ISSN No.: 2455-6130
Special Issue: 2, 2022, pp. 56-63

website: www.ijoetr.com

International Journal of Emerging Trends in Research

Review on Use of Nanofluids for Performance Enhancement of Vapour Compression Refrigeration System based Air Conditioner

Hakimuddin A. Hussain[1*], Akash Langde[2]

[1, 2]*Deptt. of Mech. Engg.Anjuman College of Engineering and Technology,Nagpur*

Abstract

Large amount of energy saving can occur by improving the performance of room air conditioners. Sharp rise in lifestyle has enhanced the use of air conditioner which consequently increased the energy consumption. Room air conditioners constitute around 50% of total energy consumption in urban homes in India. Utilising the advantage of increased thermal conductivity, nanofluid is used to enhance the performance of VCRS based air conditioner. This paper summarizes the various approach of using nanofluid to improve the performance of Vapour Compression Refrigeration System (VCRS) based air conditioning systems like using it as a secondary fluid for heat extraction, nanorefrigerant, nanolubricant which will help the researchers in exploring newer techniques of improvement. The effect of concentaration, flow rate, composition of various nanoparticles on improvement in COP (Coefficient of performance) are presented in this article. This paper also survey about nanofluid properties affecting heat transfer.

Keywords: Air conditioning;Nanofluid;Refrigeration;COP Improvement;Vapour Compression Refrigeration System;

1. Introduction

Obligation to protect environment and great uncertainty over future energy provisions has led the concentration to be more on the utilization of sustainable sources and the energy conservation methodologies. The world energy consumption is expected to increase from 575 quadrillion British thermal units (Btu) (in 2015) to 663 quadrillion Btu by 2030, and further to 736 quadrillion Btu by 2040. The total electricity consumption by air conditioning will increase to 50,000 GWh per year in 2031. Within the next two decades, the electricity demand for cooling could increase by 25 times in India. Refrigeration and air conditioning systems tend to underperform in extremely hot climatic conditions. HVAC [Heating, Ventilating, and Air Conditioning] systems comprise 40% of the energy consumed by buildings in India[1]; therefore emphasis is more on HVAC for energy saving through upgradation and optimization of system. With the advancement in cooling applications, an effective thermal management is essential for the reliable and efficient thermal system. With these conditions, saving energy by increasing the performance of air conditioning is a need of an hour.

However, there are many techniques to apply the new technologies to reduce the energy consumption of air conditioning system. Various methods like radiative cooling, cold energy storage, defrosting and frost-free, temperature and humidity independent control, ground source heat pump, refrigerant subcooling, and condensing heat recovery were applied by the researcher in this direction [2]. Increase in the Coefficient of Performance (COP) of air conditioning systems will have an effect with increased with an end objective of reducing the green house emissions is an important area of research. Enhancing the performance of cooling systems has been the point of focus during the last decade. The challenge of high energy consumption in air conditioning systems is under ongoing studies. Considering the above requirement, this work will have positive impact on saving energy.

Micro-sized solid particles dispersed in base fluid was conceptualised by Hamilton and Crosser [3] to improve its thermal conductivity has a issue of coagulation. A novel heat transfer fluid called Nanofluid by Choi and Eastman [4] contains small quantities of metallic or non-metallic nanoparticles. It is an important contribution to the application of nanotechnology, which become a good choice to the conventional heat transfer means. A nanofluid is a fluid which contains nanometer-sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. This is done by adding nanoparticles of high thermal conductivity to the base fluid of the low thermal conductivity. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes as shown in table No.1. Nanofluids are two-phase systems consisting of a base fluid and nanoparticles with atleast one of their principal dimensions smaller than100nm.Typical carrier fluids are water, organic liquids (ethylene glycol, oil, biological liquids etc.), and polymer solutions. Many researchers have concluded that there is enhancement of thermal conductivity with the use of nanoparticles in base fluid [5]–[9].The shape, size and concentration of nanoparticles affect thermal conductivity. Alumina (Al2O3), Copper (Cu), Silver (Ag), Titanium dioxide (TiO2) and Boron Nitride (BN) are the most commonly added in nanofluids. Experimentation on shell and tube heat exchanger with Alumina-Copper/water hybrid nanofluid, concluded that the heat transfer rate enhances with increase in Reynolds number [10] . The superior heat transfer performance of nanofluid is attributed to the generation of various forces such as lift, drag, electrostatic, Brownian, van der Waals, and thermophoretic forces as suggested by [11].Regression analysis [12] reveals that for laminar and turbulent flow effectiveness of evaporators and condensers is influenced mainly by the volume fraction of nanoparticles and the type nanoparticle has secondary significance level. A very strong effect of particle size and suspension temperature was observed experimentally for the thermal conductivity of nanoparticle suspensions [13]. Metallic nanofluids are found to give higher enhancements than those of oxide nanofluids. With the increase in flow rate and concentration of nanofluid in heat transfer applications, the pressure drop also increases[14].

