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Thermodynamic Analysis of Hybrid-Nanofluids-Zeotropic Mixtures in a Vapour Compression Refrigeration System (VCRS) Based on Exergy Principles

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Abstract

Cooling refrigeration systems ingest prime energy and contribute to universal negative impact due to ecologically unfavorable working fluids used. Hence, the quest to improve the performance of Vapour Compression Refrigeration System (VCRS) with more efficient and eco-friendly refrigerant such as nanoparticles becomes imperative. In this study, performance analysis of hybrid nanofluids-zeotropic mixtures in a VCRS were experimentally investigated to determine the best operating optimum performance using exergy based approach. To achieve this, varying concentrated mixtures were selected using ternary graph. The results revealed that all the designated ratios of the mixed refrigerant with different fractions achieved good performance improvement with optimum values obtained at (011) zero gram of TiO_2, 7.5g-Al_2O_3/CuO. All the selected hybrid mixtures led to an improved outcome in terms of Coefficient of Performance (COP), less power consumption and high performance exergetic efficiency, with COP values ranging from 0.31% to 3.10% and exergetic efficiency from 0.32 to 1.43%. The value for thermal conductivity, dynamic viscosity, density and specific heat were found to be highest (0.0958 W/m.K; 0.00164 W/m.K; 686.82 kg/m^3 and 359.82 kJ/kg.K) at the same concentration of zero grams TiO_2 in the mixture. Comparison made from the performance characteristics curve (with global parameters) indicated that maximum power coefficient and cooling capacity for the various concentrations were found at (001) 7.5g-TiO_2, zero grams Al_2O_3/CuO equal to 2.2 kW, and the minimum value at concentration of 5 was 0.61% at (111) 5g-TiO_2/Al_2O_3/CuO, and 0.87% for (121). An increase was observed in the maximum power coefficient, cooling capacity and COP increased by 13.51%, 5.78% and 10.33%. It was also observed that hybrid nanofluid-zeotropic refrigerant worked seamlessly with VRCS, making it a sustainable, green and clean as well as eco-friendly alternative with near-zero to zero negative effects on public health safety and environment.

Keywords: Nanofluids, Heat transfer coefficient, COP, Exergy efficiency, Exergy destruction.

1 | Introduction

The Advancement in alternative energy resources have paved way for technological innovations towards the augmentation of energy mix, utilization and conversion of alternative energy resources into viable options. Therefore, the physiognomies of the global energy patterns, which is subjugated by relic vigor, have triggered some negative environmental impairment initiated via the use of this energy options. In attempt to find a solution to these problem, alternatives that are economically viable, globally acceptable and ecologically friendly to advance the effectiveness of these energy alternatives is highly required [1]–[3]. The Vapour Compression Refrigeration System (VCRS) remains one of the promising working fluids applicable in refrigeration systems, an energy system that is commonly used for cooling and preserving perishable items [4]. Hence, working fluids that are ecofriendly have become the research hotpots of VCRS in recent times. Working fluids employed

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in the system flows via different transformative phases, interchangeably trodden and expanded from liquescent to vapour. In the process of these transformations, heat is enthralled or exorcised through the system, resulting in temperature variation of the nearby transient air along the system components. Almost all VCRS operates in this sequence to achieve chilling, and the energy expended in the system is relatively high. Prior to the 21st century, refrigerants have always been known to contribute immensely to global warming due to its constituents, some of which are major greenhouse gases [5], [6]. Upon realizing that some of the working fluids are highly combustible and noxious, scientific research by different scientists began to increase in various capacities in order to develop refrigerants that are more ecofriendly.

Ikpe et al.| Int. J. Res. Ind. Eng. 12(2) (2023) 143-154

This led to the development of Chlorofluorocarbon (CFC) in 1930 which was none flammable and toxic as well as cost effective gases that seemed to be a better alternative, but was later observed to contain toxic compounds that were depleting the ozone layer.

As a result of that, Hydrochlorofluorocarbon (HCFC) were developed in the late 70s and early 80s, which were also observed to contain compounds such as chlorine molecules which had more damaging effects on the ozone layer. Furthermore, various attempts to find a sustainable solution to this problem led to the development of HFCs which does not contain chlorine but was later found to contribute to environmental impairment since they are greenhouse gases. From the aforementioned evolutions in the development and application of working fluids for refrigeration systems, refrigerants that existed before the 21st century were obviously depleting the ozone layer and causing Global Warming Potential (GWP), and that necessitating the need for new environmentally friendly refrigerants with excellent heat transfer characteristics [7]. Conversely, selecting an eco-friendly working fluids (refrigerants) presently is an issue of concern, and alternatives available nowadays include zeotropic mixtures (R400 series), hydrocarbons and carbon dioxide (R744).

