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Investigation of the Effect of R134a/Al_2O_3 –Nanofluid on the Performance of a Domestic Vapour Compression Refrigeration System

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Abstract

The quest for the conservation of energy resources and production of energy systems that are more efficient have introduced the use of nanoparticles in heat transfer fluids. The study investigated the effect of Al_2O_3 nanoparticles on the working fluids of a vapour compression refrigeration system (VCRS) when used with refrigerant R134a. The nanorefrigerant was used in the vapour compression system without system retrofit. The system's performance analyses were carried out via the freeze capacity tests and energy consumption analysis. The outcome showed that the performance of the Al_2O_3-dispersed nano-working fluid outperformed that of the conventional working fluid mixture. Specifically, the outcome demonstrated that the system with the nanorefrigerant achieved faster cooling, better performance and improved energy consumption. Thus, using Al_2O_3 nanoparticles in combination with the working fluids of domestic refrigerators was shown to be feasible. Further to this, based on the performance results, it was necessary to find out the very reason behind the improved thermal performance of the nanoparticle dispersed working fluid. This led to the determination of the thermophysical property of the nanolubricant. The results indicate better thermal conductivity and salinity, implying that the nanolubricant has better heat transfer ability than the base oil (Capella D). In addition to this, the results of the viscosity test showed that the presence of the nanoparticles caused a reduction in the lubricant's viscosity thus portraying a reduction in the energy consumption. However, the pH test results indicate that there may be the need for an improved compressor material selection if the nanorefrigerant will be employed for vapour compression refrigeration purposes in the future.

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Keywords: Energy, Nanofluid, Nanotechnology, Power, Refrigeration, Thermal System

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1. INTRODUCTION

Nanofluids play an important role in engineering applications such as nuclear reactors, refrigeration, air conditioning, heat pumps and electronics by enhancing their heat transfers [1]. Nanofluid is a class of nanotechnology-based heat transfer fluid, containing nano-sized particles. In general, the size of a nanoparticle spans the range between 1 and 100

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nm which are uniformly and stably distributed in a conventional heat transfer fluid (base fluid). Nanofluids possess high specific surface area, thereby increasing the heat transfer surface between particles and fluids. Other advantages of nanofluid include high dispersion stability of the nanoparticles in the base fluid, reduced particle clogging and reduced pumping power when compared with micrometer sized particles [2-5]. Nanorefrigerant is a type of nanofluid which is formed when the nanoparticle is properly dispersed in the base refrigerant fluid mixture. It has the potential to enhance heat transfer rate due to its superior thermophysical properties when compared to the base refrigerants/oil mixture. Therefore, the use of nanorefrigerant in refrigeration system has the tendency to lead to smaller and lighter system, increase thermal conductivity of the working fluid and improve the heat transfer characteristics of the overall thermodynamic system [6]. Globally, HFC-134a also known as 1, 1, 1, 2-Tetrafluoroethane is widely employed as alternative refrigerant in domestic refrigeration/air-conditioning systems. It has medium global warming and zero ozone depletion potentials, and is widely used in cooling systems, especially in developing countries [7]. However, due to its strong chemical polarity, it cannot be used with traditional mineral oil as working fluid, rather Polyol-Ester (POE) lubricating oil is used. Moreover, POE as lubricant, has the problem of high friction coefficient and flow choking in the compressor. Based on this, there is the suggestion that the limitation may be resolved with the adoption of nanoparticles in the lubricants. Nanoparticles when dispersed in the lubricant have tendency to enhance the properties and energy efficiency of working fluids [8]. Recently, some research efforts have been geared towards investigating the impact of nanoparticles on refrigerant/lubricant mixtures. For instance, Babu *et al.* [9] experimentally demonstrated the influence of TiO_2 nanoparticles dispersed in POE and mineral oils with HFC-134a refrigerant in VCRS. The result showed that the Coefficient of Performance (COP) of the refrigeration system was higher with nanofluid. The optimum mixture ratio was taken as 0.2 gm/litre, beyond which will lead to mixture instability and quick particle agglomeration. Further to this, the study demonstrated that the refrigerant in mixture with the nanofluid worked smoothly and efficiently in the refrigeration system with increased COP and reduced magnitude of energy consumption by the compressor. Also, a study on the effect of TiO_2 nanoparticle dispersed lubricant on the performance of R600a refrigeration system was carried out by Bi *et al.* [10]. The results indicate the fluid system worked efficiently in the system. Comparatively, the system with 0.1 and 0.5 g/L concentrations of TiO_2 dispersed fluid system saved 5.94% and 9.60% energy consumption respectively. The freezing velocity of the nanorefrigerant system was also quicker than that of the pure working fluid mixture. This improvement was attributed to the possibility of nanoparticles enhancing the heat transport properties of the refrigerant and the dynamic viscosity of the lubricant. Subramani *et al.* [11] experimentally conducted performance analyses on a VCRS using different nanoparticles dispersed in SUNISO 3GS oil. The refrigerant used was R134a with Al_2O_3, TiO_2 and CuO at 0.06% mass concentration as nanoparticles. The particles were spherical in shape and the average particle size was about 50 nm. The result showed that the freezing capacity was higher for TiO_2-nanolubricant compared with others and the power consumption of the compressor was reduced by 15.4% when TiO_2-nanolubricant was used instead of the base SUNISO 3GS oil. The decrease in compressor work was attributed to the better lubricity of the nanolubricant. A reduction in power consumption and increase in COP of the system were also observed. Also, Bandgar *et al.* [12] reviewed the effect of nanolubricant on the performance of VCRS. The aim of the study was to investigate the type of lubricant that works better with nanoparticles in the field of refrigeration. It was reported that nanoparticles mixed with mineral oil gives better results than polyol-ester oil but the reason for this conclusion was not clearly stated. The aim of this study was therefore to experimentally investigate the performance of the vapour compression refrigerator using Al_2O_3 nanoparticles dispersed in Capella D mineral oil/R-134a working fluid. It focused on understanding the reason behind the improvement of the system's performance and enhancement of the heat transfer efficiency of the working fluid while using nanoparticles as highlighted by other researches.

