An Experimental Study on the Performance Enhancement of a Heat Pump System using Nanofluids

Vinod C. Shewale
M.V.P.S's K.B.T. College of Engineering, India
shewale.vinod@kbtcoe.org (corresponding author)

Arvind A. Kapse
M.V.P.S's K.B.T. College of Engineering, India
kapse.arvind@kbtcoe.org

Sanjay D. Barahate
K.K.Wagh Institute of Engineering Education & Research, India
sdbarahate@kkwagh.edu.in

Santosh P. Jadhav
M.V.P.S's K.B.T. College of Engineering, India
spjadhav375@gmail.com

Satish J. Suryawanshi
M.V.P.S's K.B.T. College of Engineering, India
suryawanshi.satish@kbtcoe.org

Received: 29 October 2023 | Revised: 16 November 2023 and 20 November2023 | Accepted: 22 November 2023

 DOI: https://doi.org/10.48084/etasr.6571

ABSTRACT

Heat pumps are frequently used for heating, cooling, and air conditioning. It is well known that nanoparticles can improve the coefficients of conduction and convection, increasing heat transfer along with other properties. The considered heat pump was loaded with R-134a. Titanium dioxide (TiO_2) and aluminium oxide (Al_2O_3) were blended with clean water to create a nanoscale solution used to cool the heat pump condensers. A total of three TiO_2 and Al_2O_3 proportions (0.1%, 0.2%, and 0.3%) were used. The study's findings showed that utilizing 0.3% Al_2O_3 instead of conventional clean water to cool the heat pump condenser boosted the coefficient of performance by 18% while reducing energy consumption by 26%.