McLinden and Huber [8] reported that refrigerants have continually evolved in response to evolving trends due to changes in the type of equipment and their effects on public health safety and environmental requirements. In the late 1920s, it was observed that addition of fluorine to molecules could produce a non-flammable and low toxicity refrigerant, thus giving high preference to the CFCs. During the 1980s, CFCs were observed to contribute to the destruction of stratospheric ozone, thereby, causing undesired environmental issues. From R-12 in the 1930s to R-1234yf in the early 2000s, were reported in the chemical literature, decades before they were considered as refrigerants. The search for new refrigerants continued through the 1990s even as the HFCs were becoming the dominant refrigerants in commercial use.

Studies have shown that research on hybrid-nanofluids-zeotropic mixture in VCRS application is limited, therefore, necessitating the need for alternative working fluids as well as innovative approaches to improve the cooling performance in refrigeration systems. As a result, the choice of using zeotropic mixtures as a refrigerant is becoming a bone of contention regarding the operation of vapour compression systems. In recent times, a number of studies have been conducted on the thermodynamics of hybrid-nanofluids-zeotropic mixtures in a VCRS based on exergy principles.

For example, thermodynamic analysis of VCRS with sustainable refrigerant blends as alternatives to replace R22 was investigated by Talanki and Shaik [9]. Eight (8) refrigerant blends consisting of R290, R134a, R152a, R125 and R32 at various compositions were developed. Performance characteristics of the eight studied refrigerants were computed at evaporating and condensing temperature of 7.2oC and 54.4oC via MATLAB programme. Coefficient of Performance (COP) of the refrigerant mixture RM40 (3.541) was recorded as the highest among the eight studied refrigerants with 0.2% higher than the COP of R22 (3.534). GWP of RM40 (10) was lower than GWP of R22 (1760), and those of the other eight refrigerants. Compressor discharge temperature of RM40 was the lowest among the eight refrigerants with 6.6oC reduction when compared to R22. Power spent per ton of refrigeration of RM40 (0.992 kW/TR) was the lowest among the eight refrigerant mixtures and marginally lower than that of R22

(0.994 kW/TR). Volumetric Cooling Capacity (VCC) of RM40 (2837 kJ/m3) was higher among the eight refrigerants but close to that of R22 (3086 kJ/m3).

The performance of four Al2O3 nano-refrigerants and their pure fluids (R600a, R134a, R1234yf, and R1233zd (E)) was analysed in a VCRS by Li and Lu [10]. The COP improvement of R1233zd (E) + Al2O3 nano-refrigerant was the highest, while the COP improvement of R134a + Al2O3 and R1234yf + Al2O3 were close to one another. When the mass fraction of Al2O3 nanoparticles increased to 0.30%, the COP of R1233zd (E) and R600a also increased by more than 20% with maximum exergy efficiency of 38.46% for R1233zd(E) + Al2O3 and minimum exergy efficiency of 27.06% for pure R1234yf. The findings revealed that the addition of nanoparticles to the pure refrigerant improved the heat transfer in heat exchangers, increased cooling capacity, reduced compressor power consumption, leading to improved performance of the refrigeration system.

Walid Faruque et al. [11] carried out an investigation to find an environmentally friendly refrigerants that can be applied on a Triple Cascade Refrigeration System (TCRS) for low-temperature application (-100oC to -150oC). To assess the performance of TCRS, energy analysis and exergy analysis were conducted, and analysed. The results revealed that 1-butene/heptane/m-Xylene pair gives the best performance in terms of 1st law efficiency COP and 2nd law efficiency (exergy destruction) for low-temperature applications (lower than -100°C). From the simulation model, the results also indicated that exergy destruction mainly occurs at the condenser, therefore, further studies can be carried out on the condenser to increase the overall COP.

In the same vein, Prasad et al. [12] carried out exergy analysis on VCRS based on the second law efficiency. The second law efficiency was observed to decrease with increase in evaporator temperature while COP increased with increase in evaporator temperature. Total exergy losses decreased with increase in evaporator temperature. The second law efficiency also decreased with increase in condenser temperature while COP decreased with increase in condenser temperature. The total exergy losses increased with increase in condenser temperature. The second law efficiency increased with increase in the rate of sub-cooling while COP increased with increase in the rate of sub-cooling. The total exergy losses was observed to decreases with increase in the rate of sub-cooling.

König-Haagen et al. [13] conducted an experimental study on the performance of R404A and R507A refrigerants in a double-stage VCRS with a sub-cooler heat exchanger. It was observed that R404A has a better performance at high evaporator temperature application whereas, R507A is more suitable in low-temperature applications. Flores et al. [14] theoretically investigated the function of a cascade system in an ozone friendly refrigerant pair. The results indicated that COP of the system increased from 0.7851 to 1.232 when the evaporator heat was adjusted from -80 to-50 oC with the other parameters kept constant. However, there was decrease in the COP from 0.9274 to 0.5486 when the condenser temperature increased from 25 to 50 oC respectively.

Also, Yao et al. [15] experimentally compared the performance of HCFC refrigerants such as R22, R123, and R124 with three different HFC refrigerants R417A/R422A/R422D in VCRS. The findings revealed that using R417A, R422A, and R422D refrigerants, discharge temperature of the compressor was less than that of R22; thereby, offering an advantage that exposed the compressor to less thermal stress and extended service life.

