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An experimental investigation to studythermal and tribology performance of R152a/nano-oil blendin a domestic vapor compression refrigerator

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Abstract

This article details the exercise of nano oil based on polyester oil (synthetic refrigeration compressor oil), containing MWCNT nanoparticles at distinct volume fractions of 0.1%, 0.2%, and 0.3% in a vapor compression type refrigeration unit. The synthesized nano oil was demonstrated in a refrigeratingunitin action with the environment-friendly refrigerant (R152a) with approximatelyzero ODP and very low GWP (about 140). In addition, an experimental setup was installed to determine nano-oil's influence on performance parameters,including cooling time, compressor suction and discharge characteristics, compressor energy consumption, performance coefficient (COP), thermophysical properties, and coefficient of friction (COF). All the selected nano oil with system refrigerant resulted in improved COP than the pure refrigerant due to reductions in compressor energy consumption. The overall contraction in thecompressor energy consumption and augmentation in the COPfound about 31.55% and 56%, respectively.

Furthermore, thermal conductivity was studied and observed to be high (11%) for nano oil compared to pure oil. Viscosity and density of the pure oil found promotions and reductions, respectively, for varying nano oil suspensions. The coefficient of friction (COF) of nano oil compactness of 0.3% was found to be 11.61% lower than that of pure oil.

Keywords:R152a, MWCNT, Nano oil, Nanoparticles, Thermophysical properties, Tribology

1. Introduction

Vapour compression cycles are broadly acceptable for refrigeration and air conditioning; however, their in-depth energy operation, primarily supported by fuel-based electricity, has harmful effects on the environment's health (Kadam et al.,2020). To this end, nanotechnology plays a crucial role in refrigeration and air conditioning. It offers essential merits, such as advanced thermo-physical nano-refrigerants, low electric energy consumption, and enhanced tribology characteristics of refrigeration compressors. Rapid nanotechnology advances in VCR systems birth anew age of fluid known as "nano–refrigerant."The dispersion stability of nanoparticles in the base refrigerant dramatically enhances mechanical and thermal characteristics (Saidur et al.,2011).

Elcock and Deborah (2007)mixedTiO_2 particles in pure mineral oil and reported that nanoparticles' addition to oil significantly enhanced the mixing bonding between refrigerant and lubricant inside the cycle.Wang et al. (2003)observed an enhanced thermal conductivity of R22 refrigerant using Al nanoparticles which significantly improved the heat transfer coefficient inside pool boiling of R22.Jiang et al. (2003) experimentally studied the effect of CNTs for various volume fractions using different diameter and aspect ratios on thermal conductivity characteristics of R113 refrigerant. They found that the thermal conductivity of CNTs nano–refrigerant increased significantly at large volume fractions and aspect ratio of CNTs.Tazrav et al. (2016) experimentally found that the overall flow boiling heat transfer coefficient of R141b fluid at higher vapor qualities significantly improved using TiO_2 nanoparticles. Wang et al. (2006)performeda flow boiling heat transfer study of R22 using alumina oxide nanoparticles. They reported that nano–refrigerant bubble size diminishes and travels very fast near the heat transfer surface.Xiao-Min et al. (2008)mixed various fractions of TiO_2 nanoparticles with R11 to perform a pool boiling heat transfer test. They found that 0.01g/L amount of

TiO_2particles in R11 gives a 20%enhancement in heat transfer coefficient. Park and Jung (2007)addedCNTs in both R123 and R134a refrigerants which significantly improved the nucleate boiling heat transfer rate. Asignificantincrement of 36.6% was noticed at low heat fluxes in the study.Zhang et al. (2016) studied the heat transfer coefficient of R123 using CNTs inside a horizontal circular tube. The author has predicted the correlations. The study observed that heat transfer coefficient and pressure drop significantly improved using even low fractions of CNT.Peng et al. (2009)mixed CuO nanoparticles in R113 fluid and reported an enhanced heat transfer coefficient of about 29%. Ding et al. (2009)studied the concept of nanoparticles migration of mass during phase change of both nano–oil mixture and nano–refrigerant, respectively, and reported that migrated mass of fullerene particles and migration ratio in nano–refrigerant/oil mixture was lower as compared to pure nano – refrigerant.

Jwo et al. (2009)added 0.1 wt. % of Al_2O_3 nanoparticles in the R600a/MO blend and observed reductions in power consumption of the unitby about 2.4%,which increased the system performance coefficient by 4.4%.Lee et al. (2009)mixed fullerene nanoparticles in mineral oil to study the friction coefficient test. The results reported that by mixing 0.1 vol. % amount of fullerene particles in mineral oil, the friction coefficient was reduced by about 90% compared to pure lubricant.Abbas et al. (2013) experimentally found that the usage of 0.1 wt. % of CNT nanoparticles improved the performance coefficient of domestic refrigerator units byabout 4.2%. Finally,Hussen (2016)reported an average of 13% reductions in compressor power and about a 12% increment in coefficient of performance of R22 based air conditioning unit using TiO_2 nanoparticles.

Lou et al. (2015)reported about 4.5% low energy consumption using 0.1 wt. % amount of graphite particles in R600a domestic refrigeration. Bi et al. (2008)declared that 0.1 wt. % of TiO_2 nanoparticles used inside the R134a domestic coolingunitsaved about 26.1% of pumping power consumption.Bi S. et al. (2011)reported that0.5 g/L of TiO_2 nanoparticles applied inthe R600a refrigeratorlowered the compressor energy consumption by 9.6%.Sabareesh et al. (2012)used 0.05 to 0.015 vol. %amount of TiO_2 nanoparticles in R12 based domestic refrigerator and reported 17% improvement in performance coefficient and about 11% reductionsincompressor energy consumption.Adelekan et al. (2017) performed a comparison study inside LPG and R134a refrigerators using MO nanolubricant and observed that LPG/MO nanolubricant blend gives more performanceas compared to R134a/MO blend.Kumar and Elansezhia (2012)performed an experimentalstudy by mixing Al_2O_3 nanoparticles with R134a and PAG blend and noticed an overall 10.32%reduction incompressorenergy consumption.

Kundan and Singh (2021) mixed 20 nm-sized Al_2O_3 particles in R134a refrigerating unit and reported 7.2 to 16.34% improvements in COP for selected heat flux range and flow rates using 0.5 wt.% nanoparticles fraction. The author found that the COP of the system enhanced securely at 0.5 wt.% fractions, but it starts reducing using 1.0 wt—% fraction at low evaporative heat flux and higher ambient temperature. Kaushik et al. (2021) experimentally found that the HC/CuO nanorefrigerant at fraction rates of 0.2, 0.3, and 0.4g improves the COP of the system, and the cooling rate inside the freezer becomes fast and increases through the rise in CuO fractions. Kaushik et al. (2021) did experimental work using CuO nanoparticles in R134a based refrigeration rig to test various characters at two flow rates of 0.16 and 0.23 LPM. The author declared a significant enhancement in the cooling capacity of the freezer using 1.2 and 1.5 wt. % CuO fractions, whereas the cooling capacity reduces after mixing higher CuO fractions.

Similarly, the power usage reduces at 1.2 and 1.5 wt. % of CuO but starts increasing at higher weight fractions of nanoparticles. It can be said that, at higher particles fractions, the system showed negative performance. Thenanorefrigerant, due to its superior quality, enhances the thermal characteristics of refrigeration and air conditioning units but the influence of nanorefrigerant at higher fractions is not always positive. The author suggests that nanorefrigerant should test heat transfer characters at higher fractions (Singh et al.,2015).

