Investigation of the heat transfer effect of Ni/R134a nanorefrigerant in a mobile hybrid powered vapour compression refrigerator

1Oluseyi O. Ajayi, 1Oghenefegor O. Useh, 1Solomon O. Banjo, 2Felicia T. Oweoye, 1Ameh Attabo, 1Mercy Ogbonnaya, 1Imhade P. Okokpujie, 1Enesi, 1Y. Salawu

1Mechanical Engineering Department, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria
2Department of Industrial Chemistry, Covenant University, P.M.B. 1023, Ota, Ogun State, Nigeria
*Correspondence: oluseyi.ajayi@covenantuniversity.edu.ng

Abstract. The study investigated the effect of the use of 0.04% Ni/R134a nanorefrigerant as working fluid in a vapour compression refrigeration system designed to work with hybrid power source of grid-electricity/battery/solar power. The nanoparticle was prepared via the one step method and dispersed into the mineral oil. R134a was employed as the base refrigerant and the performance of the system with the nanorefrigerant was compared, in terms of the coefficient of performance, pull down time and power consumption, with that of the base refrigerant. The results showed that the refrigeration system performed better with the nanorefrigerant as working fluid with any of the power sources and also with the hybrid solar/battery power. The system with nanorefrigerant performed better with improved coefficient of performance in the range of between 7.05% when used with solar/battery as power source and 14.12% when with only battery as power source. The system’s pull-down time showed far better results with the nanorefrigerant compared with base refrigerant. However, the system with nanorefrigerant slightly consumed more power with the highest consumption being 28.7% (with battery only as power source) higher that that with the base refrigerant. Based on the outcome of the results, the system can be deployed for vaccine preservation in off-grid remote areas, and also for domestic and commercial applications.

Key words: Nanorefrigerant, Energy System, Hybrid Power System, Solar Energy, Off-grid system, vaccine preservation

1. Introduction

Nanotechnology is a section of science and technology regarding the modification and use of particles in the atomic and molecular order (nanoparticles). A form of this technology is seen in nanofluids. Nanofluids are simply fluids that have a composition of nanoparticles and base fluid. According to application, nanofluids are classified as heat transfer nanofluids, tribological nanofluids, surfactant and coating nanofluids, chemical nanofluids, process/extraction nanofluids, environmental (pollution cleaning) nanofluids, bio- and pharmaceutical nanofluid and medical nanofluids (drug delivery, functional and tissue-cell interaction) [1]. The focus of this study is on that which belonged to the class of heat transfer nanofluids, in this case nanorefrigerant. Nanorefrigerants are special type of nanoluids which comprises of the mixture of nanoparticles and base working fluids. According to [2], there are three main advantages derived from the application of nanorefrigerants. These advantages are related to its ability to enhance the solubility between the lubricant and the refrigerant, the ability to influence thermal conductivity and heat transfer characteristics of the refrigerant and also the ability to decrease the friction coefficient and wear rate of the lubricant.
Some studies have been conducted on the effect of nanoparticles in the working fluid of vapour compression refrigeration system. Such studies have focused majorly on the performance of refrigeration system based on its freezing capacity, coefficient of performance and power consumption. For instance, [3], investigated experimentally the reliability and performance of a domestic refrigerator with nanoparticles dispersed in the working fluid. TiO$_2$ nanoparticles were mixed with mineral oil and used as a lubricant in a refrigerator system using 1,1,1,2-tetrafluoroethane (HFC134a) refrigerant. The performance of the refrigerator was investigated using energy consumption tests and freeze capacity. From the experiments, the results showed that HFC134a and mineral oil with TiO$_2$ nanoparticles was environmentally safe and worked normally. Also, the refrigerator performance was better than the conventional HFC134a and POE (Poly ol-ester) oil system, and the energy consumption was 26.1% lower when 0.1% mass fraction of TiO$_2$ nanoparticles was employed. [4] numerically investigated the heat transfer enhancement of a domestic refrigerator operated with Al$_2$O$_3$ nanorefrigerant. The study investigated the impact of different nanofluids on the heat transfer effectiveness of the system. Three base fluids were used for the experiment - pure POE oil, mineral oil and mineral oil + alumina nanoparticles (0.06% mass fraction) as lubricants for the compressor of the system. The results showed that the pull down time for the system with nanolubricant (Al$_2$O$_3$/mineral oil) was lowest. It was also observed that temperature drop in the condenser with nanorefrigerant was high, with the exit of the condenser being 39°C and subcooling obtained at 3°C. Further to this, it was found that the coefficient of performance (COP) increased by 19.6% and the power consumption reduced by 11.5% when nanorefrigerants were used.

