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Energetic and Exergetic Investigation on Vapor Compression Refrigeration System Using Ag_2O-R134a Nanofluid as Refrigerant

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Abstract

This paper experimentally explored energetic and exergetic performance investigation of VCR System using Ag_2O-R134a Nanofluid as Refrigerant. The integration of silver oxide (Ag_2O) nanoparticles within polymer and composite materials offers promising avenues for enhancing the thermal and physical properties of advanced systems. The energetic and exergetic performance study of VCR were investigated with test parameters including compressor power consumption, cooling capacity, coefficient of performance (COP), discharge temperature, irreversibility in the components, total irreversibility and second law efficiency. Findings presented that the lowest compressor power consumption and total irreversibility were observed in refrigerator with 80.5 g charge of total mass mixture (grams)Ag_2O/ R134a (10.5 g/L of R134a); these values of compressor power consumption and total irreversibility were 15.87% and 31.69% respectively, lower than for R134a refrigerant. In addition, the VCR system using refrigerant at 80.5g charge with) Ag_2O/ R134a (10.5 g/L of R134a), had the highest COP and second law efficiency among the selected nano-Refrigerants. These values of COP and second law efficiency were 56.32% and 47.06%, higher than that of Ag_2O/ R134a (80.5g/L of R134a). Furthermore, compressor discharge temperature of the domestic refrigerator with R134a was found to be lower than that of Ag_2O/ R134a (10.5 g/L of R134a).

Keywords: Ag_2O, cop, energetic, nanofluid, second law efficiency, vapor compression refrigeration

INTRODUCTION

Analysis of energy and exergy performance could be used to improve how effectively different thermodynamic systems use their sources of energy. In addition, significant improvements have been shown in many applications that have used these studies. Conventional thermodynamic investigation approaches are relatively insufficient because energy analysis was done on the First Law of Thermodynamics, which ignores changes in energy quality, the influence of the process environment, and irreversibility during the processes in systems. The concept of exergy quickly emerged in recent years as a crucial strategy to overcome this shortcoming. Exergy is defined as the useful work that can be done in a system when it is brought to a dead state or normal ambient conditions [1]. In an ideal energy transformation process, no exergy degradation is envisaged; nevertheless, in actual fact, exergy loss (irreversibility) does occur, and thus provides the basic contrast between energy and exergy. Method

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of analysis, therefore, provides a better indicator of a system [2–4]; Exergy analysis could also be used to assess subsystem performance [5] and identify the system components that lose the most and the least energy. The second rule of thermodynamics, the laws of conservation of energy and mass, and exergy analysis are used to determine how well a system functions overall and where subsystems have room for improvement.

Silver Oxide Nanoparticles Used in the Investigation

The integration of silver oxide (Ag_2O) nanoparticles within polymer and composite materials offers promising avenues for enhancing the thermal and physical properties of advanced systems, such as Vapor Compression Refrigeration (VCR) systems. The scope includes: Thermal Conductivity Enhancement: When embedded in polymer or composite matrices, they significantly improve the heat transfer performance—crucial for efficient VCR operation. Polymers doped with Ag_2O nanoparticles can be used for hygienic applications in HVAC and refrigeration systems. Ag_2O-reinforced composites can extend the operational life and reduce maintenance requirements of VCR units.

Silver oxide nanoparticles (Ag_2O, 50–150 nm) were employed in this study to forecast the thermal and physical characteristics of the VCR system [6]. The characteristics of silver oxide nanoparticles and their structure are displayed in Table 1. The oxide of silver According to Figure 1, wet chemical synthesis or the Sol-Gel method was used to create nanoparticles. The bottom-up Sol-Gel process is used to create nanomaterials. The process uses a "sol" to create an integrated "gel" network., i.e., the hydrolysis and poly-condensation reactions of the metal salts (halides, sulphates, nitrates, etc.) in "sol" form produce a colloidal "Gel" form including nanomaterials [7]. The interconnecting Oxo (M-O-M) or hydroxo (M-OH-M) bridges that result in a polymeric network are what cause metal oxides to develop. The solvent is then removed and the hydroxy groups are changed into oxides through the following drying as well as calcinations process, accordingly [8]. The key benefits of this approach are the appropriate use of ligands to cap the particles (and consequently their size & shape) in the "sol" phase and low temperature reaction conditions. SEM-EDAX and powder X-ray diffraction (PXRD) results are shown in Figure 2 alongside silver oxide nanoparticles. PXRD is an analytical technique that can provide proof of unit cell dimension and identify the stage of particles.