	Classification of Nanofluid
Metallic Nanoparticle	Nanofluids containing metallic particles such as Copper,Zinc,Aluminium,Iron,Silicon,Nickel,Gold,Silver etc.
Metallic oxide nanofluid	Nanofluids containing oxides such as Copper oxide (CuO),Titanium Di Oxide (TiO_2),Ferrous Oxide (Fe_3O_4),Zinc Oxide (ZnO),Aluminium Oxide($Al2O_3$) ,Silicon Carbide (SiC) etc.
Carbon based nanofluid	Nanofluids containing carbon nanotubes such as Single Walled carbon Nanotubes (SWCNT), Double Walled carbon Nanotubes (DWCNT) and Multi Walled carbon Nanotubes (MWCNT),
Hybrid Nanofluid	Nanofluid encompassed of composite nanoparticles such as Al2O3-cu/water, Fe_3O4-Ag/ Ethylene Glycol (EG), ZnO-TiO_2/EG, Cu-TiO_2/water-EG, Ag-MgO/water-EG, MWCNT-Fe_3O4/EG,MgO-MWCNT/water-EG

Table 1: Classification of Nanofluid

2. Using nanofluid in the secondary circuit of condenser:

The function of condenser is to allow high pressure and temperature refrigerant vapor, coming from compressor, to condense and eject heat. There are three main types: air-cooled, evaporative, and water-cooled condensers.Air cooled condenser fail to serve the requirement of air conditioning system during peak summer conditions which leads to decrease in its performance. Due to the global warming problem, the heat transfer from the condensing unit to the atmospheric air needs higher energy consumption in split air conditioner. Therefore, reduced air temperature coming out of condensing unit has been introduced as one of the techniques to reduce energy consumption of the air conditioning system, especially in the warming zone countries. Dusty environment also affects the heat transfer in air cooled condenser leading to decrease in performance.

Temperature of air-cooled condenser is directly dependent on the ambient air temperature, therefore, in the area with very hot weather temperature in summer; the condenser temperature and pressure are increased considerably which consequently increases the power consumption of the air conditioner due to the increase in the pressure ratio. Increasing condenser temperature also decreases cooling capacity of the cycle due to the reduction of liquid content in the evaporator. These two effects decrease performance of air conditioner considerably [15]. In order to increase the performance of air conditioner in this situation, one of the best solutions is decreasing the condenser temperature. Reducing the condenser temperature reduces the pressure ratio across the compressor which results power consumption reduction. It also decreases the refrigerant quality after the capillary tube and more liquid refrigerant would be available in the evaporator, therefore mass flow rate of refrigerant and the cooling capacity of the refrigerant are increased.

The thermodynamic properties associated with the relative increase in refrigerating effect, i.e. liquid specific heat and latent heat of vaporization, are dominant to determine the maximum COP improvement with condenser subcooling [16]. Subcooling is the condition where the liquid refrigerant is colder than the minimum temperature (saturation temperature) required to keep it from boiling and, hence, change from the liquid to a gas phase. Increasing efficiency of system, decreasing refrigerant flow and enhancing the life of evaporator are some of the advantages of subcooling. The state of the refrigerant entering the expansion device of conventional vapor compression cycles is usually assumed to be saturated liquid. However, liquid cooling below saturation can increase the refrigerating effect and potentially improve the COP. Nanorefrigerant is used for subcooling in air conditioning since it has improved heat capacity than refrigerant. Balaji [17] experimentally showed that with increase in mass flow rate and nanoparticle concentration there is increase in COP and reduction of power consumption. With the increase in Condenser subcooling COP in vapor-compression systems attains a maximum value as a result of a trade-off between increasing refrigerating effect and specific compression work [18].

