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PERFORMANCE ESTIMATION OF BLENDED NANO-REFRIGERANTS' THERMODYNAMIC CHARACTERISTICS AND REFRIGERATION EFFICACY

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Abstract: The use of nanoparticle-infused blended refrigerants is essential for achieving an effective sustainable system. This investigation analyses the efficiency of three nano-refrigerants (CuO-R152a, TiO2-R152a and TiO2-R113a) on the basis of the thermal performance and energy usage of the compressor using MATLAB-Simulink in the vapour compression refrigeration cycle with a two-phase flow domain. Also, nanoparticle volume concentrations of 0.1%–0.5% in the basic refrigerants are investigated. In the Simulink model, the outcomes are calculated mathematically. Using the NIST chemistry webbook, the thermo-physical characteristics of base refrigerants were calculated, and different numerical models were used to compute the characteristics of nano-enhanced refrigerants. MS Excel was used to perform the liquid–vapour interpolation. It was discovered that refrigerants with nanoparticles have superior heat-transfer properties and operate most excellently at an optimal volume fraction of 0.1% for TiO2-R152a and CuO-R152a with a coefficient of performance (COP) as 10.8. However, the other blended nano-refrigerant TiO2-R113a performed the best at 0.5% of nano-particle volume fraction with a COP value of 5.27.

Key words: Coefficient of performance, compressor power, heat-transfer rate, volume percentage, heat extraction, power consumption

1. INTRODUCTION

Scientists from around the world came to the conclusion that air conditioning and refrigeration equipment used far too much energy. As a result, there is a need to use energy-efficient technology to counteract the limited availability of energy [1–5]. In light of the present scenario, to improve the heat transfer in the vapour compression refrigeration systems (VCRSs), it needs new and advanced heat-transfer fluids. Nanoparticles suspended in refrigerants represent a suitable substitute for conventional refrigerants. Various researchers show a higher heat-transfer performance (HTP) of nano-added refrigerants [6–10].

One of the most important issues related to modern refrigeration, air conditioning and heat pump technology is the need to phase out the currently used groups of refrigerants and to replace them with alternative, environmentally safe working fluids, e.g. natural fluids [11]. The fact is that all solutions in refrigeration technology are determined primarily by the thermodynamic properties of refrigerants. In some cases, changing the refrigerant forces the modification of the construction of the device. Replacing the refrigerant may cause the energy efficiency achieved by these devices to significantly reduce. However, manufacturers are taking all measures to ensure that the energy efficiency of the devices is at least at the same level as when working with the withdrawn refrigerants. As a result of this measure, new, synthetic refrigerants are being introduced. Alternatively, the refrigerants are modified with the help of nanoparticles that improve their thermo-physical properties. There are more and more synthetic or modified refrigerants available on the market, the use of which at least minimally eliminates the need to modify the previously used technical solutions. The massive production and consumption of synthetic fluids such as chloro-fluoro-carbons (CFCs) and hydro-chloro-fluoro-carbons (HCFCs) for which negative effects have been demonstrated forced the world community to take steps to radically change this alarming situation. Currently, these refrigerants are classified as the so-called controlled substances.

The Montreal Protocol is the first international agreement on an environmental policy whose primary objective is to prevent the risks related to the emission of these fluids into the atmosphere. The current version of the Protocol deviates from the original one, as the document has been modified many times. The latest amendments from Kigali came into force on 01 January 2019. For refrigerants belonging to the HCFC group, their use in new refrigeration installations has been banned since 01 January 2004, and a timetable has been set for their complete phase-out. For HCFC refrigerants, the applicable timetable for reducing their consumption by 79% is by 2030 compared to the base year of 2015. In addition, according to the EU regulation [11], the use of refrigerants with a global warming potential (GWP)>150 is prohibited in large centralized refrigeration systems with a capacity above 40 kW and used for commercial applications from 01 January 2020. Also, since 01 January 2022, refrigerants belonging to the HFCs with a GWP > 150 cannot be used in air conditioning units. For single air conditioning split systems with refrigerant chargesof up to 3kg, the use of GWP > 750 refrigerants will be banned from 01 January 2025. As previously mentioned, scholars are making efforts to improve refrigerant properties, e.g. heat transfer coefficients (HTC), viscosity, and so on.

Nanoparticles can be used in refrigerants as additives, aimed at improving the properties such as thermal conductivity, chemical and thermal stability and lubricating properties, which in turn can contribute to increasing the efficiency of the refrigeration system. The use of nanoparticles in refrigerants can increase the production and disposal costs of refrigerants due to higher production costs of nanoparticles and potential difficulties in their disposal. Depending on the desired effect of the base fluid, copper and graphite nanoparticles can be used to improve the thermal conductivity of the refrigerant. Cerium oxide nanoparticles allow for the improvement of the chemical and thermal stability of the refrigerant. Titanium oxide nanoparticles improve the antibacterial properties of intermediate fluids, while carbon nanoparticles are used to improve lubricating properties and reduce friction in intermediate fluids. The stability of the nano-refrigerant is one of the major concerns. The agglomeration of the nanoparticles in the fluid is increased over time by disturbing the viscosity and thermal conductivity of the base fluid. Apart from that, the sustainability of the nano-fluids is not practical because of the cost issues [42–44].