In addition, [5] investigated the effect of dispersing a low concentration of TiO$_2$ nanoparticles in the mineral-oil lubricant on its viscosity and lubrication characteristics as well as on the overall performance of a Vapour Compression System using R12 (Dichlorodifluoromethane) as the working fluid. The outcome showed that there was an enhancement in the COP of the refrigeration system. It was also found that the addition of low volume fractions of titanium oxide nanoparticles in the mineral oil brought about a reduction in the compressor work. The results indicated that the increase in viscosity due to the addition of nanoparticles was more prominent in the lower temperature range. It was also realized that the friction coefficient reduces till the volume fraction got to 0.01% and then increased for volume fractions above that. Furthermore, the results demonstrated that with the presence of nanoparticles in the mineral oil, the average heat transfer rate increased by about 3.6%, compressor work decreased by about 1.1% and resulted in COP improvement of 17%. [6] investigated experimentally the reliability and performance of a vapour compression refrigeration system with ZnO nanorefrigerant. The base refrigerant used was R152a and, the particle size and volume concentrations were 50 nm and varying 0.1%, 0.3% and 0.5%, respectively. About 150 g of the refrigerant was charged into the system. The results showed that ZnO nanorefrigerant works normally and safely in the system. The performance of the system was significantly improved with 21% lower energy consumption when 0.5% volume concentration was used. Both the suction and discharge pressure were lowered by 10.5%. Also, the temperature of the evaporator reduced by 6%, and the results of the pull-down time and COP showed great improvement. This study therefore aims to extend the database of suitable nanorefrigerants that can be employed for the performance enhancement of vapour compression refrigeration systems. It employed nickel particle-dispersed into capella D oil and R134a base refrigerant to form the nanorefrigerant. However, unlike previous studies, this study used a hybrid grid-electricity/solar/battery powered vapour compression system designed for the purpose of the investigation. It investigated the performance, energy saving capacity and the compatibility of the vapour compression refrigeration system with solar power. The purpose was to have a system that can be suitably employed as off-grid refrigeration system for rural and commercial applications, and also for vaccine preservation.

2. Materials and Methods

It has been discovered that nanofluid can be prepared in two basic ways. They are, one-step method and two-step method. Popularly used for preparation is the two-step method where the nanoparticles are directly mixed with the fluid. This method is more economical but has some setbacks, like the aggregation and sedimentation of nanoparticles in the nanofluid, which impairs the performance of the
nanofluid. On the other hand, the one-step method has the nanoparticles synthesized from a salt into the base fluid. This preparation though more expensive than the two-step method, produces nanofluid without sedimentation of the nanoparticles. Nanofluid produced with the one-step method have been found to be more effective than the other. For purpose of this study, the nanofluid was prepared using the one-step method. Nickel nanoparticle prepared by the one step method was dispersed directly into Cappella D oil and the system was charged with R134a refrigerant. The suitability and performance of 0.04% Ni/R134a nanorefrigerant was investigated and compared with when the base refrigerant of R134a was used.

The refrigerating system used for this experiment was a hybrid refrigerator that can use solar/battery, only battery and grid electricity as power sources. The experiments were carried out with each of the power sources to determine the system’s effectiveness. The refrigerator was made up of a cooler that acts as the evaporator, plate-fin condenser, a hermetic compressor, capillary tube, an inverter that converts the DC to AC, a solar panel, a charge controller and a 150 Ah Deep-Cycle battery. Figs. 1 to 3 displays the results obtained when grid-electricity was used as the power source, while Figs. 4 – 7 are those obtained when the power source was just the battery. Only battery as power source was carried out to determine the performance when there is no solar capacity. Moreover, Figs. 8 – 11 displays the results obtained when a hybrid solar/battery power system was employed for the refrigeration system.

![Fig. 1: Comparison of the coefficient of performance of the system with and without nanorefrigerant when grid electricity was the power source](image1)

![Fig. 2: Plot showing the pull down time of the system with and without nanorefrigerant when grid electricity was the power source](image2)
Fig. 3: Variation of power consumption of the system with and without nanorefrigerant when grid electricity was the power source

Fig. 4: Comparison of the coefficient of performance of the system with and without nanorefrigerant when battery was the only power source

Fig. 5: Plot showing the pull down time of the system with and without nanorefrigerant when battery was the only power source
Fig. 6: Variation of power consumption of the system with and without nanorefrigerant when battery was the only power source.