The thermophysical properties of R134a (and ozone-safe refrigerant) are very close to those of refrigerant R12. Domestic appliance manufacturers widely use it as a possible replacement for environment toxic refrigerant R12 in domestic and commercial air conditioners. The ODP value of R134a is about 0, but the GWP value falls near about 1300, which demands possible replacements of R134a. According to a report, the domestic and commercial applications of R134a refrigerants will suspend in the future (Wongwises and Chimres2005). R152a (ODP = 0, GWP = 140) is a HFC series fluid and widely applied inside cooling channels for numerous years. R152a is very similar to R134a because of pressure extent and volumetric capacity, while energy order, vapor density, and mass transfer rate are also more praised(Hu and Chen 1993; Bitzer 2007)

Many reports state that the stability of nanofluid is a crucial parameter before injecting it into a working cycle. According to Heris et al. (2014), the prepared nanorefrigerant's stability improved after 24 hrs ofthe synthesis process. The author also declared that density finding during the selected time is easy to examine the mixing stability. Yang et al. (2015) synthesized a nanorefrigerant by dispersing MWCNT into R141b. The blend was prepared under a 30-minute process of ultrasonication. After that, a visual method using spectroscopy was used to analyze the stability of the prepared nanorefrigerant.Kundan et al. (2017) considered the suspension size distribution of the nano-sized particles at varying pH scales. Nanoparticles' physical character zeta potential and suspensions stability ratio havebeen presented. The author modified the available governing equations of cluster morphology considering factors like nanoparticles hydrodynamic size, chemical dimensions of aggregates, and fractal and found that the selected fractal aggregates enhanced the considerable thermal conductivity, which is significantly higher than conventional theories of colloidal suspension. Kundan et al. (2017) studied the time dependable TiO_2 nanoclusters morphology on the heat conduction mechanism of nanofluids. The study has been done at different pH values and SDBS surfactant and found a significant enhancement on the thermal conductivity of selected nanofluidobserved considering modified fractal aggregates. Mishra et al. (2014) developed a new model considering dimensionless groups like Prandlt number, Reynold number, and a dimensional less (ratio of Reynolds number to the square root of Brinkman number for particles and fluid), which is helpful to design heat exchanger through estimate the nanofluid conductivity values within the accuracy range of 5%.

All the cooling units for domestic and commercial purposes, such as air conditioners, HVAC systemsinstalled in transport vehicles,etc., have been working on the vapor compression refrigeration cycle principle. Thus,in this work, a domestic (small size) scale vapor compression refrigeration machine was designed as per ISO standards (1991). The critical potential issues facing compression refrigerating units involve energy consumption and compressor lubrication, which are focused on in the present work. It is reported in the literature that nanolubricants resolve the compressor power by improving the lubrication (friction factor) of the compressor. As MWCNT nanoparticles have high thermal conductivity values compared to other oxide particles, these were selectedfor the study (Patil et al.,2016). MWCNT dispersion POE nano–oil was synthesized and appended with pure fluid R152a. The performance parameters included: freezing time, compressor suction and discharge characteristics, compressor energy, performance coefficient (COP), thermophysical properties, and coefficient of friction (COF) studied with both R152a/nano oil mixture and pure refrigerant, respectively. The MWCNTs were applied at varying volume fractions of 0.1, 0.2, and 0.3%. In addition, thermophysical characteristics such as thermal conductivity, dynamic viscosity, and pure and nano oil density have been studied—the friction test was conducted to determine the friction coefficient for both nano–oil and pure oil.

2. Methodology

The test rig (shown in Figure 1) assembled for experimental investigation is a vapor compression refrigeration system designed to work with refrigerant R152a.

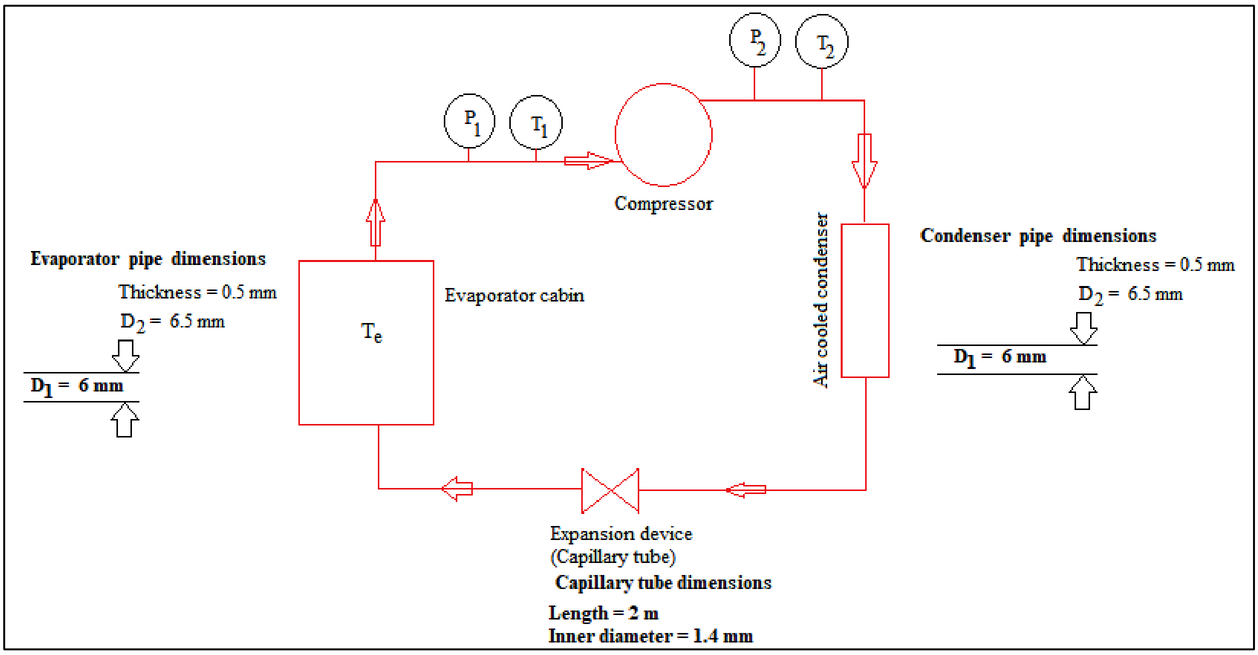

Figure 1 Design dimensions of proposed VCR cycle

Table 1 Configuration of the test setup

Sr. No.	Component	Units
1	Compressor type	1/8 HP
2	Refrigerator capacity	0.25 TR
3	Capillary tube length	2 m
4	Capillary inner diameter	1.4 mm
5	Condenser type	Air-cooled
6	Compressor oil type	POE oil
7	Refrigerant type	R152a

Table 2 Uncertainty and ranges of measuring equipment

Sr. No.	Measured data	Specification	Range	Uncertainty
1	Pressure	Analog pressure gauge	0- 2.5 MPa	±1%
2	Temperature	Digital thermocouple	-50 °C to 400 °C	± 0.32 °C
3	Energy consumption	Digital meter (kWh)	0 – 5 kW	±1%
4	Nanoparticles mass	Digital weighing machine	0-200 g/s	± 0.2%

The setupcomprisesa freezer, compressor, air-cooled condenser, expansion coil, and a drier and has a capacity of 0.25 TR. The experimental designwas provided with T-type thermocouples to inspect the temperatures of the pipe surface on the compressor discharge (T_2), evaporator cabin temperature (T_e), and the pressure sensors to collect the pressure on the suction (P_1) and discharge (P_2) ports of the compressor. In addition, the compressor energy rate was collected using a digital kilowatt (kW) meter installed in a test setup. The configuration of the experiment channel partsand the uncertainty range of measuring appliances arelisted in Tables 1and 2, respectively. All tests were performed under a well-maintained temperature of about 30 °C witha relative humidity value was about 50%.

The cooling effect and performance coefficient of pure refrigerant and refrigerant/nano oil blend were examined using the following equation:

$$\text{Refrigerant effect} = \frac{m \times c_p \times \Delta T}{t} \text{ kW} \quad (1)$$

$$\text{COP} = \frac{\text{Refrigerant effect}}{\text{Compressor work}} \quad (2)$$

Where m refers to the mass of water (kg), $C_p$refers to thespecific heat of water (kJ/kg), ΔT refers to the temperaturegapof water (°C), andt is time. Compressor power was measured directly from a digital wattmeter in terms of kW. Refrigerant R152a is used as the primary fluid inside the cycle. Theresults were collected for various refrigerant charges such as 60 g, 80 g, 100 g, and 120 g, respectively, and different MWCNT nano oil volume ratios of 0.1, 0.2, and 0.3%—the scope and order of experiments defined in Table 3.

