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RESEARCH PAPER

Thermodynamic (energy-exergy) performances comparison of VCR system using ecofriendly refrigerants in primary and nano mixed brine/glycol flow in secondary circuit evaporator and water flow in condenser

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Abstract

This work highlights the critical role of refrigeration in modern domestic and industrial applications, primarily operating on the vapour compression refrigeration system (VCRS) principle, where refrigerant selection directly influences performance and sustainability. In this study, ecofriendly refrigerants (R1234ze(Z), R1233zd(E), R1224yd(Z), R1336mzz(Z), R245fa, R152a, R1243zf, and R32) were compared with the baseline HFC-134a. Results from the developed thermal model revealed that R1234ze(Z) achieved the highest coefficient of performance (COP) of 3.19, representing a 12.7% improvement over HFC-134a (COP = 2.83), whereas R1234yf exhibited the lowest performance with a COP of 2.67 (5.9% reduction).
The influence of operating parameters was further investigated using HFC-152a. Increasing compressor speed from 2300 rpm to 3000 rpm decreased COP from 3.17 to 2.95, while exergy efficiency improved from 0.263 to 0.271. In contrast, increasing condenser water flow rate from 0.007 to 0.010 kg/s enhanced COP from 2.90 to 3.06, raised exergy efficiency from 0.259 to 0.283, and lowered compressor power consumption. Moreover, the incorporation of nanorefrigerants significantly boosted thermal performance, with CuO-based nanofluids demonstrating nearly 95% improvement in heat transfer coefficient at 5 vol% concentration and achieving a maximum effectiveness factor of 3.2 compared to base refrigerants.

1. Introduction

Refrigeration plays a significant role in the modern lifestyle we lead today. It has a wide range of applications in both household and professional contexts. Most of these systems operate on the basis of the VCR system's work-based cycle premise. By rejecting heat to the environment at higher temperatures, refrigeration technology collects heat at low temperatures and produces temperatures below normal. Compressor, expansion valve, condenser, and evaporator are the four main parts of a simple vapour compression system as shown in Fig-1. The fluid used in the VCR systems is known as refrigerant. The refrigerants can be classified as Natural refrigerants and artificial refrigerants. Natural refrigerants, such as CFCs, HCFCs, HFCs, HCs, and their mixtures, have been used for many years in a variety of applications. Several of these refrigerants have been found to be environmentally hazardous, causing the ozone layer to thin and increasing the likelihood of global warming. Since that discovery, researchers have been working to develop new refrigerants

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that address the aforementioned environmental issues and increase the efficiency of existing systems.

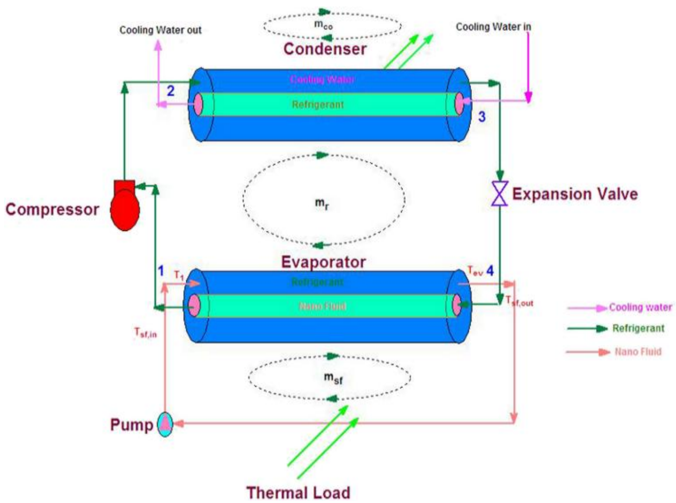

Figure 1: Vapour compression refrigeration system [1]