In addition, Oyekale et al. [16] applied HFC161 refrigerant in a small scale cooling system as substitute for HFC410A refrigerant. The performance of HFC161, HFC410A, and HFC32 refrigerants were analyzed under nominated working conditions. The theoretical results revealed that the performance of HFC161 was 10% greater than that of HFC32, but 17.8% greater than that of HFC410A. However, the tentative outcomes revealed that the COP of HFC161 was 15% greater than that of HFC410A, and 25% greater than the COP of HFC32. Furthermore, expulsion heat of HFC161 refrigerant was lesser than that of HFC32 and HFC410A.

Ikpe et al.| Int. J. Res. Ind. Eng. 12(2) (2023) 143-154

Balaji et al. [17] carried an experiment to comparatively analyze the performance of R32, R134a, and R512a in a VCRS. From the findings obtained, R32 exhibited unfavorable properties in terms of average pressure and little co-efficient of performance. The best performance was observed when R152a was applied which had a phenomenal potential of being used as direct replacement for R134a in a VCRS. Moreover, 2.5% COP as obtained for R152a was observed to be higher than that of R134a and R32, but 14.7% higher than that of R134a. It was observed that R152a yielded the most favorable outcome in terms of ecofriendly requirements, with specific universal heating potential, among other requirements.

The rationale behind combining nanofluids-zeotropic mixtures in cooling systems is reportedly viable in terms of providing substantial improvement and reduction in energy consumption compared to the early refrigerants developed before the 21st century. This study is aimed at conducting a thermodynamic analysis of hybrid-nanofluids-zeotropic mixtures in a VCRS based on exergy principles. Also, it is limited to evaluating the effects of varied nanofluid-zeotropic composition to determine the best optimum performance on the VCRS.

2 | Materials and Methods

The materials and methods employed in the study are presented in the headings captured under this section.

2.1 | Materials

The experiments were conducted using refrigerator test rig system; blends of nanofluids--zeotropic mixtures (HFC- R407C, $CuO/TiO_2/Al_2O_3$ by weight); product (water); pressure and temperature gauges; glass beaker; mechanical stirrer, gas cylinder, compressor oil, digital electronic weighing balance, among others. The system was designed with the aid of the design theory. Internal cooling capacity of the cabinet was 2208 mm, external capacity of the cabin was 2420 mm, the top/bottom cover of the cabinet was 1104 mm while the total length of the frame was 5732 mm. Other instruments/equipment included: a digital thermometer for temperature sensors measurement ranging from (-10°C-110°C, ±3°C); ankle bar (iron bar), galvanized steel, cork board material, polystyrene, aluminum plate, drilling machine, fan, and connecting wires.

2.2 | Methods

A comprehensive review of literature on VCRS with nanoparticle zeotropic mixtures was thoroughly examined. A model VCRS coupled with external fan and pipe coiled round evaporator were developed. A ternary diagram was used to determine the percentage particles proportional composition for the mixed refrigerant. For the design features/components comprised of two sections: the cabinet chamber and the measuring chamber. The major components included the frame, the body cover, fan, electric switch, condenser, evaporator and compressor motor with specifications according to design capacity of the systems. The advantage of using nanorefrigerants is that they have a greater heat transmission coefficient, which allows an increase the performance of refrigeration systems.

2.2.1 | Preparation/procedure for blending hybrid-nanofluid zeotropic refrigerants

Eleven different samples of ternary blend was done by hybridizing ($Al_2O_3/TiO_2/CuO$ into POE -Poly Ester oil), then subjecting it with zeotropic mixtures of (23% Difluromethane; 25% Pentafluroethane and 52% Tetrafluroethane by weight) to have a blending of hybrid-nanofluid zeotropic refrigerants in HFC as the base fluid. The various weights/mass were determined using a digital electronic weighing balance.

2.2.2 | Experimental setup

The experiment was conducted using a model VCRS (see *Fig. 1*) as a prime auxiliary for domestic refrigerators. Results obtain was recorded in the data acquisition template which was designed using Microsoft Excel for data processing spread sheet. To achieve this, essential apparatus was positioned at the respective required places. A calibrated temperature sensors (thermometer) were used for temperature reading of the tested product. The flow degree of the mixtures and energy intake of the compressor were analyzed according to *Eqs. (1)* to *(7)*. The analysis was done based on energy and mass stabilities in the entire constituents. *Fig. 1* shows pictorial view of the VCR test rig developed with 25 liter capacity cooling space. Moisture evacuation was done using the installed service ports, and flushed with ammonia gas and further rinsed with the mixture to eliminate remnant of the previous mixture, impurities and other particles in the device. Various samples with different concentrations were measured by digital weighing balance. After flushing, it was turned on, infused by the proper volume fraction through charging line, and monitored within a range of an hour period before taking the (SS) temperature and pressure readings by the inlet and exist of the major component, and product was introduce and monitored at intervals of 15 minutes. The tests were performed to study COP, cooling rate, energy intake, and intervals engaged for product ambient temperature change towards cooling state.