Table 3 Range and status of the experiment

Sr. No.	Parameters	Range of experiment
1	Refrigerant	R152a
2	Nanoparticles	Multi wall carbon nano tube (MWCNT)
3	Refrigerant charge	60, 80, 100, and 120 g
4	Compressor oil	POE oil and MWCNT nano oil
5	MWCNT mass concentration	0.1, 0.2 and 0.3 %
6	Test environment temperature	30 °C

2.1. Nano oil synthesis

The MWCNT nanoparticles were used to synthesize nano oil using an ultrasonic processing technique. The multi-wall carbon nanotube (MWCNT) was acquired from Nano Research Lab Corporation, India. The characteristics of pure POE synthetic oil and MWCNT nanoparticles are presented in Tables 4 and 5. Figure 2 shows scanning electron microscopy (SEM) of MWCNT nanoparticles, while the Figure3 shows a picture of pure POE and synthesized nano oil used in this work.

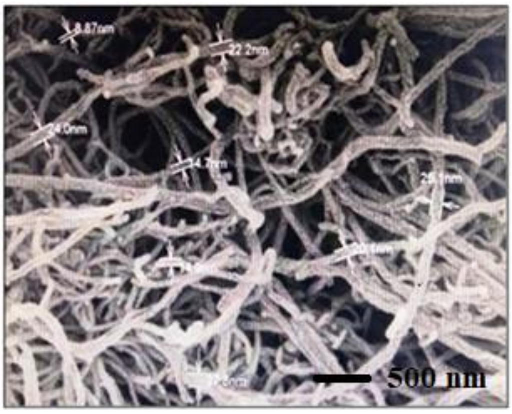

Figure2 Scanning electron microscopy (SEM) of MWCNT nanoparticles

Figure3picture of pure POE oil and synthesized MWCNT nano oil at a mass fraction of 0.3%

Table 4 Properties of POE oil

Sr. No.	Oil properties	Units
1	Oil type	POE refrigeration oil
2	Density at 40 °C	0.901 g/m^3
3	Dynamic viscosity at 40° C	0.0612 Pa.s
4	Thermal conductivity at 40° C	0.126 W/(m.K)
5	Flash point	206 °C
6	Pour point	-36 °C

The particle's mass was measured on a digital weighing machine with a precision of 0.2 mg. Then, the volume fraction of MWCNTs is determined using Eq. (3).

$$ø = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p}+\frac{m_o}{\rho_o}} \times 100 \quad (3)$$

Where ø refers to volume fraction (in percentage), ρ_p and ρ_o refers to bulk density of nanoparticles and density of the selected oil, respectively; and m_p and m_o refers to the mass of MWCNTs and oil, respectively. Uniform dispersion of nanoparticles in pure oil employed a standard ultrasonic agitator by vibrating for 5 hours.

Table 5 Properties of MWCNT nanoparticles

Sr. No.	Properties	Values
1	Specific surface area (m^2/g)	250 ~ 270
2	Length (µm)	2 – 10
3	Diameter (nm)	10 ~ 30
4	Thermal conductivity (Wm^{-1}K^{-1})	1500
5	Density (g/m^3)	2.1
6	Color	Black
7	Production method	CVD

Further, every sample was then conserved with a magnetic stirrer for an average of 90 minutes for superior dispersion of nano oil. Conventional methods for stabilizing nano–oil, such as the application of surfactants, are not tested to avoid its effect on pure refrigerant. Therefore, MWCNTs with three different volume concentrations (0.1, 0.2, and 0.3%) are selected to propose three nano–oil samples. The prepared samples of nano–oil werefurther appended with pure refrigerant one by one through the compressor suction port to prepare the required R152a/oil/MWCNT mixture within the refrigeration system.

2.2. Thermophysical test

This study measured the thermophysical characteristics of MWCNT based oil experimentally in detail (Pakdaman et al.,2012; Derakhshan and Akhavan,2015). The thermal conductivity of oil was measured using KD2 Pro with an accuracy of ± 3%. Brookfield DV-II instrument with an accuracy of ± 3% was used to measure dynamic viscosity, and the density was measured using SVM3000 with an accuracy of ± 3%.

2.3. Tribology test

The coefficient of friction (COF) was studied using the triboscopy method proposed in (Belin 1993). A universal tribometer was used for all the tests of the coefficient of friction of pure and nano oil. The tribometer has a force transducer for measuring the normal and tangential force over the sample.

3. Uncertainty calculations

The uncertainty mathematics for the present experiment was calculated using a well derived and published method by Schultz and Cole (1979) and Sheikholeslami and Ganji (2016). The below-mentioned equation is used to calculate the error value:

$$U_R = \left[\sum_{i=1}^{n}\left(\frac{\partial R}{\partial V_i} UV_i\right)^{\frac{1}{2}}\right]^2 \qquad (4)$$

Here, $U_R$refers to total uncertainty, U_V is the uncertainty of every selected independent parameter, and n is the total number of selected parameters.

The uncertainty of each measurement is classified into Random error and Systematic error. The Random error of each measurement is calculated using the variable distribution at a 95% confidence level and determined using the below-mentioned equations:

$$R_e = \frac{f.\sigma}{\sqrt{n}} \qquad (5)$$

$$\sigma = \left[\frac{1}{1-n}\sum_{i}^{i=n}(x_i - \overline{x})^2\right]^{0.5} \qquad (6)$$

fis known as the degree of freedom, which is 1.5 at a 95% confidence level. Σ is standard deviation, x_i stands for reader quantity magnitude and $\overline{x}$ is the value of the arithmetic mean.

At last, the final uncertainty value of each measurement is calculated by the below-mentioned equation:

$$U_f = \sqrt{S_e^2 + R_e^2} \qquad (7)$$

The calculated errors of all experimental variables are shown in Table 6. The results showed that the total error percentage value for all the variables observed was below 3%.

Table 6 Uncertainty of the measured variables

Measured data	Uncertainty
Suction pressure (P_1)	± 0.002 Mpa
Discharge pressure (P_2)	± 0.005 Mpa

Energy consumption (kW)	± 0.0003 kW
Evaporator cabin temperature (T_e)	± 0.3 °C
Discharge temperature (T_2)	± 0.3 °C
Thermal conductivity (λ)	± 0.0042 W/(m.K)
Density (ρ)	± 0.027 g/m^3
Viscosity (μ)	± 0.0019 Pa.s
COP	± 0.0536
COF	± 0.0042

4. Results and Discussion

4.1. Variation of rheological thermophysical properties of pure and nano oil

4.1.1 Variation of thermal conductivity

The thermal conductivity of nano-oil, for the compactness of 0.1, 0.2, and 0.3 vol. % investigated experimentally using the KD2 pro meter for different temperatures. Figure 4 describes an instant thermal conductivity for both pure and nano oil at steady-state temperature. The pure oil observed a thermal conductivity value of 0.126 W/ (m.K), while the highest was noticed at about 0.140 W/ (m.K) for 0.3% nano oil fraction at a temperature of 40 °C. The average increase in thermal conductivity of compressor oil with all selected MWCNT particles was observed at about 11%. Brownian motion of nanoparticles within pure fluid accounted as a primary responsible factor for such improvement in thermal conductivity of the pure fluid (Mukherjee et al. 2016). Therefore, the increment noticed in thermal conductivity is acceptable in the present work, resulting in increased cooling capacity for all selected nano oil mixtures, compared to pure oil-based R152a mixture within the investigation.

4.1.2. Variation of dynamic viscosity

Figure 5 shows the effect of the nano oil concentration on the dynamic viscosity of oil, showing that the dynamic viscosity of pure oil increases for the selected MWCNT nanoparticles of 0.1, 0.2, and 0.3 concentrations. The curve shows well-collaborated data that the viscosity of pure and nano oil strongly depends upon temperature and constantly reduces as the oil temperature increases. As described in Figure 5, the dynamic viscosity of POE nano oil of values 0.0696 and 0.0704 Pa.s achieved at a temperature of 40 °C for 0.1 and 0.2 % MWCNT concentrations 12% and 15% higher than that of pure oil. A low viscosity increment of about 0.75 % was noticed using nano oil compactness of 0.3%. The increased viscosity through nanoparticles in pure lubricant significantly enhanced the compressor performance (the reason discussed in section 4.6).