In this system, the evaporator carries the entire cooling load at a single temperature, but in many applications, such as large hotels, food storage facilities, and food processing plants, food items are stored in different compartments at different temperatures. Consequently, a multi-evaporator vapour compression refrigeration system is required. Systems using vapour compression technology use a significant amount of electricity; this issue can be resolved by enhancing system performance. By doing the following, systems that use vapour compression refrigeration technology can operate more efficiently [1-3]. By adding nanoparticles to the eco-friendly refrigerant or to R718/ glycol water solution flowing in the evaporator's secondary circuit improves the refrigerator's performance in terms of first law efficiency (COP), which is the ratio of the refrigeration effect to the network input supplied to the system. Increasing the refrigeration effect or decreasing the work input provided to the system are two ways to increase the COP of a vapour compression refrigeration system. This problem can be eliminated by adopting multi-stage expansion with flash chamber where the flash vapours is removed after each stage of expansion as a consequence there will be increase in cooling capacity and reduce the size of the evaporator. Single stage compression can also be used to reduce work input in place of multistage or compound compression. fter the refrigerant passes through the condenser and evaporator, it can also pass through a sub-cooler to enhance the refrigeration effect [3].

2. Ecofriendly Refrigerants

A major part of the modern lifestyle we lead today involves refrigeration. It can be used for a great deal of things in both home and business settings. The majority of these systems function according to the work-based cycle principle of a VCR system. The use of nanofluids is one of these more recent developments in refrigeration systems [4].

HFC134a is currently the most widely used refrigerant in all vapour compression refrigeration systems. However, the only issue with this kind of refrigerant is that it requires a lot of electricity. In order to improve the efficiency and effectiveness of the refrigeration process and protect the environment, we now need a new product that can either replace alternative refrigerants like HFO1234yf and HFO1234ze or have advanced thermo-physical properties, such as nanomaterials that increase the heat transfer coefficient and have low power consumption. The current study introduces new nanomaterials combined with R718/glycol water employed in the secondary circuit of evaporator technology, and the performance of VCRS is greatly enhanced by this nanotechnology. The combination of nanoparticles and refrigerant is known as nano refrigerant. in contrast to other refrigerants. The heat transfer coefficient is improved by almost 95% when nanoparticles such as AL_2O_3, CuO, and TiO_2 are combined with R718 and employed in the evaporator's secondary circuit [5]. The conductivity ratio of pure refrigerant to nano refrigerant increases with the concentration of nanoparticles in the host refrigerant. In contrast, CuO nanoparticle-based nano refrigerants have a higher conductivity ratio than other nanoparticles and have approx. Two times higher than base refrigerant at 5 vol % concentration and the eco-friendly HFC-134a with CuO nanoparticles have the maximum effectiveness factor approx. 3.2 at 5 vol %. The effectiveness factor increases with an increasing percentage of volume (vol %), and the copper mixed nano refrigerant has the maximum convective heat transfer coefficient ratio than other nanoparticles mixed in brine water in the secondary circuit of the evaporator. Numerous studies have been carried out to evaluate thermal performance of low global warming potential (GWP) refrigerants, including HFCs and HFOs, in both the primary and secondary circuits of the evaporator [6]

