K to 323 K). The Hanna pH 9813 Meter was used to measure the pH, and the pycnometer was used to measure the density at atmospheric conditions. The electrical conductivity of the nanolubricant was measured using the conductivity meter (model DDS – 307).

E. Experimental Setup of the Vapour Compression Refrigeration System

The vapour compression refrigeration test rigs R600a refrigerants were fabricated in the Refrigeration and Air-conditioning Laboratory of Covenant University, Ota, Ogun State. The test rig is made up of the evaporator, condenser, compressor, and expansion valve as shown in Figure 2. An air-cooled condenser was used in this study and the heat transfer between the fluid and the surrounding relied only on the natural circulation of the ambient air. The inner and outer diameters of the condenser were 6.5 mm and 12 mm respectively with an overall length of 9.41 m.

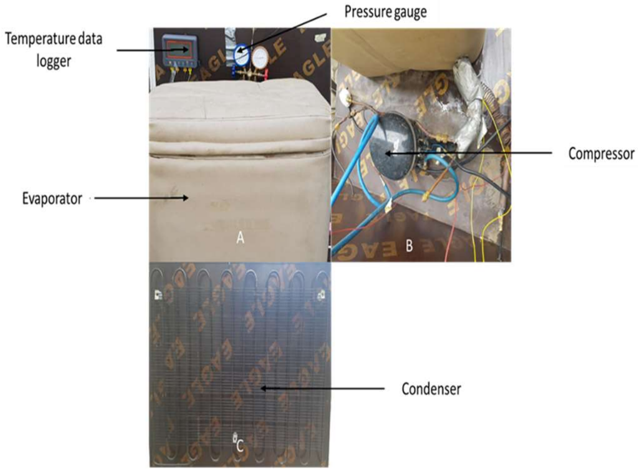

Figure 2: R600a Experimental test rig (A) Front View (B) Side view (C) Back view (Ogbonnaya *et al*, 2023)

To monitor the working fluid's temperature inside the evaporator, two K-type thermocouples were installed at the unit's inlet and outlet. The evaporator's copper tube had an outside diameter of 13 mm and an inner diameter of 10 mm. The cooling space had a volume of 70000 cm^3, and the evaporator tube was 10.24 m in total length. The Tekcoplus digital 4 channel K-type thermocouple thermometer recorder (THTK-6) was used to measure and record the temperature information for the condenser and evaporator. Compressed and pressurized gaseous refrigerant exiting the evaporator was achieved using a reciprocating R600a compressor. The device was a type of hermetically sealed compressor. The liquid nanorefrigerants were rapidly contracted and expanded by the copper throttling mechanism, which had an inner diameter of 0.6 mm and a length of 4.3 m. This caused part of the liquid to transition into gaseous state at constant enthalpy. In addition, the throttling device regulates how much refrigerant, depending on the refrigeration load, enters the evaporator. The refrigerator system was placed in an air-cooled room on a platform. The room's pressure and temperature were in laboratory conditions. Before it was charged, the system was thoroughly inspected for leakages. Eqn 2 was used to obtain the coefficient of performance of the VCRS respectively.

$$COP = \frac{\dot{Q}_E}{\dot{W}_{comp}} \quad (2)$$

where Q_E is the refrigeration capacity and W_{comp} is the work of the compressor.
The power input to the compressor (P_{com}) (Wang, 2000) is obtained using Equation (3)

$$P_{com} = \frac{\dot{m}_{nf}(h_2 - h_1)}{42.41\eta_{com}} \quad (3)$$

where η_{com} is the compressor efficiency, $\dot{m}_{nf}$ is the mass flow rate of the nanorefrigerant and h_2 and h_1 are the enthalpies at the inlet and outlet of the compressor respectively.
Exergy efficiency (η_{exe}) is the ratio of the exergy output to the exergy input (Aized et. al, 2022) expressed in Eqn (4).

$$\eta_{exe} = \left(1 - \frac{I_{total}}{\dot{W}_{comp}}\right) \times 100 \quad (4)$$

where I_{total} is the total exergy of the vapour compression refrigeration system.