Figure 1. Silver oxide nanoparticles (Ag_2O), 50–150 nm.

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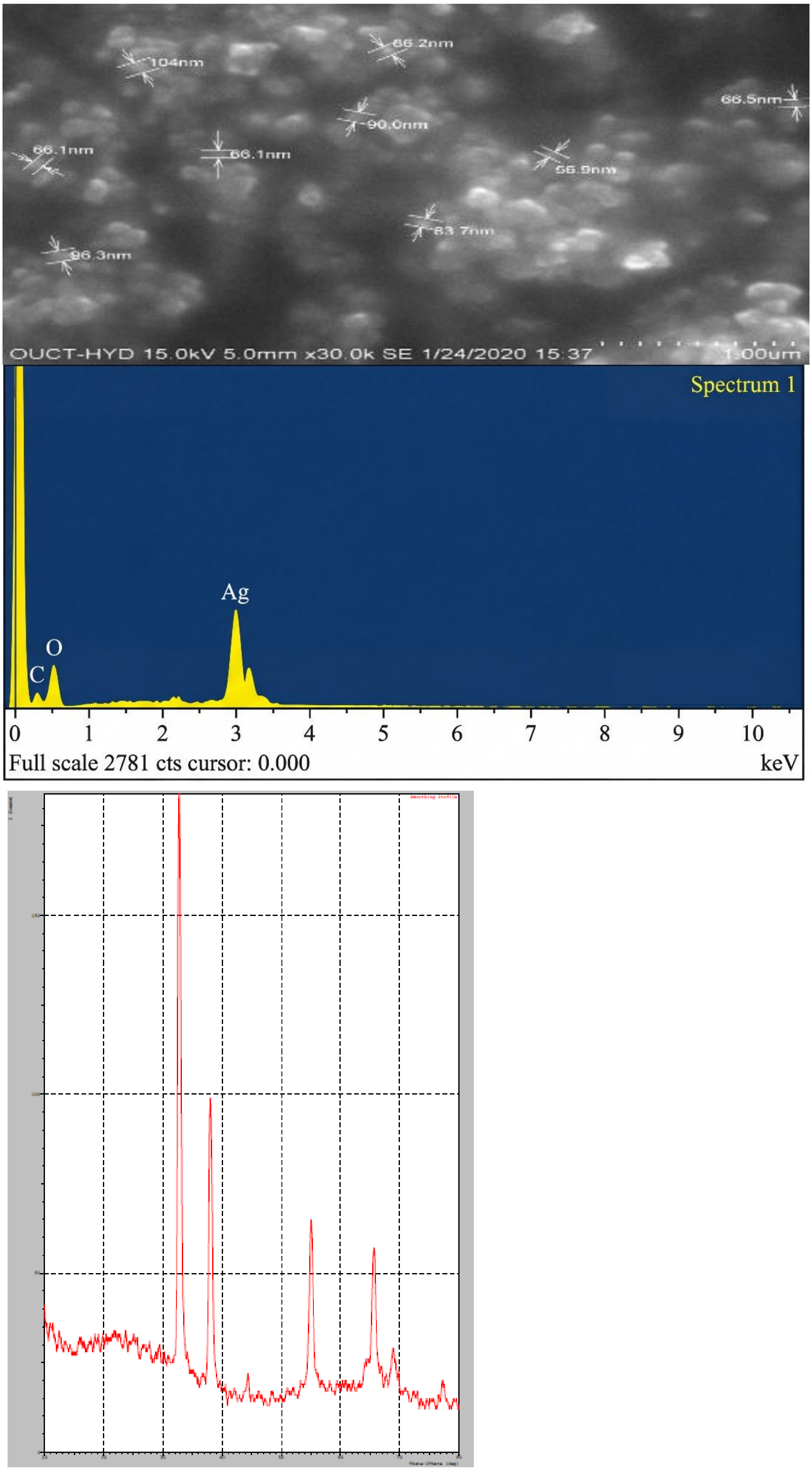

Figure 2. SEM-EDAX and PXRD data.