In this configuration, apart from conventional VCRS, secondary circuit is used to extract heat from the refrigerant passing through condenser. Nanofluid is used as a working fluid in this circuit. It usually has a pump, reservoir, rotameter to transport, store and measure the flow of nanofluid fluid.

Author (Year)	Refrigerant	Nanofluid Composition					Optimum Result/Improvement			
		Base Fluid	Nanoparticle	Concentration (%)	Flow Rate	Average Particle size	COP Increase	Power Saving	At	Heat Transfer Increase
Chandraprabu et al. (2013) [19]	R410 A	Water	CuO	1, 2, 3, and 4 vol	2.5 -5 LPM	30nm	11.4%	-	3%	58%
N.Balaji et al. (2015) [17]	R-22	(water + EG) with ratio of 70:30	Al_2O_3	0.25, 0.5, 0.75 Vol	1, 1.5 and 2 LPM	30nm	49.2%	12%	0.75 %, 2LPM	-
Elsaid (2019) [20]	R-22	Water	Magnesium oxide (MgO), TiO_2	0.1, 0.5, and 1.0 wt.	-	20-100nm	16.7% (MgO) and 11.5 % (TiO_2)	-	-	-
Manirathnam et al. (2020) [21]	R410a	Water	Al_2O_3	1, 2, 3 , 4	2.5-5 lpm					37.35 %
Faizan Ahmed et al. (2021) [22]	R134a	Water	Cu and Al_2O_3	1,2,5	-	70nm	22.8%cu ;16.9%Al2O3	22.1% (Al_2O_3) and 29.4% (Cu)	5%	24.5% cu;15 % Al2O3

3. Using nanofluid in the secondary circuit of evaporator

In a simple construction, nanofluid is circulated through one loop and conventional VCRS with refrigerant through another. Cooling tank is the common element in both the loop consisting nanofluid. Heat is transferred from nanofluid to refrigerant in evaporator section. Hady [23]concluded that with increasing the flow rate of the working fluids (alumina nanofluids), the elapsed time required to cool the alumina nanofluids comparing to the elapsed time of the pure water by about half hour for most the concentrations of alumina nanoparticles. Figure shows the increase in COP enhancement with concentration of nanofluid. Simulation reveals that the increase pressure drop of evaporator, leading to reduced evaporator heat transfer area, is due to reduced nanoparticle size from and increased volume fraction [24].

Author (Year)	Refrigerant	Nanofluid Composition					Optimum Result/improvement				Remark
		Base Fluid	Nanoparticles	Concentration (%)	Flow Rate	Average Particle size	COP Increase	Power Saving	At	Heat Transfer Increase	
Loaiza et al. (2010) [24]	Not Available	Water	Cu, Al_2O_3, CuO and TiO_2	1 to 5 Vol	-	10-50nm	-	-	CuO 5% , 10nm	-	Evaporator area reduced
Hady et al. (2017) [23]	-	Water	Al_2O_3	0.1, 0.2, 0.3, 1 wt	2, 3, 5Lit/min	20-70nm	17%	-	1%	-	For 2, 3, 5Lit/min incoming air 80, 160, and 250 CFM respectively
Ahmed et al. (2019) [25]	R-134a	-	Al_2O_3, TiO_2	0.1, 0.2, 0.3, 0.4, 0.6, 1 wt	0.12, 0.18 and 0.3 m^3/s	20–70 nm (Al_2O_3) 41.5–77.3 nm (TiO_2)	5.3% increase in Refrigerating effect with alumina as compared to titanium		-	-	Single nanofluid Al_2O_3/H_2O provides a lower compression ratio than TiO_2/H_2O. The maximum COP occurs at a single nanofluid of Al_2O_3/H_2O.

4. Using Nanorefrigerant

Nanorefrigerant is a combination of nanoparticles and conventional refrigerant. In air conditioning system the nanoparticles can be added to the lubricant (compressor oil). When the refrigerant is circulated through the compressor it carries traces of lubricant + nanoparticles mixture (nano-lubricants) so that the other parts of the system will have nanolubricant -refrigerant mixture.