III. RESULTS AND DISCUSSION

A. Characterisation of $SrAl_{12}O_{19}$

The morphology and elemental composition of $SrAl_{12}O_{19}$ are depicted in Figures 3 and 4, respectively, using Energy Dispersive X-ray (EDX) spectroscopy and Scanning Electron Microscopy (SEM). $SrAl_{12}O_{19}$ nanoparticles have a flaky shape (Figure 3). The nanoparticle/lubricant interaction and the thermophysical characteristics of the nanorefrigerant are influenced by the form and aggregation of the particles. The viscosity of nanofluids is more affected by the aggregation of nanoparticles than by their size. (Bao et al. 2019). The elemental composition of $SrAl_{12}O_{19}$, as shown by EDX analysis in Figure 4, consists primarily of oxygen, strontium, aluminium, and a small amount of silicon.

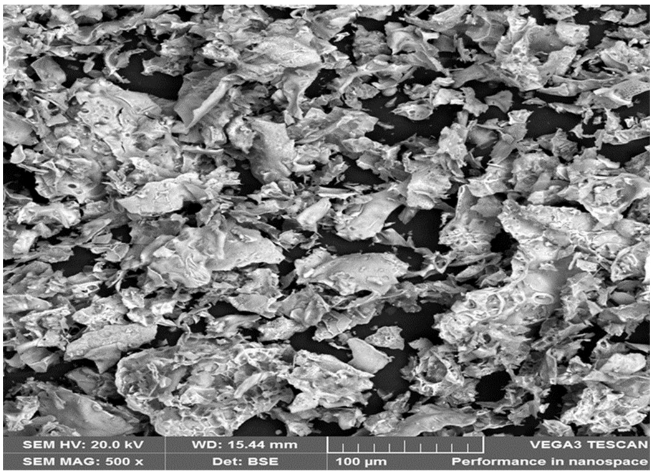

Figure 3: Micrograph for $SrAl_{12}O_{19}$

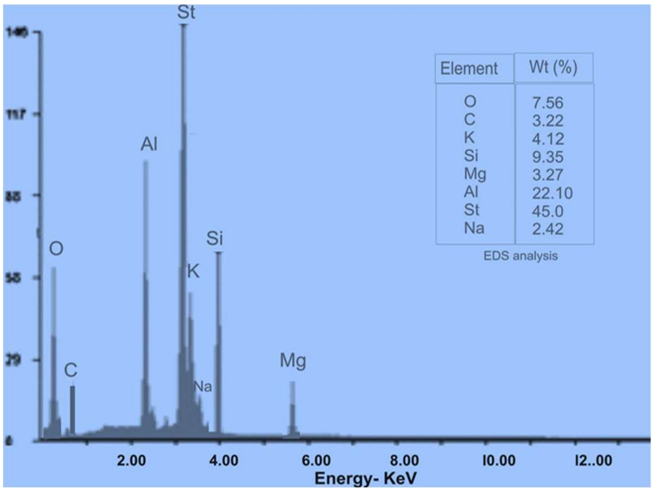

Figure 4: Energy-dispersive X-ray spectra of $SrAl_{12}O_{19}$

The X-ray powder diffractogram reveals the different diffraction peaks (intensity) for 2θ. Figure 5 shows the XRD pattern of 20 – 40 nm of $SrAl_{12}O_{19}$ nanoparticles, the intensity of the peak is high between 20° and 70°. The highest peak is obtained at 37°. The peaks for $SrAl_{12}O_{19}$ indicate the crystal phase of the nanoparticles. The predominant peaks for $SrAl_{12}O_{19}$ indicate that the structure of the nanoparticle is crystalline. In the preparation of nanorefrigerant, the structure of nanoparticles plays a predominant role. The transition from amorphous to crystalline form can affect the performance of a material (Dhawale *et al,* 2018). The thermophysical characteristics of the nanorefrigerant and its performance in the VCRS are therefore anticipated to be influenced by the structure of the nanoparticles.