The effects of temperature and volume on the viscosity of R123-TiO_2 nano refrigerant at temperatures ranging from 5°C to 20°C and with a maximum volume concentration of 2% of nanoparticles. Investigations have also been conducted into the impact of pressure drop with increasing viscosity. According to the investigation, the viscosity of the nano refrigerant reduces with rising temperatures and increases in proportion to increasing volume concentrations of nanoparticles. Also, as volume concentrations increase, pressure drop increases prominently. As a result, modest volume concentrations of nano refrigerant are recommended to improve refrigeration system performance [7-8]. R. S. Mishra and R.K. Jaiswal [2014] investigated the impact on the energy performance (C.O.P.) and the thermophysical features of various nanoparticles added to eco-friendly HFC refrigerants and their blended refrigerant mixtures. The experimental results validate in comparison to base refrigerant and found the specific heat of nano-refrigerant is slightly lower. Similarly, the thermal conductivity, dynamic viscosity, and density of nano-refrigerant (different nanoparticle such as Cu, Al2O3,CuO, and TiO2 with ecofriendly refrigerant R134a, R407c, and R404a) improved by around 15 to 25%, 20%, and 12 to 35%, respectively [9]. The effectiveness of R134a-ZrO2 nano refrigerants at a concentration of 0.2 g/l in a domestic refrigerator without altering the constituent parts were examined experimentally. After charging 140 g of R134a and 0.2 g/L of ZrO2 nanoparticles with a particle size of 1–10 nm, studies were conducted to examine the refrigerator's performance Senthilkumar Alagarsamy et.al.,[10]. At varying concentrations studies were conducted by combining two different nanoparticles, such as ZnO and SiO2 in a VCR system using R600a with ZnO and SiO2 hybrid nano lubricants. on such compressor power consumption, cooling capacity, and coefficient of performance using hybrid nano lubricants, and found experimentally more than 40% improvement in the system's performance coefficient, and rise in cooling capacity and a reduction in compressor electrical power consumption by using 40 g of R600a refrigerant and 0.4 g/L of ZnO/SiO2 and also, 0.6 g/L ZnO/SiO2 with 60 g of R600a refrigerant. the highest C.O.P. at 35%. R404a and R407c show improvements in C.O.P. of roughly 3 to 14% and 3 to 12%, respectively, when using different nanoparticles [11]. The suction and discharge pressures, refrigeration effect, power consumption, and COP) of usual refrigerants influenced by several nanoparticles such as TiO2, Al2O3, CuO, SiO2, ZnO, ZrO2, ZnO/SiO2, diamond was found [12]. A novel fluid with unique properties, nanofluid finds application in a wide range of industrial heat transfer processes. The four mixture nanofluid samples at four different volume concentrations and found that the two-step method of dispersing nanoparticles into Jatropha oil was responsible for the largest increase in thermal conductivity for CuO-Jatropha oil nanofluids. three factors: temperature, volume concentration, and volume concentrations of the mixture of nanoparticles interrupts the thermal conductivity of CuO-Jatropha oil nanofluids. The rise in thermal conductivity and viscosity was influenced by nanoparticles at temperatures ranging from 298 to 323 K, according to the results. The invention of nano refrigerants has significantly raised the productivity of refrigeration systems [13]. Nano refrigerants have superior thermal and heat transfer properties. Thermal conductivity, viscosity, COP, and energy savings were assessed theoretically for volume concentrations of 0.5, 1, 2, and 3 vol% in HFC-134a and HFC-152a refrigerants using single walled carbon nanotubes (SWCNTs) nanoparticles. A detailed investigation of nano refrigerants [13]. The improvement in the energy efficiency (COP) for both nano refrigerants was caused by the notable heat conductivity of nanoparticles. When compared to R134a-based nano refrigerants, R152a-based nano refrigerants have demonstrated the highest COP [14]. Many essential research investigations have been conducted on studying the thermal conductivity of water-based nano-fluids and nano-refrigerants. nanofluids consisting of Cu nanoparticles directly dispersed in ethylene glycol have been observed to exhibit significantly improved thermal conductivity enhancements compared to nonparticle-containing fluids or nanofluids containing oxide particles. The impacts of adding various nanoparticles combined with eco-friendly refrigerant and investigating their effects on the coefficient of performance (C.O.P.) were researched found in comparison to base refrigerant, the thermal conductivity, dynamic viscosity, and density of Nano-refrigerant (different nanoparticles, such as CuO, Al2O3, and TiO2) increased by approximately 15%, 20%, and 12%, respectively, in comparison to base refrigerant R134a, R407c, and R404A [15]. In response to various environmental resolutions, more eco-friendly refrigeration systems have been considered in recent years. Two aspects are of particular concern: ecofriendly refrigerants and electrical energy consumption. HFO & HCFO refrigerants have potential to replace R134a and found lowest thermal performance in terms of energy efficiency, exergy efficiency found lowest by using nano in the HFO-1234yf and best thermal performance in terms of first-law efficiency is found by using R1234ze(Z). He has not compared with performance parameters by using glycol-based fluid with brine water-based fluid flowing in the secondary circuit of evaporator. The comparison between both nano based fluids will be discussed in this paper.