Steep increase in solubility is observed between refrigerant and lubricant due to addition of nanoparticles in them. Nanoparticles further increase thermal conductivity and heat transfer coefficient of refrigerant, moreover decrease in friction coefficient of lubricant is expected [26], [27]. It has been found that the thermal conductivities of nanorefrigerants are higher than pure refrigerants. It was also observed that increased thermal conductivity of nanorefrigerants is comparable with the increased thermal conductivities of other nanofluids [28]. Energy requirement can be reduced by using nanorefrigerants [29]. Nanoparticles display influences the thermal, physical and heat transfer characteristics of refrigerants [30]. Nanorefrigerants have a much higher and strongly temperature-dependent thermal conductivity at very low particle concentrations than conventional refrigerant. However, the aggregation and sedimentation of nanoparticles in the nanorefrigerant may reduce the stability of nanorefrigerant and limit the application of nanorefrigerant in the refrigeration system. The nanorefrigerants are of two kinds, refrigerant based and lubricant based. In the first category, nanoparticles are directly dispersed into refrigerants, the second in which, lubricant appended with nanoparticles is ultimately circulated along with refrigerants [31]. Mahbubul [32] concluded Aluminium oxide/R-134a nanorefrigerant (15nm) shows the highest COP of 15%, 3.2%, and 2.6% for thermal conductivity, density, and specific heat, respectively compared to R-134a refrigerant. Thermal conductivity, dynamic viscosity, and density of Aluminium oxide /R-134a nanorefrigerant increased about 28.58%, 13.68%, and 11%, respectively compared to the base refrigerant (R-134a) for the same temperature.

Author (Year)	Refrigerant	Nanofluid	Average Nano Particle size	Nano particle Concentration (%)	COP Increase	Power Saving	At	Remark
Wang et al. (2010) [33]	R410a, R407C, R410a and R425a	Nanorefrigeration oil (MNRO), Nickel ferrite into naphthlene based oil B32	-	0.3wt.	-	-	MNRO/ R410a	Nanolubricant
Shanmugasundaram et al. (2014) [34]	R22	CuO, Zinc Oxide (ZnO), $Al2O_3$	50nm	0.1	COP=5.26	-	CuO	Nanorefrigerant
Papade et al, (2015) [35]	R134a	POE oil + Al_2O_3	50nm	1,2	14%	20%	-	Nanorefrigerant
Sumeru et al. (2015) [36]	R290	TiO_2 in lubricant		0.2% by wt.	8.4%	3.1%		Nanolubricant
Vara et al. (2018) [37]	R134a	CuO + PAG Oil.	40-80nm	0.01, 0.015, 0.02, 0.025	31.99%	-	0.025%	Nanolubricant
Shareef et al. (2018) [38]	R22	$Al_2O_3$and MO 4E used as a lubricant.	20nm	0.01, 0.05, 0.1, 0.15, 0.2 wt	25%	-	0.05%	Nanolubricant
Chauhan (2020) [39]	R134a	Al_2O_3/PAG, Silicon dioxide (SiO_2)/PAG and composite nanolubricant Al_2O_3– SiO_2 /PAG	13-30nm	0.02, 0.04, 0.06, 0.08, 0.1	10.89% (Al_2O_3) and 5.3% (SiO_2)	-	0.08%	Nanolubricant
Joshi et al. [40] (2021)	R134a	Al_2O_3. The polyester oil (POE) for R134a refrigerant and mineral oil for R600a refrigerant	-	0.02, 0.04, 0.07, 0.1 wt	37.2%	28.7 %	-	Nanorefrigerant

5. Conclusions

Air conditioning system using nanofluid can be great medium to reduce green house effects because it reduces the use of refrigerant. Heat carrying capacity increases with the use of nanofluids in VCRS can be applied as secondary fluid in condenser, evaporator and as nanorefrigerant. Increase in mass flow rate also increases the heat capacity of nanofluid. It reduces the power consumption of compressor due to decrease in pressure ratio. Heat transfer coefficient and Nusselt number for nanofluid is higher than those of base fluids. Water having high dielectric constant of 78.5 is observed to be used most as a base fluid for nanofluid preparation. The dielectric constant indicates high repulsive potential which results in greater stability.Time required for cooling also reduces using nanofluid [23].