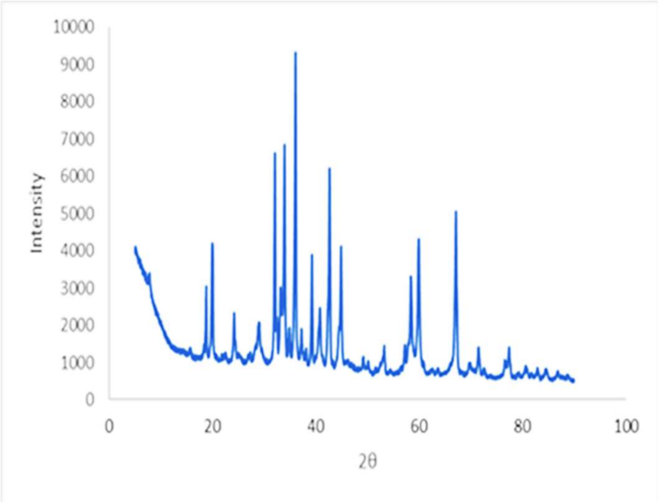

Figure 5: X-ray diffraction pattern of $SrAl_{12}O_{19}$

Figure 6 gives the thermogravimetric analysis (TGA) of $SrAl_{12}O_{19}$. The thermal decomposition of $SrAl_{12}O_{19}$ started at 50 ºC and the total mass change increased with the increase in heating rate from the onset. When deploying nanolubricant for use in VCRS, it is critical to examine the thermal stability of the nanoparticle and note any appreciable changes in the mass of the powdered nanoparticle as the temperature rises. $SrAl_{12}O_{19}$ began to decompose thermally at 50 ºC, and as the heating rate increased at the beginning, so did the total mass change.

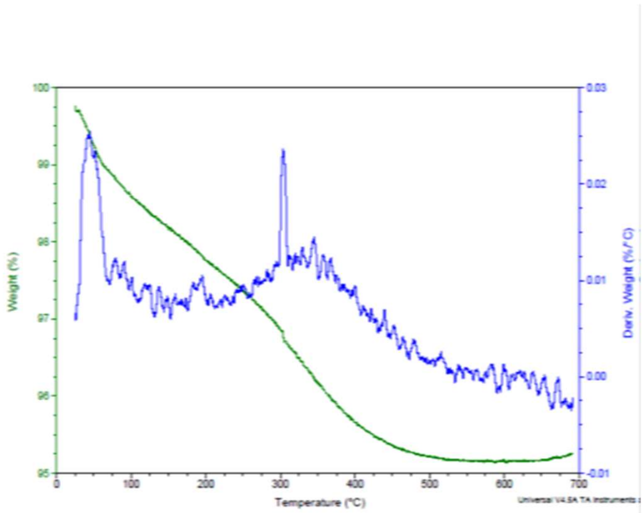

Figure 6: Thermogravimetric analysis of $SrAl_{12}O_{19}$

A. Thermophysical Properties Analysis of Nanolubricant

I. Dynamic viscosity of nanolubricant

This property influences the nanolubricant's flow rate within the VCRS. Dynamic viscosity was shown to increase with the addition of nanoparticles to the lubricant. The dynamic viscosity of $SrAl_{12}O_{19}$ nanolubricants varies with temperature and concentrations of nanoparticles, as seen in Figure 7. The measurement of the dynamic viscosity of the nanolubricant depended on the shear rate, time of test and spindle geometry. As the mass concentration of the nanoparticles increases, the viscosity of the nanolubricants also increases. The cause for the rise in dynamic viscosity is the agglomeration and clustering of nanoparticles at increasing concentrations.

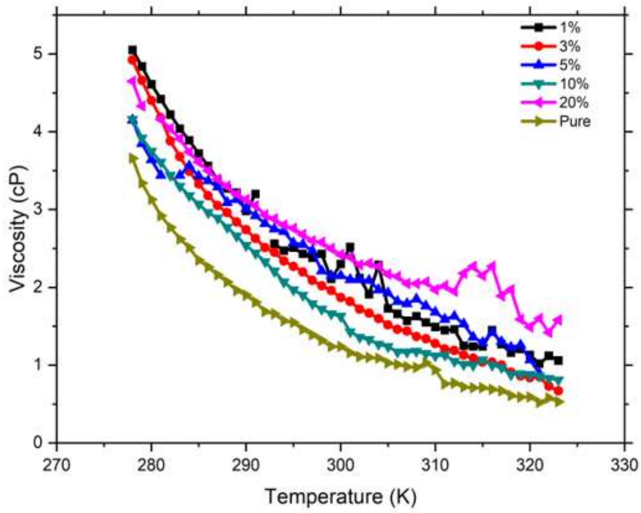

Figure 7: Dynamic viscosity of $SrAl_{12}O_{19}$ nanoparticles dispersed-Capella D oil varying with temperature and nanoparticle volume concentration

