J Ther Eng, Vol. 9, No. 5, pp. 1307−1323, September, 2023

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.18186/thermal.1377210

Research Article

Simulation of vapour compression air conditioning system using Al_2O_3 based nanofluid refrigerant

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ARTICLE INFO

Article history
Received: 06 April 2022
Revised: 10 August 2022
Accepted: 11 August 2022

Keywords:
Nanorefrigerants; Air Conditioning System; Energy Saving; Net Refrigeration Effect (NRE); Vapour Compression Cycle

ABSTRACT

The energy crisis, Greenhouse Gas (GHG) emissions, and Chlorofluorocarbon (CFC) emissions are major environmental issues at present. It is critical to achieve and reduce emissions and energy consumption through the use of environmentally friendly refrigerants. Utilizing an environmentally friendly refrigerant such as HFC-32 may offer a viable solution to the ozone depletion potential (ODP) and global warming issues. This study examines the effects of aluminium oxide (Al_2O_3) nanoparticles at volume concentrations of 0.06, 0.08, 0.1, 0.12, and 0.14% in pure refrigerants such as HFC-32 and R-410a used in air-conditioning systems based on the vapour compression refrigeration cycle. The thermophysical properties of pure and nanorefrigerants have been determined using REFPROP (NIST properties of fluid Reference) and a theoretical formulation model using MATLAB software. The important outcomes of HFC-32 nanorefrigerant show the maximum performance with 0.14% alumina nano additives which results in a 46.14% increase in the coefficient of performance (COP) and massive power savings upto 31.59%. Thermal conductivity exhibited an increase with an increment in nanoparticle concentration. Maximum thermal conductivity of 0.172 W/m-K is recorded in the case of HFC-32/Al_2O_3 nanorefrigerant with 0.14% volume concentration. The net refrigeration effect of pure refrigerants (R410a and HFC-32) is 77% and 79% and on addition of nanorefrigerants to the pure the net refrigeration effect increases to 81.2% and 83.5% for R410a and HFC-32 respectively.

Cite this article as: Dilawar M, Qayoum A. Simulation of vapour compression air conditioning system using Al_2O_3 based nanofluid refrigerant. J Ther Eng 2023;9(5):1307−1323.

INTRODUCTION

The most critical issue is to improve the performance of the vapour compression cycle in a refrigeration and air conditioning framework leading to minimizing the cooling-related greenhouse gas (GHG) emissions. This can be accomplished by selecting low Global Warming Potential (GWP) refrigerants [1–4]. Despite its high global warming potential (GWP_{100}) of 2090, the refrigerant R410a having non-depleting potential is the replacement for R22 in medium and high-temperature applications [5,6]. Due to its similarities in thermophysical properties with R410a, R32 has been used as a low-GWP and low-LCCP

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This paper was recommended for publication in revised form by Regional Editor Omid Mahian

Published by Yıldız Technical University Press, İstanbul, Turkey

alternative to R410a [7–9]. The R32 refrigerant has low lubricant-refrigerant miscibility, a high discharge temperature and pressure, chemical stability, and low flammability [10]. Nevertheless, R32 has certain advantages like high latent heat of vaporization, less refrigerant charge and high thermal conductivity compared to R410a [9]. The use of nanoparticles in R32 helps in lowering compressor discharge temperature thereby keeping the compressor cool which leads to a higher COP, energy-saving and reduction in GHG emissions [11–14].

According to a recent United Nations report, the use of air conditioners worldwide is the main cause of Global Warming even though able to maintain cool interiors. In a recent report by the International Energy Agency, improving air conditioning efficiency is critical for the conservation of energy. More than 3.6 billion cooling appliances in the form of refrigerators, freezers, and air-conditioners are used for HVAC-related applications for thermal comfort, food storage, dry preservative and various other essential services. With the use of new technologies and innovations. It is estimated that by 2050 14 billion AC units will be in operation worldwide [15].

Nano additives with enhanced thermophysical properties improve the solubility of compressor lubricant in pure ozone-friendly refrigerants with low GWP (Typically nano-additives in compressor oil are called nanorefrigerant or nanolubricant). The enhancement in properties depend upon the loading fraction, operation temperature and size of nanoparticles [16]. In addition, there is a marked decrease in the compressor discharge temperature accompanied by an increase in COP and corresponding power saving. Refrigerant with nano additives (nanolubricant) prevents direct contact between the piston and cylinder in motion and improves rolling, mending and polishing effects which increases the life span of moving parts and reduces the friction coefficient of the compressor shown in Figure 1 [17–21].

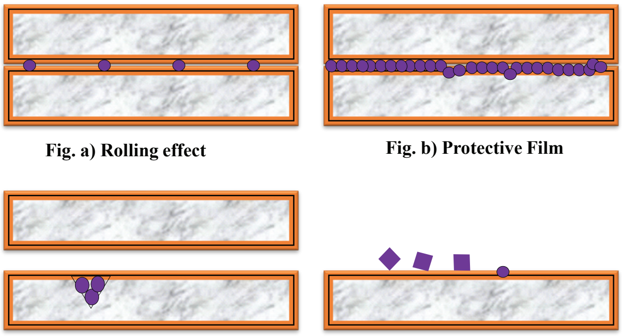


Figure 1. Lubrication mechanisms by the use of nanofluid in machining.

According to EU directives 2037/2000 and 842/2006, the use of HCFC-based refrigerants with a high greenhouse effect should be phased out permanently and replaced with low-GWP HFC-based refrigerants [22]. The best replacement of R410a with R32 refrigerant for air conditioning units has a zero ODP and a low GWP, as illustrated in Figure 2 and it requires less refrigerant charge [23].

The use of nanofluids in refrigeration, air conditioning, and heat pump (RACHP) systems may increase efficiency. "Efficiency rating" a term commonly used for performance refers to the ratio of the heat removed from a space to the amount of energy required to condition it. The higher the energy-efficiency rating, the more efficient the machine. Climate-weighted efficiency rating indicators vary by country, as illustrated in Figure 3 [24].

According to the literature, nanorefrigerants are prepared using two distinct techniques. The first method involves dispersing the nanoparticles into the refrigerant. The second method involves dispersing the nanoparticles into the compressor oil. However, researchers assert that the final products from both these approaches result in

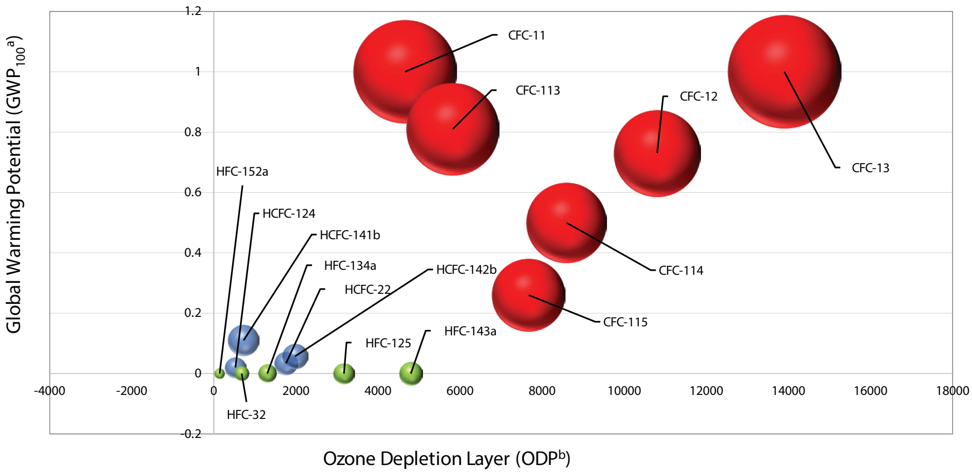


Figure 2. ODP versus GWP and lifetime of HFCs, HCFCs, CFCs (Circles).

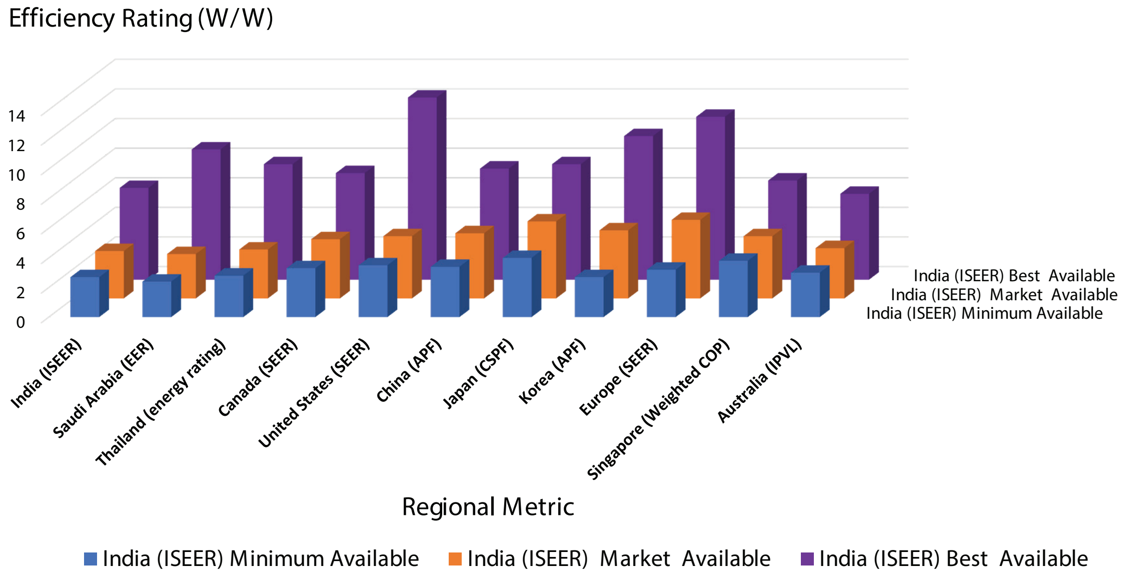


Figure 3. Efficiency ratings of available AC units by regional metric.

nanorefrigerants. Although few researchers distinguish the products from the first procedure as nanorefrigerants and the second technique as nanolubricants. The use of nanorefrigerants or nanolubricants will improve heat transfer and tribological performance leading to an increase in compressor efficiency. According to the manufacturer of HVAC products, approximately 50% of compressor oil is contained within the compressor, while the rest is in the evaporator, condenser, hoses, and drier [25,26].