Buonomo et al. [12] used TRNSYS to perform a dynamic simulation of Al_2O_3–water nanofluid in the solar cooling system for volume concentrations of 3% and 6%, and they came to the conclusion that the nanofluid showed higher energy savings for the entire summer season of the year, although the difference between the savings for the two-volume concentrations was small. The same nanofluid was used by the team for a TRNSYS modelling of the automotive cooling circuit, and they discovered that at low engine speeds, the nanofluid performed better in all circumstances and had a substantially higher HTP than the ethylene–glycol coolant [13].The convective HTC increased with a greater concentration of nanoparticles when the Al_2O_3–water nanofluid was through a rectangular micro-channel with uniform and steady heat fluxes on the top wall [14]. The improvement of the HTC that aids in reducing engine overheating was made possible by the use of nanofluids as a cooling system for radiators in automotive vehicles [15]. This results in its utilisation as an engine-coolant substitute [16, 17]. Al_2O_3–mono ethylene glycol (MEG)–water nanofluid's effect on car radiators was examined by Subhedar et al. [18], who also improved the overall HTC and enabled a 36.69% reduction in the radiator surface area. The researchers analyzed the HTP and pressure drop of the new-generation refrigerants such as R1234yf. The investigation shows that the HTC and the pressure drop of the CuO/R1234yf nano-refrigerant are enhanced by 45% and 36%, respectively [45]. Similarly, the HTC and pressure drop of the TiO_2-doped R1234yf refrigerant is improved by 134.03% and 80.77% [46].

One method to reduce the energy requirement of the VCRS is to use nano-fluid, which is a combination of a specific quantity of nano-sized particles dissolved in a fluid to create a colloidal solution. When these substances are employed for refrigeration, they are referred to as nano-refrigerants. The chemically stable metals like Au and Cu and metal oxides such as Al_2O_3, SiO_2, TiO_2, zirconia, and oxide ceramics are commonly used as nano-sized particles in VCRS [19, 20]. Nano-refrigerants are synthesized by two techniques: (i) the single-stage process and (ii) the double-stage process. The double-stage technique [23] divides the two processes; the single-stage technique [21, 22] combines the creation and mixing of nanoparticles into pure fluid concurrently. Coumaressin and Palaniradja [24] studied the HTP of CuO nanomaterials added to an R134a-based refrigerant in VCRs. By increasing the volume fraction of CuO from 0.1% to 0.8%, the HTC of CuO-R134a was increased. Anish et al. [25] studied the effects of adding CuO to the refrigerant R-22 and found that total coefficient of performance (COP) was improved while power consumption was reduced. When 0.05% CuO nanoparticles were introduced, the COP rose from 0.58 to 0.62. According to Bi et al.'s research [26], adding 0.5g/L of TiO_2 to R600a reduced the energy consumption by 9.6%. Kumar et al. [27] demonstrated the influence of the CuO nanometal oxide on liquid petroleum gas–based VCRS, following the efficacious validation of nano-refrigerants in residential VCRs. Figure 1 shows that the system's performance and heat-transfer rate both increased by 36% and 46%, respectively.

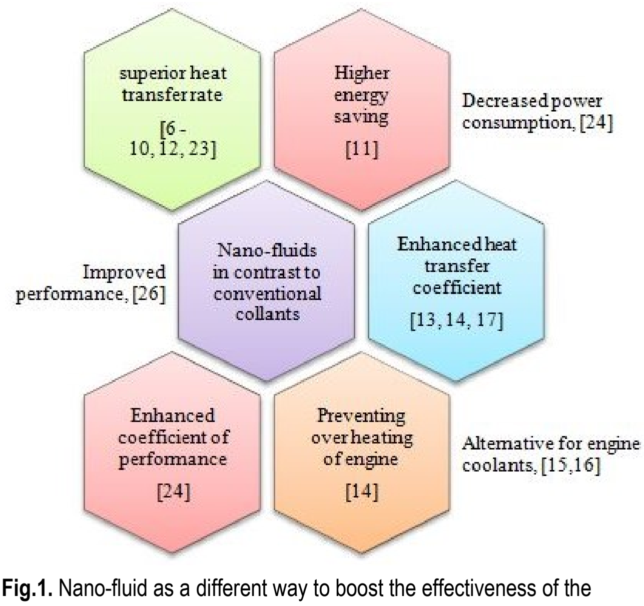

Fig.1. Nano-fluid as a different way to boost the effectiveness of the system

The three nano-added refrigerants, which the MATLAB model simulated, form the primary focus of the study. The main goal of the article is to use nano-enhanced refrigerants to improve system performance and decrease compressor energy usage. Hence, improvising on the performance of the VCR system with nano-refrigerants such as TiO_2-R113, TiO_2-R152a and CuO-R152a forms the crux of this research. Also, in this paper, the thermal properties of these nano-refrigerants are identified, which were crucial for the analysis.