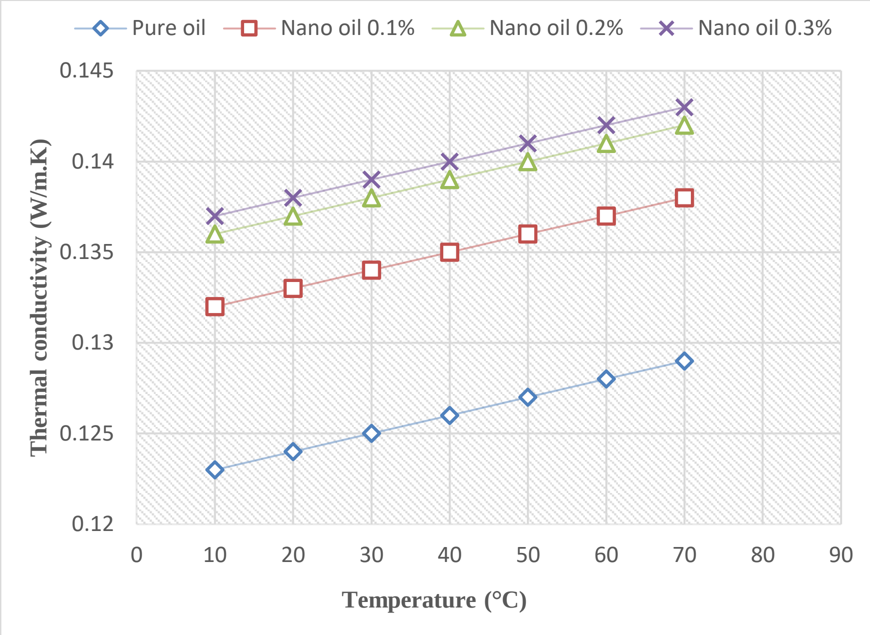

Figure 4 Variation of thermal conductivity of pure oil using MWCNT fractions as a function of temperature

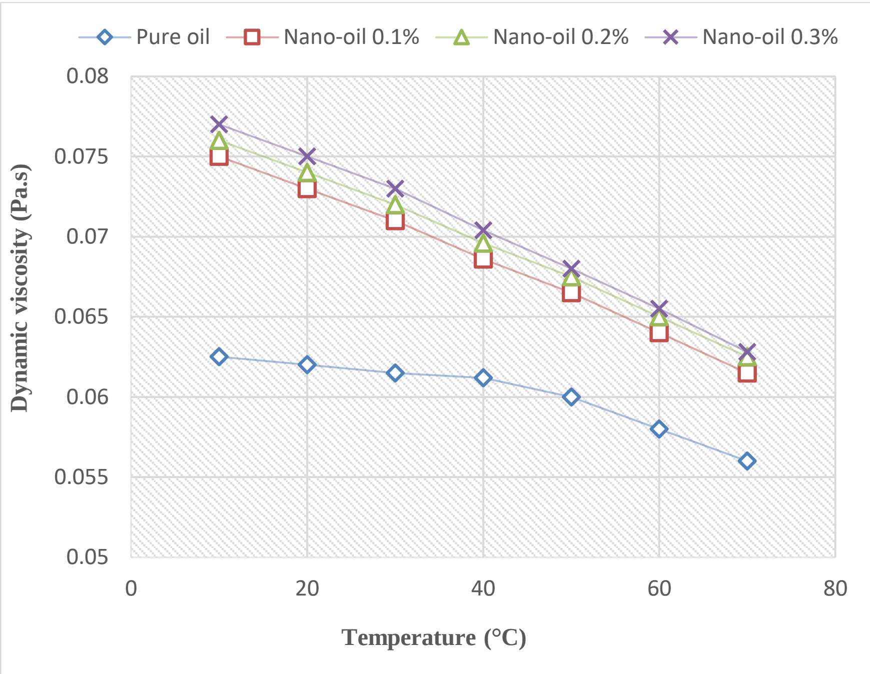

Figure 5 Variation of dynamic viscosity of pure oil using MWCNT fractions as a function of temperature

4.1.3. Variation of density

In Figure6, it is clear that the density of pure and nano oil is a function of temperature and volume fraction of nanoparticles, which constantly reduces as the oil temperature and particle volume fraction increase. For example, at 40 °C, the pure oil gave a density value of 0.9013 g/m^3, while the lowest was achieved with 0.3% nano oil suspension as 0.8910 g/m^3. Also, with 0.1% and 0.2% nano oil volume fraction at 40 °C, the reduction in oil density was observed as 0.8928 and 0.8912 g/m^3, respectively. Therefore, the reduction noticed in compressor oil density lowered the compressor pressure and pumping power for all applied nano oil suspensions, then the pure oil – R152a blended inside the refrigeration system.

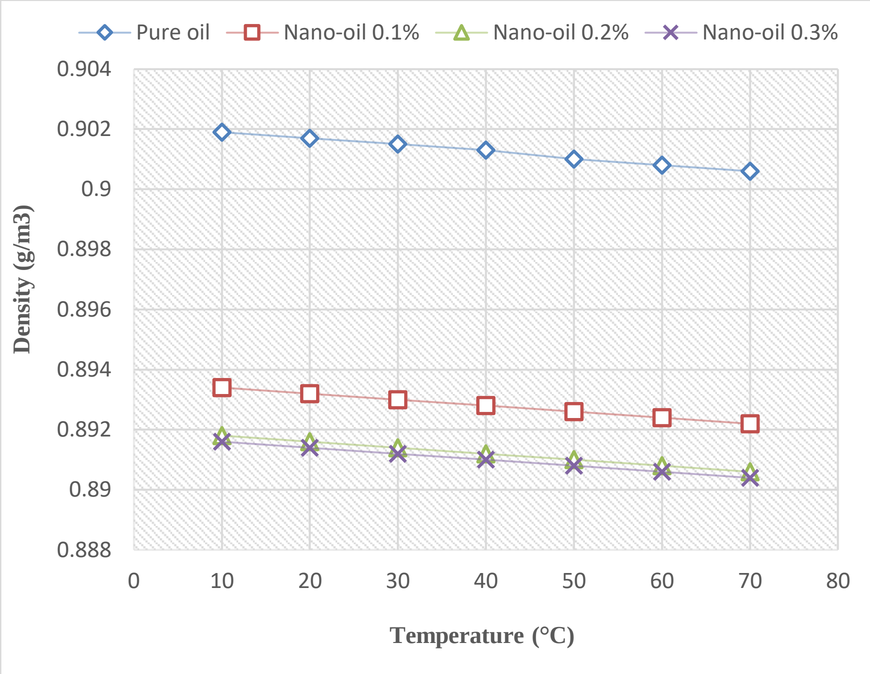

Figure 6 Variation of the density of pure oil using MWCNT fractions as a function of temperature

4.2. Variation of coefficient of friction (COF)

Under evaluation conditions, Figure 7 illustrates COF measurements for pure and selected nano oil suspensions. The lowest COF value of 0.114 was found using 0.3% nano oil for the transient period (up to 3000 cycles), while the lowest COF value of 0.135 was noticed with pure oil for the stationary period (from 3000 to 10000 cycles). The application of MWCNT particles in pure oil resulted in an 11.61% reduction of the COF for the transient period. The reduction corresponded to the increase in nanoparticle fractions due to the rolling friction mechanism, which polished the roughness in a shorter time with a greater number of nanoparticles (Pakdaman et al.,2012; Darminesh et al. 2017; Raina and Anand,2018). To this end, during the stationary period of friction test, the oil without nanoparticles suspension observed the highest COF, while oil containing 0.1% and 0.2% concentrations of nanoparticles revealed similar values of COF (about 0.135), and that carried 0.3% nanoparticles showed the lowest value of COF (about 0.133), demonstrated in Figure 8. The work of sabareesh et al. (2012) and Raina and Anand (2018) also show a similar COF trend as obtained in the present study. The possible reason for reductions in COF using nano oil is the evolution of wear operation within the metal moving parts in a compressor. Therefore, the refrigeration system presented lower energy consumption caused by reducing friction coefficient using MWCNT particles with R152a.

