Short Communication

ANALYSIS OF NOVEL REFRIGERATION SYSTEMS PERFORMANCE WITH AND WITHOUT NANOPARTICLES

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ABSTRACT

Due to their high rate of heat transfer and better thermo-physical properties, the application of nanoparticles in cooling systems results in better enhancement, improved reliability and efficiency of refrigeration and air conditioning systems, and hence, they are widely used in domestic and industrial sectors. It has been found that the major contribution to global warming potential (GWP) and depletion of ozone layer (ODP) is due to the over usage of conventional refrigerants; thus, the utilization of nanoparticles in refrigeration and air conditioning systems is highly recommended. The application of nanorefrigerants not only increases the thermal conductivity and heat transfer characteristics but also improves the coefficient of performance (COP) effectively, leading to energy savings. This article comprises the theoretical analysis of R134a-Al_2O_3, R134a-ZnO, R134a-TiO_2 and R134a-CuO mixtures as replacements of pure R134a refrigerant in vapour compression refrigerants (VCRs). For comparison, the COP and refrigeration effect (RE) of the system with and without the addition of nanoparticles are determined from reported observations. It is concluded that the COP of a refrigeration system with added nanoadditives in refrigerant fluid is higher than that of systems running with pure refrigerant fluid. Around 38% increase in COP has been recorded in this study. Moreover, CuO nanoparticles showed high value of COP when blended with R134a compared to other nanoparticles. The COP of the refrigeration systems varies with the type of refrigerants used in the system.
Keywords: nanoparticles, nanorefrigerant, ozone depletion potential, vapour compression refrigeration.

1 INTRODUCTION

Nanofluids play an important role in engineering applications such as nuclear reactors, refrigeration and air conditioning, heat pumps and electronic components by enhancing their heat transfer [1]. Expansion of urbanization, increase in temperature by burning fossil fuels, and cutting down rainforests and farming livestock add enormous amounts of greenhouses gases to those naturally occurring in the atmosphere, increasing the greenhouse effect and global warming [2]. Falling oil prices and usage of fossil fuels are considered the main contributors to ozone layer depletion and global warming. Due to these factors, most of the developed countries are focusing on renewable energy sources with ultimate goal the development of green earth [3, 4]. There is a high demand for energy efficient systems called thermal systems like air conditioners and refrigerators, having the capability to consume less electric power. Refrigerators and air conditioners running on environment friendly refrigerants need to be developed efficiently which is essential. The most commonly used refrigerant is HFC 134a, which has the capability to run air conditioners and refrigerators for both domestic and industrial sectors.

This article is based on investigations published recently [5]. Observations are carried out to determine the coefficient of performance (COP) of a vapour compression refrigeration system (VCRS) and its refrigeration effect (RE). The system COP can be improved by replacing conventional refrigerants with nanorefrigerants.

Nanoparticles of sizes ranging from 10 to 70 nm are mixed with base fluids such as water and a concentration of nanoparticles of around 0.05%–1%. Thermal conductivity eventually increases compared to that of the fluids. This is due to various factors which are listed below:

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1. Nanofluids help in decreasing clogging of particles.
2. Since the nanoparticles have higher surface area, nanofluids have the capability of increasing the heat transfer rate between the fluids and particles.
3. Nanofluids help in improved dispersion.
4. Nanofluids play a vital role in reducing the power for pumping for obtaining heat transfer.

It is found that when nanoparticles are mixed with refrigerants, heat transfer characteristics and thermo-physical properties will show a significant improvement, thereby better operational performance for the refrigeration system. In this project, Al_2O_3, CuO, ZnO and TiO_2 nanoparticles are used by mixing them with refrigerant R134a. With the help of existing data, enthalpies are found from p-h charts, and hence, RE and COP are calculated. The main aim is to find nanoparticles with better COP. In this article, the concentration for the nanoparticles is assumed to be around 0.05%–1%.

1.1 Nanofluids

Nanofluids are prepared by mixing nanoparticles (both metallic and non-metallic) with base fluids. The nanoparticles have the ability to react with liquids at molecular level due to their size which is usually small, that is, less than 100 nm, resulting in conduction of heat compared to other heat transferring liquids. Due to the conduction and convection process, nanofluids result in an enhanced and a better heat transfer process [6]. In order to achieve better thermo-physical properties like thermal diffusivity, viscosity, thermal conductivity and heat transfer coefficients, metallic nanofluids are used widely. They possess better properties compared to base fluids like water and oil. In this project, alumina oxide (Al_2O_3), zinc oxide (ZnO), titanium oxide (TiO_2) and copper oxide (CuO) are used. These nanoparticles are allowed to disperse in an R134a type refrigerant.