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2. METHODOLOGY AND MATERIALS

2.1. Materials

The VCRS is used in this investigation with three nano-enhanced refrigerants, namely, TiO_2-R113a, TiO_2-R152a and CuO-R152a. The pure refrigerant has nanoparticle volume concentrations in the range of 0.1%–0.5%. This range is chosen to obtain a stable nano-refrigerant; beyond this range, there could be the challenge of agglomeration. SRD 69 computed several input parameters for basic refrigerants using the NIST chemistry webbook. Several numerical models were used to determine the thermo-physical parameters of nano-refrigerants.

2.2. Numerical models

There are various ideas and models for determining nano-refrigerant characteristics. Information on the state and type of nanoparticles used must be included in these models. The Cp, k, ρ and size of nano-materials that will be employed in models are given in Tab. 1. These characteristics vary somewhat depending on particle size. It is assumed that the spherical nanoparticles are spread throughout the pure refrigerant.

Tab.1. Nanoparticle properties at environmental temperature

Nano-materials	ρ ($kg \cdot m^{-3}$)	k($W \cdot m^{-1} \cdot K^{-1}$)	C_p ($J \cdot kg^{-1} \cdot K^{-1}$)	R (nm)
CuO[28]	6,500	20	535.6	20
TiO_2[29]	4,230	8.4	692	21

'k' is one of the most important aspects of improving nano-refrigerant performance. Several models were evaluated in this work, including Maxwell's [30], Hamilton and Crosser's [31], Yu and Choi's [32] and Koo and Kleinstreuer's [33]. The *'k'* is determined in this study using Maxwell's model. As Simulink software is used here instead of a real setup, the continuous phase with spherical nanoparticles matches Maxwell's model perfectly.

$$\frac{k_{nf}}{k_{ref}} = \frac{k_{np}+2\,k_{ref}-2\phi(k_{ref}-k_{np})}{k_{np}+2\,k_{ref}-\phi(k_{ref}-k_{np})} \qquad (1)$$

The Gherasim model [34] gave the viscosity of nano-refrigerants with sphere-shaped nanoparticles, which is dependent on the volume concentration and viscosity of the basic refrigerant.

$$\frac{\mu_{nf}}{\mu_{ref}} = 0.904e^{14.8\phi} \qquad (2)$$

The nanoparticle's 'ρ', the 'ρ' of the base refrigerant and the volume fraction all influence the effective 'ρ' of the nano-refrigerant [35].

$$\rho_{nf} = (1-\phi)\rho_{ref} + \phi\rho_{np} \qquad (3)$$

This $C_{p,ref}$ value is needed to determine $C_{p,nf}$ using Eq. 4, which is also dependent on base refrigerant densities, nanoparticles, nanoparticle Cp and volume concentration [36]:

$$C_{p,nf}\rho_{nf} = (1-\phi)C_{p,ref}\rho_{ref} + \phi C_{p,np}\rho_{np} \qquad (4)$$

The *Pr* is identified by the following correlation, which uses the μ_{nf}, k_{nf}, and $C_{p,\,nf}$.

$$Pr = \frac{viscous\ diffusion\ rate}{thermal\ diffusion\ rate} = \frac{\mu \times Cp}{k} \qquad (5)$$

2.3. Simulation and modelling

The investigations were accomplished with the help of a VCRS model that was created utilizing a unique Simscape two-phase flow domain. The present VCRS cycle is based on the MATLAB–Simulink platform, which is freely accessible on the MathWorks File Exchange [37]. The setup and its characteristics are shown in Figs. 2 and 3. An evaporator, thermostatic expansion valve, condenser, compressor, compartment and controller constitute the VCRS model. The temperature of the compartment is kept at 277K in this analysis by regulating the compressor parameters. The controller is used to turn the compressor on and off. When the temperature of the compartment rises over the set temperature, the compressor is turned on and it cools the compartment below the set temperature.