Exergy and Energy Analysis

Exergy offers a way to quantify the degree to which a given system deviates from both the provided phase and the standard level. Figure 3 shows the overall exergy balances. A few of the exergies in a technology are used during its actual operation. As a result, the total exergy accessible at a system's output (Eout) is less than the total exergy at the system's entrance (Ein). The total dissipation of a system refers to the quantity of energy that is used as a result of the irreversibilities in that system (Itotal). The general exergy balance can be expressed in Equation (2) [9].

Ein − Eout= Itotal (2)

where Ein and Eout are the total exergies transferred by heat, work, and mass. Equation (2) can also be written as exergy balance for a control volume in a steady state process as expressed in Equation (3):

$$I\ total = \sum_{in} \varepsilon\ e - \sum_{out} \varepsilon\ e + \sum[Q(1 - \frac{T0}{Tb}]_{in} - \sum[Q(1 - \frac{T0}{Tb}]_{out} + \sum w_{in} - \sum w_{out} \quad (3)$$

In which the first terms are stream exergy flows ξ and e, respectively, are the refrigerant mass flow rate and specific exergy flow rates. Every next two words are exergy flows for heat transfer, where is the amount of heat transfer over the interface at temperature Tb, and the final two are exergy flows for work, where W is the rate of work. Due to the obvious elevation, potential, kinetic, and chemical exergies are assumed to be unimportant. In a refrigeration system, speed, and chemical changes are similarly thought to be unimportant, and only physical exergy is properly considered. The VCR system's fluid's specific exergy could be represented as seen in Equation (4)

e=(h−T0S)−(h0−T0S0) (4)

where S0 and h0 are the entropy and enthalpy values of the dead state of the refrigerant at temperature T0.Equations(5) – (8) (Padmanabhan and Palanisamy, 2012) could be used to estimate component-wise irreversibility for the exergy equations above conducted on the key components (compressor, evaporator, condenser, and capillary tube) of the household refrigerator system. The property database REFPROP 9.1 was used to get the thermophysical characteristics of the refrigerants employed in this investigation [10–14].

Irreversibility in Compressor (*Icomp*)

Icomp= To{ξ(S2−S1) + [WComp−ξ(h2 –h1)]/To} (5)

The refrigerant's entropy and specific enthalpy at the compressor's exit are S2 and h2, whereas it's entropy and enthalpy at the compressor's inlet are S1 and h1. To also represents the outside temperature.

Irreversibility in Condenser (Icond)

Icond=To{ ξ[(S2 –S3)−(h2 –h3)/Tcond]} (6)

whereS3andh3aretheentropyandspecificenthalpyoftherefrigerantattheexitofthecondenser, and Tcond is the condenser temperature.

Irreversibility in Capillary Tube (Icap)

Icap=To{ξ[(S4–S3)−(h4–h3)/Tcap]} (7)

Where S4 and h4 are the entropy and specific enthalpy of the refrigerant at the exit of the capillary tube.

Irreversibility in Evaporator (Ievap)

Icap=To{ξ[(S1–S4)−(h1–h4)/Tevap]} (8)

Where Tevap is the evaporator temperature. Total irreversibility can also be written as:

Itotal = Icomp + Icond+ Icap + Ievap (9)

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The ratio of the cycle's actual COP to its maximum COP under identical conditions can be used to express the second law of efficiency of the vapor compression refrigeration system [15]. The vapor compression refrigeration system's second law of efficiency (ηex) can be summed up as follows:

$$\eta_{ex} = \frac{E_{out}}{E_{in}} = 1 - \frac{I_{total}}{E_{in}} \quad (10)$$

The second law of efficiency can further be written as:

$$\eta_{ex} = \frac{E_{out}}{E_{in}} = 1 - \frac{I_{total}}{W_{comp}} \quad (11)$$