1.2 Various applications

Application of nanofluids can be seen in many industries today for the purpose of efficient heat transfer. The development and application of nanofluids help industries in energy saving, reducing emissions, increase in thermal rating, increase in equipment life and reducing the process time [7].

The power industry was reported with energy savings of around 20 trillion Btu per year when nanofluids were chosen for cooling [8]. In tyre industry, various industrial processes are used to cool rubber in the most effective way which requires around 2 million gallons of fluid for heat transfer. It is one of the aims of this industry to increase productivity by 10% by utilizing nanofluids.

A pressurized water reactor (PWR) system uses the application of nanofluid for cooling nuclear reactors efficiently [9]. This process eliminates bubbles, and a vapour layer is formed on the surface of fuel rods, thereby increasing critical heat flux (CHF).

Reduction of automobile energy consumption leads to better fuel efficiency. Improved position and compact size of radiators in automobiles can be achieved by the effective usage of nanofluids. Nanofluids are also applied in automobile fuel resulting to improved combustion process by mixing with diesel fuel.

2 OBJECTIVES

Nanotechnology helps the modern world to achieve clean and sustainable environment by eliminating environmentally hazardous energy. According to studies, metal nanoparticles are most widely used in the industries. The applications of nanoparticles are considered safe due to the interaction between the particles and liquids. The liquid phase of metal and metal oxide nanoparticles is vital, as it is through the liquid phase that materials come in contact with living systems.

In this study, investigations are conducted to compare the refrigeration systems with and without the application of nanoparticles for the improved system performance of refrigeration system. The heat transfer coefficient for various nanofluids is analysed and compared with a refrigeration system without any addition of nanoparticles by using p-h charts to calculate COP and RE.

3 VAPOUR COMPRESSION REFRIGERATION SYSTEMS

3.1 Simple VCR systems

Figure 1 depicts a simple VCR system, where the sequence of refrigeration cycle is said to be compressor › condenser › throttling valve › evaporator. Evaporator and condenser consist of series of coils to achieve heat transfer. Compressor and expansion valve are driven by mechanical means to regulate temperature and pressure changes during the stages. Operating under the reverse Carnot cycle, the VCRS has been considered the most widely used cooling system in industries. Ammonia was considered the refrigerant for VCR systems, but later, it was replaced by Freon due to its high nature of toxicity.

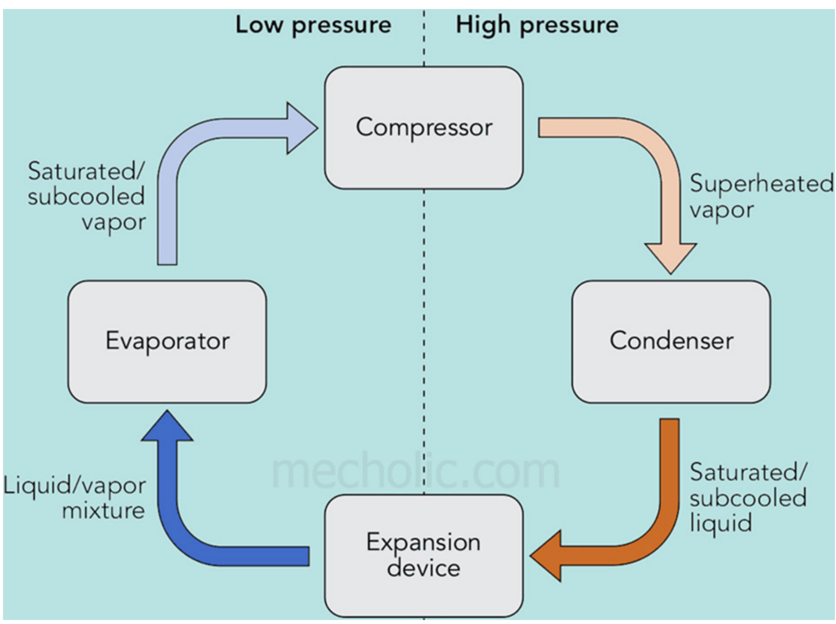

Figure 1: VCR system [10].