Keywords-heat pump; TiO_2; Al_2O_3; R-134a; coefficient of performance

I. INTRODUCTION

The rapid development of nanotechnology has led to the emergence of a new class of heat transfer fluids called nanofluids. Many researchers have recently studied the effects of nanoparticles in different refrigerants/lubricants on the efficacy of vapor compression refrigeration systems. Authors in [1] studied the performance of heat pumps using the nanofluid R22+TiO_2 as the working fluid. Authors in [2] studied forced convection nanofluid heat transfer in the automotive cooling system. Authors in [3] conducted an experimental study on heat pumps considering different concentrations of CuO and Al_2O_3 with pure water for performance enhancement. Authors in [4] discovered that nanofluids have a significantly higher thermal conductivity than basic fluids. They also discovered that the crucial heat flux significantly increases when nanoparticles are added. Authors in [5] used TiO_2-R600a nanorefrigerant as a working fluid in an experimental investigation of a home refrigerator for performance evaluation. They demonstrated that the TiO_2-R600a system operated in the refrigerator normally and effectively, saving 9.6% of electricity. They too stated that the nano refrigerating system had a higher freezing pace than a system using only pure R600a. Authors in [6] used nanorefrigerants in experiments on a domestic refrigerator. They used R134a as a primary refrigerant and a mixture of mineral oil and TiO_2 as lubricant in their experiments. They discovered that the nanorefrigerant-equipped refrigeration system operated regularly and effectively, consuming 21.2% less energy compared to a device using R134a/POE oil. In [7], it was discovered that the power usage had been noticeably reduced and the freezing capacity had significantly improved. The authors emphasized that better mineral oil thermophysical properties and the existence of nanoparticles in the refrigerant are responsible for the system's improved performance. Authors in [8] studied a cooling system with a refrigerant made of hydrocarbons and mineral lubricant instead of R-134a and polyester lubricant. Al_2O_3 nanoparticles were added to the mineral lubricant to enhance heat transmission and lubrication, with 60% R-134a and 0.1% by weight Al_2O_3 nanoparticles being the best combination. In these circumstances, the performance coefficient rose by 4.4% while the power consumption decreased by about 2.4%. Authors in [9] performed an experimental study on the heat transfer of nanofluids with R134a and POE oil In a horizontal tube. They discovered better dispersion of CuO nanoparticles, whereas the coefficient of heat transfer increased by more than 100% in comparison to the initial R134a/POE oil findings. In [10], the effects of individual wall carbon and TiO_2 dispersion on POE oil's tribological properties and R134a's solubility at various temperatures were examined. The authors demonstrated how the addition of nanoparticles can either enhance or worsen the behavior of the base lubricant. Using Brinkman's model, authors in [11] investigated R123-T_iO_2 nanorefrigerant viscosity at various nanoparticle concentrations and found that pressure drop dramatically increases as viscosity increases. Authors in [12] looked the ways a two-phase constant area ejector could enhance a VCR system's performance by collecting kinetic energy during the expansion process and so lessening the compressor's workload. Authors in [13] showed that the performance of A VCR system using the refrigerant R-134a improves when different blends of hydrocarbons are utilized. By the development of nanotechnology, numerous studies have investigated the impact of additives such as nanoparticles to the lubricant or refrigerant, or both, on the Coefficient of Performance (COP) of the VCR system. Authors in [14] investigated how the inclusion of nanotubes made of carbon improved the heat transfer in refrigerants. Authors in [15] found improved lubricating properties in mineral oil with 0.1% nanoparticles by volume. Authors in [17] imply that the viscosity fluctuations or the changing lubrication characteristics may be the causes of increased COP when nanoparticles are added to the lubricating oil. According to [17], TiO_2 nanoparticles can be added to mineral oil to improve its solubility with hydrofluorocarbon (HFC) refrigerants. Additionally, the HFC134a and mineral oil refrigeration systems with TiO_2 nanoparticles appear to operate similarly to HFC134a and POE oil systems while returning more lubricating oil from the compressor. Authors in [18] conducted an experimental investigation on the heat transfer properties of R22 refrigerant with Al_2O_3 nanoparticles. It was discovered that the nanoparticles improved the refrigerant's heat transfer qualities with smaller bubble sizes. The heat transfer properties of R11 refrigerant with TiO_2 nanoparticles were examined in [19], where the heat transfer augmentation reached 20% for 0.01 g/L particle loading. The impact of nanotubes made of carbon on the heat transfer of R123 and R134a was examined in [20]. CNTs improved these refrigerants' nucleate boiling coefficient of heat transfer and large improvement (36.6%) was observed at very low heat fluxes. Authors in [21] observed that the addition of carbon nanotubes made of multiwall increased the thermal conductivity of polyoil by 150%.

TiO_2 nanoparticles can be utilized as additives to improve the mineral oil's solubility in HFC refrigerants [22]. Additionally, compared to systems employing R134a and POE oil, refrigeration systems using blend of R134a and mineral oil containing TiO_2 nanoparticles seem to operate well by returning more lubricating oil from the compressor [22]. Authors in [23] studied a non-flammable low-GWP refrigerant blending for the replacement of HFC-134a. Authors in [24] conducted an experimental investigation of an ice plant using different concentrations of nano lubricants with R-134a as the primary refrigerant. Authors in [26] studied the impact of adding nanoparticles to the working Heat Transfer Fluid (HTF), employing an Al_2O_3-H_2O based nanofluid at various volume concentrations. Authors in [27] investigated the nanofluid flow in a porous pipe with Navier slip. Copper (Cu) and alumina (Al_2O_3), two water-based nanofluids, were taken into consideration. The momentum and energy equations were non-dimensionalized, and a governing equation was presented. Authors in [28] investigated the convective heat transfer of CuO/(W-EG) and Al_2O_3/Water-Ethylene Glycol (EG) nanofluids passing through a circular tube with laminar flow conditions and circumferentially non-uniform heating (constant heat flux).

II. MATERIALS AND METHODS

A. *Experimental Set Up*

The set up of the experiment, shown in Figure 1 and the simulation shown in Figure 2 mainly, consist of a hermetically sealed compressor, a drier-filter, an expansion device, and a heat absorption chamber.

Fig. 1. Experimental set up.