Senthilkumar *et al.* [27] carried experimental investigation of CuO-SiO_2 hybrid nanolubricant in R600a refrigeration system. There was an improvement in COP by 35% and cooling capacity by 18%. This resulted in reduced power consumption of 75 W using 0.4 g/L nanolubricant with 60 g of R600a.

HudaElsam *et al.* [28] has investigated Cerium Oxide nanoparticle as a single material and as a blend with copper oxide to verify the feasibility of this oxide to increase nanolubricant stability and enhanced thermal characteristics. Pritam and Bijan [29] carried study on the performance enhancement of a shell and tube evaporator using Al_2O_3/R600a nanorefrigerant. A multi-object optimization has been carried out for cooling the right combination for maximizing heat transfer and minimizing power requirements. 5 times above that of a base refrigerant at a concentration of 5 wt.% nanoparticles.

Suraj *et al.* [30] observed the effect of Aluminum oxide of 20-30 nm nanoparticles used in hydrocarbon refrigerant at various mass concentrations of nanoparticles are 0.20 gm, 0.30 gm and 0.40 gm respectively. The addition of nanoparticles to the refrigerant improved the thermophysical properties and heat transfer characteristics of the refrigeration system. It is observed that there are more temperature reductions have been reported for the nanorefrigerant (14.4 – 20%) compared with pure refrigerant R600a. Similarly, evaporator temperature a gain of 2.33- 5.55% and also improved in COP by 3.68 - 11.05% respectively.

Desai and Patil [31] observed that nano-additives possess significant properties that enhanced the thermophysical properties of refrigerant compressor oil. The optimal COP increases by approximately 14% and power saving by approximately 12.30% using R-134a and POE/SiO_2 at a concentration of 2% (by mass). Krishnan *et al.* [32] investigated enrichment in the coefficient of performance of the refrigerator by adding various nanoparticles such as Al_2O_3, SiO_2, ZrO_2, and CNT in pure Polyolester oil. Attributed the use of nano lubricants for COP improvement at various concentrations (0.1, 0.2, and 0.3% w/v). The coefficients of performance of POE/Al_2O_3 at 0.3% (w/v), POE/SiO_2 at 0.1% (w/v), POE/ZrO_2 at 0.1% (w/v), and POE/CNT at 0.1% (w/v) were 1.59, 1.73, 1.505, and 1.49 as compared to the base lubricant at (1.42).

Deokar and Cremaschi [33] used R-410 as the refrigerant and found that dispersing Al_2O_3 and ZnO nanoparticles in POE oil leads to a 15% increase in heat transfer coefficient (HTC) over ZnO nano oil, as well as improved vapour quality and greater refrigeration effect. The deposition of nanoparticles on the inner wall of smooth copper tubes increases nucleates boiling thereby increasing heat dissipation and frictional pressure drop. Marcucci *et al.* [34] investigated the use of R-410a as a refrigerant by dispersing diamond nanoparticles in pure POE (32-3MAF) oil at two different concentrations (0.1 and 0.5% mass). The study concentrated on key performance indicators, such as energy savings, increased cooling capacity, and lower oil sump and discharge temperature. Another study reported improved tribological performance in terms of wear and friction with R32 refrigerant instead of R-410a [35].

Jwo *et al.* [36] has investigated the possibility of replacing the POE lubricant and R-134 refrigerant with mineral oil (MO) and hydrocarbon refrigerant. Aluminium oxide nanoparticles dispersed in MO at various concentrations (0.05, 0.1, and 0.2 wt%) have been used to improve the lubrication and heat dissipation rates. The obtained results indicate that R-134a at 0.1 wt% nanoparticles, was the optimal choice for lower power consumption and increased coefficient of performance.

Adelekan *et al.* [37] studied the effects of different mass of charge (40, 60, and 80g) of R-600a refrigerant and graphene nanoparticles dispersed in mineral oil (MO) at concentrations of 0.2, 0.4, and 0.6 g/L. The highest power per tonne of refrigeration (PPTR) value of 5.22 was obtained. The maximum coefficient of performance (COP) of 0.76 at 0 g/L concentration with 70 g of refrigerant charge. Sanukrishna and Prakash [38] investigated the refrigeration system using TiO_2 nanoparticles. The optimal concentration was 0.4% volume fraction, and the results obtained in an increase in thermal conductivity, viscosity, or rheological properties.

Sendil and Elansezhian [39] studied the R152 refrigeration system using PAG/ZnO nanolubricants. The optimum volume concentration of 0.5% gave an improved COP value of 3.56 resulting in power savings and a reduction in both suction and discharge temperature to 10.5%. Abdur and Ahamed [40] has investigated the drop replacement of R22-POE with a mixture of R22 and R600a (80:20) by mass of refrigerant, with TiO_2-MO as a lubricant (0.1% -0.4%). The experimental results indicated that both exergetic and energetic performance was improved; the compressor discharge temperature was reduced by 15°C for the mixture containing 0.4% MO/TiO_2 nano-oil, and the compressor coefficient of performance was increased by 10-19.5%.

Kumar *et al.* [41] studied the effect of copper oxide (CuO) nanolubricant on the performance and characteristics of LPG nanorefrigerant and observed improvement in the viscosity which leads to a significant decrement in friction coefficient. The coefficient of the performance was enhanced by 46% and power saving by 7%.

It is clear that scanty literature is available on the enhancement of the refrigeration effect accompanied by reduced power consumption using eco-friendly and low GWP HFC refrigerants. Adding alumina nanoparticles at various volume concentrations in such cases may lead to further enhancement in the performance of HFC-32 (Low GWP-675) systems. The novelty of the work stems from the fact that this is one of its kind Matlab simulation-based analysis of nanorefrigerants. Furthermore, a detailed comparison has been made between the refrigerants to arrive at the best alternative based on sustainable development goals, which is in itself a peculiarity of this work.

MATERIAL AND METHODS

Theoretical Formulation and Simulation Model of R32/Al_2O_3 And R410a/Al_2O_3 for Vapour Compression Air Conditioning System

The vapour compression air conditioning framework comprises four major components namely, compressor, condenser, expansion valve, (or capillary tube) and the evaporator as shown in Figure 4. The figure illustrates a simple cycle with no superheating or undercooling.

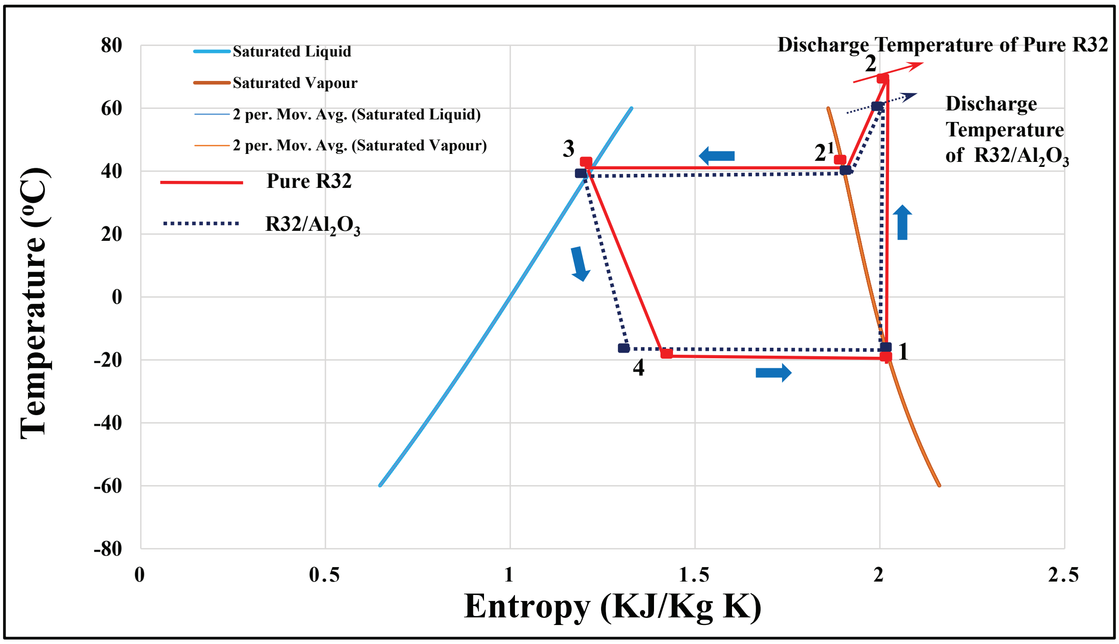


Figure 4. T-s diagram for pure and Al_2O_3 nanorefrigerant cycle (R32).

- Process (1-2) Isentropic Compression in compressor
- Process (2^1-3) Constant pressure heat dissipation in a condenser
- Process (3-4) Isenthalpic throttling process in an expansion device.
- Process (4-1) Constant pressure heat extraction in an evaporator

The enthalpy and other properties of the nanorefrigerants are evaluated using a density of the refrigerant [42]. Mollier chart is used to evaluate the properties of pure and nanorefrigerants. The density of nanorefrigerant (ρ_{NR}) at points 1 and 3 is calculated from Equation 1 given by Pak and Cho [43]. This research study uses Al_2O_3 (Alumina) nanoparticle having density and thermal conductivity of 3.9 g/cm^3 and 40 W/m-k [44]. The use of R32 and R410a refrigerants with various volume concentrations of Alumina nanoparticles (0.06, 0.08, 0.1, 0.12, and 0.14%). A sample of calculations for NRE, COP, power-saving and reduction in discharge temperature of R32/R410a/Al_2O_3 are presented in Table 1 and Table 2 using Alumina at the volume concentration of 0.14%.

$$\rho_{NR} = m_p\, \rho_{NP} + \left(1 - m_p\right) \rho_{PR} \qquad (1)$$

$$\phi = \frac{m_p / \rho_p}{m_p/\rho_p + m_R/\rho_R} \text{x } 100 \qquad (2)$$

where,
ρ_{NR} = Density of nanorefrigerant in g/m^3,
ρ_{NP} = Density of nanoparticle in g/m^3,
ρ_{PR} = Density of pure refrigerant in g/m^3,
ϕ = volume concentration (%),
m_p = mass of nanoparticle in grams,
ρ_p = Density of particle in g/m^3,
m_R = mass of refrigerant in grams,
ρ_R = Density of refrigerant in g/m^3.