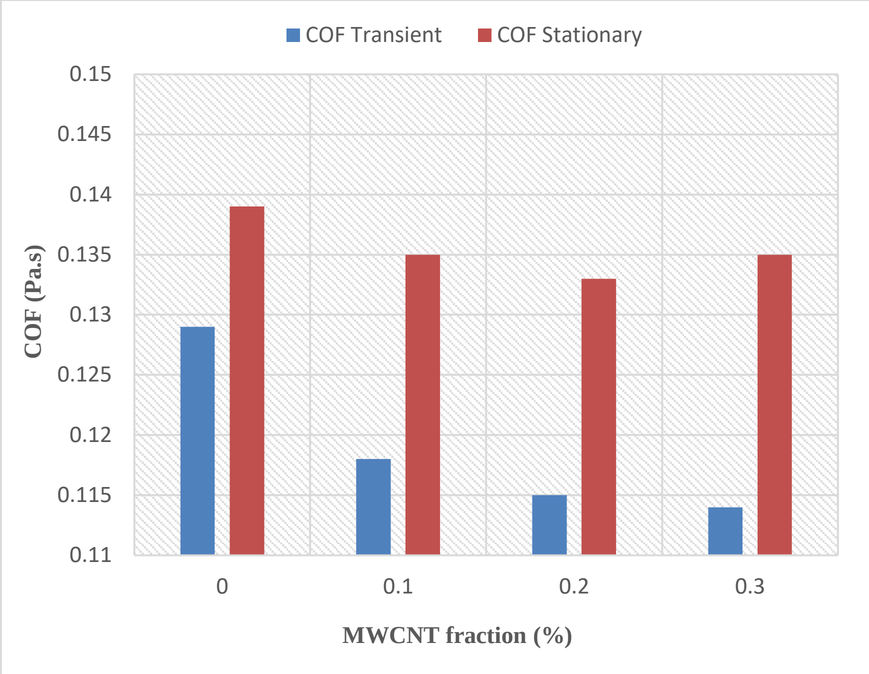

Figure 7 Coefficient of friction of the MWCNT nano oil during transient and stationary stage

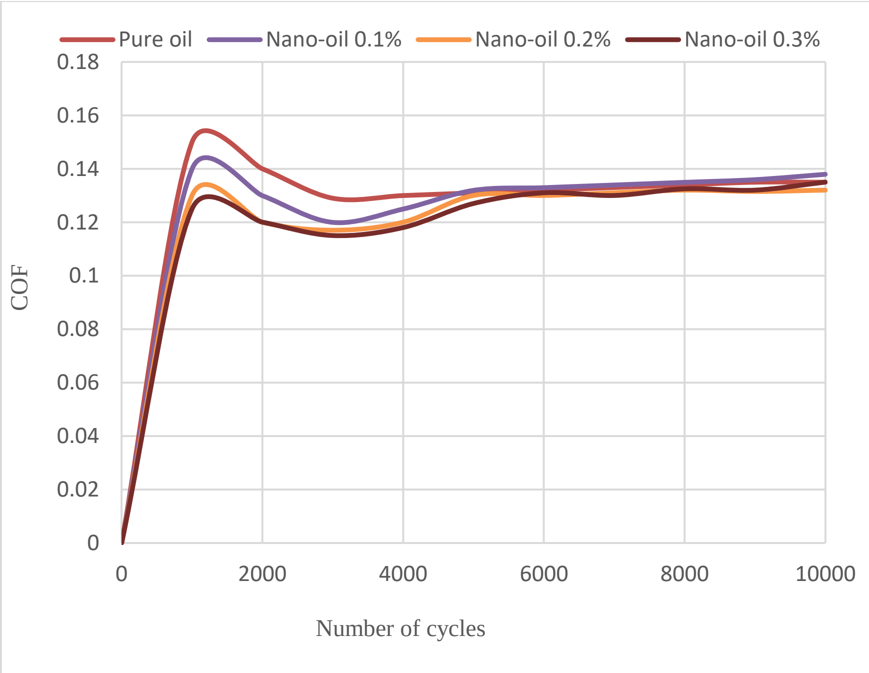

Figure 8 Coefficient of friction of the MWCNT nano oil as a function of the number of cycles

4.3. The temperature on the compressor discharge point

Figure 9 shows the temperature profile on compressor discharge point for refrigerant charge taken and selected nano oil concentrations, showing continuous increment for the selected charge from 60 g to 120 g, while substantial reductions in discharge temperature for selected nano oil compactness of 0.1, 0.2, and 0.3%. The high rate of reduction in discharge temperature on nano oil compactness of 0.1% and 0.2% for the selected refrigerant charge of 60, 80, and 100 g was noticed at about 5°C (approximately 8%). The increased heat transferrate using nanoparticles with base refrigerant was primarily responsible for the acceptable reductions in compressor discharge temperature (Bhattad et al. 2018).

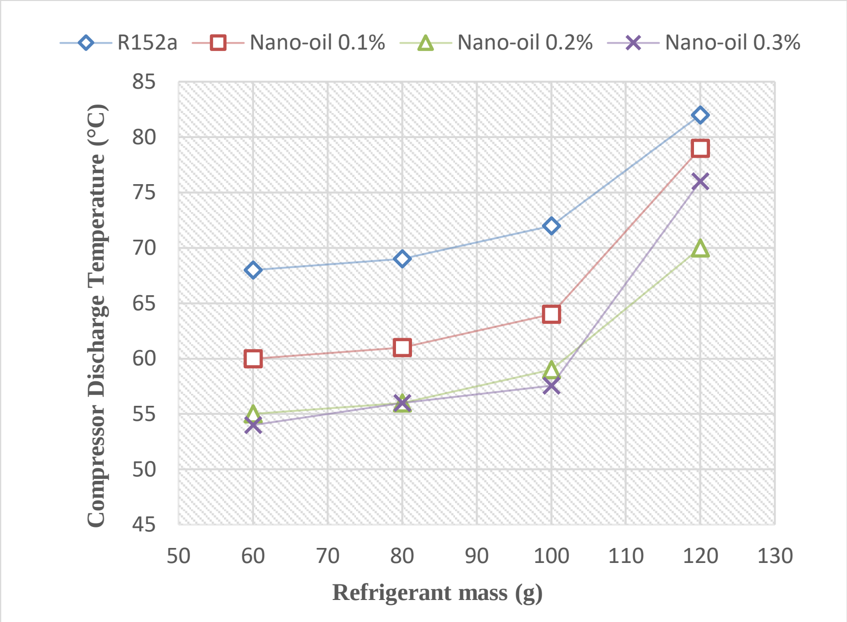

Figure 9 Effect of refrigerant charge and nano oil on compressor discharge temperature

4.4. Pressure on compressor suction and discharge point

Figures10 and 11 shows the effect of refrigerant charges with contrasting nano oil fractions (0.1, 0.2, and 0.3 vol. %) of MWCNT nanoparticles on compressor suction and discharge pressure and observing that the increment in R152afluid charge is increasing the pressure on compressor suction and discharge point constantly up to 80 g charge of R152a refrigerant. Still,the maximum discharge pressure was observed when the mass charge raised from 100 g to 120 g. This similar trend is also perceived in Bolaji (2010) and Choi and Kim (2002).

Further, the graphical trend showed substantial reductions in pressure at suction and discharged points for all the selected nano oil compared to pure 152a refrigerant. The average percentage reductions in suction and discharge pressure of 10% and 7.6%, respectively, were observed for nano oil compactness of 0.1% and 0.2%, while the reductions in suction and discharge pressure of about 1% and 3.1%, respectively, were noticed for nano oil fraction of 0.3% for 100 g charge of R152.