The test rig specifications are mentioned in Table I. Low pressure and low temperature vapor refrigerant coming from the evaporator are sucked by the compressor and in compressor its temperature and pressure increases and it releases its heat in to the condenser. After the condenser, it passes through the capillary tube in which the liquid refrigerant is converted into vapor and liquid which again goes to the evaporator where we get the refrigerating effect. For measuring the high and low pressures, separate pressure gauges are fitted into the set up. All temperatures are recorded with the help of a temperature indicator at different states of the refrigerant and a digital energy meter provided to record the input power required to run the compressor. The data acquisition system is incorporated to display all the data on a PC. The specifications of the instruments used for are given in Table II.

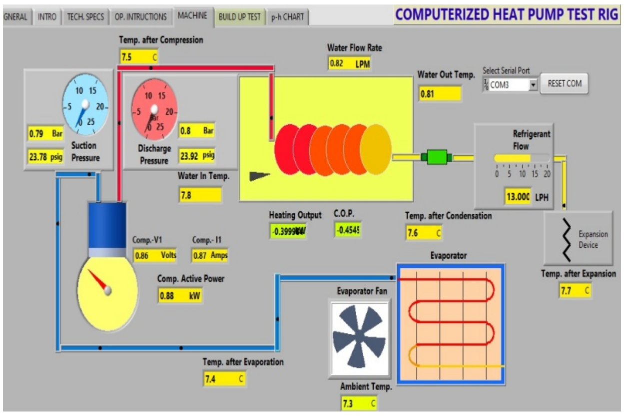

Fig. 2. Simulation set up.

TABLE I. TEST RIG SPECIFICATIONS

Heating capacity	3.0 kW @ rated test conditions
Heating capacity	100 L/hr
Max. temperature attained	55 °C
Input power	1.01 kW
Compressor make	Emerson Climate Technology Ltd.
Compressor type	Reciprocating, hermetically sealed
Refrigerant	R134a
Condenser	Tube in tube, co-axial
Expansion device	Capillary tube
Evaporator	Forced convection air cooled. Copper tubes, Al fins
Evaporator fan	VBM/HICOOL make axial flow
Temperature control	SUBZER make-automatic, digital
HP cut out	Danfoss
Pressure gauge	Wika
Electrical switchgear	Schnider make, MCB, Power contactor
Indications	Temperature in °C, mains on
Fault indications	HP fault. Low flow
Supply	230 V, 50 Hz,1 hp, AC
Construction	Sheet metal:1.2 mm CRCA, powder coat
Circulation pump	Kirloskar

TABLE II. MEASUREMENT INSTRUMENT SPECIFICATIONS

Measured parameter	Instrument	Range	Uncertainty
Temperature	PT100	-50 °C to 100 °C	±0.5%
Pressure	B.T. pressure gauge	0-15 bar (L. Press.) 0-20 bar (H.Press.)	±0.5%
Power of compressor	Digital energy meter	0-2000 W	±0.2%
Nanoparticles mass	Digital electronic balanced	0.001 g to 250 g	±0.5%

B. *Preparation of TiO_2 and POE Nanolubricant*

The TiO_2 and Al_2O_3 nanoparticles used in this study have an average diameter of 15 nm. The first-step procedure was to prepare the nanofluid. This technique entails employing nanoparticles and adding enough water to the bottle. The water is mixed with the nanoparticles (Al_2O_3 and TiO_2) using an ultrasonic vibration homogenizer system. To prevent the device from being damage, the ultrasonic unit was filled with water and left inside the bath for 60–90 min [25]. Al_2O_3-water and TiO_2-water nanofluids were generated in 3 volume fractions (0.1%, 0.2%, and 0.3%), as shown in Figure 3.

Fig. 3. The ultrasonic immersible transducer with generator and nanofluid samples.

C. *Performance Analysis*

To determine the rate of heat transfer from the evaporator and the condenser, the enthalpy values were plotted at various locations on the refrigerant pressure-enthalpy diagram (refrigerant R-134a) as shown in Figure 4. The Labview software was used to calculate the values of enthalpy based on the relationship between temperature and pressure. The key elements of heat pump efficiency are the coefficient of performance, the heat-rejection ratio, and the work done by the compressor.