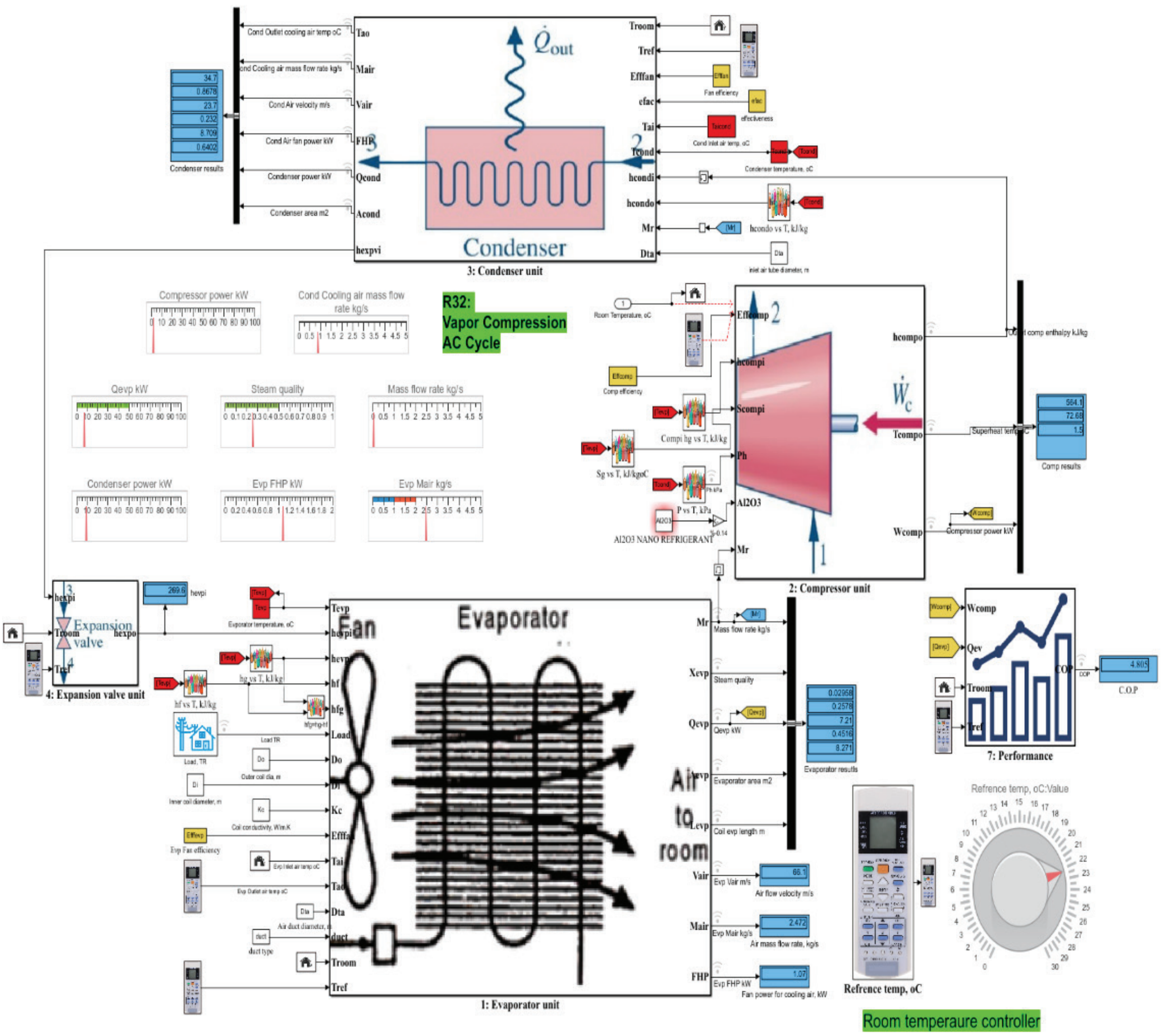


Figure 5 (a). Air Conditioning Framework used R32/Al_2O_3 Nanorefrigerant in Simulink.

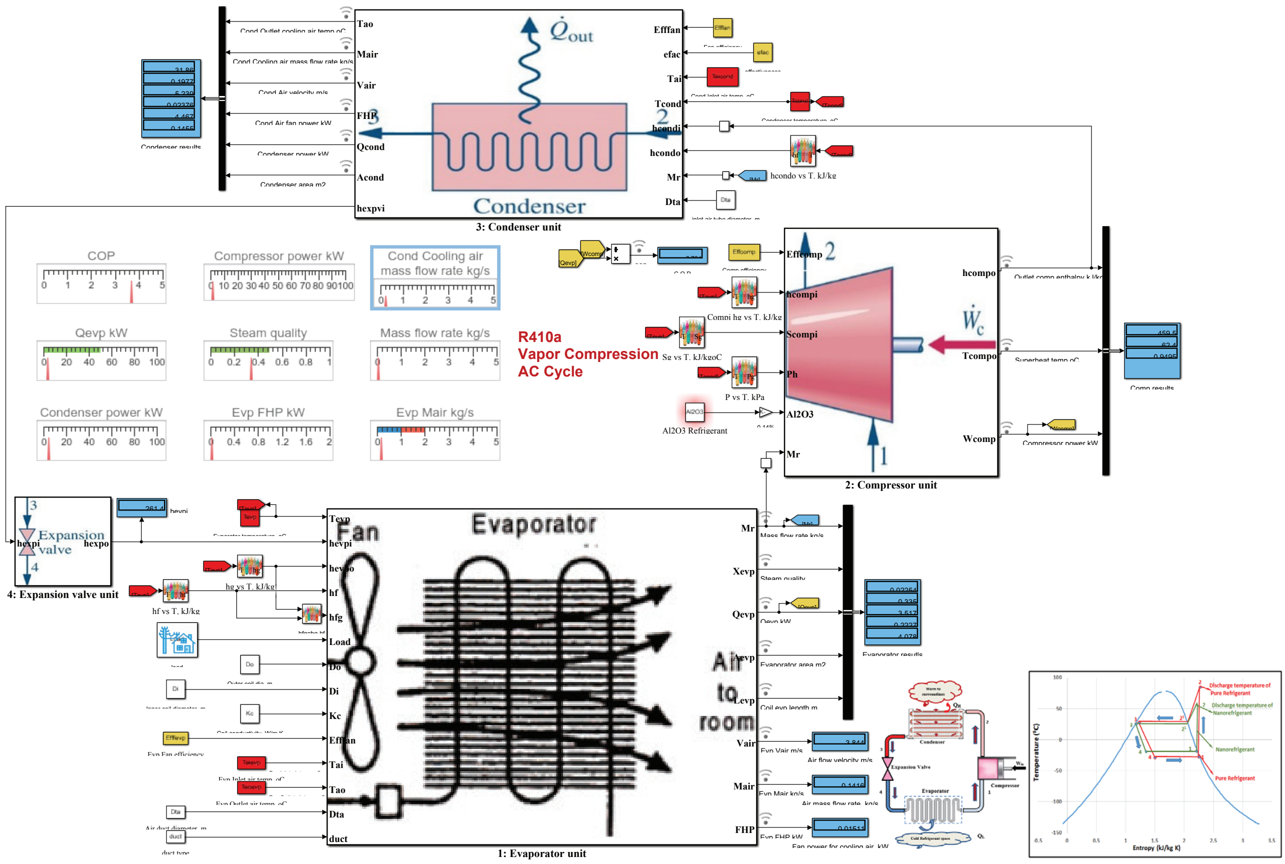


Figure 5 (b). Air Conditioning Framework used R410a/Al_2O_3 Nanorefrigerant in Simulink.

A MATLAB/Simulink model has been developed to assess the performance of the air conditioning framework in terms of properties of refrigerants/nanorefrigerants through the density of nanorefrigerant by using Equation 1, to evaluate NRE, COP, and power consumption as depicted in Figures 5(a) and 5(b). The schematics of the algorithm used in Simulink of Matlab for R32/Al_2O_3 and R410a/Al_2O_3 are illustrated in Figures 5(a), 5(b), and 6 in terms of block diagrams and flowchart.

Theoretical Formulation Used as Coding in MATLAB

The results of R32/Al_2O_3 nanorefrigerant have been analysed and compared with the performance of R410a/Al_2O_3 in the system using Equations (3)-(9).

Cooling capacity (Q_{evap}) is given by

$$Q_{evap} = \dot{m}(h_4 - h_1) \quad \text{(kW)} \tag{3}$$

The compressor power (kW) input is given by

$$W_C = \dot{m}(h_2 - h_1) \quad \text{(kW)} \tag{4}$$

Heat rejected in condenser (kW) is given by

$$Q_C = \dot{m}\,(h_2 - h_3) \quad \text{(kW)} \tag{5}$$

Refrigerant mass flow rate is given by

$$\dot{m}_{ref} = \frac{Q_{evap}}{h_1 - h_4} \quad \left(\frac{\text{kg}}{\text{s}}\right) \tag{6}$$

Coefficient of performance

$$COP = \frac{Q_{evap}}{W_{Comp}} \tag{7}$$

Effective thermal conductivity (k_{eff}),

$$\frac{K_{eff}}{K_f} = \frac{K_p + 2K_f + 2\phi(K_p - K_f)}{K_p + 2k_f - \phi(K_p - K_f)} \tag{8}$$

Viscosity of nanofluid is given by

$$\mu_{nf} = \mu_{bf}(1 + 2.5\phi) \tag{9}$$

where h_1 is the enthalpy of saturated vapour (kJ/kg), h_2 is the enthalpy of superheated vapour (kJ/kg), h_3 is the

