Experimental Investigation into the Effects of Al-composite Nanolubricants on the Energy and Exergy Performance of Vapour Compression Refrigerator Compressor

Oluseyi O. Ajayi, Daniel E. Ukasoanya, Felicia T. Owoeye, Enesi Y. Salawu, Idehai O. Ohijeagbon, Festus A. Oyawale, M.C. Agarana

Abstract **-Nanofluids played significant role in enhancing the thermophysical properties of a refrigerant which can lead to an improved performance of the refrigerator compressor. This study investigated the performances of four Aluminium based nanolubricants in a vapour compression refrigeration compressor system. Various tests which include evaluation of the thermophysical properties and the determination of thermodynamic parameters such as exergy, power consumption, cooling load and coefficient of performance of the refrigerator compressor system were carried out. The outcome showed that the nanoparticles influenced greatly the thermophysical properties of the base oil (Capella D) and improved its thermodynamic properties. All the nanolubricants showed improved better results in terms of thermal conductivity and salinity, depicting better heat transfer and thermal capacity. Also, the results of the viscosity tests showed that the nanolubricants have lower values than the conventional base oil, indicating good pumping ability of the compressor and lower energy consumption. In addition, the results of exergy analyses reveal that most of the nanofluids systems generally showed better performance with higher values. It thus can be concluded that the nanofluids systems seem to provide better compressor/refrigerator working fluid alternative with careful selection.**

***Index Terms*— Energy system, Nanorefrigerant, Nanolubricants, Power consumption, Heat transfer, Nanotechnology, Thermal system**

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I. INTRODUCTION

THE advancement in the field of nanotechnology has given rise to the development of new trend of heat transfer fluids. Such development has grown to include nanolubricants or nanorefrigerants which invariably enhances the operating efficiency of refrigerating or thermal systems. Moreover, Nanolubricants otherwise known as nanofluids exhibit exceptional characteristics ranging from thermal, chemical, physical and mechanical properties. These properties can be harnessed to improve stable and efficient operating conditions for the working fluids in energy systems such as refrigerators. For instance, in terms of the measure of stability and productive achievements, titanium oxide (TiO_2) nanoparticle synthesized with diathermic oil formed good nanofluids. This stable nanofluids gave a good thermal conductivity with increase in volume fractions and temperature. Further to this, TiO_2 nanoparticles synthesized with base fluids was reported to enhance heat transfer in refrigerating systems [1]. According to [2-3], application of nanofluids in the working fluids of thermal systems has proven to be an alternative means of improving the performance efficiency of the systems. Based on this, an experiment was carried out to investigate the influence of mass fraction of TiO_2 nanoparticles/water and CuO nanoparticles on nucleate pool boiling. The result revealed that the smallest mass fraction of TiO_2 nanoparticles/water gave the largest improvement and further effort to increase the mass fraction also increased the heat transfer compared to pure water. However, it is worth noting that nanoparticle mass fraction corresponding to the heat transfer improvements depends on the type of nanoparticles. This has led to various investigations on the application of different nanoparticles, nanofluids and nanorefrigerants on thermal performance of energy systems. Such studies have focused on both metallic and nonmetallic nanoparticles dispersed fluids.

To predict the combined heat transfer behavior of nanofluids, [4] hybridized Al_2O_3 with TiO_2 and SiO_2 to determine the thermophysical properties of the resulting nanofluids. The numerical analysis of the oxides revealed that the thermophysical properties changes with the addition of the nanoparticles as well as increase in thermal conductivity. However, the viscosity of the hybrid nanofluids was low which enable free flow of the nanofluids. According to [5], a comparison between carbon

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nanoparticles and copper nanoparticles in terms of mass fraction, yielded an increase in thermal conductivity of the system with carbon nanoparticles giving the highest significance than the copper nanoparticles.

Study has shown that conductivity of a ferro-nanofluid compared with its organic base oil increases when examined in a spherical cavity heated from above or below the surface [6]. Low thermal conductivity reduces the energy storage applications of phase change materials and also the melting/solidification rates, thus making the system response time to be too long. However, this limitation can be corrected using fins with nanoparticles volume fraction on evolution solid-liquid interfaces [7]. Based on this, Pryazhnikov *et al.* [8] presented a study where it was established that thermal conductivity of nanofluids does not wholly depend on the particle concentration factor, but depend on the size, material content as well as the base fluids. Hence, giving rise to the need for more investigations to discover best material-material-base fluid combination for efficient heat transfer management in energy systems. More so, early studies on nanolubricants or nanorefrigerants application to energy systems such as vapour compression refrigerators majorly focused on monometallic nanoparticle dispersed fluids [9-13].