Compressor, condenser, expansion valve and evaporator are the major components that constitute a VCR system. To run effectively, a VCR system undergoes multiple stages as following:

Stage 1, compressor: This is the main component of the device that drives the entire system efficiently. The compressor used in this device can be of centrifugal, reciprocating or rotary type. There are usually two pressures acting in a refrigeration system: low pressure and high pressure. Low pressure or evaporator pressure is regulated by the expansion device, whereas the high pressure or condenser pressure is regulated by the compressor. The pipeline that connects from the evaporator outlet to compressor inlet can be called as suction line, and the pipeline connecting from the compressor outlet to condenser inlet can be called as discharge line. Electric power is used to run the compressor.

Stage 2, condenser (heat exchanger): At this stage, the refrigerant at high temperature and pressure enters the condenser through the discharge line from compressor outlet. The cooling process in the condenser is attained in three ways. At first, the vapour refrigerant from compressor at superheated state is de-superheated. Second, the vapour refrigerant changes its state to liquid refrigerant, and finally, the liquid refrigerant is sub-cooled. Larger surface area and long duration of contact help to increase the heat transfer rate. Either water or air or combination of both can be used as the medium of cooling in condenser.

Stage 3, throttling valve (expansion): At this stage, the refrigerant in liquid phase at high pressure enters the throttle valve through a filter, where any foreign particles or dirt can be removed. These filters also contain a silica gel to absorb any moisture content. In this valve, expansion takes place lowering the pressure of the refrigerant. The refrigerant at this stage is of low pressure. The expansion valve also helps in regulating the flow of liquid refrigerant entering the evaporator and the pressure difference.

Stage 4, evaporator: At this stage, the liquid refrigerant at low temperature and pressure enters the evaporator inlet from the expansion valve outlet and the phase change from liquid to vapour takes place. The vapour refrigerant formed in the evaporator absorbs heat from the space or surroundings to be cooled, and the vapour refrigerant enters the compressor inlet at low temperature and pressure and begins the next cycle.

4 REFRIGERANTS

4.1 R134a refrigerants

Refrigerant R134a can also be termed as 1,1,1,2-Tetrafluoroethane under hydrofluorocarbon (HFC) refrigerants. CF3CH2F is the chemical formula of R134a. Hydrofluorocarbon, a fluorinated refrigerant, has been considered a green refrigerant [11]. HFC refrigerants are known as the alternative refrigerants to hydrogen chlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC) refrigerants because HCFCs and CFCs are considered having global warming potential (GWP) and ozone depletion potential (ODP). R134a refrigerants are extensively used in air conditioning units as well as refrigeration units in industries for cooling purposes. R23, R32, R134a, R404a, R407a, R407c and R410a are some of the refrigerants that fall under the category of HFC refrigerants.

R134a refrigerant is resistant to corrosion, non-toxic in nature and inflammable. Today, the application of R134a can be seen in air conditioning systems in automobile industries. It is found that lubricants are not compatible with R134a refrigerant. The properties of R134a refrigerant are presented in Table 1.

Table 1: R134a properties [11].

Parameters	**R134a**
Global warming potential (GWP)	1430
Ozone depletion potential	0
Colour	Blue
Boiling point	–26 °C
Critical temperature	122 °C
Ignition temperature	700 °C
Solubility	0.1% soluble in weight at 25 °C

4.2 Nanofluid preparation

A mixture of metallic oxide and base fluids like water, oil and ethylene glycol is termed as nanofluid. With reference to [6], nanofluids are prepared by implementing a two-step technique [7]. Surfactant is also used during the preparation to ensure complete dispersion of base fluids and nanoparticles. Addition of surfactants ensures proper dispersion of nanoparticles when mixed with base fluid.

The beaker containing the mixture of nanoparticles and base fluid is placed on a magnetic stirrer. A magnetic bead (stir bar) is also added in the solution for stirring action. The rotating magnetic field, placed beneath the vessel, rotates the stir bar. The rotation motion of the stir bar immersed in liquid spins and the sample gets mixed thoroughly. Glass type beakers or non-metal beakers are recommended to prevent stirrers from any interference with magnetic field.

In this article, Al_2O_3, ZnO, CuO and TiO_2 nanoparticles are considered, while water has been chosen as the base fluid.