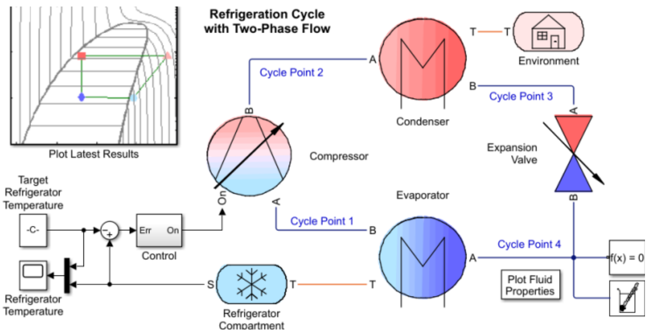

Fig. 2. Layout of simulation [37]

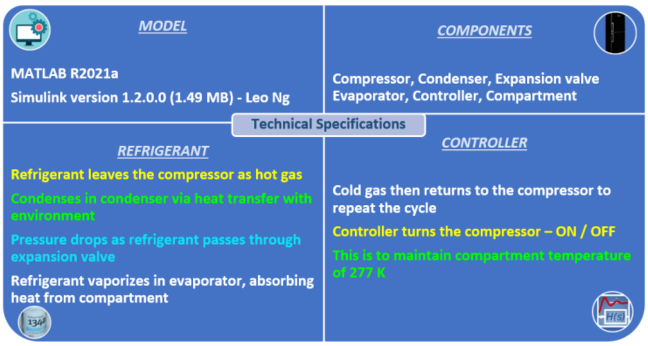

Fig. 3. Defined specifications

The goal of the simulation is to examine how adding nanoparticles to basic refrigerants affects power usage and COP. There is always an ideal volume fraction when the COP is at its highest. There could be enhancement in the refrigeration effect as the heat-transfer characteristics are improvised with the addition of nanoparticles. As a result, research into that impact might be advantageous.

Many factors, both inside and outside the cycle, influence the compartment heat, extracted compressor power and COP. All these variables are included in all the simulations. Furthermore, using the facility and infrastructure accessible to them, research-

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ers have investigated physical setups for different nano-refrigerants. This analysis is using a single platform to run a variety of combinations. The main goal is to detect a broad trend in all of these variables. The cycle conditions are shown in Tab. 2.

Tab. 2. VCRS cycle boundary values

Charge pressure	87 psi
Flow of mass	14.4 kg·h^{-1}
Compressor time constant	20 s
Length of condenser	1,500 mm
Conductivity of Cu	400 W·m^{-1}·K^{-1}
‘ρ’ of Cu	8,940 kg·m^{-3}
Specific heat of Cu	390 J·kg^{-1}·K^{-1}
Temperature of surrounding	293 K
Length of evaporator	15 m
Surface area of exterior	6 m^2
Area of fin	1 m^2
Fin convention coefficient	150
Conductivity of foam	0.03 W·m^{-1}·K^{-1}
Thickness of foam	0.03 m
Liquid fraction	0.8
Interior area of surface	4.5 m^2
Max area of the throat	2.7 m^2
Max. temperature of throat	230 K
Min. area of the throat	0.1 m^2
Min. temperature of throat	280 K
Coefficient of natural convection	20 W·m^{-2}K^{-1}
Diameter of pipe	15 mm
Thickness of pipe	5 mm

Tab.3. Runtime conditions for a refrigeration cycle

Refrigerant	Nano-concentration (%)	Pressure range (MPa)	Temperature range (K)	Run time (s)
TiO_2-R113a	0	0.01–3	240–420.6	509
	0.1			488.5
	0.3			484.5
	0.5			472
TiO_2-R152a	0		160–420.4	769
	0.1			854
	0.3			834.5
	0.5			823.5
CuO-R152a	0		160–420.4	769
	0.1			854.5
	0.3			830
	0.5			824

Throughout the refrigeration cycle, the mass flow rate of the refrigerant is kept constant. As a result, the pipe's velocity was not estimated. The phenomenon of sedimentation was not considered. The working conditions used to be similar to the home freezers. Most residential refrigerators have a charge pressure ranging from 0.3 MPa to 1 MPa. Copper is used as the heat exchanger material in the VCRS model, typically with grooves or a tube or coil. Aluminium, brass, stainless steel and other metals are also utilized. Insulation in the refrigerator compartment is provided by polyurethane foam. A compressor on/off mechanism was included in the model. The cycle run times for various combinations of refrigerants are shown in Tab. 3.

It is expected that nano-fluids will behave differently in a real configuration because their stability affects their HTP as well as their flow properties. The kind of nanoparticles employed, the heating surface and the base type are all aspects that will differentiate the simulation research from the real-world arrangement. The boiling HTC decreases when porous deposits form on the heated surface of the nano-materials. The critical flux is significantly impacted by the nano-refrigerant. Because of the high volume fraction of nano-sized materials in the fluid, the critical flux is lowered. The higher viscosity of a base fluid can lessen the influence of the boiling HTP of a nano-refrigerant, resulting in improved HTP since stability is better and nanoparticles exhibit a greater boost in the ‘*k*’ value. Higher viscosity also results in less nanoparticle sedimentation on the heated surface [38].