Varied concentration of nanofluid with different combination is still required to be explored in air conditioning as secondary coolant in condenser and evaporator. Even hybrid nanofluid has very less research into it. The suspended nanoparticles remarkably increase heat transfer performance of base fluid. Relative enhancement of heat transfer coefficient increases with the increment in the nanoparticles concentration. Relative enhancement of heat transfer coefficient increased upto the 4000 Reynolds number, and after that it decreased. Nanorefrigerant has an effect on increment in compressor discharge pressure, lowered evaporator pressure, and lowered the pull-down compared to the conventional refrigeration system. Increased Nusselt number is also observed when using nanoparticles.

References

[1] [P. Zhao *et al.*, "Cryogenic power generation system recovering LNG's cryogenic energy and generating power for energy and CO2 emission savings," *Energy*, vol. 35, no. 1, pp. 2–15, 2015, [Online]. Available: http://www.sciencedirect.com/science/article/pii/0360544280901048%5Cnhttp://dx.doi.org/10.1016/j.oceaneng.2015.05.030%5Cnhttp://dx.doi.org/10.1016/j.enconman.2011.02.015%5Cnhttp://dx.doi.org/10.1016/S1004-9541(11)60006-2%5Cnhttp://solarenergyengineering.a.

[2] X. She *et al.*, "Energy-e ffi cient and -economic technologies for air conditioning with vapor compression refrigeration : A comprehensive review," *Appl. Energy*, vol. 232, no. June, pp. 157–186, 2018, doi: 10.1016/j.apenergy.2018.09.067.

[3] R. L. Hamilton, "Thermal conductivity of heterogeneous two-component systems," *Ind. Eng. Chem. Fundam.*, vol. 1, no. 3, pp. 187–191, 1962, doi: 10.1021/i160003a005.

[4] S. U. S. Choi, "Enhancing thermal conductivity of fluids with nanoparticles," *Am. Soc. Mech. Eng. Fluids Eng. Div. FED*, vol. 231, no. March, pp. 99–105, 1995.

[5] J. Albadr, S. Tayal, and M. Alasadi, "Case Studies in Thermal Engineering Heat transfer through heat exchanger using Al 2 O 3 nanofluid," *Case Stud. Therm. Eng.*, vol. 1, no. 1, pp. 38–44, 2013, doi: 10.1016/j.csite.2013.08.004.

[6] Z. Alhajaj, A. M. Bayomy, and M. Z. Saghir, "International Journal of Thermo fl uids A comparative study on best con fi guration for heat enhancement using nano fl uid," vol. 8, 2020, doi: 10.1016/j.ijft.2020.100041.

[7] P. B. Maheshwary, C. C. Handa, and K. R. Nemade, "A comprehensive study of effect of concentration, particle size and particle shape on thermal conductivity of titania/water based nanofluid," *Appl. Therm. Eng.*, vol. 119, pp. 79–88, 2017, doi: 10.1016/j.applthermaleng.2017.03.054.

[8] A. K. Starace, J. C. Gomez, J. Wang, S. Pradhan, and G. C. Glatzmaier, "Nanofluid heat capacities," *J. Appl. Phys.*, vol. 110, no. 12, 2011, doi: 10.1063/1.3672685.

[9] V. Kumaresan and R. Velraj, "Experimental investigation of the thermo-physical properties of water-ethylene glycol mixture based CNT nanofluids," *Thermochim. Acta*, vol. 545, pp. 180–186, 2012, doi: 10.1016/j.tca.2012.07.017.

[10] S. Anitha, T. Thomas, V. Parthiban, and M. Pichumani, "What dominates heat transfer performance of hybrid nanofluid in single pass shell and tube heat exchanger?," *Adv. Powder Technol.*, vol. 30, no. 12, pp. 3107–3117, 2019, doi: 10.1016/j.apt.2019.09.018.

[11] H. M. Maghrabie *et al.*, "Intensification of heat exchanger performance utilizing nanofluids," *Int. J. Thermofluids*, vol. 10, p. 100071, 2021, doi: 10.1016/j.ijft.2021.100071.