5 METHODOLOGY

In order to compare the performance of refrigeration systems, COP and RE are calculated and analysed with and without the addition of nanoparticles. Al_2O_3, ZnO, CuO and TiO_2 nanoparticles are mixed with R134a refrigerant, and enthalpy values are plotted from the R134a p-h chart shown in Fig. 2, to obtain the COP and RE. The properties of nanoparticles are required to calculate enthalpy, COP and RE and are retrieved from various research articles [3]. These properties are tabulated in Table 2.

The following are the parameters required for the calculation of enthalpy, COP and RE involved in the various experiments [3]: P_1, evaporator pressure (bar); P_2, condenser pressure (bar); T_1, evaporator outlet temperature (°C); T_2, condenser inlet temperature (°C); T_3, condenser outlet temperature (°C); T_4, evaporator inlet temperature (°C); T5, evaporator water temperature (°C).

Table 2: Selected physical properties.

Physical properties	**R134a**	**Al_2O_3**	**CuO**	**ZnO**	**TiO_2**
Density (kg/m^3)	1206	3880	6310	5610	4230
Thermal conductivity (W/mK)	0.0824	40	33	23.5	11.8

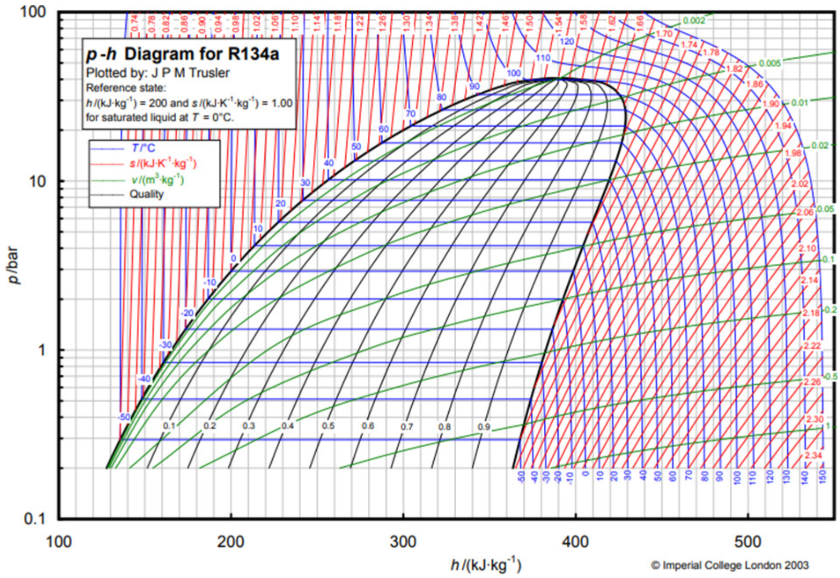

Figure 2: R134a p-h chart [12].

The following notation is also adopted: H_1, evaporator outlet temperature enthalpy (kJ/kg); H_2, condenser inlet temperature enthalpy (kJ/kg); $H_3 = H_4$, condenser outlet temperature enthalpy (kJ/kg). During the expansion of the refrigerant in the expansion stage, the enthalpy remains constant and hence $H_1 = H_4$.

The refrigeration system COP is defined as the ratio of heat produced inside the chamber to the power consumed by the compressor. Heat produced inside the chamber is the heat absorbed by the condenser, i.e. $H_2 - H_1$, since the enthalpy of the refrigerant entering the condenser is more than the enthalpy of refrigerant leaving the condenser. The power consumed by the compressor is $H_3 - H_2$. Hence, the COP of the refrigeration system is $(H_2 - H_1)/(H_3 - H_2)$.

The existing enthalpy values for R134a are obtained from various research papers and are tabulated in Table 3 [13].

With reference to Table 3, the COP of pure R134a refrigerant can be calculated:

$$\mathrm{COP} = (H_2 - H_1)/(H_3 - H_2) = 1.90$$
$$\text{Refrigeration effect (RE)} = (H_2 - H_1) = 124\ \text{kJ/kg}$$

The required properties retrieved from various experiments and previous publications [3] [13] for the selected nanoparticle-R134a mixtures are listed in Table 4.

Table 3: Existing enthalpy values for R134a [13].

Existing enthalpy values of R134a (kJ/kg)			
$\mathbf{H_1}$	$\mathbf{H_2}$	$\mathbf{H_3}$	$\mathbf{H_4}$
256.40	380.30	445.33	256.40

Table 4: Properties of nanofluids.