The simulations are based on theoretical discoveries and an idealized design, for the most part. The stability of the nano-refrigerant is not taken into consideration in the formulae. The article's main goal was to evaluate nano-refrigerants to see which one was superior based only on the thermo-physical qualities. In future, laboratory studies may be conducted to confirm these theoretical conclusions. Mechanisms for regulated stability may be devised in the future; at that point, the current research will be useful in determining which combination provides the best performance of the system.

2.4. Simulation model's summary

An experimental configuration is comparable to the Simulink model. If any of the parameters are incorrect, errors are prompted, and various parameters are checked. Only after all mistakes are fixed does the simulation start and then end. Regardless of the pressure differential, the compressor maintains the prescribed mass flow rate. The Fourier law governs heat transfer in condensers and evaporators. It argues that the temperature differential, the area normal to the direction of heat flow, material thermal conductivity and layer thickness are all directly and inversely correlated with the heat transfer. Between the fluid and the pipe wall of both parts, there occurs convective heat transfer. Pressure loss is modelled for the local control restriction elements such as valves and orifices. They are adiabatic devices [39]. Components of the heat exchange use various kinds of friction correlations:

Halland correlation used for identifying the turbulent pipe flow friction factor:

$$f_d = \frac{1}{\left(-1.8\, x \log\left(\frac{6.9}{Re}+\left(\frac{eps}{3.7}\right)^{1.11}\right)\right)^2} \tag{6}$$

Laminar regime viscous friction force:

$$F_f = \frac{4\ f_S \mu V L e}{D_h^2 m} \tag{7}$$

Turbulent regime viscous friction force

$$F_t = \frac{4\ f_d\ Le}{m\ v} \tag{8}$$

The net power delivered to the fluid flowing from the inlet to the outlet of the compressor is given by

$$W = m\left[\left(u_{out} + (P_{out}V_{out}) + \frac{v_{out}^2}{2}\right) - \left(u_{in} + (P_{in}V_{in}) + \frac{v_{in}^2}{2}\right)\right] \tag{9}$$

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The heat extracted from the evaporator is determined by:

$$Q_{extract} = h\, S_{sur}\, \Delta T \tag{10}$$

The system performance is expressed by the COP, which is the ratio of the heat extracted from the evaporator to the compressor power input (or net power delivered).

2.5. Model validation

Tsvetok et al.'s [40] experiment is used to determine the thermal conductivity of the R134a refrigerant at low temperatures to validate the Simulink model with base properties. The thermal conductivity was measured at quasi-static isobars at a total of around 54 experimental locations using a coaxial cylinder technique. Figure 4 demonstrates how closely experimental values and simulation results correspond.

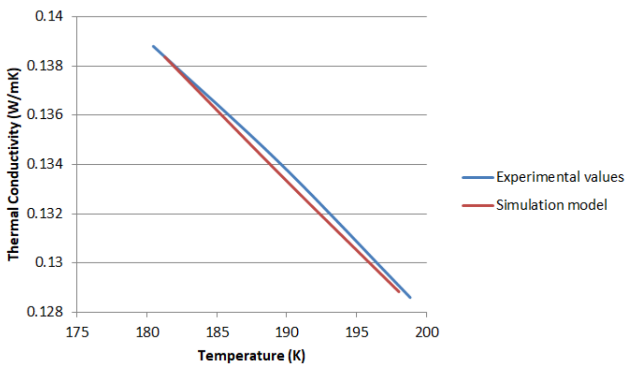

Fig. 4. Validation of simulation model

3. RESULTS AND DISCUSSION

3.1. Nano-enhanced refrigerants' thermodynamic states

As demonstrated in Tab. 4, the *'k'* value of the nano-refrigerant enhances as the volume concentration of nanoparticles in the pure fluid increases. The absorbency of the nanofluid is crucial because it enhances the *'k'* value of the nano-enhanced refrigerant. Tab. 3 indicates that a 0.1% addition of nanoparticles in CuO-R152a with TiO_2-R152a shows only a 0.019% variation in the *'k'* value. Meanwhile, the refrigerant is changed with R113a; the *'k'* is reduced by 1.33 times.