When the temperature of the nanolubricants was taken into consideration, it was found that the viscosities significantly decreased as the temperature increased. It is well known that most Newtonian fluids become less viscous as temperature rises. The nanoparticles moved more rapidly apart because of the temperature rise. The movement of the nanoparticles increases the flow of the nanolubricant, which lowers viscosity. Additionally, because of the temperature increase, the cohesive force between the fluid's molecules decreased, and the adhesion forces between molecules and particles weakened. This result corroborates those of Kole and Dey (2011) and Mahbubul et al (2013). According to Kole and Dey (2011), the weakening of intermolecular and interparticle adhesion interactions is the cause of the viscosity's decrease as temperature rises. Thus, the fluid's viscosity, or resistance to flow, diminishes as the fluid's particle movement intensifies. In the work of Mahbubul et al (2013), at high temperatures (308 K to 323 K), the Brownian motion of the nanoparticles increases, which results in a sharp drop in the nanolubricant's viscosity. Furthermore, because of the higher viscosity of the base fluid at lower temperatures, Brownian diffusion may be weaker. Higher viscosity at the same volume fraction is caused by elongated particles, aggregation of particles, and structural limitation of rotational and transitional Brownian movements (Timofeeva et al, 2009).

II. Density of nanolubricant

Figure 8 illustrates how the concentration of nanoparticles affects the $SrAl_{12}O_{19}$ nanolubricant's density. Pure lubricant exhibited the lowest density, whereas the density of the nanolubricant increased as the concentration of the nanoparticle increased. The density of the lubricant increased with the incorporation of nanoparticles, and this has a significant impact on the vapour compression refrigeration system's compressor capacity. The mass flow rate of the nanolubricant through the compressor is determined by its density.

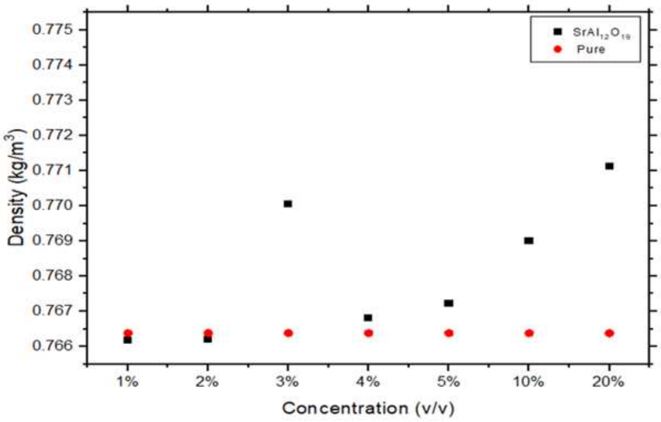

Figure 8. Density of $SrAl_{12}O_{19}$ nanolubricant varying with volume concentration

III. Electrical conductivity of nanolubricant

Figure 9 shows the effect of the concentration of nanoparticles on the conductivity of ions. There is a noticeable increase in the conductivity of ions in the nanolubricant as the concentration of nanoparticles is increased. A fluid's electrical conductivity refers to its capacity to transmit electrical current. Since ions carry this current, the conductivity of the fluid is dependent upon the ion concentration, ion mobility, and fluid temperature (Bagherzadeh et al, 2017). $SrAl_{12}O_{19}$ conductivity is maximum at concentrations of 10% and lowest at concentrations of 1%, and it increases with increasing nanoparticle concentration. The conductivity of the nanolubricant is significantly influenced by the ionic stability of the nanoparticles in the base lubricant. Consequently, the kind of nanoparticle and base fluid employed determines the relationship between conductivity and nanoparticle concentration. Thus, conductivity is influenced by the solubility and stability of the nanoparticles in the base fluid as well as the mobility of ions within it. The electrical conductivity of the 10% concentration was maximum and higher than that of the 20% concentration due to the aggregation of the nanoparticles. The aggregation of the nanoparticles blocks the path of the ions in the nanolubricant, thereby reducing the electrical conductivity of the lubricant (Minea, 2019).