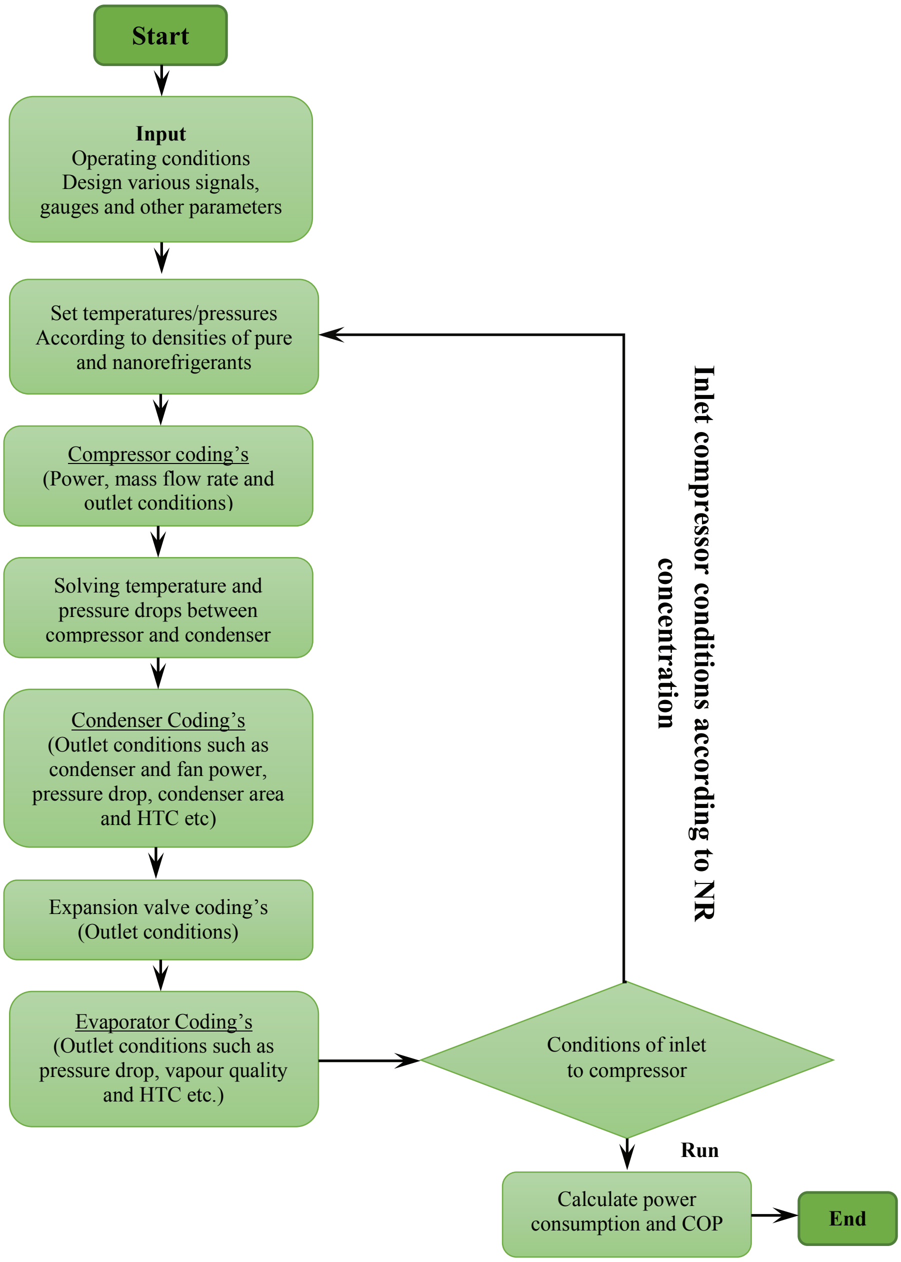


Figure 6. Simulation flowchart.

enthalpy of saturated liquid (kJ/kg), m is the mass flow rate (kg/s).

where ϕ, is the volume concentration of nanoparticles. k_{eff} is the effective thermal conductivity of the nanorefrigerant. k_f and k_p are the thermal conductivities of pure refrigerant and nanoparticles respectively. μ_{bf}, is the viscosity of base fluid and μ_{nf} is the viscosity of nanofluid.

Assumptions

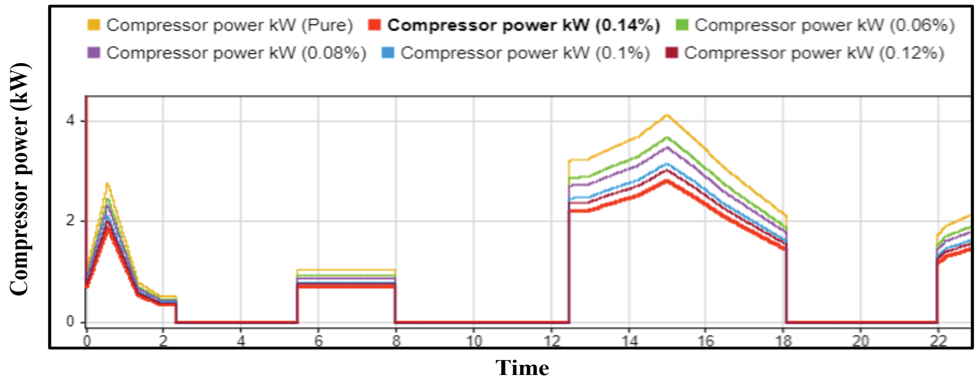
The important assumptions for leading this kind of theoretical model-based study are.

- Pressure losses at the compressor inlet and outlet ports are neglected.
- Pipelines pressure losses are neglected.
- Heat losses and heat gains from or to the system are ignored.
- Isentropic, mechanical and electric motor compressor efficiencies are considered.
- Degree of undercooling and superheating before compression are neglected.
- No deposition of nanoparticles at the solid wall.

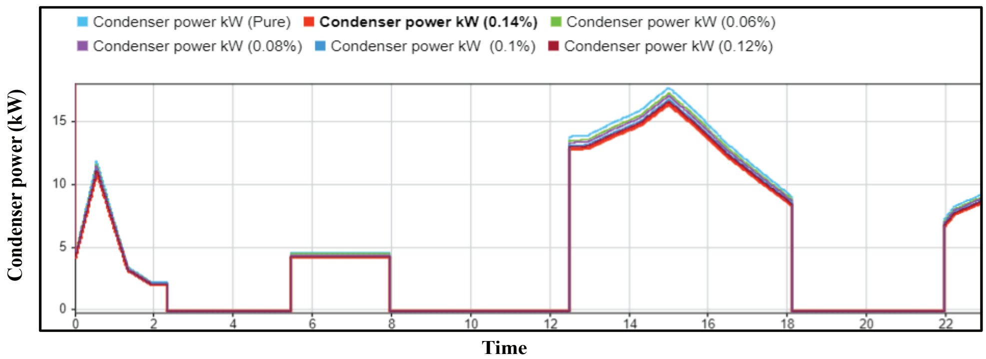
RESULTS AND DISCUSSION

The results are presented using MATLAB graphs. Figures 7(a-f) shows the time response of compressor power, condenser power, mass flow rate, steam quality and condenser cooling air mass flow rate variations up and down according to the load at a various volume concentration of (0, 0.06, 0.08, 0.1, 0.12 and 0.14%) Al_2O_3 in R410a and R32 refrigerants at reference temperature respectively. The maximum reduction in compressor and condenser power at 0.14%vol concentration and improved vapour quality of nanorefrigerant. Figure 7 (c) indicates that fluctuation in mass flow rate according to the controlling cooling load and temperatures.

The simulation data in Figure 8 (a) shows that a maximum reduction in compressor discharge temperature of 6.7% takes place in R410a/Al_2O_3 compared to a reduction of 18% in R32/ Al_2O_3 on increasing the nanoparticle content of Al_2O_3 in the respective refrigerants. The addition of alumina nanoparticles to the refrigeration system boosted cooling capacity and COP, while the discharge and oil sump temperatures of the compressor have been reduced. The reduction in the discharge temperature and pressure leads to an increase in COP and power-saving [34].



(a)



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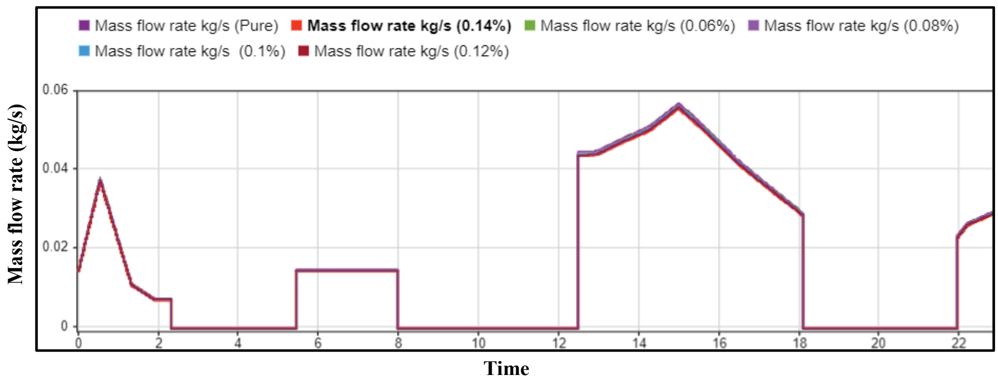
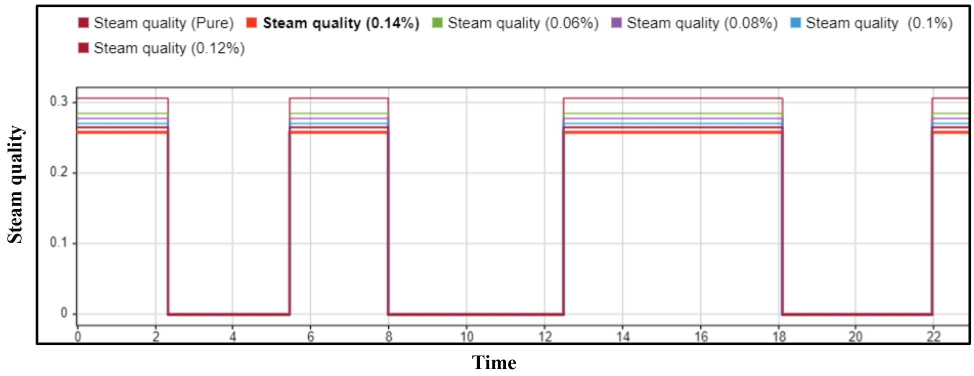


(c)



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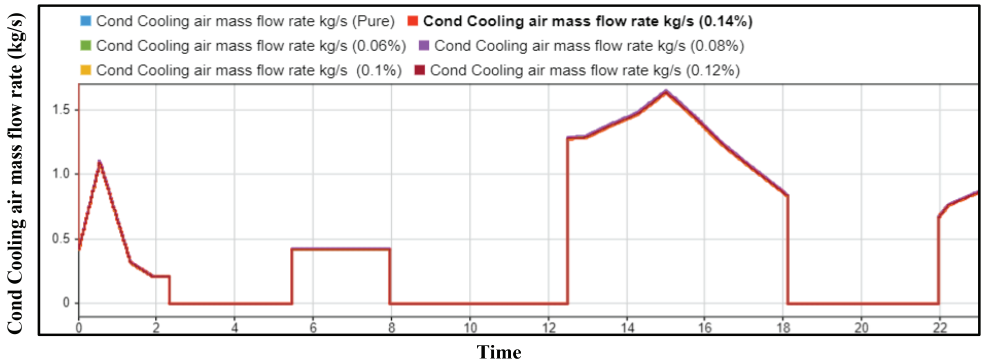