Fig. 1. Vapour compression refrigeration test rig.

2.2.3 | Calculated performance parameters (assumptions made)

The following assumptions were being observed for the analysis of the system: steady-state flow operation is assumed in all the system individual parts; the working fluid has varied percentage composition throughout the cycle; pressure losses along each component are neglected with 75% isentropic proficiency. By applying Stable Stream Drive Equation (SSDE), energy balance mathematical model expression is given by *Eqs. (1)* to *(7)* according to Balaji et al. [17].

Work consumed by the compressor ($\dot{W}_C$) is given according to *Eq. (1)* as:

$$\dot{W}_C = \dot{m}(h_1 - h_2). \tag{1}$$

The work done per kg of refrigerant by the compressor is given as (compressor work input required):

$$W = h_2 - h_1. \tag{2}$$

Heat rejected in the condenser (Q_c) from *Eq. (3)* is thus:

$$Q_c = \dot{m}(h_2 - h_3). \tag{3}$$

For capillary tube (expansion valve);

$$h_3 = h_4. \tag{4}$$

Heat absorbed in the evaporator (Q_e) is given by *Eq. (5)*:

$$Q_e = \dot{m}(h_1 - h_4). \tag{5}$$

VCC is given by *Eq. (6)*:

$$VCC = \frac{\text{Refrigeartion Effect}}{\text{Compressor input specific volume}} = \frac{(h_1 - h_4)}{v_1}. \tag{6}$$

The COP was determined using *Eq. (7)*:

$$COP = \frac{Q_e}{\dot{W}_C}. \tag{7}$$

2.2.4 | Exergy destruction in each parts of the cycle

Exergy destruction in a compressor is given by *Eq. (8)*:

$$I_{comp} = ED_{xd\,1-2} = \dot{m}T_0(\psi_{out} - \psi_{in}) + W_{el} = \dot{m}T_0(S_1 - S_2) + W_{el}. \tag{8}$$

The irreversibility or the exergy loss in condenser is expressed in *Eq. (9)*:

$$I_{dest,cond} = ED_{xd\,2-3} = T_0 S_{gen} = \dot{m}T_0\left(S_3 - S_2 + \frac{q_c}{T_c}\right). \tag{9}$$

Exergy of expansion valve is expressed in *Eq. (10)*:

$$I_{dest,exp} = ED_{xd\,3-4} = T_0 S_{gen} = \dot{m}T_0(S_4 - S_3). \tag{10}$$

Exergy of evaporator is expressed in *Eq. (11)*:

$$I_{dest,evap} = ED_{xd\,4-1} = \dot{m}T_0\left(S_1 - S_4 - \frac{q_{Evap}}{T_{Evap}}\right). \tag{11}$$

The total exergy destruction rate ($\dot{X}_{Total}$) is given by *Eq. (12)*:

$$\dot{X}_{Total} = (ED_{xd\,total}) = ED_{xd\,1-2} + ED_{xd\,2-3} + ED_{xd\,3-4} + ED_{xd\,4-1}. \tag{12}$$

Second law efficiency of the system according to ketan Nayak et al. [18] is the ratio of exergy output (X_{output}) to exergy input (X_{input}) given as thus:

$$\eta_{exergetic} = \frac{\text{Exergy output}}{\text{Exergy input}}. \tag{13}$$

$$\eta_{exergetic} = \left[\frac{X_{output}}{X_{input}}\right] \times 100\%. \tag{14}$$

$$X_{output} = X_{input} - X_{total}. \tag{15}$$

Where $\eta_{exergetic}$ (see *Eq. (16)*) is the exergy efficiency of the whole actual VCS, and exergy input to the system is supplied through the compressor work. This implies that $X_{input} = \dot{W}_c$.

$$\eta_{exergetic} = \left[1 - \frac{X_{total}}{\dot{W}_c}\right] \times 100\%. \tag{16}$$

3 | Results and Discussion

This section shows the results obtained during experimental investigation. Exergy destruction in each part of the cycle based the relation in *Eqs. (1)* to *(16)* was collated in *Table 1* which correlates with the results of ketan Nayak et al. [18] and Abhishek and Gupta [19].

Ikpe et al. | Int. J. Res. Ind. Eng. 12(2) (2023) 143-154

Table 1. Calculated values of exergy destruction in each component at various % fractions.