Those that focused on bimetallic nanoparticles are scanty. Worth noting is also the fact that, most of the studies on bimetallic nanoparticles are mostly limited to characterization and thermophysical investigations. They however do not consider direct application to the energy systems. This is the aim of this study. It considered the impact of bimetallic nanoparticle dispersed fluids on the performance of the compressor of a vapour compression refrigeration system. The choice of the compressor was based on the fact that it is one of the essential components in the refrigerating system where the major work is done. Thus, the study investigated the effects of different bimetallic-nanolubricant of aluminium composite on the exergy and energy consumption of the compressor.

II MATERIALS AND METHOD

A vapour compression refrigeration system was used. The suction and discharge pressure were evaluated by means of two attached inlet and outlet pressure gauges. The temperature of the refrigerants was measured using a thermocouple, antilog thermometer and a clamp meter fixed at three different points of inlet and outlets. Service ports were used at the inlet of the compressor and expansion device for charging and recovering the refrigerant. Moisture evacuation was done using the installed service ports. The refrigerator was kept at 80% charge and readings were taken at the standard atmospheric conditions. The experiment was repeated three different times for the different nanolubricants. The base oil employed was Capella D while the refrigerant was R134a (1, 1, 1, 2-Tetrafluoroethane). The combination of the conventional Capella D/R134a was used as the control while the results of the different combination of the bimetallic aluminium based-nanolubricant/R134a was compared with those of the control. Table 1 displays the vapour compression refrigerator system component specification and the material component of the working fluids, while Fig. 1 shows the pictorial view of the analog pressure gauge. The various thermosphysical tests were conducted using the appropriate apparatuses. For instance, the viscometer for the viscosity test and the refractometer for the refractive index. Table 2 displays the properties of the base oil (i.e. Capella D).

Fig. 1**.** A view of the analog pressure gauge employed during the experiment

TABLE I
COMPONENT SPECIFICATION OF THE REFRIGERATOR SYSTEM ANDTHEWORKING FLUIDS

Material	Specification
Refrigerator	Internal volume of 65 litres
Conventional Refrigerant/Lubricant	R134a/Capella D
Nanofluid combination	0.5g/l of five bimetallic nanolubricants of oxides of aluminium, nickel, silver and cobalt
Compressor	Reciprocating compressor
Evaporator	Natural cooling hot plate type heat exchanger
Condenser	Cross flow fin and heat exchanger
Expansion valve	Capillary tube
Charged mass	100

TABLE II
PHYSICAL PROPERTIES OF THE CAPELLA D OIL

Property	**Value**
ISO Viscosity Grade	46
Density at 15°C, kg/L	0.9
Flash Point, COC, °C	238
Freon Floc Point, °C	-50
Freon Haze Point, °C	-43
Pour Point, °C	-45
Total Acid Number	0.02
Viscosity at 40°C	42.54
Viscosity at 100°C	6.45
Viscosity Index	100
Breakdown Voltage, kV min	40

III. RESULTS AND DISCUSSION

Figs. 2 to 6 present the results of the thermophysical properties of the Capella D oil and the different configurations of the aluminium based bimetallic nanolubricants. Fig. 2 displays the results of thermal conductivity tests for each of the nanolubricants and base oil at ambient temperature of 29.3^{o}C. Thermal Conductivity indicate the amount of heat a particular substance can carry through in unit time. It shows that the nanolubricants have far better thermal conductivity values than the base oil. This is suggestive of the fact that when employed in an energy system, each of the nanolubricants will perform better than the base oil. In a vapour compression refrigeration system, the results show that the nanolubricants are able to enhance the refrigerant's ability to achieve cooling much better than the conventional lubricant by removing more heat from the evaporator and compressor. Fig. 3 follows the same trend with Fig. 2. It displays the results of the salinity tests and shows that the salinity values of the nanolubricants are higher than that of the conventional base oil. Moreover, salinity is a thermodynamic state variable that, along with temperature and pressure, governs physical characteristics like the density and heat capacity. The property indicates the ability of the fluid to retain heat. Thus, the values of the salinity show clearly that, just like the thermal conductivities depicts better heat transfer performance, the nanolubricants have higher capacity for heat transport (i.e. from the evaporator and compressor) thereby showing that the compressor performs better with the nanolubricants in terms of heat rejection and thermal enhancement of the refrigerating space.