3. Results and Discussion

Table 1 presents the essential input parameters considered in the vapour compression refrigeration (VCR) system analysis. The evaporator tube length was fixed at 7.2 m, while the condenser tube length was 12.5 m, which ensures sufficient heat transfer surface area for effective system operation. The mass flow rate of cooling water circulating through the condenser was maintained at 0.008 kg/s, whereas the brine flow rate at the evaporator was slightly lower at 0.007 kg/s. Both the condenser water and brine water inlet temperatures were set at 27°C, reflecting typical operating conditions in controlled laboratory or industrial setups. These input parameters form the foundation of the thermodynamic and exergetic evaluation of the system, as they directly influence heat exchange rates, refrigerant performance, and system efficiency.

Table-1: Input data used in VCR system

S.No.	Description	Value with unit
1	Length of evaporator tube	7.2m
2	Length of condenser tube	12.5m
3	Mass flow rate of water flow	0.008kg/sec
4	Mass flow rate of brine flow	0.007kg/sec
5	Condenser water inlet temperature	27°C
6	Brine water inlet temperature	27°C

Table 2(a) summarizes the coefficient of performance (COP) of the VCR system when operated with different ecofriendly refrigerants compared to the baseline refrigerant R134a. Among the tested refrigerants, R1234ze(Z) exhibited the highest COP of 3.1929, corresponding to a 12.7% enhancement over R134a (COP = 2.8347). This indicates its strong potential as a sustainable alternative. Close performance values were achieved with R1233zd(E) (COP =

3.1519, 11.3% improvement) and R1224yd(Z) (COP= 3.0819, 9.2% improvement). Moderate performance was obtained with R1336mzz(Z) (COP = 3.0701, 8.3% enhancement), while R245fa and R152a offered smaller improvements of around 4.6% and 4.3%, respectively. On the lower side, R1243zf and R32 provided marginal enhancement of 1.8% and 0.35%, respectively, relative to R134a. These results highlight that certain low-GWP refrigerants, particularly R1234ze(Z), offer both energy efficiency and environmental benefits, making them promising replacements for R134a.

Table-2(a): The performance evaluation of vapour compression refrigeration systems using ecofriendly refrigerants.

Ecofriendly refrigerants	COP	% enhancement
R1234ze(Z)	3.1929	12.701
R1233zd(E)	3.1519	11.318
R1224yd(Z)	3.08195	9.201
R1336mzz(Z)	3.0701	8.324
R245fa	2.9629	4.5859
R152a	2.9601	4.339
R1243zf	2.780	1.829
R32	2.8449	0.352
R134a	2.8347	0.0

Table 2(b) focuses on refrigerants that displayed either comparable or slightly reduced performance compared to the baseline R134a. The COP of R134a was 2.8347 and treated as the reference with zero enhancement. In contrast, R1234ze(E) demonstrated a COP of 2.8049, which reflects a 1.62% reduction relative to R134a. Similarly, R1225ye(Z) showed a COP of 2.751, corresponding to a 2.93% decrease, while R1234yf delivered the lowest COP of 2.6703, amounting to a 5.93% reduction. These findings indicate that while these refrigerants may be more environmentally friendly, their thermodynamic performance is slightly compromised compared to R134a. Thus, they may require system optimization or hybrid approaches (e.g., blending, nano refrigerants, or cycle modifications) to offset their lower efficiency. The performance evaluation of vapour compression refrigeration systems using low GWP ecofriendly refrigerants have been calculated using developed thermal model and it was found that HFO 1234ze(Z) gives better thermodynamic performances than using HFC-134a is shown in Table-2(a) respectively. However lowest thermodynamic performances were found using HFO-1234yf. The performance of VCR system has been compared with using HFC-134a and final results were shown in table-2(a) respectively.