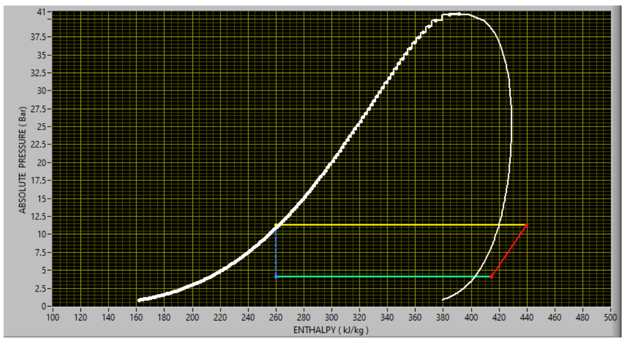

Fig. 4. Pressure enthalpy diagram for the heat pump cycle.

The COP of the heat pump system is:

COP = Heat removal / Work done

$$= (h_2 - h_3)/(h_2 - h_1) \tag{1}$$

The Heat Rejection Ratio (HRR) of the heat pump system is calculated by:

HRR = Rate of heat rejection in the condenser / rate of heat absorbed in the evaporator

$$= (h_2 - h_3)/(h_1 - h_4) \quad (2)$$

Work done by the compressor:

$$Win = m \times (h_2 - h_1) \quad (3)$$

where m is the mass flow rate of the refrigerant in Kg/s, h_1 is the enthalpy of refrigerant at the inlet of the compressor in kJ/kg, and h_2 is the enthalpy of the refrigerant at the outlet of the compressor in kJ/kg.

III. RESULTS AND DISCUSSION

In this experimental study, three TiO_2 and AL_2O_3 proportions (0.1%, 0.2%, and 0.3%) were used for the evaluation of the performance of a heat pump system. Figure 5 depicts the plot of COP against various mixtures. The value of COP increases as the concentration of nanoparticles in the fluid increases, indicating that the COP values are improved when Al_2O_3 is added to the pure water. Additionally, we deduce that the value of COP rises as the fluid's nanoparticle concentration does. The highest value is obtained for the mixing ratio 0.3% of Al_2O_3 and water. Employing Al_2O_3 results in a performance boost of 18%. The microscopic size of the Al_2O_3 nanoparticles added to the distilled water [8] can be used to explain this finding. The sub-cooling of the nano-refrigerant in the condenser and decreased energy consumption of the compressor will lead to an improvement in cycle coefficient performance.

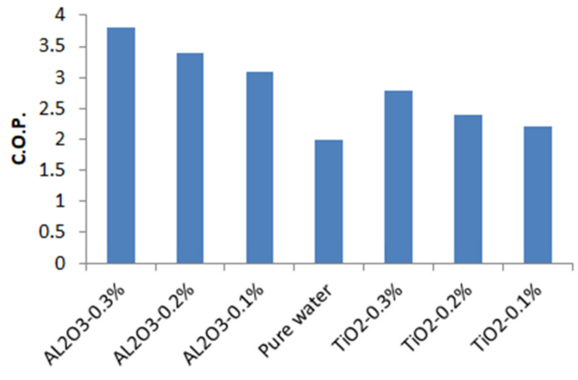

Fig. 5. COP of different mixtures.

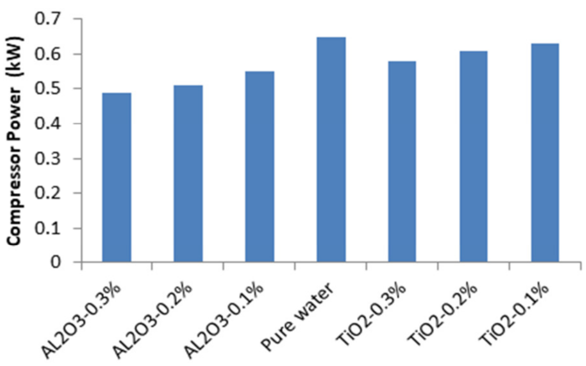

Fig. 6. Compressor power for different mixtures.