2. MATERIALS AND METHOD

2.1 Preparation of nanorefrigerant

The procedure used for the preparation of Al_2O_3 nanoparticles dispersed in the Capella D mineral oil was the wet chemical reduction method. The poly vinyl pyrrolidone (PVP) matrix was used. A constant mass charge of R134a refrigerant of 100g was employed throughout at ambient temperature of 31°C and three different experimental replications. The nanolubricant was a combined fluid system of 0.5g/l concentration nanoparticles dispespered in the oil.

2.2 Experimental Setup

The vapour compression refrigeration system (VCRS) employed for this study is a single temperature domestic refrigerator. It works with R134a refrigerant. Two two pressure gauges, at the inlet and outlet of the compressor, were used to measure the suction and discharge pressures. Antilog thermometer, type k thermocouples, and clamp meter were employed for other data capture. Service ports were installed at the expansion valve's inlet and compressor for charging and recovering the refrigerant. Moisture evacuation was carried out through the service ports. The system was checked for leakages and error in connection before it was engaged for the tests. The evacuation was carried out using a vacuum pump while the refrigerant was charged into the refrigerator using a charging system. The compressor was a reciprocating type compressor.

2.3 Performance Analysis

This involved the determination of the system's temperature, pressure and power consumption to evaluate the COP, pull down time, exergy of the compression process, energy consumption and cooling load analyses.

Measure of system's efficiency

The efficiency of a refrigeration system can be determined as a function of its COP. This is given as:

$$COP = \frac{Desired\ output}{Required\ input} = \frac{Q_L}{W_{net,in}} \tag{1}$$

Equation (1) can be rewritten as:

$$COP = \frac{Q_L}{Q_H - Q_L} - \frac{1}{\frac{Q_H}{Q_L} - 1} \tag{2}$$

where Q_L and Q_H are the amount of heat received from the low temperature source and heat rejected to the high temperature reservoir respectively.

The COP can also be determined by replacing the heat transfer ratio with the absolute temperature ratio

$$COP = \frac{1}{(T_H/T_L) - 1} \tag{3}$$

Physical Exergy of the compression process

This is expressed as:

$$e_x = h_2 - h_1 - T_0(S_2 - S_1) \ \ (\text{kJ/kg}) \tag{4}$$

where h_2 = Enthalpy measure at the compressor outlet (kJ/kg); h_1 = Enthalpy measure at the evaporator inlet (kJ/kg); T_o = Ambient temperature (K); S_1 = Entropy at the compressor outlet (kJ/kg) and S_2 = Entropy at the evaporator inlet (kJ/kg).

3. Results and Discussion

3. 1. Results of performance analysis

Figs. 1 – 5 show the results of the performance analysis tests carried out on the system with nanorefrigerant ($R134a/Al_2O_3$). Fig. 1 shows the comparison between the coefficient of performance of the system when the conventional working fluid (R134a + Capella D oil) was employed and that with the nanorefrigerant. As shown, apart from the initial values, the COP values were much related. However, the values for the conventional fluid were slightly