Particles Concentration (%)	Compressor (kW)	Condenser (kW)	Expansion Valve (kW)	Evaporator (kW)	Total Exergy Destruction	Mean Cooling Time (S)	R_E	W_c (kJ/kg)	$\eta_{exergetic}$ (%)	$\dot{m}$(kg/s)	COP	Power Consumption (kW)
(001)	3.283	68.46	44.41	-2.415	111.54	19.5	3.1	2.048	0.54	0.225	0.53	2.199
(010)	1.062	45.77	40.62	-0.651	86.71	18	2.3	1.132	0.76	0.222	0.45	1.216
(100)	1.394	47.96	42.66	-1.129	90.89	12.5	3.6	1.229	0.73	0.236	0.69	1.319
(011)	41.99	48.48	44.72	-9.369	125.82	14	12.1	0.888	1.43	0.225	3.10	0.942
(111)	1.332	46.15	40.76	-1.059	39.73	18	3.5	0.648	0.32	0.224	1.21	0.696
(211)	1.071	51.67	45.31	-0.663	97.39	20	2.3	1.040	0.94	0.226	0.50	1.117
(121)	0.671	41.43	36.83	0.248	78.57	17	1.2	0.806	0.97	0.207	0.31	0.866
(112)	0.839	48.85	43.87	0.937	94.41	15.5	6.5	1.006	0.93	0.219	1.41	1.081
(221)	1.395	40.32	43.98	0.964	84.11	15.5	5.7	1.488	0.57	0.216	0.83	1.598
(212)	1.454	39.63	43.86	1.266	82.71	14.5	8.7	1.497	0.55	0.214	0.59	1.608
(122)	1.550	45.31	41.86	1.525	90.25	14	3.0	0.881	1.02	0.210	0.71	0,955

3.1 | Mass Flow Rate

Fig. 2 illustrates the plot of measured mass flow rate as a function of nanoparticle zeotropic mixtures volume fraction of a VCR cooling system working with eleven different concentration ratios ranging from 3.0 to 15.0g bulk fluid control having a mass flow rate between 0.207 to 0.236 (kg/s). Conversely, higher performance was obtain between (100) 15g- CuO, zero gram of Al_2O_3/TiO_2 and (211) 7.5-TiO_2; 3.75-Al_2O_3/CuO concentration ratio (refrigerant) charge with optimum mass flow rate of 0.236 (kg/s) and 0.226 kg/s, greater than (121) and (112)% fraction with six based optimum mass volume fraction as tabulated in *Table 1*. Cooling result of the system was boosted due to increase in mass composition as observed with those obtained by Oyewola et al. [20].

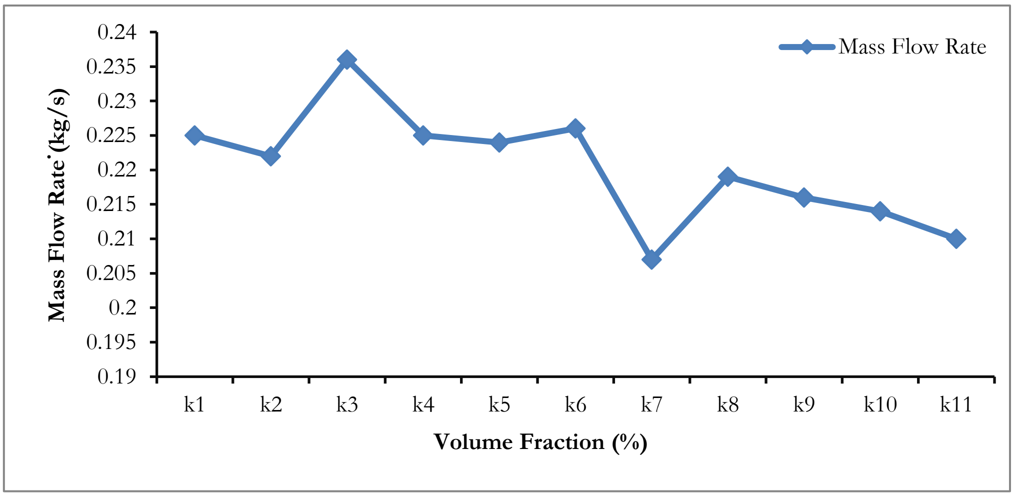

Fig. 2. Plot of mass flow rate versus volume fraction.

3.2 | Compressor Power Consumption (kW)

Fig. 3 shows a plot of compressor power consumption as a function of nanoparticle zeotropic mixture volume fraction. The fig indicates that decrease in energy feedback to the compressor increases the COP and drops the evaporator temperature of the system. The experimental survey clearly show that four different ratio composition in the other of (0.942, 0.696, 0.866 and 0.955 kW) produced the base lower power output that were (011) zero gram-TiO_2; 7.5g-Al_2O_3/CuO; (111) 5.0g-TiO_2/Al_2O_3/CuO; (121)

3.75g-TiO_2/CuO, 7.5g-Al_2O_3 and (122) 3.0g-TiO_2, 6.0g-Al_2O_3/CuO, but obtained the highest power output of 2.199 kW at the ratio of (001) 15.0g-TiO_2, and zero gram-Al_2O_3/CuO. It was further observed that the hybridization of nanofluid-zeotropic mixtures of TiO_2/Al_2O_3/CuO with a less volume fraction and evaporation temperature had the capacity of lowering power consumptions in a refrigeration system from 2.199 kW to 0.696 kW when compared with pure LPG refrigerants which yielded the highest consumption power of 73.20 kW as reported in literature. However, in the study conducted by Bi et al. [21], using R134a refrigerant with TiO_2/SiO_2 lubricant, the power consumption rate increased to about 23.5 kW compared to that of the current study which brought about reduction in the energy consumption.