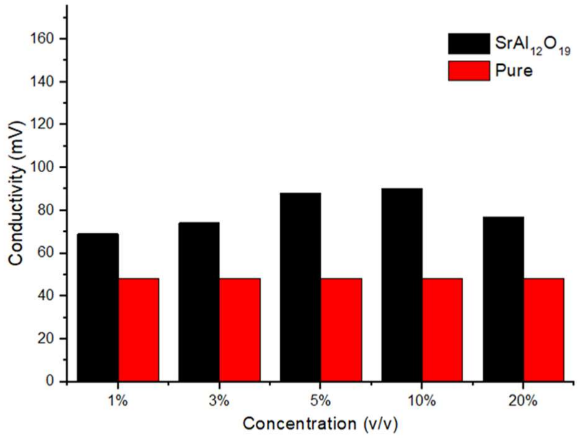

Figure 9: Electrical conductivity of nanolubricant and base fluid at various volume concentrations and nanoparticle sizes

IV. pH of nanolubricant

The pH of a fluid is an important factor that determines the acidity or alkalinity of the fluid. Figure 10 depicts the plot of the pH of nanolubricants and base fluid at various volume concentrations and nanoparticle sizes. This is an indication that nanolubricant is appropriate for use in the VCRS compressor, as the metal components of the VCRS are susceptible to corrosion from very acidic fluids. Except at 20% concentration, where there was an increase, the pH of the $SrAl_{12}O_{19}$ nanolubricant decreases as concentration increases. The fluid's conductivity and pH in connection to each other demonstrate that the two parameters are inversely related. As a result, adding nanoparticles changes the lubricant into a conducting fluid, especially at greater concentrations. A more conductive fluid must also be more acidic.

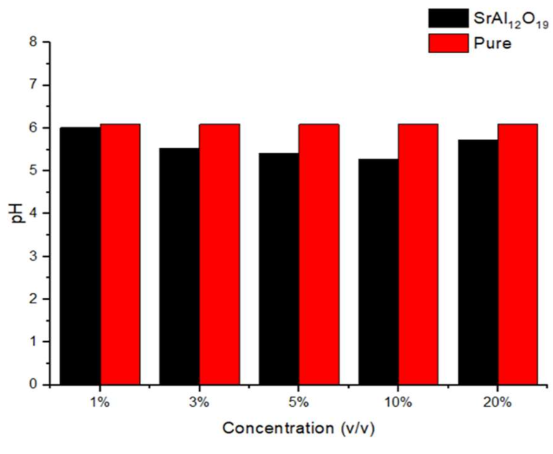

Figure 10: pH of nanolubricants and base fluid at various volume concentrations and nanoparticle sizes

A. Performance of the vapour compression refrigeration system.

I. Coefficient of performance (COP) for pure R600a and nanoR600a

The result of the average COP of the VCRS using R600a as refrigerants and varying volume concentrations of $SrAl_{12}O_{19}$ nanolubricants is presented in Figure 11. The best VCRS performance is found to be at 3%, with a COP that is 1.40 percent greater than that of pure refrigerant. With 10 and 20 percent volume concentrations performing the worst due to their high viscosity, and since the concentration of nanoparticles reflects viscosity, then COP decreases as nanoparticle concentration increases. Higher viscosity of the nanolubricant results in greater pumping power which increases the energy consumption of the compressor. The low performance of $SrAl_{12}O_{19}$/R600a nanorefrigerant may be attributed to the low thermal stability of $SrAl_{12}O_{19}$ nanoparticles, as shown by the TGA investigation.