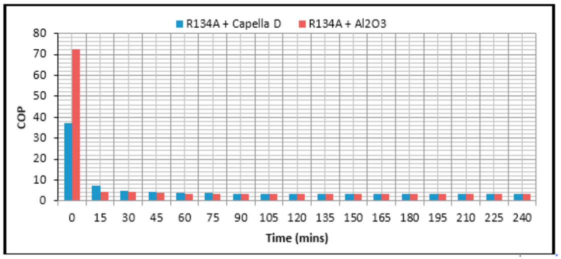

Fig.1: Comparison of the COP values between

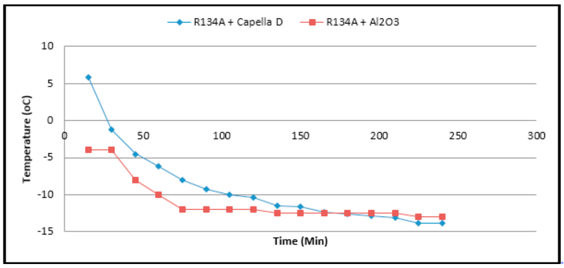

Fig.2: Results of pull down time for both the system with

the conventional working fluid and the nanorefrigerant

conventional working fluid and that with R134a/Al2O

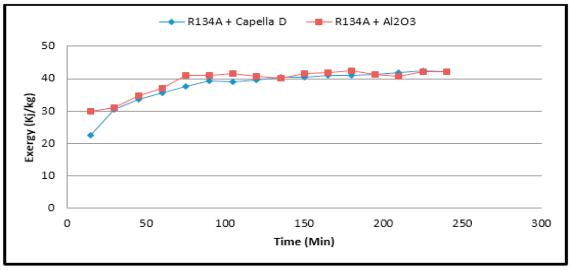

Fig. 3: Results of exergy of the compressor process for both the system with conventional working fluid and that with R1 R134a/$Al_2O_3$34a/Al_2O_3

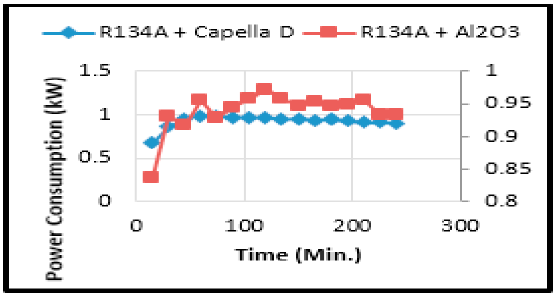

Fig. 4: Variation of Power Consumption with time for Al_2O_3

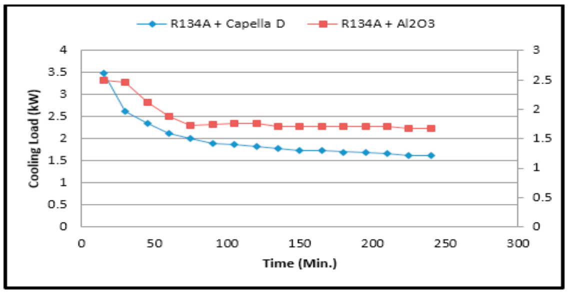

Fig.5: Results of cooling load analysis

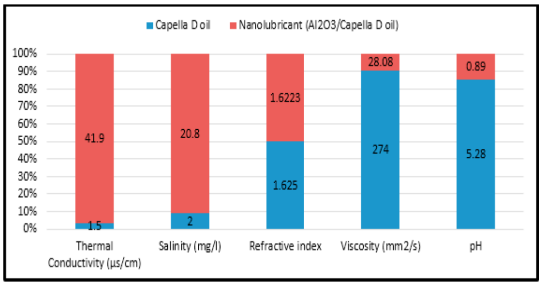

Fig.6: Results of thermophysical analyses on the nanolubricant and base oil

higher until after the 180th minute when those of the nanorefrigerant slightly began to go beyond the conventional fluid. The results suggest that the nanorefrigerant's performance improves with time and may eventually become the preferred.

3.2. Results of Pull-Down Time (PDT) Analysis

PDT is the time required to change the temperature of the evaporator compartment from ambience to the final temperature. The system employed was designed to operate at – 10ºC. Thus, Fig. 2 indicates the system achieved better results with the nanorefrigerant than the conventional working fluid throughout the period of the experiment. The cooling rate was three times faster for the nanorefrigerant and achieved the results within the first 30 minutes of operation. This therefore demonstrate that, the Al_2O_3 nanoparticles enhanced the freezing capacity of the system by enabling faster cooling of the refrigerated space to -10°C at the end of 1 hour compared to the conventional working fluid that achieved the same result 45 minutes later.

3.3. Result of the Exergetic Analysis of the Compression process

Exergy of a system indicates the measure of the maximum useful work obtainable from the system at a given state, in a given environment. The greater the value of exergy of the compression process the better the performance of the system. Fig. 3 depicts the results and shows that the system had higher values of exergy when nanorefrigerant configuration was employed.