Figure 6 shows the effect of TiO_2 and Al_2O_3 volume fractions on the amount of energy used by the compressor. One of the seven scenarios being studied indicates a significant decrease in power consumption when the volume fractions are minimized. When utilizing 0.3% Al_2O_3, the power consumption was reduced by about 2%, and when using TiO_2 at the same volume fraction, the reduction was about 11%.

Figure 7 shows the impact of nanoparticle volume fraction on the heat rejection ratio. It is a term that commonly refers to the evaporator's contribution to the condenser's heat flow rate. Figure 7 demonstrates that the HRR falls if the nanofluid is employed to cool the cycle's condenser. The Figure demonstrates that employing combinations of Al_2O_3-water at 0.1%, 0.2%, and 0.3%, TiO_2-water at 0.1%, 0.2%, and 0.3%, the value of HRR decreases by roughly 1.1%, 1.3%, 1.6%, 0.7%, 0.8%, and 1.0%, respectively. Inferred from decreasing heat rejection ratio figures is an increase in cooling and a decrease in compressor operation.

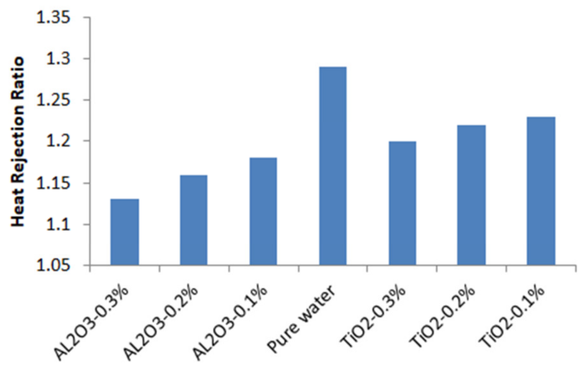

Fig. 7. Heat rejection ratio for different mixtures.

Figure 8 shows the effect of the volume fractions of nanoparticles on the cooling effect throughout time. It was discovered that employing nanoparticles to cool the condenser works better when 0.3% Al_2O_3 and water are mixed. Furthermore, the picture clearly shows that the cooling impact grows with the volume fraction of Al_2O_3 nanoparticles as a result of subcooling in the condenser. The compressor's workload and energy consumption have lowered as a result of increased refrigerant mass flow rate and improved heat transfer rate.

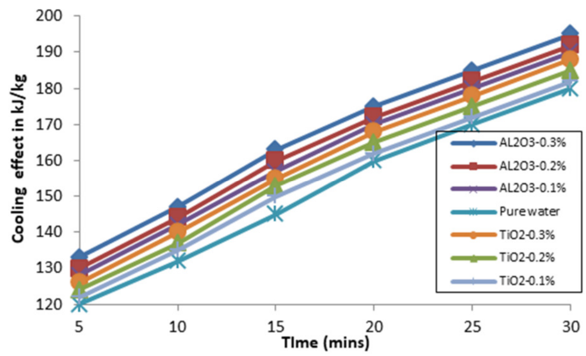

Fig. 8. Cooling effect versus time for different mixtures.

Figure 9 shows the variation of compressor work with compressor discharge temperature and demonstrates the effect of nanoparticle volume fraction on the compressor work. According to the graph, compression work decreases as compressor discharge temperature increases. The figure also demonstrates that the 0.3% Al_2O_3-water mixture required more compressor work than the other mixtures. This is predicated on the idea that as the compressor discharge temperature rises, the compressor suction temperature will rise as well due to the occurrence of subheat in the suction line. This will increase the mass of the refrigerant flowing through the compressor, reducing the amount of work required by the compressor by lowering the amount of energy consumed.

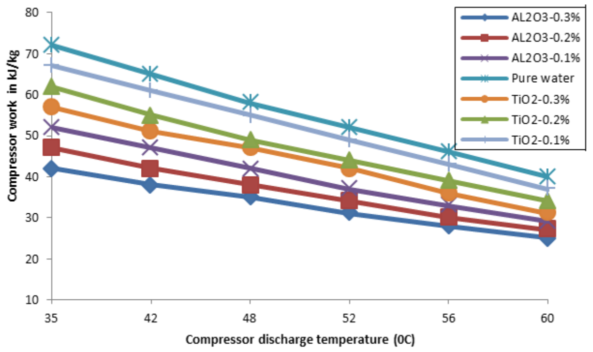

Fig. 9. Compressor work versus compressor discharge temperature for different mixtures.