Nanofluid	Pressure (bar)		Temperature (°C)			
	P_1	P_2	T_1	T_2	T_3	T_4
R134a-Al_2O_3	1.90	11	30	60	37.5	21
R134a-CuO	1.50	9	17	47	33	20
R134a-TiO_2 [14], [15]	2	16	21	60	26	6
R134a-ZnO [16]	1.85	12.5	23	59	30	19

6 RESULTS

From the values of Table 3, the enthalpy values are found from the p-h charts of R134a-nanoparticle mixtures. The following steps are considered to find the enthalpy values from the p-h charts shown in Figs 3, 4, 5 and 6.

1. Since the R134a refrigerant is used in this project, the R13a p-h chart has been considered for plotting.
2. The condenser pressure (Pc) and evaporator pressure (PE) lines are drawn from P_2 and P_1 values, respectively, as tabulated.
3. T_1 as constant temperature line is drawn. The point where the constant temperature line and evaporator pressure line meets is identified as H_2.
4. Since the compression of the system is said to be isentropic in the process, the constant entropy line is drawn from H_2. The point where the constant entropy line meets the condenser pressure line is identified as H_3.

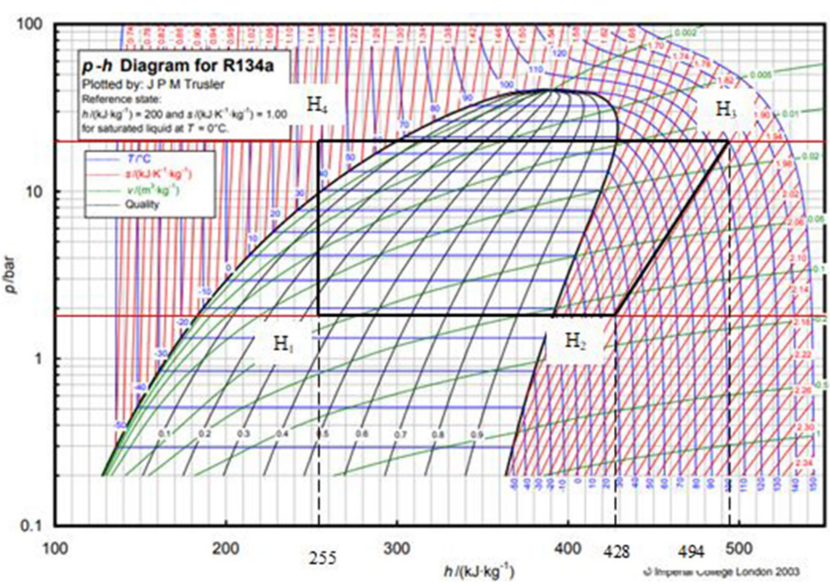

Figure 3: R134a-Al2O3 p-h chart.

5. Now, T_3 line is drawn and extended to condenser pressure and the point is termed as H_4.
6. Point H_4 is extended to evaporator pressure line; that point is identified as H_1.

- Stage $H_1 - H_2$: The fluid experiences constant pressure evaporation and hence undergoes isobaric evaporation.
- Stage $H_2 - H_3$: The fluid experiences constant entropy and the process is both reversible and adiabatic and undergoes isentropic compression.
- Stage $H_3 - H_4$: The fluid experiences constant pressure condensation and hence undergoes isobaric condensation.
- Stage $H_4 - H_1$: The fluid experiences constant entropy in throttle valve and hence undergoes isentropic expansion.

From the p-h chart of Fig. 3:

$$H_1 = H_4 = 255 \text{ kJ/kg}, H_2 = 428 \text{ kJ/kg}, H_3 = 494 \text{ kJ/kg}$$

Thus, for the R134a-Al_2O_3 mixture:

$$COP = (H_2 - H_1)/(H_3 - H_2) = 2.62$$
$$RE = (H_2 - H_1) = 173 \text{ kJ/kg}$$

From the p-h chart of Fig. 4:

$$H_1 = H_4 = 246 \text{ kJ/kg}, H_2 = 418.50 \text{ kJ/kg}, H_3 = 461 \text{ kJ/kg}$$