For a reversible process the second law of efficiency is equal to one, and may be less than one in another case. The cooling capacity of the evaporator on refrigerant side as, i.e.,

$$Q = \xi(h1 - h4)(kW) \quad (12)$$

The coefficient of performance of the domestic refrigerator is given by Equation (13):

$$COP = \frac{Q}{W_{comp}} \quad (13$$

In Equation (13), is the compressor power consumption

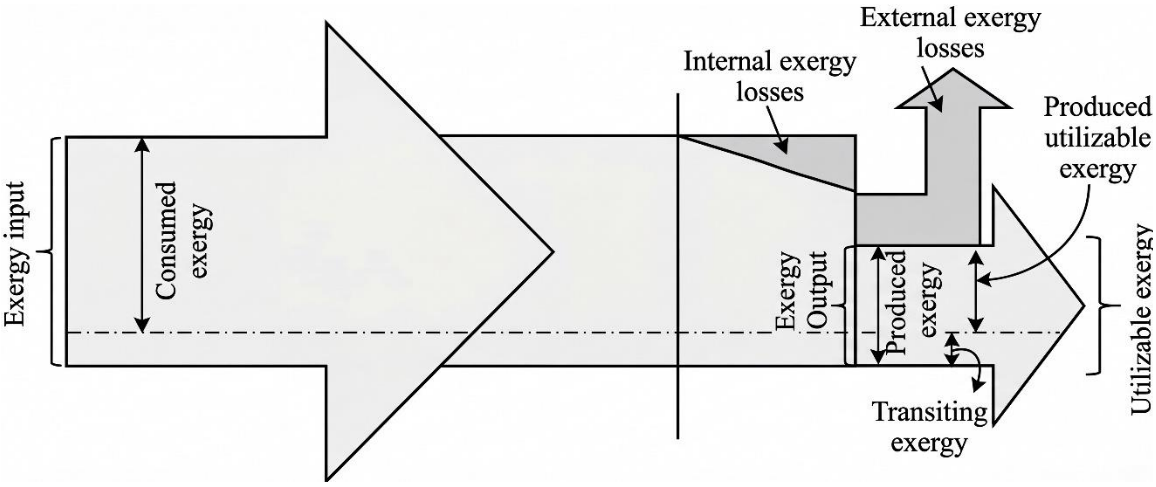

Figure 3. Graphical presentation of general exergy balance (GillandSingh,2017a).

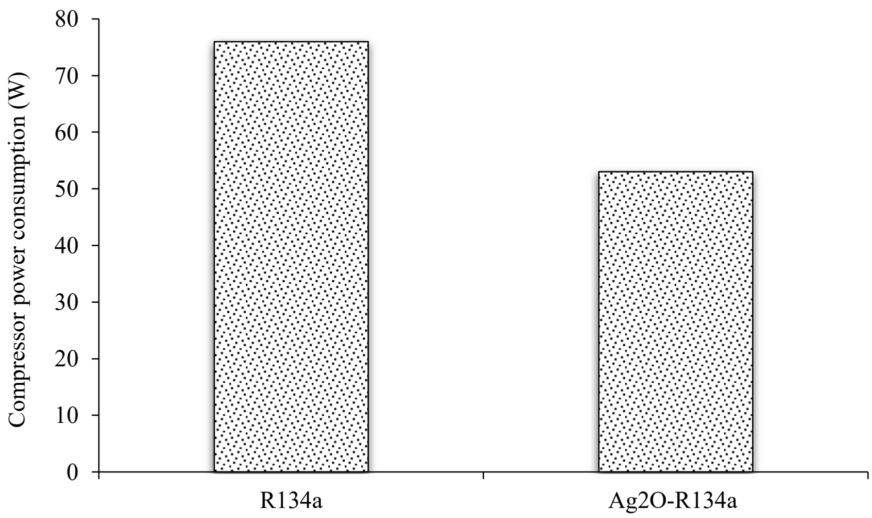

Figure 4. Comparison of compressor power consumption between R134a and Ag_2O-R134a at 10.5 g/L concentration of nanoparticles.