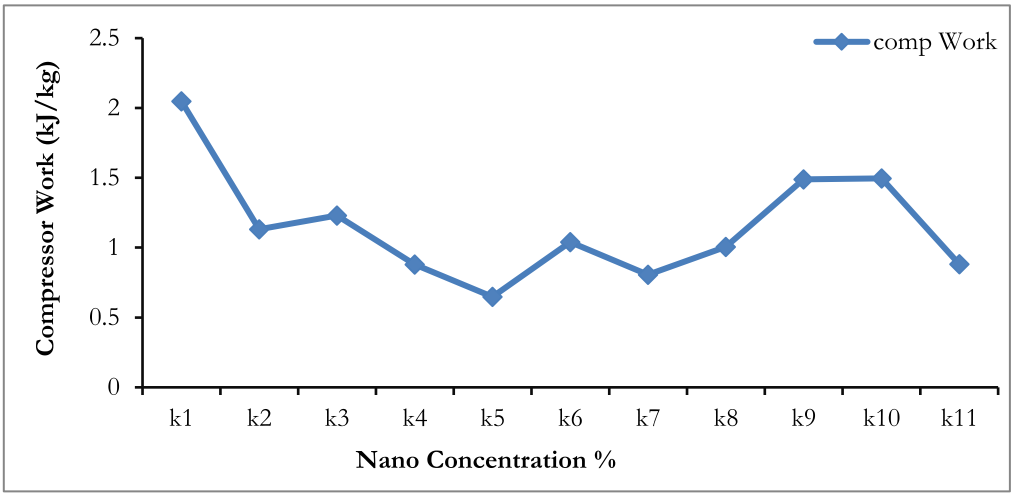

Fig. 3. Plot of compressor power consumption versus volume fraction.

3.3 | Refrigerating Effect

Fig. 4 illustrates the distinction of Refrigerating Effect (RE) and volume fraction cooling outcome through vaporizing temperature from -11°C to -5°C at 16°C condensation temperature. The fig revealed that cooling outcome of the system increased when the vaporizing temperature decreased from (001) 15g-TiO_2, zero gram-Al_2O_3/CuO with 3.1 to 1.2 kJ/kg, having an optimum operating system of 12.1kJ/kg under volume fraction of (011) with zero gram of -TiO_2 and 15g of -Al_2O_3/ CuO. From the aforementioned, the RE of the system increased when the volume fraction decreased. Bolaji et al. [17] and Mohanraj et al. [22] had similar refrigeration output and power coefficient which agrees with the findings of this study.

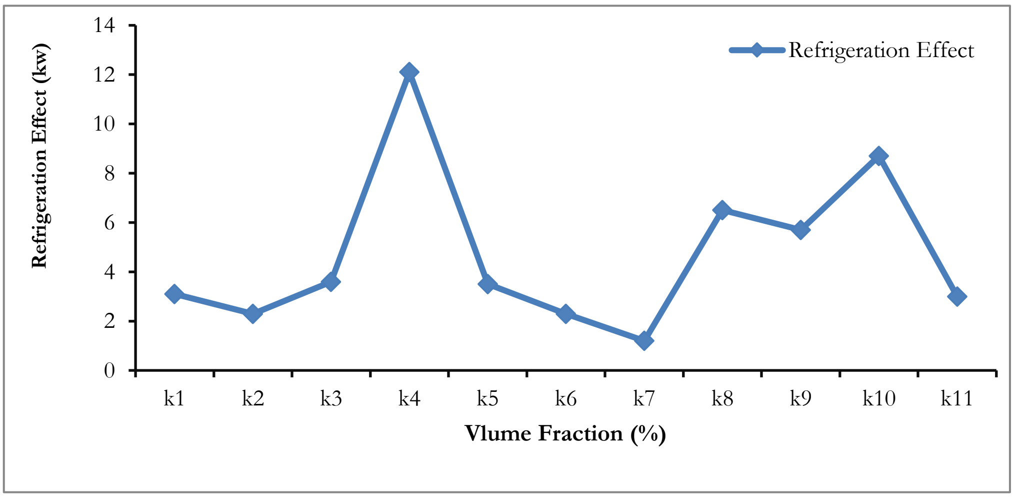

Fig. 4. Plot of RE versus volume fraction.

3.4 | The Volumetric Cooling Capacity

Fig. 5 demonstrates the distinction between VCC and volume fraction for the various mixture concentrations of nanofluid-zeotropic refrigerants. The zigzag trend of the plot shows the refrigeration effect per unit volume of vapor entering the compressor with a decrease in evaporator temperature. This is due to particles size concentration of each mixture, which implies that the greater the VCC, the lesser the compressor power consumption required. Results obtain revealed three optimum volume fraction at (011) zero gram-TiO_2, 7.5g-Al_2O_3/CuO having 68.03 (kJ/m^3), followed by (121) 3.75g-TiO_2/CuO, 7.5g-Al_2O_3 with 67.03 (kJ/m^3) and (212) 6.0g-TiO_2/CuO, 3.0g- Al_2O_3 having 48.84 (kJ/m^3). Other possible combination to be considered were (112) 3.75g-TiO_2/ Al_2O_3, 7.5g- /CuO; (221) 6.0g-TiO_2/ Al_2O_3, 3.0g-CuO with 37.03 and 32.01 (kJ/m^3).