Figure 10 demonstrates the impact of the nanoparticle size on the outlet temperature of the condenser. The relationship between the temperature of the evaporator and the temperature of the condenser outlet shows that when the Al_2O_3-water mixture is used to cool the condenser in the cycle, both the evaporator's temperature and the temperature of the output condenser decrease. Additionally, it has been observed that the temperature drop in the evaporator and exit condenser is greater when the Al_2O_3-water 0.3% mixture is utilized. However, the addition of nanoparticles to the water used for condenser cooling, which boosts the condenser's rate of heat transfer, boosts the heat pump's effectiveness.

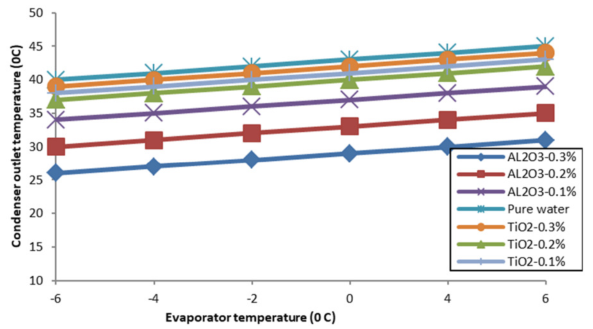

Fig. 10. Condenser outlet temperature versus evaporator temperature for different mixtures.

IV. CONCLUSIONS

Although many researchers have worked on this topic, very few investigations have been carried out on different nanoparticles blended with clean water in the area of heat pump, air conditioning, and domestic refrigerator, and, to the best of our knowledge, no research has been conducted on blending titanium dioxide (TiO_2) or aluminum oxide (Al_2O_3) with clean water to enhance the performance of a heat pump system application. In this study, the experimental analysis of a heat pump system was carried out for performance enhancement using different nanofluids. In this paper, three TiO_2 and AL_2O_3 proportions (0.1%, 0.2%, and 0.3%) were used and the performance of the heat pump system was studied.

The main conclusions of this study were that when the volume fraction of the Al_2O_3-water nanofluid increases, the cooling impact increases. Using Al_2O_3-water with a volume percentage of 0.3% was found to improve COP by 18%, reduce compressor power usage by around 26%, and reduce heat rejection by about 1%, which were the best acquired results among the six trials taken into account. Additionally, the evaporator and condenser outlet temperatures dropped much more when applying this mixture.

ACKNOWLEDGEMENT

The authors like to express their thanks to the final year students of the Mechanical Department of the MVPS KBT College of Engineering, Nashik, India for their support during the experimental study and the research implementation.

REFERENCES

[1] P. Keblinski, J. A. Eastman, and D. G. Cahill, "Nanofluids for thermal transport," *Materials Today*, vol. 8, no. 6, pp. 36–44, Jun. 2005, https://doi.org/10.1016/S1369-7021(05)70936-6.

[2] S. Bi, K. Guo, Z. Liu, and J. Wu, "Performance of a domestic refrigerator using TiO2-R600a nano-refrigerant as working fluid," *Energy Conversion and Management*, vol. 52, no. 1, pp. 733–737, Jan. 2011, https://doi.org/10.1016/j.enconman.2010.07.052.

[3] S. H. Bi, L. Shi, and L. Zhang, "Performance study of a domestic refrigerator using R-134a/mineral oil/nano-TiO2 as working fluid.," in *ICR 2007. Refrigeration Creates the Future. Proceedings of the 22nd IIR International Congress of Refrigeration*, Aug. 2007.