Using nanorefrigerant, most of the research examined the COP of VCRS over a brief period—typically four hours. To evaluate the impact of nanoparticle concentration on the improvement or decline in the system's performance, the number of hours the nanorefrigerant was employed in the system was considered. Table 3 compares the COP of VCRS after 4 hours and 24 hours. This data emphasises how the performance of the VCRS is influenced by the interplay between surface roughness, nanoparticle deposition, and nanoparticle size. The findings indicated that at all concentrations other than 1%, the VCRS's performance had decreased after 24 hours. To fully comprehend the relationship between the size and concentration of nanoparticles and the roughness of the heat transfer surface, a more extensive investigation of VCRS performance over an extended time frame is required. The surface roughness of the heater surface and the relative sizes of the nanoparticles influence how they deposit on it (Ogbonnaya et al *2019). Scientists can predict more accurately how various nanoparticle sizes and concentrations interact with the wettability and surface roughness of the condenser and evaporator to enhance the heat transfer within the VCRS*

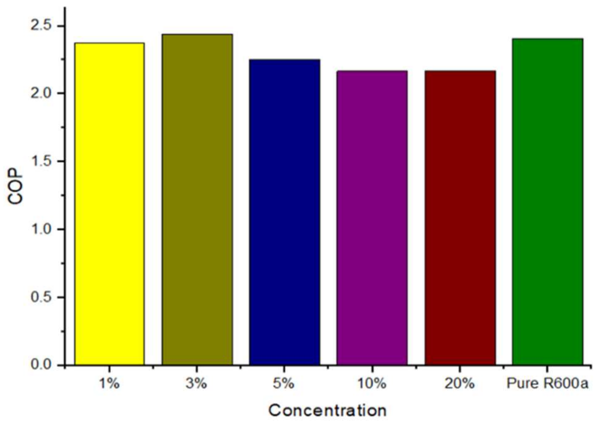

Figure 11: Average COP at varying volume concentrations of $SrAl_{12}O_{19}$ nanoparticles in R600a refrigerant

Table 3: Comparison of COP after 4 hours and 24 hours for pure R600a and $SrAl_{12}O_{19}$/R600a

Nanoparticle size	Concentration	4 hours	24 hours
$SrAl_{12}O_{19}$	1%	2.3411	2.4959
	3%	2.4462	2.4394
	5%	2.3631	2.1690
	10%	2.2616	2.2066
	20%	2.3618	2.0820
Pure	0%	2.2525	2.2806

II. Power input

One of the causes of the high energy consumption in the VCRS compressor is frictional loss. Reducing frictional loss and hence energy consumption is one of the key objectives behind dispersing nanoparticles into the compressor lubricants. Figure 12 illustrates the influence of $SrAl_{12}O_{19}$ nanoparticle concentration on power input into the compressor for R600a. At a 5 percent concentration, 0.3604 kW of power was used, which was 26.58 percent less than the power used in pure R600a. When the concentration of nanoparticles increased, the power input into the compression reduced. Nevertheless, at greater concentrations, the power input increased. The power input drops even more after 4 hours, as illustrated in Table 4, although the power input for pure refrigerant and 20% concentration increased at 24 hours. This increase is attributed to the higher viscosity of 20% $SrAl_{12}O_{19}$ nanolubricant and the poor lubricity of the pure refrigerant. It is evident from this that the incorporation of nanoparticles reduces wear and friction in the compressor's moving component.

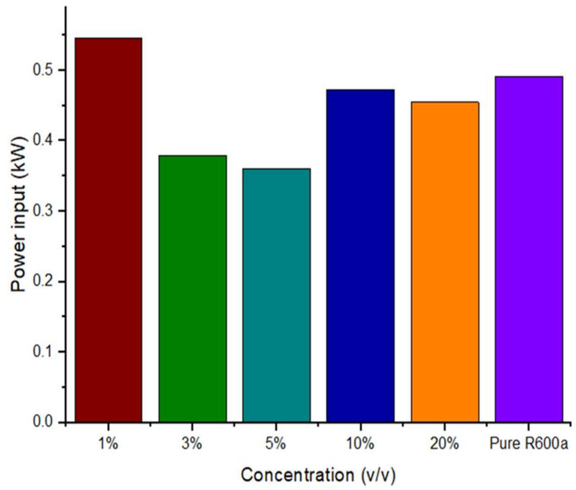

Figure 12: Average power input at varying volume concentrations of $SrAl_{12}O_{19}$/R600a nanorefrigerant and pure R600a