[12] M. T. Nitsas and I. P. Koronaki, "Investigating the potential impact of nanofluids on the performance of condensers and evaporators-A general approach," *Appl. Therm. Eng.*, vol. 100, pp. 577–585, 2016, doi: 10.1016/j.applthermaleng.2016.02.059.

[13] H. E. Patel, T. Sundararajan, and S. K. Das, "An experimental investigation into the thermal conductivity enhancement in oxide and metallic nanofluids," *J. Nanoparticle Res.*, vol. 12, no. 3, pp. 1015–1031, 2010, doi: 10.1007/s11051-009-9658-2.

[14] S. Baskar, M. Chandrasekaran, T. Vinod Kumar, P. Vivek, and S. Ramasubramanian, "Experimental studies on flow and heat transfer characteristics of secondary refrigerant-based CNT nanofluids for cooling applications," *Int. J. Ambient Energy*, vol. 41, no. 3, pp. 285–288, Feb. 2020, doi: 10.1080/01430750.2018.1456970.

[15] R. J. Dossat, *Principles of refrigeration*, vol. 3, no. 3. JOHN WILEY & SONS, INC., 1980.

[16] A. Setyawan *et al.*, "Pengaruh Penggunaan LSHX pada Kinerja Mesin Refrigerasi pada berbagai Temperatur Evaporasi," *Tetrahedron Lett.*, vol. 81, no. 2, pp. 1–11, 2019, [Online]. Available: http://docs.lib.purdue.edu/iracc/1328.

[17] N. Balaji, P. S. Mohan, and K. R. Velraj, "Experimental Investigations on the Improvement of an Air Conditioning System with a Nanofluid-Based Intercooler," pp. 1681–1693, 2015, doi: 10.1007/s13369-015-1644-7.

[18] G. Pottker and P. Hrnjak, "ScienceDirect Effect of the condenser subcooling on the performance of

vapor compression systems mes a compression de vapeur performance de syst e," *Int. J. Refrig.*, vol. 50, no. 217, pp. 156–164, 2014, doi: 10.1016/j.ijrefrig.2014.11.003.

[19] V. Chandraprabu, G. Sankaranarayanan, S. Iniyan, and S. Suresh, "Performance of CuO/Water Nanofluid as Outer Fluid in the Tube in Tube Condensing Unit of Air Conditioner: Experimental Study," *J. Nanofluids*, vol. 2, no. 3, pp. 213–220, 2013, doi: 10.1166/jon.2013.1057.

[20] A. M. Elsaid, "A novel approach for energy and mass transfer characteristics in wet cooling towers associated with vapor-compression air conditioning system by using MgO and TiO 2 based H 2 O nano fl uids," *Energy Convers. Manag.*, no. August, p. 112289, 2019, doi: 10.1016/j.enconman.2019.112289.

[21] A. S. Manirathnam, K. Senthil Kumar, R. Prabhu, M. Sivashankar, and N. Hariharan, "Experimental study of the performance of Al2O3/water nanofluid in condensing unit of air conditioner," *Mater. Today Proc.*, vol. 33, no. xxxx, pp. 208–213, 2020, doi: 10.1016/j.matpr.2020.04.011.

[22] F. Ahmed and W. A. Khan, "Efficiency enhancement of an air-conditioner utilizing nanofluids : An experimental study," vol. 7, pp. 575–583, 2021.

[23] M. R. A. Hady, M. S. Ahmed, and G. Abdallah, "Experimental investigation on the performance of chilled - water air conditioning unit using alumina nanofluids," *Therm. Sci. Eng. Prog.*, 2017, doi: 10.1016/j.tsep.2017.07.002.

[24] J. C. V. Loaiza, F. C. Pruzaesky, and J. A. R. Parise, "A numerical study on the application of nanofluids in refrigeration systems," 2010.

[25] M. S. Ahmed and A. M. Elsaid, "Effect of hybrid and single nanofluids on the performance characteristics of chilled water air conditioning system," *Appl. Therm. Eng.*, vol. 163, no. September, 2019, doi: 10.1016/j.applthermaleng.2019.114398.

[26] W. Jiang, G. Ding, and H. Peng, "Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants," *Int. J. Therm. Sci.*, vol. 48, no. 6, pp. 1108–1115, Jun. 2009, doi: 10.1016/J.IJTHERMALSCI.2008.11.012.