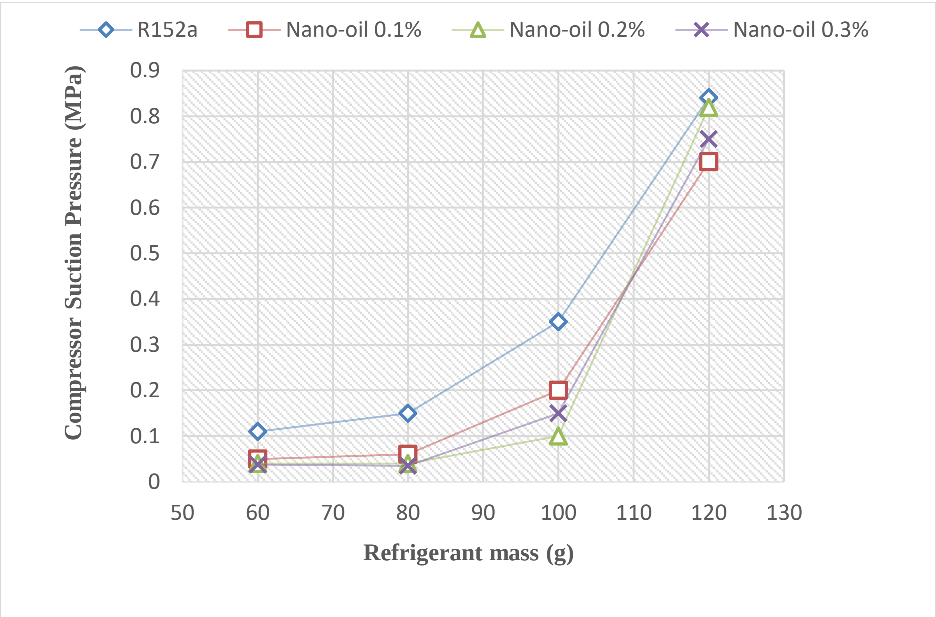

Figure 10 Effect of refrigerant charge and nano oil on compressor suction pressure

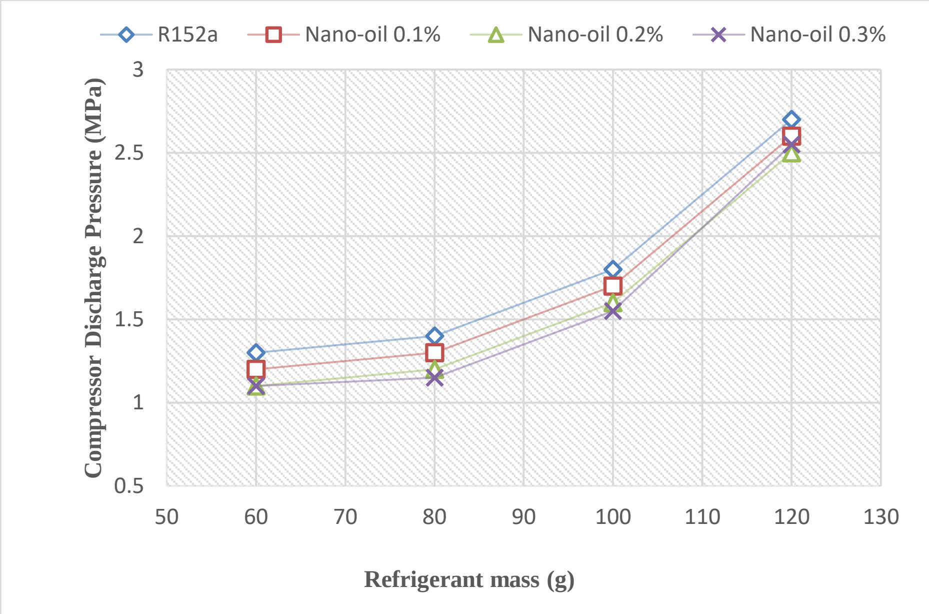

Figure 11 Effect of refrigerant charge and nano oil on compressor discharge pressure

Since the temperature of a fluid is related directly to pressure, the reductions in temperature on compressor discharge resulted in similar reductions in pressure at the compressor discharge end for all the applied nano oil fractions. Although the reductions in compressor discharge pressure are not much favorable on this end, nano oil increased the tribology characteristics of the compressor; thus, this pressure decrease has no negative effect on the act of the R152a/nano–oil cooling system. This trend of reductions in compressor suction and discharge pressures for different nanoparticles normally observed in earlier investigations (Kumar and Elansezhian2014; Kumar et al. 2018; Bi et al. 2018; Shengshan and Lin 2007).

4.5. Variation of pull down time of VCR cycle

Figures12 – 15 presents the comparison between a pull-down time for changing the operating temperatures of selected refrigerant charge and nano oil fractions inside the evaporator cabin of the test rig. The operating temperaturesabout2 °C, 0 °C, and – 3 °C, respectively, wereobserved at the pull-down time of 180, 160, and100 minutes, respectively for 60, 80, and 100 g charge of R152a fluid. The highest rate of cabin temperature (about – 3 °C)was noticed for 100 g and 120 g charge of refrigerant; thissimilar trend was also observed in the work of Bolaji (2010). Itis shown in Figure 12 that the operating temperature of about – 3 °C and cooling time of about 100 minuteswere obtained for 80 g charge of refrigerant using selected nano oil fraction of 0.2%, while for 80 g charge with 0.2% nano oil, the operating temperature of – 5 °C was received at cooling time of 100 minutes. A high rate of cabin temperature of – 5 °C was observed for a refrigerant charge of 80 g, with0.2, 0.3 % nano oil at the pull-down timeof100 minutes (Figure 13). Consequently, compared to Bolaji (2010), the present work achieved more cooling (about – 2 °C) inside the evaporator cabin at a similar pull-down time of 80 minutes for a low-rate refrigerant chargeof 80 gwithinR152a/MWCNT VCR system.

The nanorefrigerantwas found to have a positive impact on the system characteristics such as solubility, thermal conductivity, and flow regime, which further affects the cooling capacity of the refrigerating system, so far the heat transfer rate of the heat exchanger (i.e., evaporator and condenser)increased (Azmi et al. 2017; Xing et al. 2014).