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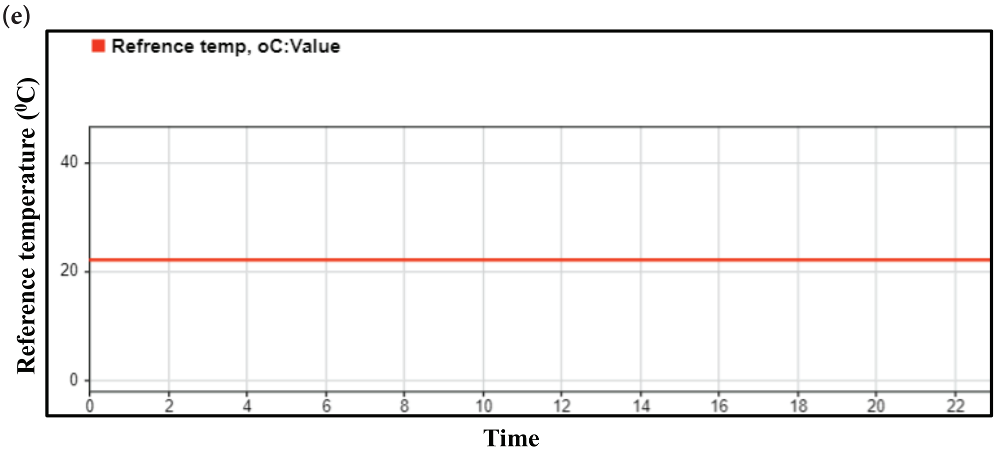


(f)

Figure 7. Performance of AC system with HFC-32/Al_2O_3 nanorefrigerant according to cooling load with time response.

Table 1. Sample Ideal calculations for pure and R410a/Al_2O_3 nanorefrigerant, at condenser and evaporator temperature, are T_3= 38°C and T_1= -20°C.

S.No		R-410a (Pure)	R410a/ Al_2O_3 0.06% vol	R410a/ Al_2O_3 0.08% vol	R410a/ Al_2O_3 0.1% vol	R410a/ Al_2O_3 0.12% vol	R410a/ Al_2O_3 0.14% vol
1	ρ_1 (kg/m^3)	15.42	17.75	18.52	19.30	20.08	20.85
2	ρ_3 (kg/m^3)	987.52	989.27	989.85	990.43	991.02	991.59
3	T_c (°C)	38	37.71	37.61	37.51	37.41	37.32
4	T_{sup} (°C)	66.89	64.84	64.22	63.34	62.92	62.4
5	P_2=P_3 (bar)	23.10	22.94	22.88	22.83	22.77	22.72
6	Power (kW)	1.181	1.071	1.039	1	0.9759	0.9495
7	COP	2.978	3.282	3.383	3.517	3.604	3.704
8	NRE (%)	77.73	79.31	79.80	80.27	80.73	81.17
9	$COP_{Increase\ (\%)}$	-	10.21	13.60	18.10	21.02	24.38
10	Power Saving (%)	-	9.31	12.02	15.33	17.37	19.60

Table 2. Sample calculations for pure and R32/Al_2O_3 nanorefrigerant, at condenser and evaporator temperature, are T_3= 38°C and T_1= -20°C.

S.No		R-32 (Pure)	R-32/ Al_2O_3 0.06% vol	R-32/ Al_2O_3 0.08% vol	R-32/ Al_2O_3 0.1% vol	R-32/ Al_2O_3 0.12% vol	R-32/ Al_2O_3 0.14% vol
1	ρ_1 (kg/m³)	11.15	13.48	14.26	15.04	15.82	16.59
2	ρ_3 (kg/m³)	902.833	904.63	905.23	905.83	906.43	907.03
3	T_c (°C)	38	37.65	37.45	37.38	37.25	37.12
4	T_{sup} (°C)	88.6	83.85	80.9	78.17	75.51	72.68
5	P_2=P_3 (bar)	23.60	23.38	23.30	23.24	23.16	23.08
6	Power (kW)	1.07	0.9559	0.8968	0.8413	0.7879	0.732
7	COP	3.288	3.679	3.922	4.180	4.464	4.805
8	NRE (%)	79.31	81.26	81.89	82.43	82.98	83.5
9	$COP_{Increase\ (\%)}$	-	11.89	19.28	27.13	35.77	46.14
10	Power Saving (%)	-	10.67	16.19	21.37	26.36	31.59

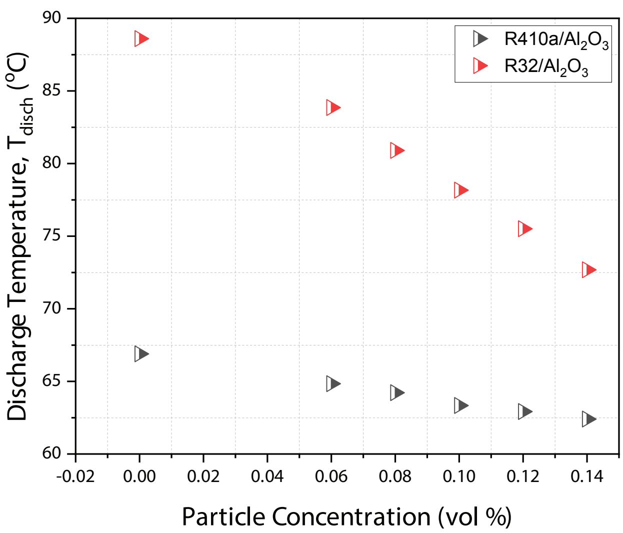


Figure 8 (a). Discharge temperature versus particle concentration.

In addition, figures 8(b) and 8(c) shows the corresponding variation of COP with discharge temperature at different concentrations of nanoparticles for R32/Al_2O_3 and R410a/Al_2O_3 respectively. A maximum improvement in COP of 24.4% and 46.2% are obtained for R410a/Al_2O_3 and R32/Al_2O_3 nanorefrigerants. All the data for the two refrigerants have been tabulated in Table 1 and Table 2 respectively. Figure 9 shows the graphical representation of variation in COP with particle concentration for the two refrigerants in terms of bar charts. The charts clearly show that incorporating Al_2O_3 in R32 improves the COP and compared to R410a.

Effect of Nanoparticle Concentration on Net Refrigeration Effect (NRE)

Figures 10(a) and 10(b) shows the net refrigeration effect versus evaporation temperature at various particle concentrations for R410a and R32 respectively. There is a marked increase in the net refrigeration effect with a

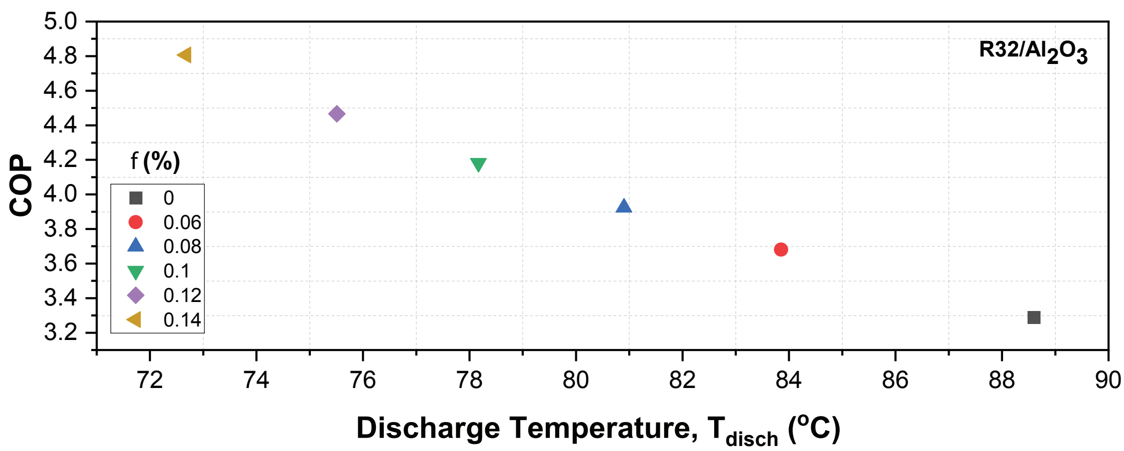


Figure 8 (b). COP of R32/Al_2O_3 as the function of discharge temperature.

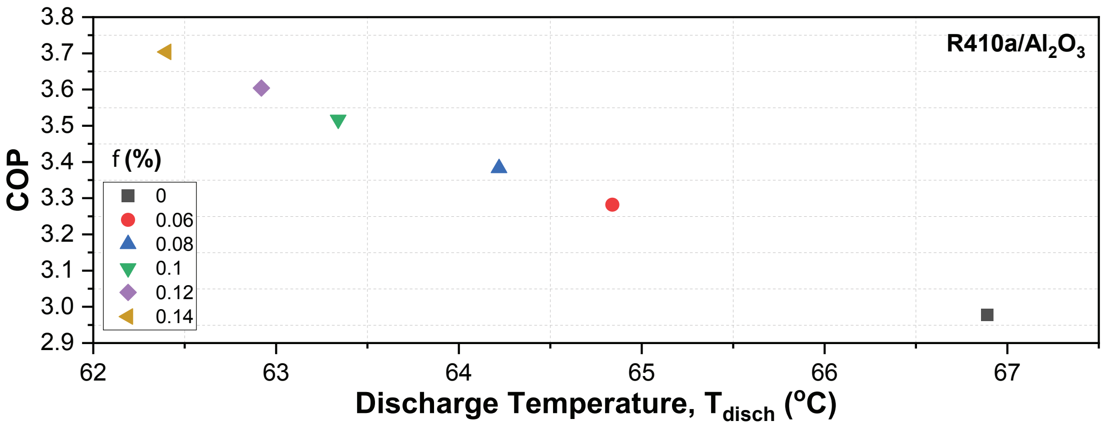


Figure 8 (c). COP of R410a/Al_2O_3 as the function of discharge temperature.