Thus, for the R134a-CuO mixture:

$$COP = (H_2 - H_1)/(H_3 - H_2) = 4.06$$
$$RE = (H_2 - H_1) = 172.5 \text{ kJ/kg}$$

From the p-h chart of Fig. 5:

$$H_1 = H_4 = 238 \text{ kJ/kg}, H_2 = 422 \text{ kJ/kg}, H_3 = 489 \text{ kJ/kg}$$

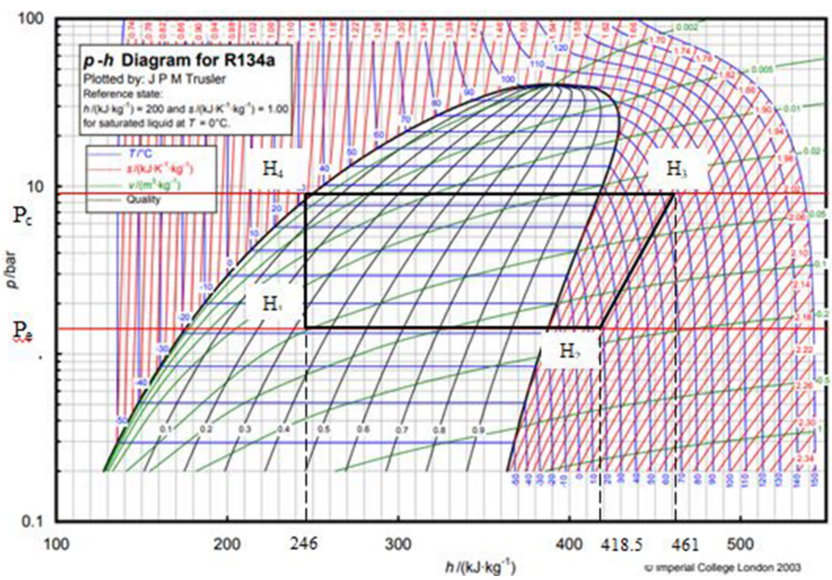

Figure 4: R134a-CuO p-h chart.

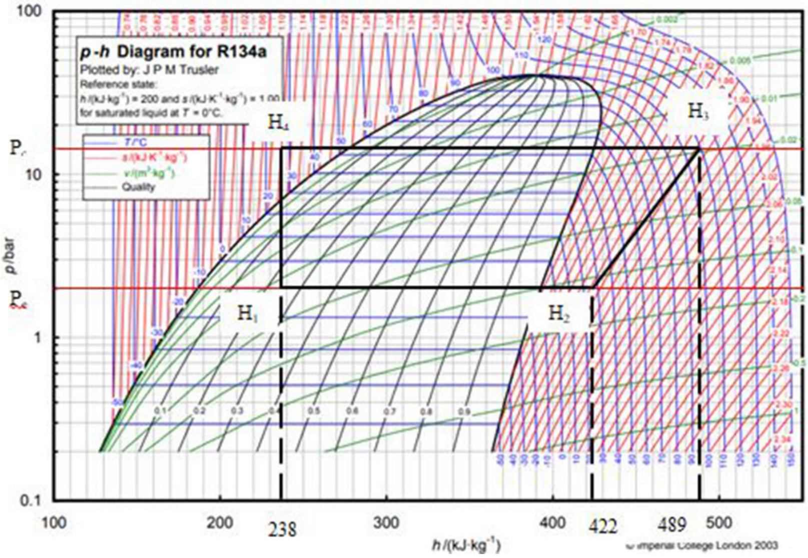

Figure 5: R134a-TiO2 p-h chart.