Table 4: Comparison of power input after 4 hours and 24 hours for pure R600a and $SrAl_{12}O_{19}$/R600a

Nanoparticle size	Concentration	4 hours	24 hours
$SrAl_{12}O_{19}$	1%	0.5606	0.5230
	3%	0.3819	0.3750
	5%	0.3694	0.3469
	10%	0.5134	0.4451
	20%	0.4381	0.4393
Pure	0%	0.5024	0.5109

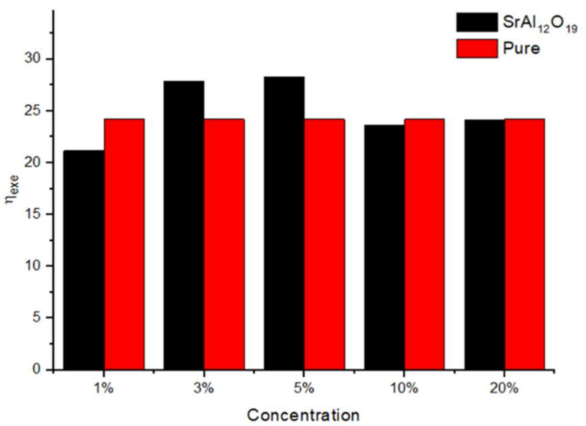

Figure 12: Exergy efficiency for varying volume concentrations of $SrAl_{12}O_{19}$/R600a nanorefrigerant and pure R600a

III. Exergy efficiency

Figure 18 displays the exergy efficiency for different volume concentrations of pure R600a and $SrAl_{12}O_{19}$/R600a nanorefrigerant. Efficiency increased as the concentration of nanoparticles did, but when concentration went further, energy efficiency decreased. At 5% volume concentration, the energy efficiency is at its highest, while at 1% volume concentration, the effectiveness is at its lowest. The irreversibilities in the various components of the VCRS affected the overall exergy efficiency of the VCRS

Table 5: Percentage difference in exergy efficiency at various concentrations for $SrAl_{12}O_{19}$/R600a nanorefrigerant with respect to pure R600a

Nanoparticle size	Concentration (%)	$SrAl_{12}O_{19}$/R600a
$SrAl_{12}O_{19}$	1%	-12.61
	3%	26.53
	5%	30.71
	10%	2.98
	20%	7.17

When compared to pure refrigerants, Table 5 displays the percentage increase and decrease in energy efficiency at different volume concentrations of $SrAl_{12}O_{19}$/R600a nanorefrigerant. The system's exergy efficiency increased when nanoparticles were added to the VCRS

IV. CONCLUSION

This study examined the thermophysical characteristics of the nanolubricant used in the compressor as well as the performance and energy efficiency of the system to determine whether bimetallic oxide of $SrAl_{12}O_{19}$/R600a nanorefrigerants could be used in the traditional vapour compression refrigeration system without changing the system. Nanolubricants with concentrations of 1, 3, 5, 10, and 20 percent were made using $SrAl_{12}O_{19}$ nanoparticles, which had a size range of 20 to 40 nm. It was found that temperature and the concentration of nanoparticles affected the viscosity of the nanolubricants, whereas the concentration of nanoparticles increased the density, acidity, and pH. The $SrAl_{12}O_{19}$/R600a nanorefrigerants with the best performance, energy efficiency, and lowest energy consumption were also found regarding nanoparticle concentration. Based on the study, it is possible to enhance a VCR system's efficiency and lower energy consumption by mixing strontium hexaluminate oxide ($SrAl_{12}O_{19}$) nanoparticles with compression oil (POE). Using environmentally friendly refrigerant and the VCRS's decrease energy consumption when nanorefrigerant is employed which will lessen the detrimental effects of refrigeration systems to global warming.

AUTHOR CONTRIBUTIONS

M. Ogbonnaya: Conceptualization, conduct experiment, writing – original draft, review, and editing. **O. O. Ajayi**: Conceptualization, supervision, writing – review, and editing. **M. A. Waheed**: Conceptualization, supervision, writing – review, and editing. **A. P. I. Popoola**: Methodology, project administration, and characterisation funding.

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