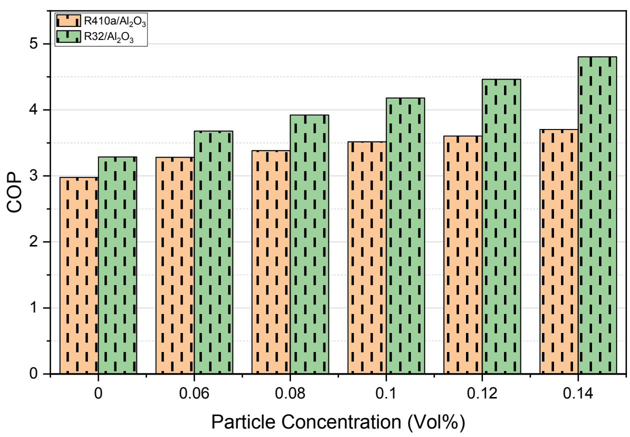


Figure 9. COP of the system as the function of various particle concentrations.

volume concentration of 0.14% to R410a/Al_2O_3 and R32/Al_2O_3, the net refrigeration effect increased to 81.2% and 83.5% respectively.

Effect of Nanoparticle Concentration on Power Saving

Figure 11 (a) shows the effect of power consumption with particle concentration for R410a and R32 with cooling load ranging from 1 to 5 tons of refrigeration in terms of bar charts. A closer look at the plot shows that R410a/Al_2O_3 and R32/Al_2O_3 involves the maximum power reduction at 0.14% volume concentration at all cooling loads. The minimum power required to drive the compressor per ton of refrigeration is obtained by using R32/Al_2O_3 at all cooling loads shown in Figure 11 (b).

Figures 12 (a-d) indicates the effect of compressor work with discharge temperature at different alumina nanoparticle concentrations for R32 and R410a respectively. These plots show the lowest compressor work done for R32/Al_2O_3

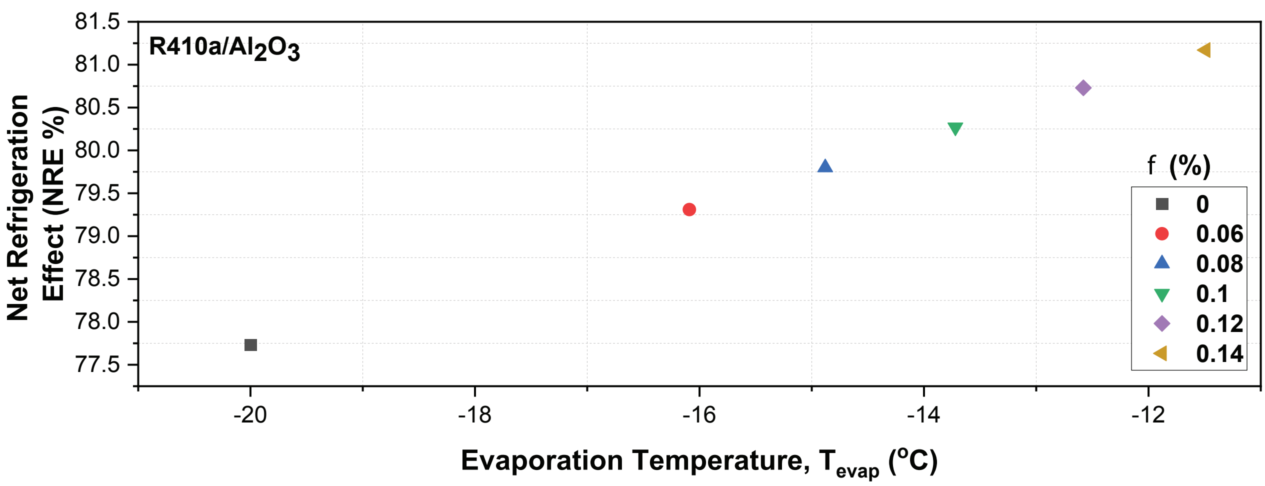


Figure 10 (a). Net refrigeration effect of R410a/Al_2O_3 as the function of evaporator temperature

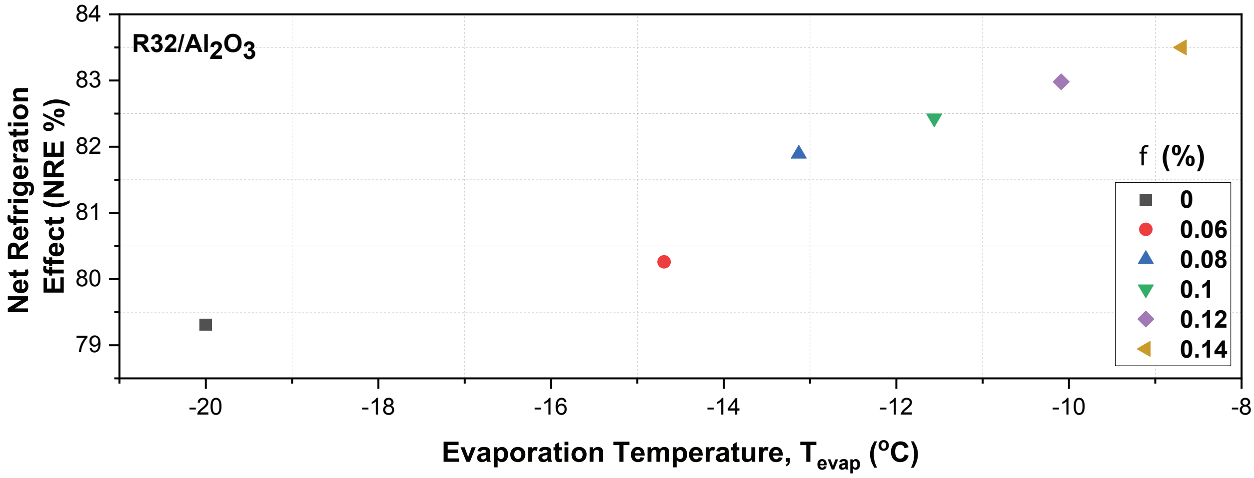
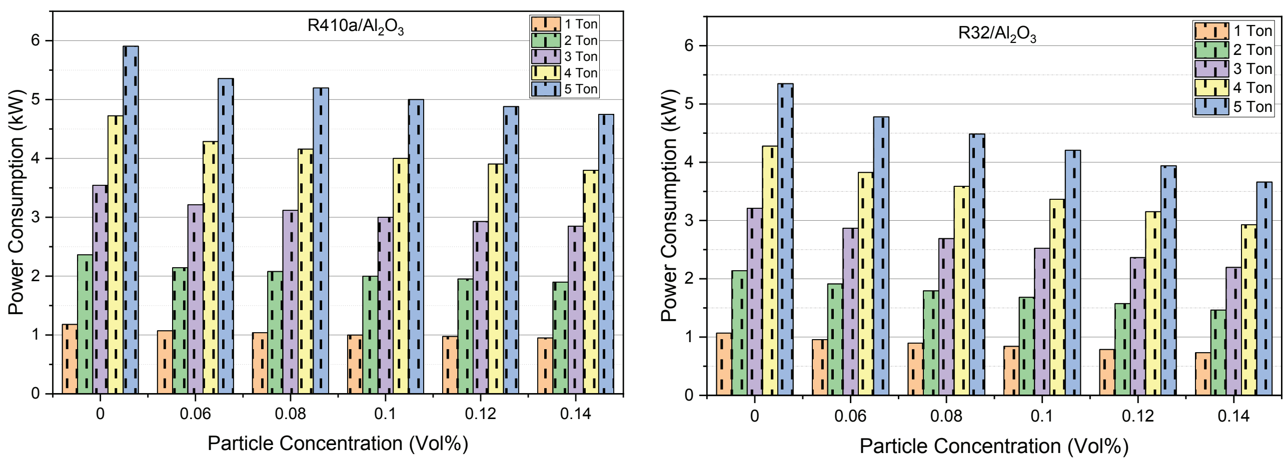


Figure 10 (b). Net refrigeration effect of R32/Al_2O_3 as the function of evaporator temperature



(a) (b)

Figure 11. (a) and (b). Power Consumption vs Particle Concentration from 1 to 5 tons of refrigeration.

and R410a/Al_2O_3 is obtained at a volume concentration of 0.14% and compared with base refrigerants. As the concentration of alumina nanoparticles in both the refrigerants increases, the reduction in discharge temperature and pressure leads to reduced compressor work and improved the coefficient of performance of the system.

Numerical Method for Characterization of Nanorefrigerant

Effect of nanoparticle concentration on thermal conductivity

Figure 13 shows the thermal conductivity variation with variation in nanoparticle volume concentration from 0.06% to 0.14%. The effective thermal conductivity of spherical nanoparticles is calculated by using Equation 8 [45]. The maximum thermal conductivity of Al_2O_3/R32 and Al_2O_3/R410a is observed by 48.1% and 47.7% at a volume concentration of 0.14%. Increased Brownian motion, as well as the improved thermal conductivity of Alumina nanoparticles, contributed to the improvement in suspension stability [46].

Effect of nanoparticle concentration on viscosity

Variations of viscosity of Al_2O_3/R32 and Al_2O_3/R410a at various particle concentrations are shown in Figure 14. As particle volume concentration increases, the viscosity of nanorefrigerant also increases. The pioneering model for estimating the viscosity of nanofluids was proposed by Einstein in Eq. 9 [47].

Effect of nanoparticle concentration on density

The density of R410a/Al_2O_3 and R32/Al_2O_3 nanorefrigerant is determined by using above mentioned Equation 1.

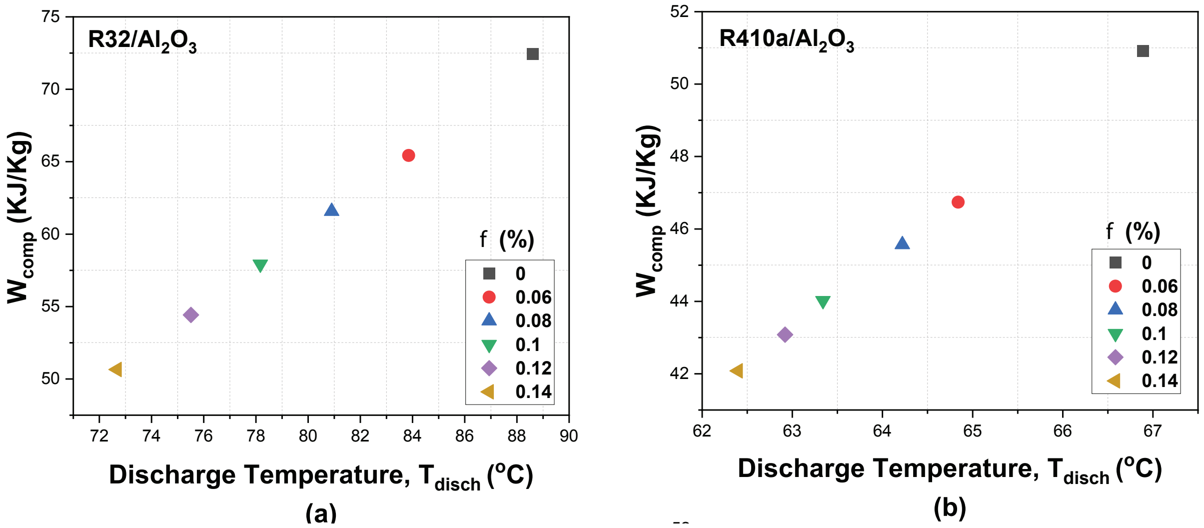


Figure 12 (a) and (b). Compressor work done versus discharge temperature.