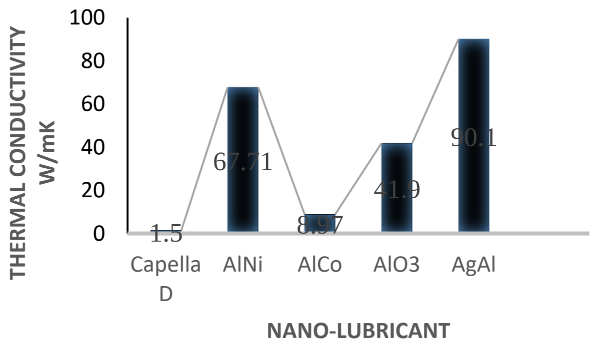

Fig.2. Comparative analysis of results of thermal conductivity Tests for the different nano-lubricant

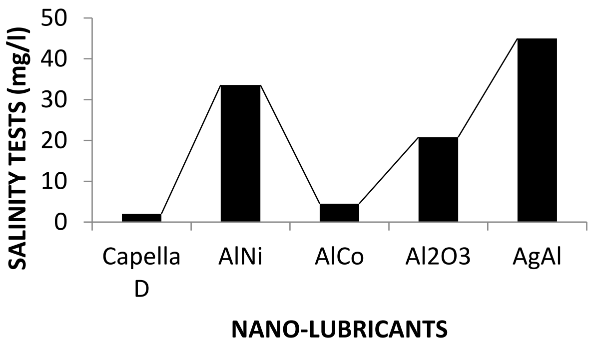

Fig. 3. Comparative analysis of results of Salinity Tests for the different nano-lubricant

Fig. 4 displays the results of the refractive index tests. While refractive index is a ratio that measures the velocity of light in a vacuum to that in a medium. It measures the degree of transparency of the fluids. The Figure shows that apart from aluminium-nickel-composite nanolubricant, the other lubricants have very close values to that of the conventional base fluid.

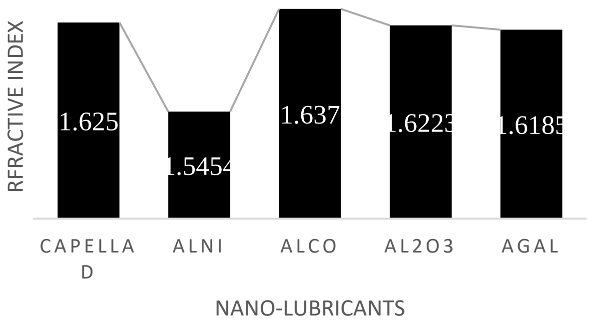

Fig. 4. Comparative analysis of results of Refractive Index Tests for the different nano-lubricant

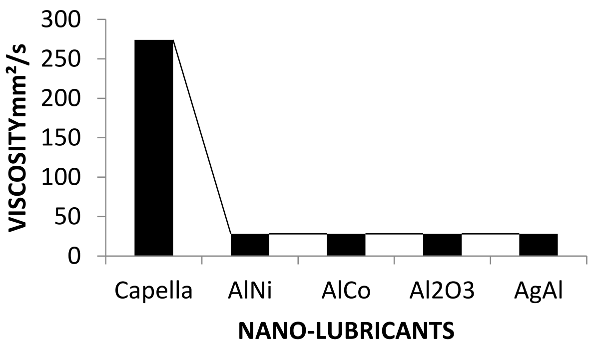

Fig. 5: Comparative analysis of results of Viscosity Tests for the different nano-lubricant