[27] 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," *Curr. Appl. Phys.*, vol. 9, no. 2 SUPPL., pp. e128–e131, 2009, doi: 10.1016/j.cap.2008.12.054.

[28] O. A. Alawi, N. Azwadi, C. Sidik, and H. A. Mohammed, "A comprehensive review of fundamentals , preparation and applications of nanorefrigerants ☆," *Int. Commun. Heat Mass Transf.*, vol. 54, pp. 81–95, 2014, doi: 10.1016/j.icheatmasstransfer.2014.03.001.

[29] O. A. Alawi, N. Azwadi, C. Sidik, and M. Beriache, "Applications of nanorefrigerant and nanolubricants in refrigeration , air-conditioning and heat pump systems : A review ☆," *Int. Commun. Heat Mass Transf.*, vol. 68, pp. 91–97, 2015, doi: 10.1016/j.icheatmasstransfer.2015.08.014.

[30] S. S. Sanukrishna, M. Murukan, and P. M. Jose, "An Overview of Experimental Studies on Nanorefrigerants: Recent Research, Development and Applications," *Int. J. Refrig.*, 2018, doi: 10.1016/j.ijrefrig.2018.03.013.

[31] V. Nair, P. R. Tailor, and A. D. Parekh, "Nanorefrigerants: A comprehensive review on its past, present and future," *Int. J. Refrig.*, vol. 67, pp. 290–307, 2016, doi: 10.1016/j.ijrefrig.2016.01.011.

[32] I. M. Mahbubul, A. Saadah, R. Saidur, M. A. Khairul, and A. Kamyar, "International Journal of Heat and Mass Transfer Thermal performance analysis of Al 2 O 3 / R-134a nanorefrigerant," *HEAT MASS Transf.*, vol. 85, pp. 1034–1040, 2015, doi: 10.1016/j.ijheatmasstransfer.2015.02.038.

[33] R. Wang, Q. Wu, and Y. Wu, "Use of nanoparticles to make mineral oil lubricants feasible for use in a residential air conditioner employing hydro-fluorocarbons refrigerants," *Energy Build.*, vol. 42, no. 11, pp. 2111–2117, 2010, doi: 10.1016/j.enbuild.2010.06.023.

[34] V. Shanmugasundaram and R. Elansezhian, "Performance Evaluation of Air Conditioning System Using Nanofluids Performance Evaluation of Air Conditioning System Using Nanofluids," no. February 2015, 2016.

[35] C. V Papade and R. S. Wale, "Performance Improvement of Air Conditioning System by Using Nanorefrigerant," no. 10, 2015.

[36] Sumeru, T. P. Pramudantoro, F. N. Ani, and H. Nasution, "Enhancing Air Conditioning Performance Using TiO_2 Nanoparticles in Compressor Lubricant," *Adv. Mater. Res.*, vol. 1125, pp. 556–560, 2015, doi: 10.4028/www.scientific.net/amr.1125.556.

[37] G. V. V. S. Vara and K. Dilip, "ScienceDirect Employing Magnetic Field to Liquid Channel of Nano Lubricant (CuO & PAG Oil) Rigged VCR System by Using R134a Refrigerant," *Mater. Today Proc.*, vol. 5, no. 9, pp. 20518–20527, 2018, doi: 10.1016/j.matpr.2018.06.429.

[38] A. S. Shareef, D. H. N. Azziz, and H. S. Hadi, "Experimental Study: The Effects of Using Nano-Lubrication on the Performance of Refrigeration Systems," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 433, no. 1, 2018, doi: 10.1088/1757-899X/433/1/012052.

[39] S. S. Chauhan, "Performance evaluation of ice plant operating on R134a blended with varied

concentration of Al2O3–SiO2/PAG composite nanolubricant by experimental approach," *Int. J. Refrig.*, vol. 113, pp. 196–205, 2020, doi: 10.1016/j.ijrefrig.2020.01.021.

[40] Yogesh Joshi, Dinesh Zanwar, and Sandeep Joshi, "Performance investigation of vapor compression refrigeration system using R134a and R600a refrigerants and Al2O3 nanoparticle based suspension," *Mater. Today Proc.*, vol. 44, pp. 1511–1519, Jan. 2021, doi: 10.1016/J.MATPR.2020.11.732.