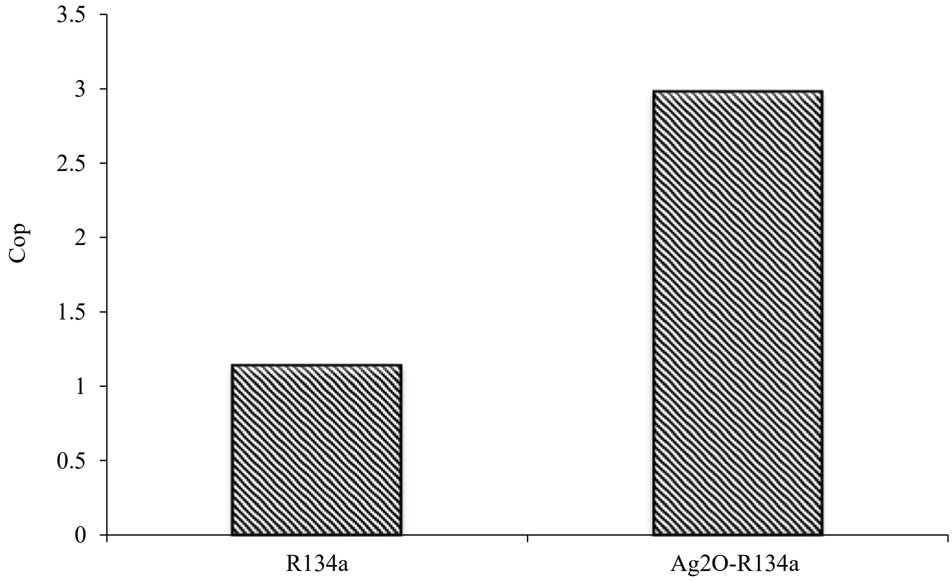

Figure 5. Comparison of COP between R134a and Ag_2O-R134a at 10.5 g/L concentration of nanoparticles.

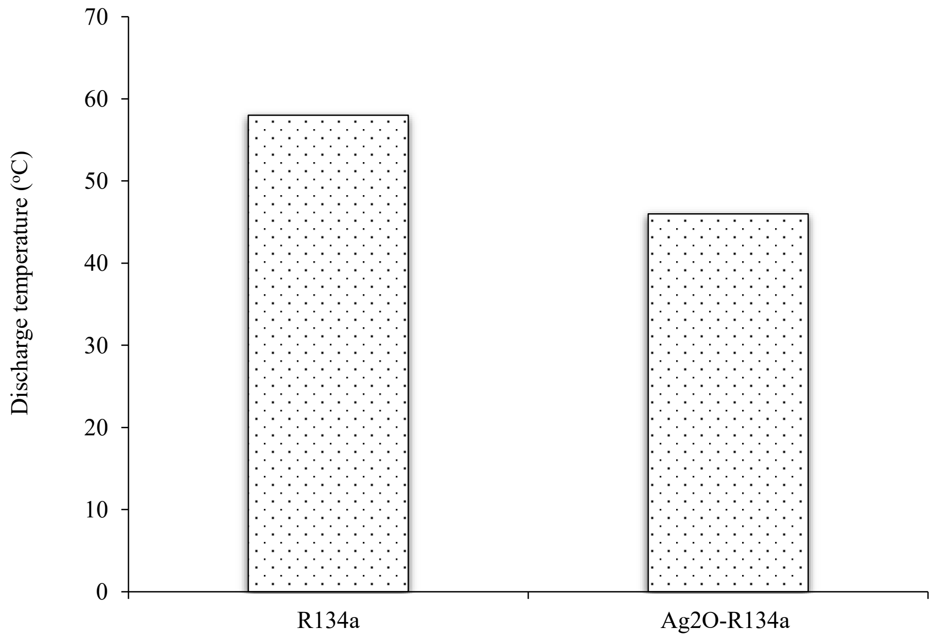

Figure 6. Comparison of Discharge temperature between R134a and Ag_2O-R134a at 10.5 g/L concentration of nanoparticles.

RESULT AND DISCUSSIONS

Figure 4 illustrates the difference in the household refrigerator's COP between R134a and Ag_2O-R134a at a nanoparticle concentration of 10.5 g/L. The results indicated that the refrigerator system's COP was greatest for Ag_2O-R134a at 10.5 g/L of nanoparticles; this could be because Ag_2O-R134a at that concentration used the least number of compressor power. Additionally, the COP of the test rig utilizing Ag_2O-R134a at 10.5 g/L was 30.42% greater than that of R134a refrigerant, as seen in the figure. In terms of energy performance, the Ag_2O-R134a mixture at 10.5 g/L was chosen as the best of the various refrigerant mixtures that could replace 100g of R134a. This mixture may alternatively be called the ideal blend.