Fig. 7: Variation of battery discharge rate when battery was the only power source.

Fig. 8: Comparison of the coefficient of performance of the system with and without nanorefrigerant when hybrid solar/battery was the power source.
Fig. 9: Plot showing the pull down time of the system with and without nanorefrigerant when hybrid solar/battery was the power source.

Fig. 10: Variation of power consumption of the system with and without nanorefrigerant when hybrid solar/battery was the power source.

Fig. 11: Variation of battery discharge rate with hybrid solar/battery as the power source.
3. Result and Discussion

Fig. 1 shows that the nanorefrigerant performed better than the conventional R134a when grid-electricity was employed as the power source with a better COP value of 12.8% higher. In the same vein, the pull-down time values (Fig. 2) showed better performance with the 0.04% Ni/R134a. The difference in temperature attained for the nanorefrigerant system was about 82.8% lower than that of R134a. The time taken to attain the lowest temperature stability was in the neighborhood of between 30 to 45 minutes. The magnitude of power consumption when grid-electricity was employed is shown in Fig. 3. The figure shows that, the system with nanorefrigerant slightly consumed a higher magnitude of power with the difference being about 17.4% higher. This result is however a contradiction when compared with other results of similar tests [7]; [8], pointing to a need for further investigation.

Moreover, when only battery was used as the power source, the COP results showed that the nanorefrigerant did not perform as the conventional R134a as shown in Fig. 4. The reason may be due to the fact that, the initial power requirement from the battery to start the compressor and make it function was somewhat inadequate when employed on the nanorefrigerated system. However, after operation for over two hours, the performance became very close. Thus, the overall COP drop from that of the conventional R134a was about 14.12%. Despite this result, the system with 0.04% Ni/R134a operated with better pull-down time (Fig. 5), attaining twice lower temperatures within the refrigerated space. Worth noting is also the fact that, while the conventional refrigerant R134a was not able to take the temperature of the refrigerated space below 0°C, the 0.04% Ni/R134a took it up to –18°C within the same time interval. The power consumption tests of Fig. 6 shows that the system consumed about 28.9% more power with nanorefrigerant as the working fluid, when compared to the conventional refrigerant. These results were supported by the COP values of Fig. 4. An investigation into the battery capacity showed that the rate of battery discharge was slower with nanorefrigerant as the working fluid when compared with the conventional refrigerant. The results are displayed in Fig. 7.

To further determine the suitability of the hybrid system for off-grid application, the system was powered with solar/battery arrangement. The performance (Fig. 8) showed that the system performed better with 0.04% Ni/R134a nanorefrigerant as against the conventional R134a. The COP value was higher with about 7.05%. The pull-down time results (Fig. 9) shows that the temperature attained in the refrigerated space, when the nanorefrigerant was used was more than twice lower than that of the conventional as was the case with only battery. The lowest temperature of the refrigerated space was as low as -19°C. In terms of the power consumption (Fig. 10), the refrigerator consumed power of about 15.9% more with nanorefrigerant as the working fluid, when compared to the conventional refrigerant. Unlike when only battery was used as the power source (Fig.7), Fig. 11 shows that as a result of the solar power, the battery was sustained at a high percentage. Also, the battery capacity in percentage, reduced at a slower rate with the nanorefrigerant as the working fluid when compared with the conventional refrigerant. Comparing Fig. 7 with Fig. 11 shows that very similar results were obtained for the two test scenarios.

4. Conclusion

The study investigated the suitability and applicability of employing 0.04% Ni/R134a with vapour compression refrigeration systems. It also demonstrated the potential of employing such nanorefrigerated system for an off-grid application, and also for vaccine preservation. The performance analyses showed that the nano-refined heat transfer fluid of 0.04% Ni/R134a is suitable as a working fluid for a vapour compression refrigeration system. The outcome also showed that the nanorefrigerant can be used in an off-grid vapour compression refrigerating system without any retrofitting. Going by the ability of the 0.04% Ni/R134a nanorefrigerant to drop the temperature of the refrigerating space to below 0°C within very short time, employing adequate thermostat with the refrigerating system will ensure the system’s suitability for off-grid vaccine preservation. However, despite the good performance results, it was discovered that the 0.04% Ni/R134a nanorefrigerant consumed slightly more power than
the conventional R134a refrigerating system. The result contradicts some of those of previously studies, thereby bringing about the need for further studies.

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