3.4. Analysis of Energy Consumption

The effect of Al_2O_3 based nanofluid mixture on the energy consumption of the system is highlighted with Fig.4. It shows that the system with nanorefrigerant consumed less power than that with the conventional refrigerant mixture. The values of the power consumption with nanorefrigerant fell between 0.83 and 0.97 kW, while that with conventional refrigerant mixture were between 0.68 and 0.98 kW. However, it is worth noting that majority of the savings were achieved pre-180 minutes while only minimal savings were achieved after the 180 minutes' mark when compared with the system with conventional refrigerant mixture.

3.5. Cooling Load Analysis

This is otherwise referred to as thermal load. It is the magnitude of heat energy that must be removed from a space. The desire is that the cooling load be small with time. Fig. 5 shows the results of the cooling load obtained from using the nanorefrigerant as compared to the conventional refrigerant mixture. The results indicate that in the first 150 minutes of operation, lower magnitudes of cooling load were achieved with the nanorefrigerant. The values ranged between 1.72 and 2.49 kW compared to between 1.74 and 3.50 kW for the conventional refrigerant mixtures. After this time, the cooling loads of both systems were about the same values. Thus, it strongly implies that Al_2O_3 based nanofluids makes the refrigeration system more efficient with lower cooling effort.

Based on the results, it can be concluded that the presence of Al_2O_3 nanoparticles in the working fluid of the refrigeration system enhanced the cooling, reduced energy consumption and boosted the system's overall performance. Worthy of note is the fact that, the nanofluid was employed without any system retrofitting making it an economically sustainable and design insensitive application. Moreover, going by the impact of the nanoparticles on the thermal performance of the working fluid, the study sought to find out the reason behind the contribution of the nanoparticles to the enhancement of the heat transfer efficiency of the working fluid. This led to the determination of the thermophysical property of the Al_2O_3 nanoparticle dispersed Capella D oil (i.e. nanolubricant). The results are displayed in Fig. 6. It shows that, in terms of thermal conductivity and salinity, the nanolubricant had higher values. This implies that the nanolubricant has better heat transfer ability. Whereas, the thermal conductivity demonstrates that the nanofluid has higher ability to improve the refrigerant's ability to achieve cooling much faster and better than the conventional lubricant. The salinity is related to heat capacity and the higher its value, the better the material capacity to retain more heat. Thus, enhancing the nanolubricant's capacity to transport more heat from the refrigerator. Moreover, the results of the viscosity tests show that the presence of the nanoparticles reduced the viscosity. The implication is the fact that, although the nanoparticles enhanced the thermal property of the nanolubricant-refrigerant combination, it however also reduced the base oil's resistance to flow. This consequently may influence the energy consumption going by the principle that for a fully laminar flow, the overall energy consumption is directly proportional to the kinetic viscosity of the lubricant. Hence, the lowered viscosity value portrays a reduction in energy losses in the hydrodynamic lubrication. This invariably may be because the power requirement by the compressor drops to cover only for that needed to overcome viscous drag and also transport the lubricant through the lubricated parts. Further to this, the reduced viscosity has a direct relationship with the reduction of heat generation that may arise due to the lubricant's internal friction. This invariably will make the compressor more efficient and improves startup. However, more research may be required to understudy the effect of the nanolubricant on the wear rate at the compressor wall. This will be required to investigate its anti-wear properties.

In addition to the aforementioned, the results of the pH tests show that the addition of aluminum oxide nanoparticles reduced the pH value from 5.28 to 0.89. Thus, demonstrating that the nanolubricant may have an aggressive or corrosive effect on the compressor material. This therefore brings about the need to have an improved compressor material selection that caters for eventual acid attack if such nanorefrigerant configuration will be adopted in the future. The results of the refractive index typically show the nature of the appearance of the fluids. The results suggest that the nanolubricant is opaquer than the base oil and would not easily allow light rays.

4. CONCLUSIONS

The performance evaluation of R134a/Al_2O_3 nanorefrigerant in domestic refrigerator was investigated in terms of Thermodynamic and energy consumption properties. The outcome revealed that the Al_2O_3 nanoparticle enhanced the performance of the refrigeration process with better efficiency. Moreover, in order to determine the degree to which the Al_2O_3 nanoparticles influenced the heat transfer ability of the conventional refrigerant mixture, the thermophysical property analyses were carried out. The outcome showed the results of the thermal conductivity and salinity, depicting the positive influence of the nanoparticles on the thermal performance of the nanorefrigerant while the results of the viscosity tests showed that the nanolubricant has impact on the energy consumption ability. The lower viscosity values indicate a better energy saving capacity. Moreover, the pH analyses indicate that the presence of the Al_2O_3 nanoparticles in the working fluid may have negative effects on the compressor walls and material [13-15]. Further work will however be required to determine the anti-wear properties of the nanolubricant and ascertain the reliability of its application in a vapour refrigeration system.

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