Table-2(b): Thermal performance evaluation of vapour compression refrigeration systems using ecofriendly refrigerants

Ecofriendly refrigerants	COP	% enhancement
R134a	2.8347	0.0
R1234ze(E)	2.8049	-1.6202
R1225ye(Z)	2.751	-2.929
R1234yf	2.6703	-5.928

3.1 Effect of compressor speed on thermodynamic performances

The detailed thermal performances of VCR system using eco-friendly HFC -152a have been computed by changing compressor speed from 2300rpm to 3000 rpm it was found that by increasing compressor speed, the first law efficiency (COP) decreasing while exergy efficiency is increased because increase in compressor speed helps decrease the heater surface temperature, which is good for cooling and the power required by the compressor is increasing as shown in table 3.

Table 3: Effect of compressor speed on thermal performances of vapour compression refrigeration system using HFC-152a

Compressor speed (rpm)	2300	2400	2500	2600	2700	2800	2900	3000
COP	3.168	3.12	3.08	3.045	3.04	2.988	2.9601	2.948
Relative COP	0.5393	0.5405	0.5423	0.5443	0.5465	0.5489	0.5516	0.5544
Irreversibility Ratio (I.R.)	2.801	2.786	2.77	2.752	2.77	2.713	2.716	2.694
Exergy Efficiency	0.2631	0.2612	0.2623	0.2665	0.2679	0.2693	0.2907	0.2725
Exergy of Fuel (kW)	9.171	9.427	9.668	9.896	10.11	10.31	10.5	10.68
Exergy of Product (kW)	2.396	2.473	2.547	2.62	2.69	2.759	2.826	2.892
Exergy Destruction Ratio (EDR)	2.828	2.813	2.796	2.778	2.768	2.738	2.692	2.670
Exergetic Efficiency	0.2631	0.2641	0.2635	0.2647	0.2661	0.2675	0.2691	0.2707
Evaporator Efficiency	0.4657	0.4640	0.4628	0.4619	0.4613	0.4609	0.4608	0.4609
Compressor Efficiency	0.5141	0.5142	0.5144	0.5148	0.5154	0.5161	0.5170	0.5180
Evaporator temperature (°C)	2.148	1.744	1.366	1.012	0.6779	0.3631	0.0651	(-0.2176)
Condenser temperature (°C)	48.99	48.14	49.68	50.58	50.29	50.58	50.84	51.09
Condenser water temperature out (°C)	38.3	38.49	38.67	39.17	39.01	39.17	39.33	39.48
Brine water temperature out (°C)	15.43	15.28	15.14	15.0	14.86	14.72	14.59	14.45
Compressor work (kW)	9.171	9.427	9.668	9.896	10.11	10.31	10.5	10.68
Heat Capacity of condenser fluid(J/K)	17.33	17.30	17.27	17.25	17.23	17.21	17.19	17.18
Heat Capacity evaporator fluid(J/K)	11.57	11.57	11.57	11.58	11.59	11.62	11.64	11.65
Second law efficiency	0.5393	0.5404	0.5423	0.5443	0.5465	0.5489	0.5516	0.5564
Compressor work (kW)	9.171	9.427	9.668	9.896	10.11	10.31	10.5	10.68