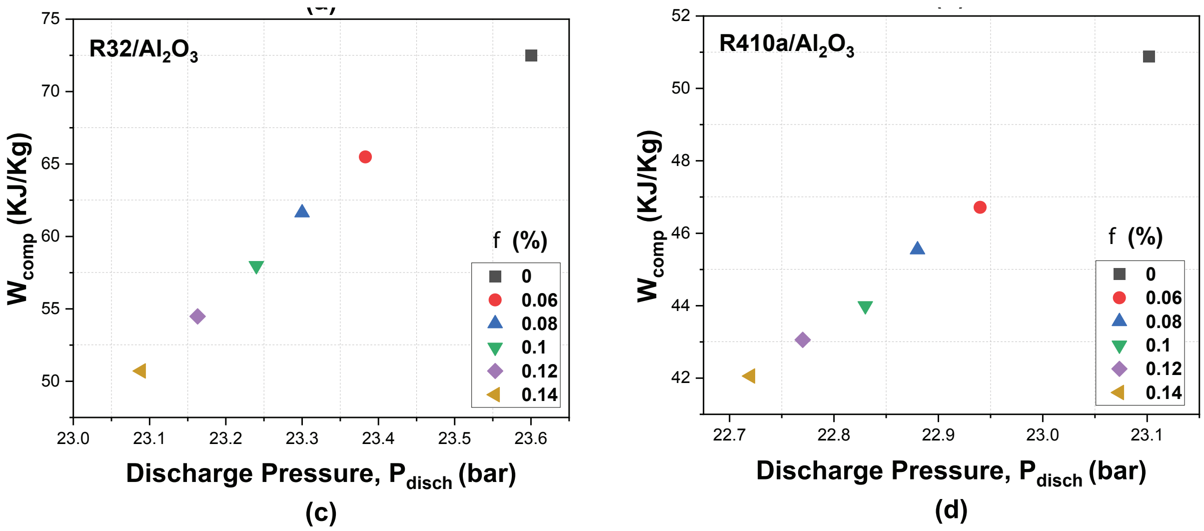


Figure 12 (c) and (d). Compressor work done versus discharge pressure

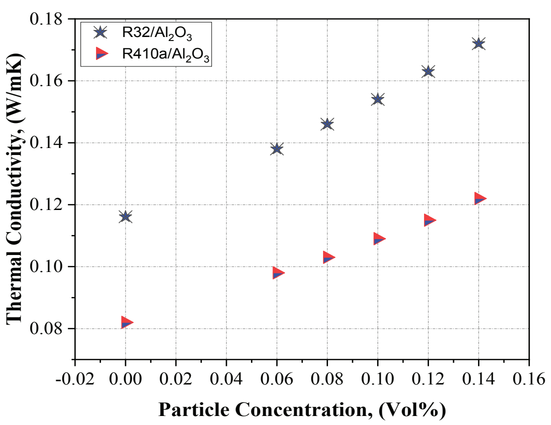


Figure 13. Increment of thermal conductivity of nanorefrigerants ($R32/Al_2O_3$ and $R410a/Al_2O_3$) with the increase in particle concentration.

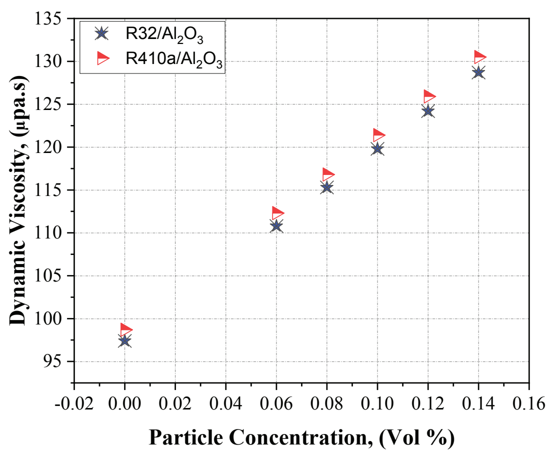


Figure 14. Variation of viscosity of ($R32/Al_2O_3$ and $R410a/Al_2O_3$) with the increase in particle concentration.

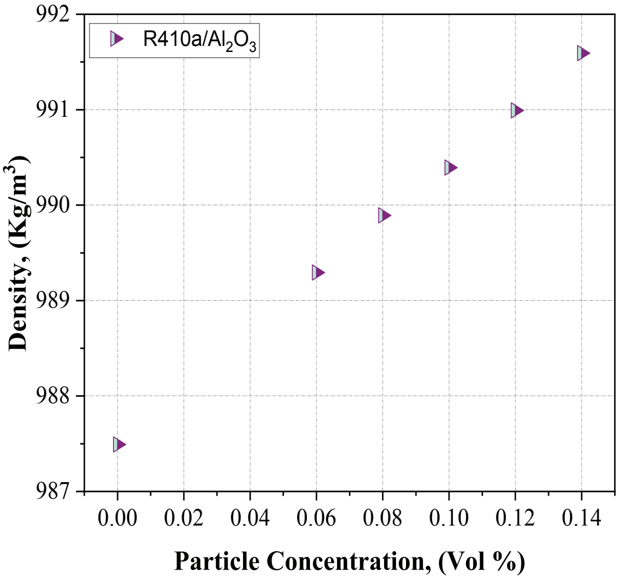


Figure 15 (a). Variation of density of R410a/Al_2O_3 with particle volume concentrations.

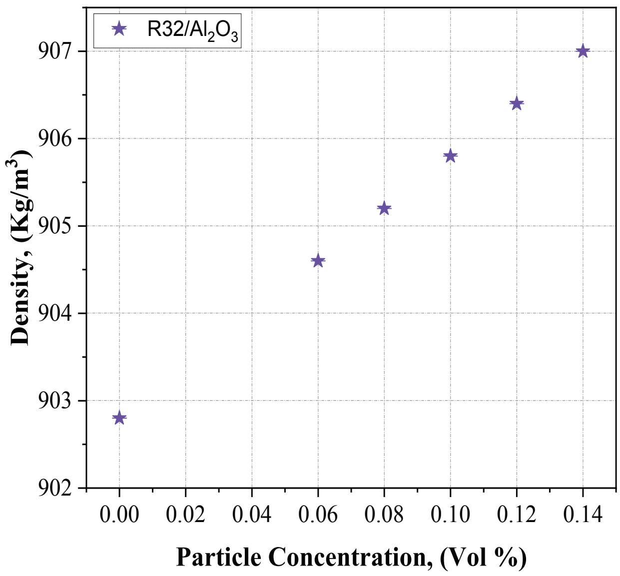


Figure 15 (b). Variation of density of R32/Al_2O_3 with particle volume concentrations.

Figures 15(a) and 15(b) demonstrates the variation of density of nanorefrigerants with various volume concentrations.

CONCLUSIONS

This study provides the illustrated simulated effect of alumina (Al_2O_3) nano additives at various volume concentrations (0.06, 0.08, 0.1, 0.12, and 0.14%) on long-term environmental-friendly and low global warming potential (GWP) refrigerant HFC-32. The results of the nanorefrigerants provide guidelines for using this as a viable alternative to HCFC-22 and R410a.

A MATLAB Simulink program has been developed to measure the refrigerating effect, power saving, the density of nanorefrigerants, COP, and compressor discharge temperature of R32 and R410a nanorefrigerants. The maximum volume concentration of nano additives (R-410a/Al_2O_3 and HFC-32/Al_2O_3) of 0.14% was used. The following conclusions have come to light through this study.

- The COP of R410a and R32 nanorefrigerants increased by 24.38% and 46.14% respectively at a 0.14% volume concentration of alumina.
- The discharge temperature of R410 and R32 nanorefrigerants was reduced by 6.7% and 17.97% respectively.
- In addition of alumina nano additives to R410a and R32 with a volume concentration of 0.14%, the net refrigeration effect increased to 81.2% and 83.5%.
- Use of nano additives in the refrigerants R410a and R32 lower the power consumption of the system by 19.6% and 31.6% respectively.
- The thermal conductivity of R32/Al_2O_3 is 40.9% more than as compared to R410a/Al_2O_3 nanorefrigerant at a volume concentration of 0.14%.

LIMITATIONS

Even though with the increase of nanoparticle concentration the overall effectiveness of the system increases. However, there is a threshold limit below which the system can perform continuously. The reason for this is, that if the concentration of the nanoparticle is increased beyond this limit there is agglomeration and sedimentation associated with the nanoparticles which restrict the smooth operation of the system.

IMPORTANCE AND FUTURE RESEARCH

- More refrigerants (or a mixture of refrigerants) can be considered for the study
- Extensive experimentation can be carried out in the laboratory under controlled conditions.
- Hybrid nanoparticles can be employed to synthesize the effect on nanorefrigerants.
- Effect of surface functionalization and surfactants can be incorporated to impart stability and longevity to the nanofluids.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

NOMENCLATURE

Al_2O_3	Aluminium oxide
COP	Coefficient of Performance
NRE	Net Refrigeration effect, (%)
GWP	Global Warming Potential
$(GWP)_{100}$	Global Warming Potential over 100 years
ODP	Ozone Depletion Potential
Q	Heat Transfer per Unit Mass, (kW)
Φ	Volume Concentration, (%)
NR	Nanorefrigerant
T	Temperature, (°C)
H	Enthalpy of Refrigerant, (kJ kg^{-1})
GHG	Greenhouse Gas
Vol.	Volume
m_r	Mass flow rate of Refrigerant, (kg s^{-1})
ρ	Density, (kg m^{-3})
PAG	Polyalkylene Glycol
POE	Poly-Easter Oil
MO	Mineral Oil
LCCP	Life Cycle Climate Performance
CFC	Chlorofluorocarbon
HFC	Hydrofluorocarbon

Subscripts

Comp	Compressor
Disch	Discharge
c	Condenser
Evap	Evaporator
Sup	Superheated

REFERENCES

[1] Velders GJM, Madronich S, Clerbaux C, Derwent R, Grutter M, Hauglustaine D, et al. Chemical and Radiative Effects of Halocarbons and Their Replacement Compounds. IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System 2005:134–180.