Tab. 4. The *'k'* value of refrigerants at atmospheric conditions

Nano-refrigerant	Volume concentration		
	0.1% ($W{\cdot}m^{-1}{\cdot}K^{-1}$)	0.3% ($W{\cdot}m^{-1}{\cdot}K^{-1}$)	0.5% ($W{\cdot}m^{-1}{\cdot}K^{-1}$)
TiO_2-R113a	0.0663	0.0676	0.0687
TiO_2-R152a	0.0883	0.0899	0.0915
CuO-R152a	0.0883	0.0900	0.0916

According to the findings of Mahdi et al. [41] and the current study, adding nanoparticles increases the viscosity of the basic refrigerant. When the volume fraction increases as a result of more surface area coming into contact with the refrigerant, the viscosity rises. The presence of nanoparticles is not necessary. At 25°C and 1 atm, Tab. 5 displays the viscosities of the TiO_2-R113a, TiO_2-R152a, and CuO-R152a refrigerants. The table makes it evident that the viscosity of the nano-refrigerant increases dramatically as the volume percentage of the nano-sized material increases. For instance, TiO_2-R113a has a 4.8% increase in viscosity.

Tab.5. Viscosity of combinations at atmospheric condition

Nano-refrigerant	Particle concentration		
	0.1% (10^{-4} $kg{\cdot}m^{-1}s^{-1}$)	0.3% (10^{-4} $kg{\cdot}m^{-1}s^{-1}$)	0.5% (10^{-4} $kg{\cdot}m^{-1}s^{-1}$)
TiO_2-R113a	5.209	7.004	9.417
TiO_2-R152a	1.281	1.722	2.315
CuO-R152a	1.281	1.722	2.315

Tab. 6. 'ρ' of combination at atmospheric condition

Nano-refrigerant	Nanoparticle loading		
	0.1% ($kg{\cdot}m^{-3}$)	0.3% ($kg{\cdot}m^{-3}$)	0.5% ($kg{\cdot}m^{-3}$)
TiO_2-R113a	1,567.66	1,572.99	1,578.32
TiO_2-R152a	834.19	840.99	847.79
CuO-R152a	836.47	847.81	859.15

Tab.7. Specific heat of the combinations at atmospheric condition

Nano-refrigerant	Volume fraction		
	0.1% ($J{\cdot}kg^{-1}{\cdot}K^{-1}$)	0.3% ($J{\cdot}kg^{-1}{\cdot}K^{-1}$)	0.5% ($J{\cdot}kg^{-1}{\cdot}K^{-1}$)
TiO_2-R113a	911.95	911.84	911.73
TiO_2-R152a	1,794.4	1,783.3	1,772.4
CuO-R152a	1,790.2	1,770.9	1,752.2

The specific volume of each nano-refrigerant is determined by its 'ρ'. According to Tab. 6, the 'ρ' of nano-refrigerants is quite high compared to the 'ρ' of its basic refrigerant and gets better as nanoparticles are added. As a result, the specific volume reduces as particle concentration rises. When 0.1% of nanoparticles are introduced into the pure refrigerant, the 'ρ' value of the TiO_2-R152a refrigerant is two times greater than that of TiO_2-R113a. This is owing to the density variation of the base refrigerants such as R152a and R113a. The percentage increase in 'ρ' of TiO_2-

R113a is 0.34% when the nanoparticle concentration changes from 0.3% to 0.5%. However, it is 0.8% in the case of TiO_2-R152a.

Table 7 gives the specific heat of all mixtures. The nano-refrigerants' specific heat is shown to increase with volume fraction. At 0.5% nano concentration, TiO_2-R152a had the highest specific heat.

3.2. System performance using different nano-enhanced refrigerants

The VCRSs' performance is denoted in terms of the COP. The COP is influenced by compressor power and the heat extracted from the evaporator.

3.2.1. Influence of nanoparticles on heat extraction from the evaporator

For various nano-refrigerants, the heat evacuated from the evaporator is shown in Fig. 5. Fig. 5 clearly shows that the TiO_2-R113a nano-refrigerant removes significantly more heat than the R113a refrigerant. In contrast to the pure refrigerant, the heat extraction rose by 170.05% for 0.1% TiO_2-R113a nano-refrigerant, while it was only 1.68kW for 0.3% TiO_2-R113a, which was somewhat less than 0.1%. The amount of heat extracted for 0.5% TiO_2-R113a was the highest at 1.79 kW or nearly three times the amount of heat extracted by the R113a refrigerant. In contrast, the heat extraction for TiO_2-R152a and CuO-R152a followed a different pattern. The heat extraction decreased by 9.2% and 9.5% in the cases of 0.1% and 0.5% TiO_2-R152a, respectively, but was still higher than that of 0.3% TiO_2-R152a, which saw a reduction of 13.13% and reached 0.923 kW. The heat extraction from the evaporator is also reduced with the addition of nanoparticles to the CuO-R152a nano-refrigerant. Heat extraction in nano-refrigerants performed best for 0.1% CuO-R152a and worst for 0.3% CuO-R152a, as 1.03kW and 0.97kW, respectively.