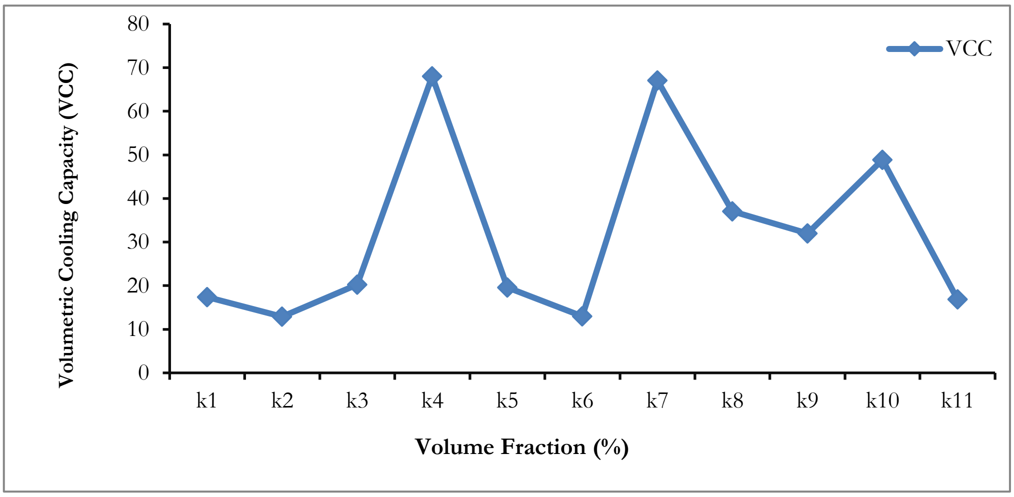

Fig. 5. Plot of variation of VCC versus volume fraction.

3.5 | Coefficient of Performance

Fig. 6 describes the COP as a function of volume fraction. It is found that the COP increased with varied volume fraction ratios and increased as the evaporation temperature (T_{evap}) decreased for the condensation temperature ranging from 11 to 16 ^{0}C, having the optimum COP of 3.1% at particles combination of (011) as also observed in *Fig. 5*. This implies that volume fraction of (011) is a desirable refrigerant mixture alternative, followed by (211) with 0.83%, (112) with 0.71% and (100) with 0.69%. COP of 2.06% was observed from the study conducted by König-Haagen et al. [13], Flores et al. [14] and Dossat and Horan [23] with SiO_2 and TiO_2 established oils with both having COP of 2.97.

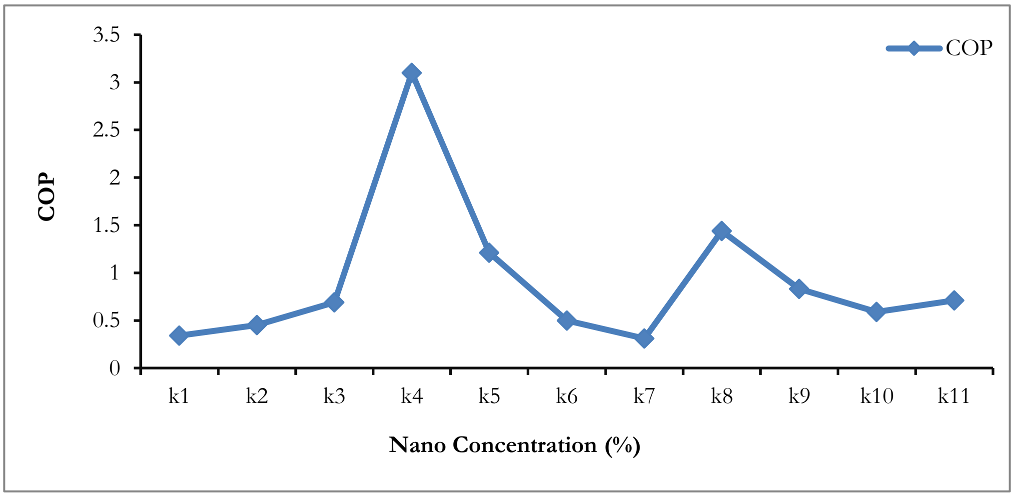

Fig. 6. Plot of COP versus volume fraction.