[2] Montzka SA, Dutton GS, Yu P, Ray E, Portmann RW, Daniel JS, et al. An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. Nature 2018;557:413–417. [CrossRef]

[3] United Nations Environment Programme. The Importance of Energy Efficiency in the Refrigeration and Heat Pump Sectors. Environment Programme, Briefing Note A 2018:1–15.

[4] Dameris M. Climate change and atmospheric chemistry: How will the stratospheric ozone layer develop? Angewandte Chemie - International Edition 2010;49:8092–8102. [CrossRef]

[5] Research I-PE supported by A. https://www.ashrae.org/technical-resources/ashrae-handbook. 2017.

[6] US Environmental Protection Agency. Phasing Out HCFC Refrigerants To Protect The Ozone Layer. US Environmental Protection Agency 2020:1–2.

[7] Benhadid-Dib S, Benzaoui A. Refrigerants and their environmental impact substitution of hydro chlorofluorocarbon HCFC and HFC hydro fluorocarbon. Search for an adequate refrigerant. Energy Procedia 2012;18:807–16. [CrossRef]

[8] Mohanraj M, Jayaraj S, Muraleedharan C. Environment friendly alternatives to halogenated refrigerants-A review. Int J Greenhouse Gas Control 2009;3:108–119. [CrossRef]

[9] Pham H, Rajendran R. R32 And HFOs As Low-GWP Refrigerants For Air Conditioning. Int Refrig Air Condit Confer 2012:2262:1–10.

[10] Tanaka M, Matsuura H, Taira S, Nakai A. Selection of a Refrigeration Oil for R32 refrigerant and Evaluation of the Compressor Reliability. International Compressor Engineering Conference at Purdue 2014:1–10.

[11] Adelekan DS, Ohunakin OS, Gill J, Atiba OE, Okokpujie IP, Atayero AA. Experimental investigation of a vapour compression refrigeration system with 15nm TiO_2-R600a nano-refrigerant as the working fluid. Proced Manufact 2019;35:1222–1227. [CrossRef]

[12] Krishna Sabareesh R, Gobinath N, Sajith V, Das S, Sobhan CB. Application of TiO_2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems - An experimental investigation. Int J Refrig 2012;35:1989–1996. [CrossRef]

[13] Bi S, Guo K, Liu Z, Wu J. Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as working fluid. Energy Convers Manag 2011;52:733–737. [CrossRef]

[14] Yang S, Cui X, Zhou Y, Chen C. Study on the effect of graphene nanosheets refrigerant oil on domestic refrigerator performance. Int J Refrig 2020;110:187–195. [CrossRef]

[15] World Commission on Environment and Development. UN Report. Availabla at: https://WwwMicCom/p/a-New-Un-Report-Says-Air-Conditioning-Is-Absolutely-Killing-Our-Planet-29518397 Last Accessed Date: 27.09.203.

[16] Bhat AY, Qayoum A. Viscosity of CuO Nanofluids : Experimental Investigation and Modelling with FFBP-ANN. Thermochim Acta 2022:179267. [CrossRef]

[17] Ali B, Qayoum A, Saleem S, Mir FQ. Synthesis and characterization of high-quality multi layered graphene by electrochemical exfoliation of graphite. Research on Engineering Structures and Materials 2022;8:447–462. [CrossRef]
[18] Ali B, Qayoum A, Mir FQ. Experimental investigation of nanofluids for heat pipes used in solar photovoltaic panels. J Therm Eng 2022. [Preprint]. doi: 10.18186/thermal.1285179. [CrossRef]
[19] Gulzar O, Qayoum A, Gupta R. Photo-thermal characteristics of hybrid nanofluids based on Therminol-55 oil for concentrating solar collectors. Appl Nanosci (Switzerland) 2019;9:1133–1143. [CrossRef]
[20] Gulzar O, Qayoum A, Gupta R. Experimental study on stability and rheological behaviour of hybrid Al_2O_3-TiO_2 Therminol-55 nanofluids for concentrating solar collectors. Powder Technol 2019;352:436–444. [CrossRef]
[21] Ali MKA, Xianjun H. Improving the tribological behavior of internal combustion engines via the addition of nanoparticles to engine oils. Nanotechnol Rev 2015;4:347–358. [CrossRef]
[22] Khetib Y, Meniai AH, Lallemand A. Computer-aided design of CFC and HCFC substitutes using group contribution methods. Desalination 2009;239:82–91. [CrossRef]
[23] Yilmaz AC. Performance evaluation of a refrigeration system using nanolubricant. Appl Nanosci (Switzerland) 2020;10:1667–1678. [CrossRef]
[24] Delmastro C. https://www.iea.org/reports/cooling 2020.
[25] Refrigeration Service Engineers Society n.d.:1–17.
[26] Sharif MZ, Azmi WH, Mamat R, Shaiful AIM. Mechanism for improvement in refrigeration system performance by using nanorefrigerants and nanolubricants – A review. International Communications in Heat and Mass Transfer 2018;92:56–63. [CrossRef]
[27] Senthilkumar A, Abhishek P V, Adithyan M, Arjun A. Experimental investigation of CuO/Sio_2 hybrid nano-lubricant in R600a vapour compression refrigeration system. Materials Today: Proceedings 2020. [CrossRef]
[28] Mohamed HAS, Camdali U, Actas M. Evaluation of a Refrigeration System Based on Nano-Refrigerants and Nano-Lubricants. American Journal of Engineering and Applied Sciences 2021;14:371–82. [CrossRef]
[29] Dey P, Mandal BK. Performance enhancement of a shell-and-tube evaporator using Al_2O_3/R600a nanorefrigerant. International Journal of Heat and Mass Transfer 2021;170:121015. [CrossRef]
[30] Kumar S, Kanimozhi B, Sunil Kumar M. Performance evaluation of refrigeration system using nano-fluid. Materials Today: Proceedings 2021;44:3838–45. [CrossRef]
[31] Desai NS, Patil PR. Application of SiO2 Nanoparticles as Lubricant Additive in VCRS: An Experimental Investigation. International Journal of Engineering Research and Applications 2016;6:62–38.
[32] Santhana Krishnan R, Arulprakasajothi M, Logesh K, Dilip Raja N, Rajendra M. Analysis and feasibilty of nano-lubricant in vapour compression refrigeration system. Materials Today: Proceedings 2018;5:20580–7. [CrossRef]
[33] Deokar PS, Cremaschi L. Effect of nanoparticle additives on the refrigerant and lubricant mixtures heat transfer coefficient during in-tube single-phase heating and two-phase flow boiling. International Journal of Refrigeration 2020;110:142–52. [CrossRef]
[34] Marcucci Pico DF, da Silva LRR, Schneider PS, Bandarra Filho EP. Performance evaluation of diamond nanolubricants applied to a refrigeration system. International Journal of Refrigeration 2019;100:104–12. [CrossRef]
[35] Marcucci Pico DF, da Silva LRR, Hernandez Mendoza OS, Bandarra Filho EP. Experimental study on thermal and tribological performance of diamond nanolubricants applied to a refrigeration system using R32. International Journal of Heat and Mass Transfer 2020;152:119493. [CrossRef]
[36] Jwo C-S, Jeng L-Y, Teng T-P, Chang H. Effects of nanolubricant on performance of hydrocarbon refrigerant system. Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures 2009;27:1473. [CrossRef]
[37] Adelekan DS, Ohunakin OS, Gill J, Okokpujie IP, Atiba OE. Performance of an iso-butane driven domestic refrigerator infused with various concentrations of graphene based nanolubricants. Procedia Manufacturing 2019;35:1146–51. [CrossRef]
[38] Sanukrishna SS, Jose Prakash M. Experimental studies on thermal and rheological behaviour of TiO_2-PAG nanolubricant for refrigeration system. International Journal of Refrigeration 2018;86:356–72. [CrossRef]
[39] Sendil Kumar D, Elansezhian R. ZnO nanorefrigerant in R152a refrigeration system for energy conservation and green environment. Frontiers of Mechanical Engineering 2014;9:75–80. [CrossRef]
[40] Abdur Razzaq ME, Ahamed JU. Thermodynamic analysis of an air conditioner using R22/HC blend with TiO_2/Mineral oil nanolubricant to retrofit R22/POE oil. Results in Engineering 2020;8. [CrossRef]
[41] Kumar R, Singh J, Kundal P. Effect of CuO nanolubricant on compressor characteristics and performance of LPG based refrigeration cycle: experimental investigation. Heat and Mass Transfer/Waerme- Und Stoffuebertragung 2018;54:1405–13. [CrossRef]

[42] Aktas M, Dalkilic AS, Celen A, Cebi A, Mahian O, Wongwises S. A Theoretical Comparative Study on Nanorefrigerant Performance in a Single-Stage Vapor-Compression Refrigeration Cycle. Advances in Mechanical Engineering 2015;7. [CrossRef]

[43] Bock Choon Pak YIC. Hydrodynamic and Heat Transfer Study of Dispersed Fluids With Submicron Metallic Oxide. Experimental Heat Transfer : A Journal of Thermal Energy Transport Storage and Conversion 2013:37–41.

[44] Gulzar O, Qayoum A, Gupta R. Experimental study on thermal conductivity of mono and hybrid Al_2O_3–TiO_2 nanofluids for concentrating solar collectors. International Journal of Energy Research 2021;45:4370–84. [CrossRef]

[45] Clerk MJ. maxwell 2010.

[46] Toghraie D, Chaharsoghi VA, Afrand M. Measurement of thermal conductivity of ZnO–TiO_2/EG hybrid nanofluid: Effects of temperature and nanoparticles concentration. Journal of Thermal Analysis and Calorimetry 2016;125:527–35. [CrossRef]

[47] A. Einstein. Viscosity 1905.