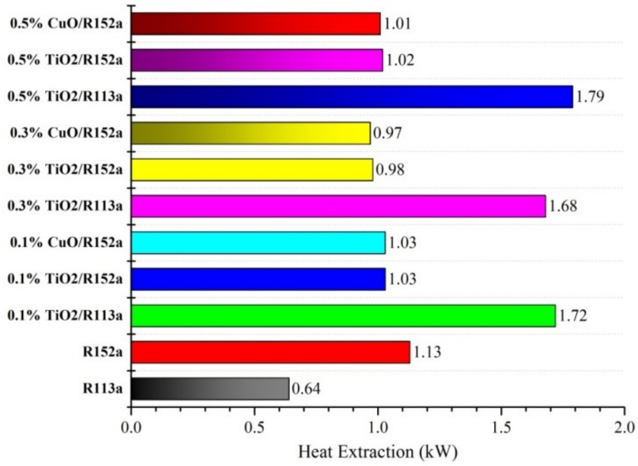

Fig.5. The heat extraction from evaporator

3.2.2. Impact of a nano-sized particle on compressor power usage

Figure 6 illustrates the variation of compressor power usage for TiO_2-R113a, TiO_2-R152a and CuO-R152a nano-refrigerant. Figure 6 show the use of nano-refrigerants might reduce compressor energy consumption. For nano-refrigerant containing 0.1% TiO_2-R113a, energy consumption decreased by 19.9%. Similarly, at 0.3% of TiO_2 in R113a refrigerant, the energy consumption is decreased by 17.7% and it is reduced by 9.91% for 0.5% TiO_2-R113a. The power consumption decreased by 35.4% when 0.1% TiO_2-R152a was used, but only little when 0.3% and 0.5% of TiO_2 in R152a were used. It is decreased by 9.302% and 16.78%, respectively. Likewise, is decreased by about 50% for 0.1% CuO-R152a. However, the drop was 15% and 10%, respectively, for 0.3% and 0.5% CuO-R152a.

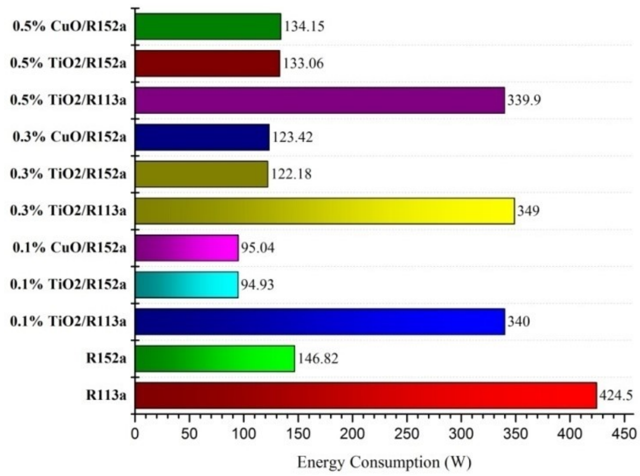

Fig.6. The energy consumption of the compressor

Generally, the power consumption enhances with the nanoparticle addition in the refrigerant. This is due to the viscosity of the fluid increasing with the concentration of the particles. It leads to improving the resistance to flow. This is the reason for the rise in the power consumption of compressors with nano-enhanced refrigerants.

3.2.3. Effect of nanoparticle on COP

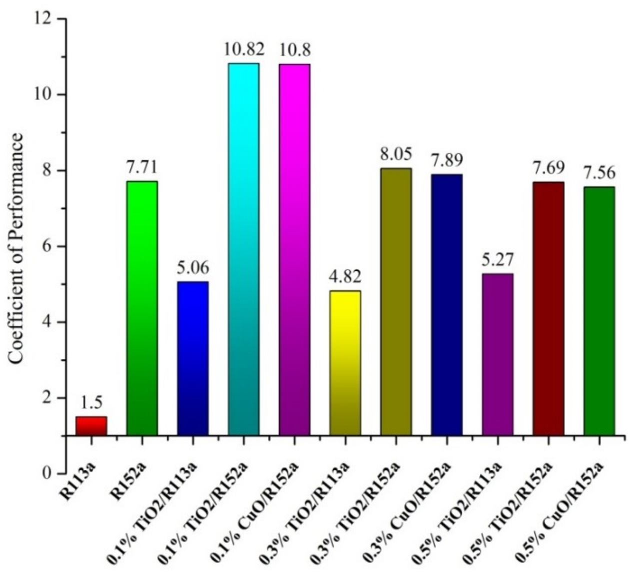

Fig. 7. Variation of systems' performance

Figure 7 demonstrates how the nanoparticles in the refrigerant affect the COP. Figure 7 shows that the COPs for nano-refrigerants are nearly three times more than those for basic refrigerants.