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In addition to the aforementioned, fig. 5 displays the comparative results of the viscosity tests of the lubricants. It shows that the conventional base oil (i.e. Capella D oil) has far higher viscosity index than the nanolubricants. Worth noting is the fact that the introduction of the nanoparticles into the lubricants (base oil) greatly reduced the viscosity from 274 to about 28. Consequently, this will have impact on the energy consumption of the compressor. Hence, the power demand by the compressor to transport the lubricant through and also to overcome the viscous drag reduce proportionally to the viscosity values. Hence, going by this, the heat generation in the compressor also reduces in relation to the reduction in the internal friction of the nanolubricant as compared to the base oil, thus promoting better efficiency and enhanced performance. Furthermore, the implication of the reduction in the viscosity values and better performance also has a bearing on the compressor life, making the compressor more durable

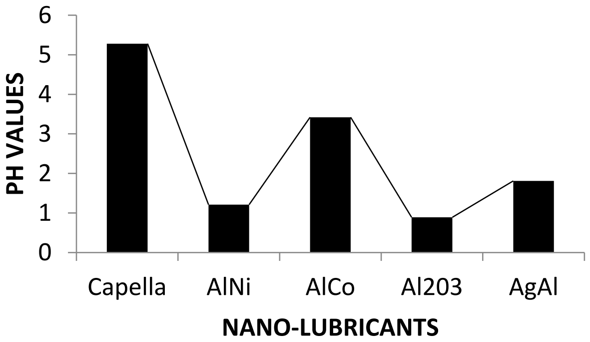

Fig. 6. Comparative analysis of results of pH Tests for the different nano-lubricant

Figure 6 also presents the pH results of various nanolubricants which was done to determine the degree to which the nanolubricants will influence the alkalinity of the standard Capella D oil. The result showed that the nanolubricants tends more towards the strongly acidic values while, the Capella D oil which showed the highest pH value of 5.28 tends towards the fairly alkaline level. Thus, it can be concluded that the nanofluids may react aggressively with the metallic materials used in the construction of the compressor housing. Consideration therefore may need to be given to the development of new compressor models that can accommodate this characteristic feature of the nanofluids [14-15].

Based on the performance of the nanolubricants, the exergy, power consumption and cooling load analyses were carried out and the results are displayed in Figs. 7 to 9. Fig. 7 presents the results of exergy analyses for the conventional fluid system and nanolubricant/R134a systems. It indicates the maximum useful work that can be achieved from the system. Thus, the higher the value of the exergy of the compression process, the better the performance. Generally, Fig. 7 shows that all the nanolubricant/R134a systems performed better than the conventional base oil system with the exception of AgAl-composite fluid system that gave poorest results between the 105 and 225 minutes' data points. Overall, AlNi-composite nanolubricant/R134a system showed the best performance in terms of exergy and closely followed by that of the oxide of aluminium. However, in terms of the power consumption, the magnitude of power consumed during operation with the conventional fluid system was closely related to those of Al_2O_3 and Al-Co nanolubricant fluid systems. Overall, the silver-aluminium composite fluid system performed best. It showed averagely the least power consuming fluid system. Moreover, the cooling load, which

Depicts the total amount of heat that must be ejected from a reference space was analyzed and the results are displayed in Fig.9. It is expected that the values be as small as possible with lower values indicative of efficient energy usage. The Figure shows that apart from the AlNi and AlCo, Al_2O_3 and AgAl are the preferred nanofluids systems with AgAl nanofluids system being the best.

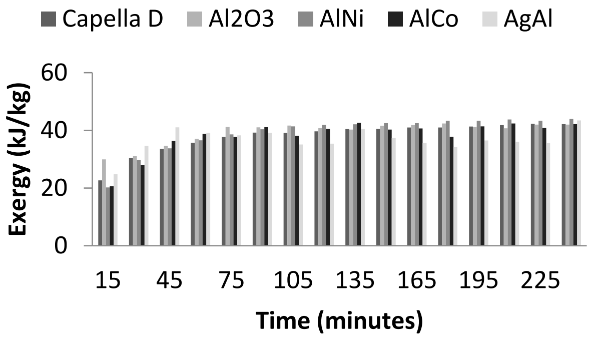

Fig 7. Comparative analysis of results of the results of exergy analyses for the different nano-lubricants