3.6 | Exergy Destruction Ratio in the System Components

Fig. 7 shows variation of individual system components versus volume fraction. Experimental data obtained from the test rig agreed with the findings of other researchers such as Adelekan et al. [24], Ohunakin et al. [25], Sajid and Ali [26] and many others, confirming that to specify the exergy losses or destructions in the system, exergy analysis is necessary. The result revealed that maximum exergy damage value is obtain via the condenser with 68.46 kW at volume fraction of (001), with 7.5g-TiO_2, zero gram-Al_2O_3/CuO, followed by (211), 7.5g-TiO_2, 3.75g-Al_2O_3/CuO with 51.67 kW and (112), (011) and (100) with 48.85, 48.48 and 47.96 kW. The second highest exegetic loss is observed in expansion valve at (211) and (011) with 45.31 and 44.72 kW. The next loss is found in compressor at (011) with 41.99 kW and subsequently followed by evaporator at (011) with -9.37 Kw. The survey indicated that optimum cooling rate in the evaporator is at volume fraction of (011) zero gram-TiO_2, 15g-Al_2O_3/CuO with the compressor efficiency showing maximum performance at the same volume fraction of (011) with 41.99 kW. The variation in individual components is at the increase, based on nanofluid porosity and size. As compared with work done by others researchers, it was observed that nano-zeotropic mix has the ability to stabilize vapour compression system with less power consumption as in agreement with those obtained by Mohanraj et al. [22], Padilla et al. [27] and Ziegler and Alefeld [28].

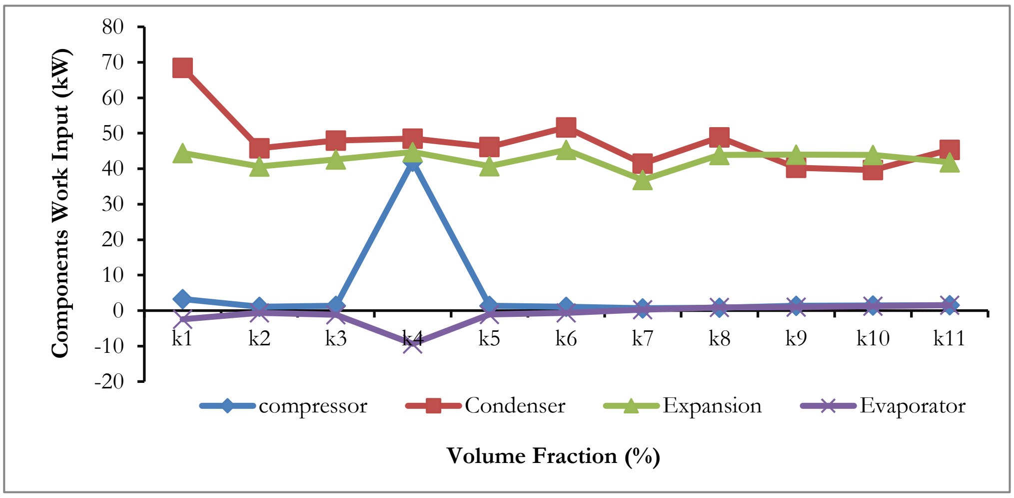

Fig. 7. Variation of individual system components versus volume fraction.

4 | Conclusions

In this work, the thermodynamic analysis of hybrid-nanofluids-zeotropic mixtures in a VCRS based on exergy principles was experimentally investigated. Measurements of the global parameters (compressor power consumption, cooling time, VCC, refrigeration effect, mass flow rate, condenser, exergy damage ratio in each component, heat transfer rate, among others) were investigated. The results showed different effects that each concentration had on these parameters based on the individual concentrations mixtures. It further revealed that (011) zero gram-TiO_2, 7.5 g-Al_2O_3/CuO and (112) 3.75 g-TiO_2/Al_2O_3, 7.5 g-/CuO–concentration mixtures enhanced the demonstration of the cooling process with better efficiency and maximum COP in all phases of measured measurements done in this study. The study indicated that (111) 5 g-TiO_2/Al_2O_3/CuO with 0.65% showed the lowest compressor work with low GWP value whereas, characterization tests conducted revealed that the hybrid-refrigerant shows optimistic influence on the energy intake capacity. Comparisons made shows that maximum power coefficient and cooling capacity for the eleven different volume concentrations was found at (001) 15 g-TiO_2, zero gram-Al_2O_3/CuO equal to 2.2 kW, and the minimum value of power coefficient at concentration 5 remained establish in the direction equal to 0.61% at (111) 5 g-TiO_2/Al_2O_3/CuO, and 0.87% for (121). Hence, the maximum power coefficient, cooling capacity, and COP increased by 13.51%, 5.78%, and 10.33% respectively. This implies that nanoparticles can significantly improve the power output and cooling capacity even in a low volume concentration and complex system. From the analysis carried out in this study, further analysis is recommended for determining the anti-wear characteristics of the hybrid nanofluid-zeotropic mixtures to establish the dependability of its use in a VRCS. Moreover, considering the effects of nanofluid-zeotropic mixture refrigerant on public health safety and environment, permissible refrigerant control, wellbeing standard and codes should be taken into consideration.

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Ikpe et al.| Int. J. Res. Ind. Eng. 12(2) (2023) 143-154