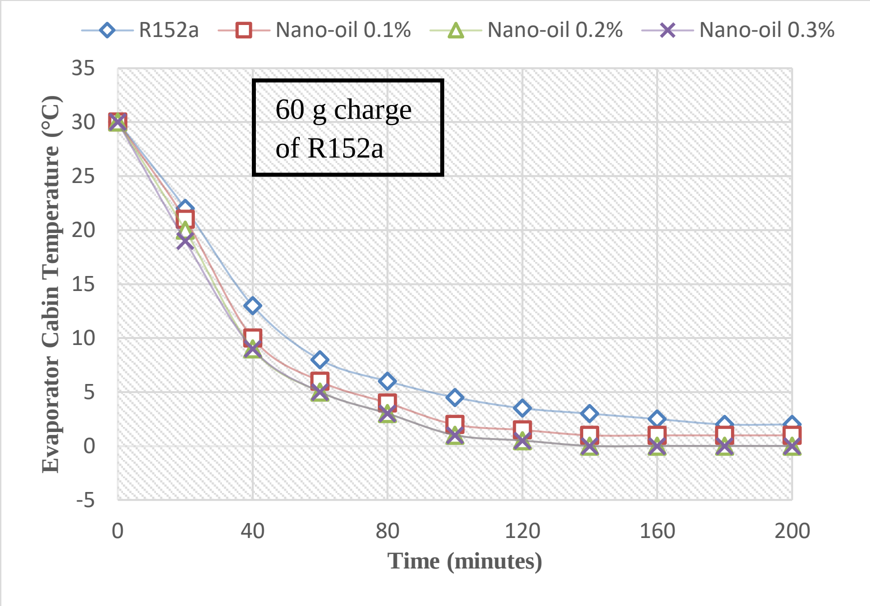

Figure 12 Pull down time for 60 g charge of R152a with nano oil

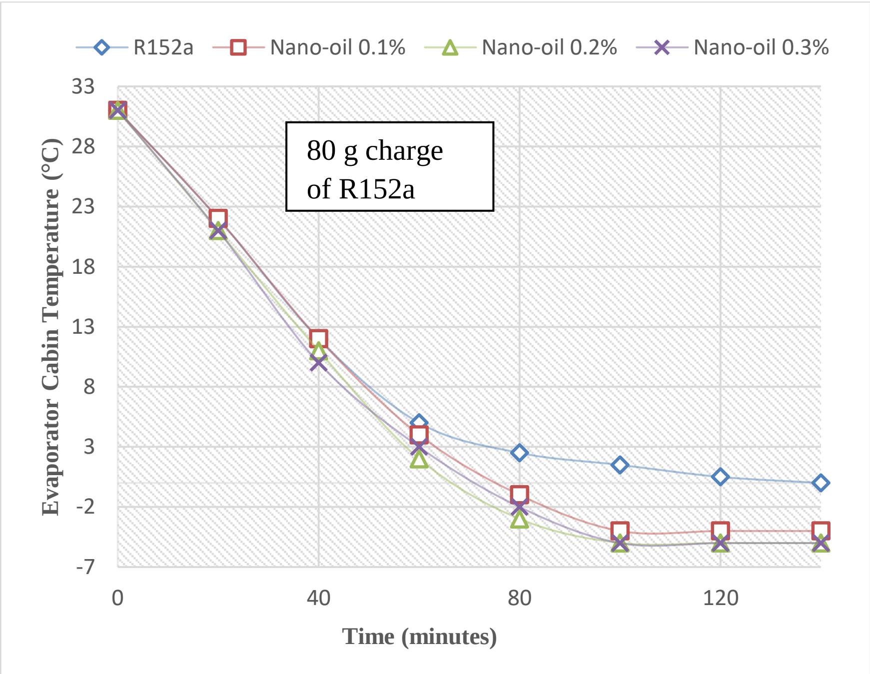

Figure 13 Pull down time for 80 g charge of R152a with nano oil

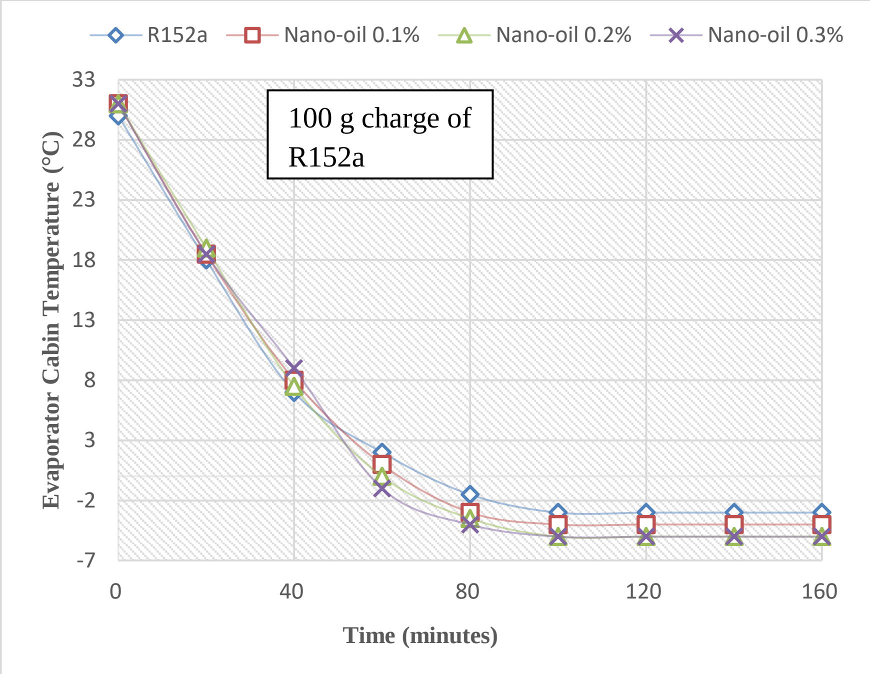

Figure 14 Pull down time for 100 g charge of R152a with nano oil

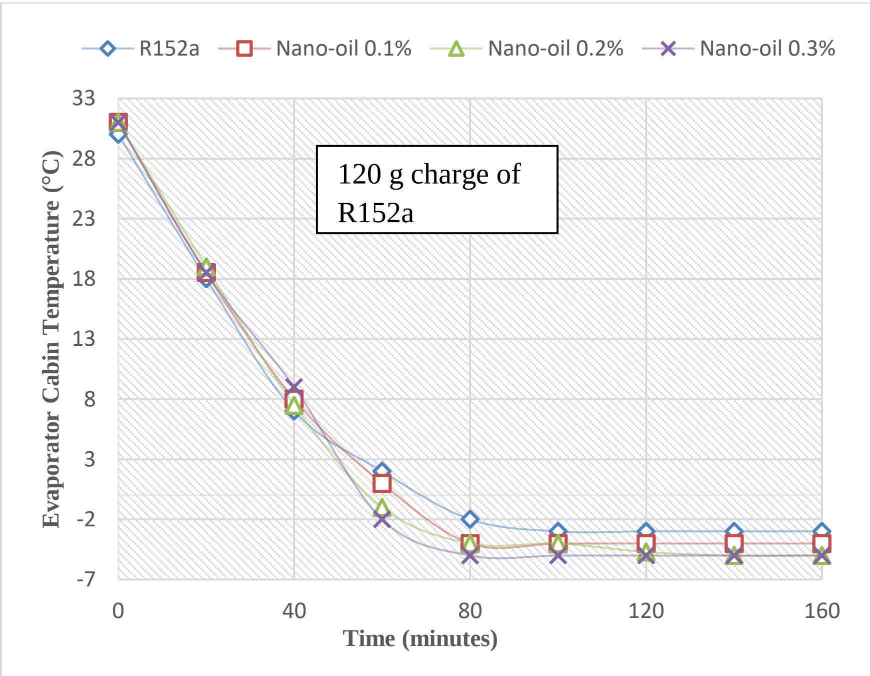

Figure 15 Pull down time for 120 g charge of R152a with nano oil

4.6. Variation of compressor energy expenditure

Figure16 indicates the graphical picture of compressor power consumption with applied MWCNT nano oil within the R152a refrigeration system. The table illustrated the compressor power consumption measured with a watt-meter during experimental investigation for all the R152a refrigerant charges using selected nanoparticle fractions. As aresult, the total energy consumed by the compressor was saved by about 2.7 to 31.55% by employing MWCNT nano oil within the R152a VCR system (Figure 17). In Kumar and Elansezhian's (2014) work, the author found reductions in compressor energyconsumption byabout 21% by employing ZnO nanolubricant with a R152a VCR system, which is 10.55% lower than the performance of the R152a/ MWCNTblend.

There are two possible causes of reductions in energy consumption using nanolubricant with basic refrigerants. Firstly, mixing nanoparticles in primary (pure) oil increased its dynamic viscosity. The particles push up the viscous nature of oil and, when it flows inside the channel, significantly reduce the pressure on the compressor discharge point. The pressure reductions at the compressor discharge end further lowered the electric consumption of the compressor. Secondly, the solid metallic nature of nanoparticles enhanced the lubrication inside the moving cranks of a compressor. Due to its higher viscous and dense nature, Nano oil established a thin oil film inside the piston and cylinder sliding surface. The film further resisted any direct bonding between piston–cylinder walls and lowered the tribology characteristics such as rate of wear, friction effect, and surface roughness of compressor (Xing et al.,2014).