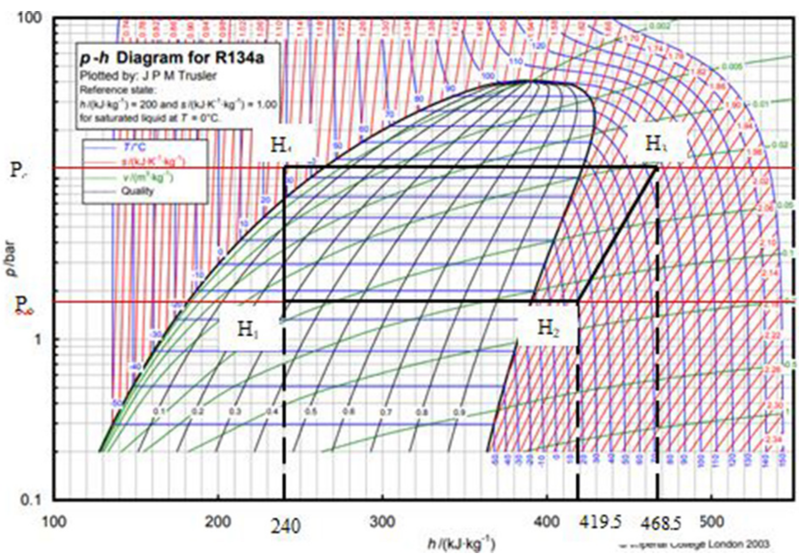

Figure 6: R134a-ZnO p-h chart.

Thus, for the R134a-TiO_2 mixture:

$$COP = (H_2 - H_1)/(H_3 - H_2) = 2.75$$
$$RE = (H_2 - H_1) = 184 \text{ kJ/kg}$$

From the p-h chart of Fig. 6:

$$H_1 = H_4 = 240 \text{ kJ/kg}, H_2 = 419.5 \text{ kJ/kg}, H_3 = 468.5 \text{ kJ/kg}$$

Thus, for the R134a-ZnO mixture:

$$\mathrm{COP} = (H_2 - H_1)/(H_3 - H_2) = 3.66$$
$$\mathrm{RE} = (H_2 - H_1) = 179.5\ \mathrm{kJ/kg}$$

7 CONCLUSION

The refrigeration effect and coefficient of performance are calculated for R134a mixed with different nanoparticles based on already existing observations from previously published articles. Table 5 lists the experimental results for COP and RE for different mixtures of nanoparticles and the R134a refrigerant.

Figure 7 shows the graphical representation of RE and COP for different nanoparticles so that performances can be compared. It can be clearly seen that the RE and COP of nanorefrigerants are higher compared to those of pure R134a.

With reference to the above results, COP is highest for the R134a-CuO mixture with a value of 4.06 compared to the other mixtures. The coefficient of performance for pure R134a is 1.90. The COP values for the different mixtures tabulated above are higher than that of pure R134a.

Nanoparticles dispersed in refrigerant fluid help in increasing the heat transfer coefficient, thermal conductivity and other heat transfer characteristics, thus improving the overall performance and efficiency of the refrigeration systems. This essentially proves that the application of nanoparticles is the best suited alternative solution to improve refrigerants for the future with the purpose of achieving green environment.

Table 5: Calculated RE and COP based on published experimental data.

R134a-nanoparticles	**Refrigeration effect (RE)**	**Coefficient of performance (COP)**
R134a-Al_2O_3	173	2.62
R134a-CuO	172	4.06
R134a-TiO_2	184	2.74
R134a-ZnO	179.5	3.66

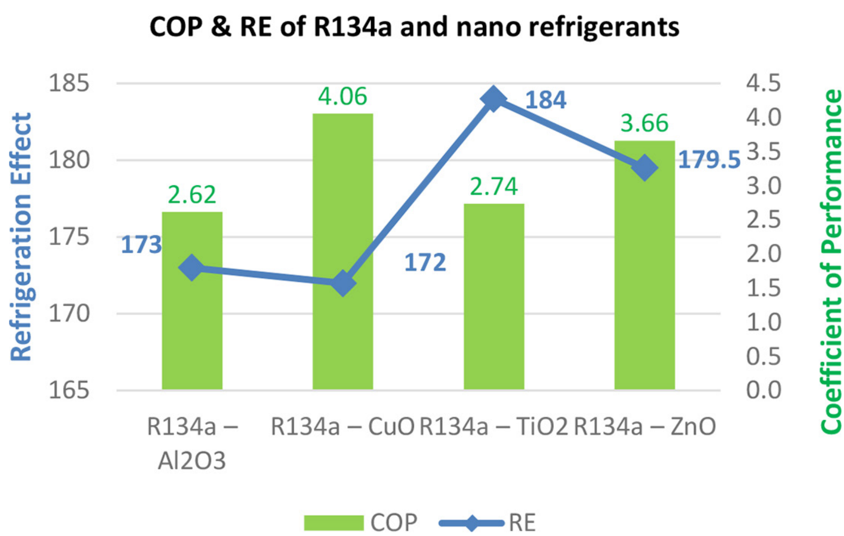

Figure 7: COP and RE of R134a and nanorefrigerants.

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