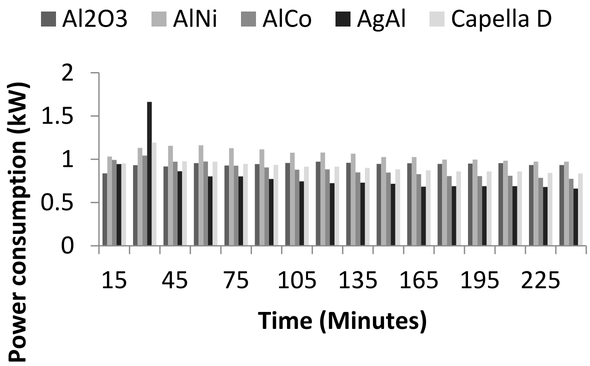

Fig 8. Comparative analysis of results of power consumption analyses for the different nano-lubricants

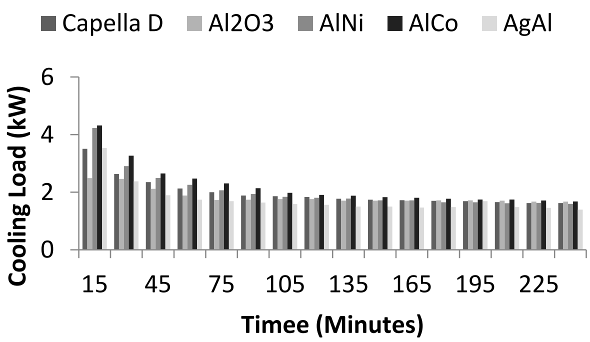

Fig 9. Comparative analysis of results of cooling load analyses for the different nano-lubricants

Hence, matching performance with energy savings, the nanofluids systems seem to provide better choice with careful selection. Otherwise, the conventional fluid system can arguably still be preferred, since the results in terms of

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energy savings are not far from those of the nanofluid systems.

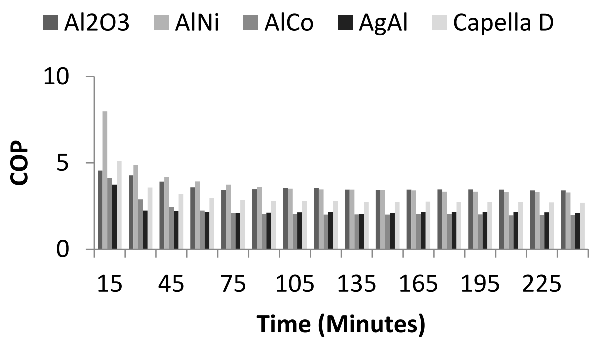

Fig. 10: Coefficient of performance versus Time for Aluminium Composite Nanolubricants

In addition to the aforementioned, when the system's performance was generalized to determine the cost effectiveness of operating the fluid systems with a functioning vapour compression refrigeration system, Fig. 10 results. It displays the variations in the results of the coefficient of performance of the refrigerator with the fluid systems employed separately as working fluids. It shows that Al_2O_3 and AlNi nanoparticle dispersed working fluid systems outperformed all the other fluid systems. Al_2O_3 showed the best performance. However, the conventional fluid system (Capella D/R134a) gave better performance than the other two, with AgAl coming out with least performance.

IV. CONCLUSION

An experimental study was conducted to investigate the exergy and energy performance of Aluminium composite nanolubricant in a refrigerator compressor system. The aluminium based nanolubricants investigated were Al_2O_3, AlNi, AlCo and AgAl and the results were compared with the conventional base oil (i.e. Capella D), which served as the control fluid system. Thermophysical tests and analyses were carried out which include the salinity, conductivity, refractive index, viscosity and pH tests to determine their properties and implicative influence on the compressor of a vapour compression refrigeration system. The outcome indicated that in terms of the thermophysical properties, the nanofluids systems showed better performance when compared with the conventional base oil of Capella D/R134a system. However, when the fluid systems were applied to a working vapour compression refrigeration system, the performance for specific nanofluids system varied relative to each other. Also, the energy and exergy analyses pointed to different fluid system as it concerns best performance. However, in general terms, the nanofluids systems showed good performance with more work required to ascertain the long-term effect of the nanolubricant/R134a fluid systems. More so, when performance is matched with energy savings, the nanofluids systems seem to provide better choice with careful selection.

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