[4] S. Bi, L. Shi, and L. Zhang, "Application of nanoparticles in domestic refrigerators," *Applied Thermal Engineering*, vol. 28, no. 14, pp. 1834–1843, Oct. 2008, https://doi.org/10.1016/j.applthermaleng.2007.11.018.

[5] C.-S. Jwo, L.-Y. Jeng, T.-P. Teng, and H. Chang, "Effects of nanolubricant on performance of hydrocarbon refrigerant system," *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena*, vol. 27, no. 3, pp. 1473–1477, May 2009, https://doi.org/10.1116/1.3089373.

[6] K. Henderson, Y.-G. Park, L. Liu, and A. M. Jacobi, "Flow-boiling heat transfer of R-134a-based nanofluids in a horizontal tube," *International Journal of Heat and Mass Transfer*, vol. 53, no. 5, pp. 944–951, Feb. 2010, https://doi.org/10.1016/j.ijheatmasstransfer.2009.11.026.

[7] S. Bobbo, L. Fedele, M. Fabrizio, S. Barison, S. Battiston, and C. Pagura, "Influence of nanoparticles dispersion in POE oils on lubricity and R134a solubility," *International Journal of Refrigeration*, vol. 33, no. 6, pp. 1180–1186, Sep. 2010, https://doi.org/10.1016/j.ijrefrig.2010.04.009.

[8] I. M. Mahbubul, R. Saidur, and M. A. Amalina, "Investigation of viscosity of R123-TIO 2 nanorefrigerant," *International Journal of Mechanical and Materials Engineering*, vol. 7, no. 2, pp. 146–151, 2012.

[9] N. Bilir and H. K. Ersoy, "Performance improvement of the vapour compression refrigeration cycle by a two-phase constant area ejector," *International Journal of Energy Research*, vol. 33, no. 5, pp. 469–480, 2009, https://doi.org/10.1002/er.1488.

[10] M. A. Sattar, R. Saidur, and H. H. Masjuki, "Performance Investigation of Domestic Refrigerator Using Pure Hydrocarbons and Blends of Hydrocarbons as Refrigerants," *World Academy of Science, Engineering and Technology*, vol. 5, pp. 223–228, 2007.

[11] K.-J. Park and D. Jung, "Boiling heat transfer enhancement with carbon nanotubes for refrigerants used in building air-conditioning," *Energy and Buildings*, vol. 39, no. 9, pp. 1061–1064, Sep. 2007, https://doi.org/10.1016/j.enbuild.2006.12.001.

[12] K. Lee, Y. Hwang, S. Cheong, L. Kwon, S. Kim, and J. Lee, "Performance evaluation of nano-lubricants of fullerene nanoparticles in refrigeration mineral oil," *Current Applied Physics*, vol. 9, no. 2, Supplement, pp. e128–e131, Mar. 2009, https://doi.org/10.1016/j.cap.2008.12.054.

[13] B.-C. Ku, Y.-C. Han, J.-E. Lee, J.-K. Lee, S.-H. Park, and Y.-J. Hwang, "Tribological effects of fullerene (C60) nanoparticles added in mineral lubricants according to its viscosity," *International Journal of Precision Engineering and Manufacturing*, vol. 11, no. 4, pp. 607–611, Aug. 2010, https://doi.org/10.1007/s12541-010-0070-8.

[14] H. Yu, Y. Xu, P. Shi, B. Xu, X. Wang, and Q. Liu, "Tribological properties and lubricating mechanisms of Cu nanoparticles in lubricant," *Transactions of Nonferrous Metals Society of China*, vol. 18, no. 3, pp. 636–641, Jun. 2008, https://doi.org/10.1016/S1003-6326(08)60111-9.

[15] D. Elcock, "Potential impacts of nanotechnology on energy transmission applications and needs," Argonne National Lab, Lemont, IL, USA, ANL/EVS/TM/08-3, Nov. 2007. https://doi.org/10.2172/924389.

[16] J. A. Eastman, U. S. Choi, S. Li, L. J. Thompson, and S. Lee, "Enhanced Thermal Conductivity through the Development of Nanofluids," in *Materials Research Society Symposium*, Boston, MA, USA, Dec. 1996, vol. 457, pp. 3–11, https://doi.org/10.1557/PROC-457-3.