The greatest COP, 5.27, is for 0.5% TiO_2-R113a, whereas 0.1% has a COP of 5.06. Although the COP of 0.3% TiO_2-R113a has grown by 221.193% than base refrigerant R113a, it remains below that for 0.1% and 0.5%. Figure 7 explains that the maximum COP for adding 0.1% TiO_2 nanoparticles to R152a is 10.82, whereas for 0.3%, the improvement in COP over the base refrigerant is just 4.39%. When compared to R152a, the COP is practically the same at 0.5%. Similar to this, R152a's 0.1% addition of CuO nanoparticle results in a 10.8 COP. The COP for base and nano-refrigerants with 0.5% is almost the same. A bit higher than the base refrigerant, the COP for the 0.3% CuO-R152a refrigerant is 7.89.

The difference in the thermo-physical characteristics between nano-refrigerants and base refrigerants can be attributed to this behaviour. As the viscosity increases as the particle concentration, the value of COP declines.

4. FUTURE SCOPE

In the present situation, no software platform exists where a researcher may input nano-refrigerant parameters and obtain results. All of the analyses are carried out theoretically and numerically; therefore, experimental studies are needed in future. The stability of the nano-refrigerant is not taken into consideration in the formulae. The article's main goal was to evaluate nano-refrigerants to see which one was superior based only on thermo-physical qualities. In future, experimental investigations may be conducted to confirm these theoretical conclusions. So, in the near future, there is a possibility of developing a programme for nano research utilizing software such as MATLAB, which may aid in providing different inputs such as nanoparticle diameter, nanoparticle type, base refrigerants, charge value and so on. The exergy and environment analysis of the system should become more reliable and the life cycle assessment will provide an idea about the performance of the system. These are the futuristic scope of this work.

Furthermore, it is important to undertake future research regarding theoretical analysis and validation studies of the impact of nanoparticles on the thermal properties of environmentally friendly refrigerants from the HC group such as R600a or R290, as well as other refrigerants with low GWP values such as R1233zd, R1233ze or R1234yf. Additionally, it is extremely important to determine, through research, the impact of lubricating oil in the refrigeration compressor system on the stability of the refrigerant and the uniform concentration of nanoparticles throughout the volume of the refrigerant.

5. CONCLUSION

The addition of the nanoparticles to the refrigerant improves the COP of the refrigeration system and reduces the power consumption by the compressor than the base refrigerants. Except for TiO_2-R113a, it can be inferred that the 0.1% concentration of nano-sized materials in the pure refrigerant has the greatest COP. The efficiency was lowered by 0.3% and 0.5% owing to an improvement in viscosity. The maximum COP obtained for adding 0.1% TiO_2 nanoparticles to R152a is 10.82. Meanwhile, the power consumption decreased by 35.4% when 0.1% TiO_2-R152a was used, but only to a lesser extent when 0.3% and 0.5% TiO_2-R152a were used. Two of the features of blended nano-refrigerants, including viscosity and thermal conductivity, were also examined in the study that is presented. According to sources, the use of nanoparticles increases viscosity, improving the compressor's tribology. The system's performance thus declines to some extent as a result of the system's increased viscosity and the ensuing decrease in pressure. Additionally, a mixed nano-refrigerant with low viscosity and excellent heat conductivity maximizes the efficacy of nano-refrigeration systems. An investigation implies that blended nano-refrigerant systems could be one of the sustainable energy solutions. Hence, energy-efficient nano-refrigeration systems with compressors consuming less power and systems giving more COP could curtail the global warming. Also, one could optimize the efficacy of the refrigeration system by choosing the appropriate percentage of volume concentration of the nanoparticles.

Nomenclature:

Abbreviation:

CFC	Chloro-fluoro-carbon
COP	Coefficient of performance
EU	European Union
GWP	Global warming potential
HCFC	Hydro-chloro-fluoro-carbon
HTC	Heat-transfer coefficient, W·m^{-2}K^{-1}
HTP	Heat-transfer performance
NIST	National institute of standard and technology
VCRS	Vapour compression refrigeration system

Symbols:

Cp	Specific heat, J kg^{-1} K^{-1}
D_h	Hydraulic diameter, m
eps	Internal surface absolute
f_d	Flow fraction factor
f_s	Shape factor
k	Thermal conductivity, W
m	Mass flow rate, kg s^{-1}
v	Specific volume, m^3·kg^{-}
F_f	Laminar flow friction forc
F_t	Turbulent flow friction fo
L_e	Effective length, m
P	Pressure, MPa
Pr	Prandtl number
R	Radius of nanoparticle, nm
Re	Reynolds number
S_{sur}	Surface area of evaporator, m^2
T	Temperature, K
U	Internal energy, kJ kg^{-1}
V	Velocity, ms^{-1}

Subscripts:

ref	Base refrigerant
nf	Nano-refrigerant
sat	Saturation
np	Nanoparticle

Greek Symbols:

ρ	Density, kg m^{-3}
ϕ	Concentration
μ	Viscosity, kg·m^{-1}s^{-1}

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