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Table 1. Parameters of exergetic performance analysis of domestic refrigerator.

S no	Refrigerant	Wcomp (W)	COP	T_D	Q_c (W)	Itotal (W)	Hex (%)
1	71	76	1.14	58	115.68	55	25.57
2	71.5	74.15	1.28	56	118.89	54.36	28.56
3	72	73.41	1.34	56	120.36	52.12	32.15
4	72.5	72.12	1.42	56	122.45	50	36.56
5	73	71.14	1.49	56	124.36	48	38.12
6	73.5	70.12	1.5	56	129.01	46.33	39.85
7	74	69.16	1.54	54	132.05	44.12	40.12
8	74.5	67.29	1.58	54	134.63	42.52	41.78
9	75	65.35	1.62	52	136.23	40.42	42.01
10	75.5	63.45	1.7	53	138.25	38.42	42.68
11	76	62.12	1.82	49	140.23	36.36	43.33
12	76.5	60.48	1.87	49	144.73	34.25	45.14
13	77	59.55	1.92	49	152.32	34.01	46.47
14	77.5	58.12	1.96	48	167.7	33.47	47.45
15	78	57.14	2.12	48	170.98	33.01	48.12
16	78.5	56.02	2.58	48	180.45	32.45	49.72
17	79	55.39	2.72	47	184.23	32	50.47
18	79.5	54.89	2.88	47	189	31.87	51.13
19	80	54.14	2.93	47	190.25	31.12	52.12
20	80.5	53.03	2.98	46	194.23	31	55.42

The difference in the household refrigerator's COP between Ag_2O-R134a and R134a at a nanoparticle concentration of 10.5 g/L. is displayed in Figure 5. The Ag_2O-R134a nanoparticle concentration of 10.5 g/L had the maximum COP on the refrigerator system, according to the findings. When compared to R134a refrigerant, it was discovered that Ag_2O-R134a produced a lower discharge pressure at 10.5 g/L of refrigerant.

As seen in Figure 6 the compressor discharge temperature of the home refrigerator employing Ag_2O-R134a at a concentration of 10.5 g/L of nanoparticles had lower values than R134 refrigerant. The figure also makes it evident that the compressor discharge temperature of the home refrigerator employing Ag_2O-R134a at a concentration of 10.5 g/L of nanoparticles was lower than that of R134a refrigerant. A prolonged compressor life may be anticipated with the Ag_2O-R134a at 10.5 g/L concentration of nanoparticles, as approximately 12 reduction was noted during the investigation.

CONCLUSION

From the study, the following conclusions were drawn:

The integration of silver oxide (Ag_2O) nanoparticles within polymer and composite materials offers promising avenues for enhancing the thermal and physical properties of advanced systems.

Based on the energetic performance analysis of the domestic refrigerator system, using Ag_2O-R134a Nanofluid as Refrigerant, the COP value of the Ag_2O/ R134a was the highest. An enhancement of about 46.28 % was found when compared with the R134.

The pull-down time and compressor discharge temperature of the system with Ag_2O-R134a Nanofluid as Refrigerant were lower than that of R134a refrigerant. It was also found that the pull down

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time and compressor discharge temperature with the 80.5g charge of Ag_2O-R134a Nanofluid as Refrigerant, were lower than the R134a refrigerant, by around 20 minuteand14 respectively. However, the least pull down time and compressor discharge temperature was observed with the 80.5g charge of Ag_2O-R134a Nanofluid as Refrigerant.

Ag_2O-R134a Nanofluid refrigerants' energetic performance analysis revealed that, when used in a household refrigerator, the 80.5 g Ag_2O-R134a Nanofluid refrigerants provided the lowest and maximum values of total irreversibility and second law efficiency. The system 80.5 g Ag_2O-R134a Nanofluid refrigerants were found to have a total irreversibility and second law efficiency that were, respectively, lower, and greater than those of R134a refrigerants by roughly 30.29 and 45%.

In this study, Ag_2O-R134a Nanofluid mixture was stated as the optima nano particle mixture refrigerant among the selected mixture, in terms of energetic and exergetic performances of the working fluids.

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