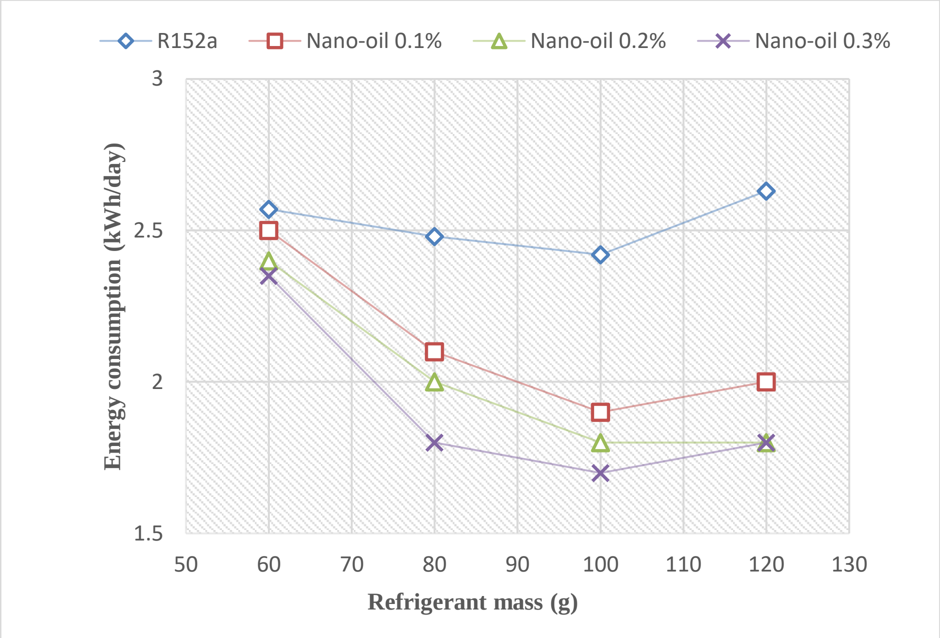

Figure 16 Effect of refrigerant charge and nano oil on the energy consumption

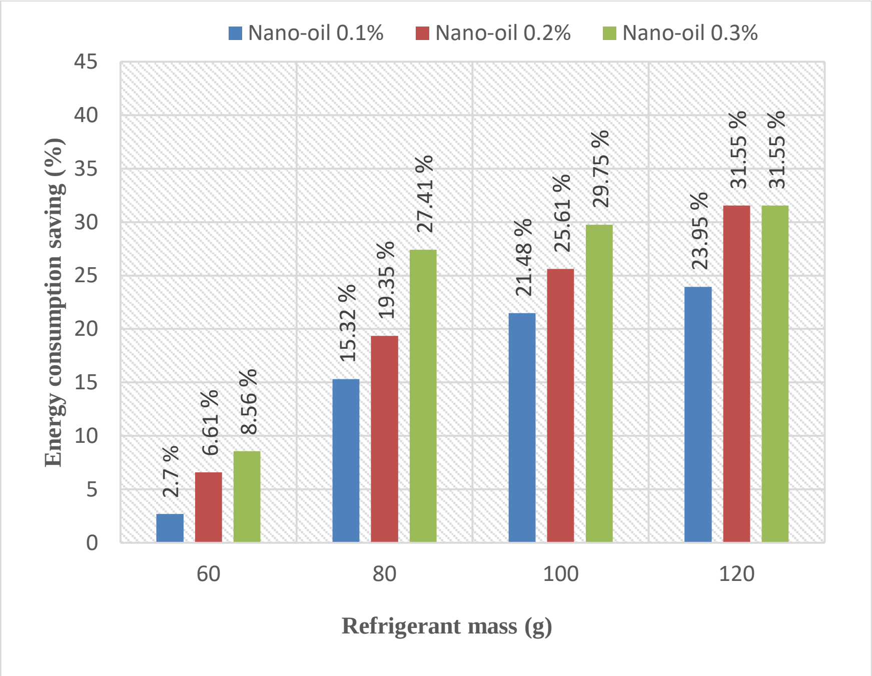

Figure 17 Energy saving percentage for the selected refrigerant charge using nano oil

4.7. Variation of COP

Figure 18 illustrates the effect of refrigerant charge with all selected nano oil suspensions on the performance coefficient of the cooling unit—the performance rate increases with nano oil fractions for all selected mass charges of R152a refrigerant. The highest COP of 11.24 was observed with 100 g and 120 g charges for 0.2 and 0.3 % nano oil suspension. The average COP achieved using R152a/nano oil mixture is 56% higher relative to pure R152a/oil mixture.

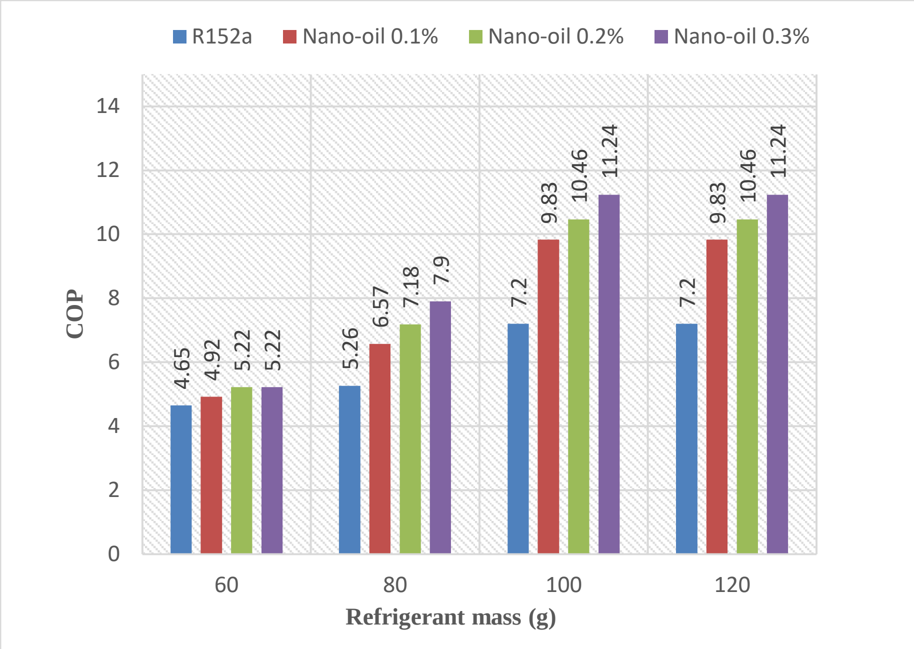

Figure 18 Variation of COP for selected refrigerant charge and nano oil fraction

5. Conclusions

The present experimental report concluded that R152a/nano-oilblend is a possible andsuitable candidate for the domestic VCR unit, given excellent resultsforthe parameters includingcooling time, compressor energy consumption, compressor suction and discharge characteristics, thermophysical properties, and coefficient of friction. After the successful study on the performance of R152a – nano oil mixture, the below-written conclusions extracted from obtained results:

- The design temperature (of -3 °C) andcooling time (about 100 minutes) were decided by ISO for domestic vapor compression refrigeration systems obtainedearlierusing nano oil/R152a mixture than pure R152a.
- At steady state, the evaporator cabin temperature obtained– 3 °C and – 5 °C with 80 g charge ofR152a using 0.2% 0.3% nano oil suspension.
- R152a/MWCNT nano oil mixture continually offers thelowest compressor power consumption from 2.57 to 31.55% than the pure R152a/oil mixture for all selected refrigerant charges.
- The compressor discharge temperature of the pure refrigerant and R152a/nano oil mixture was recorded as increased for all the selected refrigerant charges. In contrast, continual reductions in discharge temperature were observed for almost all the selected nano oil suspensions than the pure refrigerant charges. The least discharge temperature, about 54 °C, was noticed with a 60 g mass charge of R152a using 0.3%, and the highest was 79 °C with 120 g using 0.1% nano oil mixture.
- The high rate of compressor energy saving percentage (that of 31.55%) was attained using 0.3% nano oil suspension for 120 g charge of refrigerant.
- Thermal conductivity of pure oil using selected nano oil compactness simultaneously increased. The average increasein thermal conductivity was about 11% of pure oil for all the selected MWCNT fractions.
- Dynamic viscosity of nano oil of values 0.0696 and 0.0704 Pa. swas achieved at a temperature of 40 °C for 0.1 and 0.2 % MWCNT concentrations, 12% and 15% higher than that of pure oil. Thepure and nano oil density constantly reduces as the oil temperature and nanoparticles volume fraction increase. Further,

applying MWCNT nanoparticles in pure oil resulted in an 11.61% reduction of the COF for the transient period.

- The average COP achieved using R152a/nano oil mixture is 56% higher relative to pure R152a/oil mixture. In addition, the improvements in cooling capacity rate and reductions received in compressor pumping power increased the COP of the VCR system.
- R152a/MWCNT nano oil blend within the VCR system performed better than R152a single fluid and acted as a suitable candidate for improving the COP of the system.

Declaration of Interest

None

Nomenclature

LPG	liquid petroleum gas
ODP	ozone depletion potential
GWP	global warming potential
HFC	hydro flouro carbon
SEM	scanning electron microscopy
MWCNTs	multi walled carbon nanotubes
CNTs	carbon nanotubes
COP	coefficient of performance
COF	coefficient of friction
VCR	vapor compression refrigeration
CuO	copper oxide
SiO_2	silica oxide
ZnO	zinc oxide
TiO_2	titanium oxide
Ag	silver
Al_2O_3	alumina oxide
ZrO_2	zirconium oxide
MgO	magnesium oxide
MO	mineral oil
POE	polyester
PAG	polyalkylene glycol
HP	horse power
C_p	specific heat [kJ/(kg.)]
t	time [s]
P	pressure [MPa]
T	temperature [°C]
U_R	total uncertainty
U_V	uncertainty of variable

Subscripts

g	gram
°	degree

K Kelvin

s second

W watt

D diameter

Pa pascal

L liter

wt. weight

m meter

k kilo

o oil

f fluid

v vapor

in inlet

L liquid

k kilo

W watt

nm nanometer

1 suction

2 discharge

e evaporator cabin

n total number

R parameter

Greek Symbols

φ nanoparticles fraction [%]

ρ density [g/m^3]

λ thermal conductivity [W (m·K)]

μ micro

Δ difference

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