[17] M.-S. Liu, M. C.-C. Lin, I.-T. Huang, and C.-C. Wang, "Enhancement of Thermal Conductivity with CuO for Nanofluids," *Chemical Engineering & Technology*, vol. 29, no. 1, pp. 72–77, 2006, https://doi.org/10.1002/ceat.200500184.

[18] S. U. S. Choi, Z. G. Zhang, W. Yu, F. E. Lockwood, and E. A. Grulke, "Anomalous thermal conductivity enhancement in nanotube suspensions," *Applied Physics Letters*, vol. 79, no. 14, pp. 2252–2254, Oct. 2001, https://doi.org/10.1063/1.1408272.

[19] R. X. Wang, B. Hao, G. Z. Xie, and H. Q. Li, "A refrigerating system using HFC134a and mineral lubricant appended with n-TiO2 (R) as working fluids," in *4th International Symposium on Heating, Ventilating and Air Conditioning*, Oct. 2003, pp. 888–892.

[20] H. M. Skye *et al.*, "Non-flammable Low-GWP Refrigerant Blends to Replace HFC-134a," in *26th IIR International Congress of Refrigeration*, Paris, France, Aug. 2023.

[21] M. Salem Ahmed, M. R. A. Hady, and G. Abdallah, "Experimental investigation on the performance of chilled-water air conditioning unit using alumina nanofluids," *Thermal Science and Engineering Progress*, vol. 5, pp. 589–596, Mar. 2018, https://doi.org/10.1016/j.tsep.2017.07.002.

[22] A. S. Majgaonkar, "Use of Nanoparticles In Refrigeration Systems: A Literature Review Paper," in *16th International Refrigeration and Air Conditioning Conference*, West Lafayette, IN, USA, Jul. 2016, pp. 1–10.

[23] G. Yildiz, U. Agbulut, and A. E. Gurel, "A review of stability, thermophysical properties and impact of using nanofluids on the performance of refrigeration systems," *International Journal of Refrigeration*, vol. 129, pp. 342–364, Sep. 2021, https://doi.org/10.1016/j.ijrefrig.2021.05.016.

[24] V. C. Shewale, A. A. Kapse, and S. P. Mogal, "Experimental investigation of Ice plant using different concentrations of Nano lubricant with primary refrigerant R-134a," *Journal of Applied Science and Engineering*, vol. 27, no. 3, pp. 2201–2209, 2023, https://doi.org/10.6180/jase.202403_27(3).0006.

[25] A. A. Karamallah and K. A. Jehhef, "Application of Nanofluids for Cooling Newtonian and Non-Newtonian Blood Mimicking Fluids Flow in Annular Space," *Engineering and Applied Sciences*, vol. 2, no. 1, pp. 1–16, Jan. 2017, https://doi.org/10.11648/j.eas.20170201.11.

[26] D. Guerraiche, K. Guerraiche, Z. Driss, A. Chibani, S. Merouani, and C. Bougriou, "Heat Transfer Enhancement in a Receiver Tube of Solar Collector Using Various Materials and Nanofluids," *Engineering, Technology & Applied Science Research*, vol. 12, no. 5, pp. 9282–9294, Oct. 2022, https://doi.org/10.48084/etasr.5214.

[27] W. N. Muyungi, M. H. Mkwizu, and V. G. Masanja, "The Effect of Navier Slip and Skin Friction on Nanofluid Flow in a Porous Pipe," *Engineering, Technology & Applied Science Research*, vol. 12, no. 2, pp. 8342–8348, Apr. 2022, https://doi.org/10.48084/etasr.4763.

[28] K. Boukerma and M. Kadja, "Convective Heat Transfer of Al2O3 and CuO Nanofluids Using Various Mixtures of Water-Ethylene Glycol as Base Fluids," *Engineering, Technology & Applied Science Research*, vol. 7, no. 2, pp. 1496–1503, Apr. 2017, https://doi.org/10.48084/etasr.1051.