3.2 *Effect of condenser water flow rate on thermodynamic performances*

Table 4 highlights the influence of varying condenser water mass flow rates (0.007–0.010 kg/s) on the thermal and exergetic performance of a vapour compression refrigeration system using the ultra-low GWP refrigerant HFC-152a. A clear improvement in overall system performance is observed as the water flow rate increases. The coefficient of performance (COP) rises steadily from 2.901 at 0.007 kg/s to 3.063 at 0.010 kg/s, accompanied by a marginal rise in relative COP from 0.5496 to 0.5543. This indicates enhanced energy efficiency due to better heat rejection in the condenser. Simultaneously, the irreversibility ratio (I.R.) declines from 2.83 to 2.507, suggesting reduced system losses. The exergy efficiency also improves consistently, rising from 0.2594 to 0.2833, while the exergy destruction ratio (EDR) decreases, reflecting improved second-law performance. The thermodynamic balance shows that the exergy of fuel decreases slightly from 10.63 kW to 10.32 kW, while the exergy of product increases from 2.756 kW to 2.924 kW, reinforcing that higher condenser water flow improves useful work output. However, compressor efficiency declines notably from 0.5563 to 0.4523, indicating increased compressor load with higher flow rates. In contrast, evaporator efficiency remains nearly constant (~0.46), highlighting its relative insensitivity to condenser-side variations. Temperature trends confirm better thermal management: the condenser temperature drops from 52.19°C to 48.96°C, while the condenser water outlet temperature decreases from 41.01°C to 36.93°C, showing effective heat rejection. The brine outlet temperature reduces slightly from 14.72°C to 14.41°C, which helps maintain effective cooling. Heat transfer coefficients provide further evidence of enhanced condenser performance, with the condenser heat transfer coefficient increasing from 632.74 W/m²K to 673.8 W/m²K, while the evaporator coefficient remains almost constant (~647 W/m²K). Pressure trends also align with thermal improvements, as both evaporator pressure and condenser pressure decrease with increasing flow rate, lowering system stress. Additionally, the condenser fluid capacity rises from 16.29 J/K to 18.92 J/K, supporting higher heat absorption capability.

Table 4: Effect of water mass flow rate in condenser on *thermal performances of vapour compression refrigeration system using ultra-low GWP ecofriendly HFC-152a refrigerant*

water mass flow rate in condenser (kg/sec)	0.007	0.008	0.009	0.010
COP	2.901	2.9601	3.019	3.063
Relative COP	0.5496	0.5516	0.5531	0.5543
Irreversibility Ratio (I.R.)	2.83	2.692	2.588	2.507
Exergy Efficiency	0.2594	0.2709	0.2769	0.2833
Exergy of Fuel (kW)	10.63	10.50	10.40	10.32
Exergy of Product (kW)	2.756	2.826	2.881	2.924
Exergy Destruction Ratio (EDR)	2.716	2.716	2.611	2.530
Exergy Efficiency	0.2611	0.2691	0.2787	0.2852
Evaporator Efficiency	0.4618	0.4608	0.4603	0.4603
Compressor Efficiency	0.5563	0.5170	0.4826	0.4523
Evaporator temperature (°C)	0.3942	0.0651	(-0.1840)	(-0.3787)
Condenser temperature (°C)	52.19	50.84	49.79	48.96
Condenser water temperature out (°C)	41.01	39.33	38.0	36.93
Brine water temperature out (°C)	14.72	14.59	14.49	14.41
Evaporator heat transfer coefficient (W/m²K)	649.65	648.04	647.04	646.42
Condenser heat transfer coefficient (W/m²K)	632.74	649.19	662.63	673.8
Evaporator pressure (Bar)	2.972	2.937	2.910	2.89
Condenser pressure (Bar)	13.93	13.47	13.12	12.84
Evaporator fluid capacity (J/K)	11.59	11.57	11.55	11.55
Condenser fluid capacity (J/K)	16.29	17.3	18.17	18.92
Evaporator heat transfer coefficient (W/m²K)	649.65	648.04	647.04	646.42

4. Conclusion

The performance evaluation of vapour compression refrigeration systems using ecofriendly refrigerants have been calculated using developed thermal model and the following conclusions were drawn.

(i) HFO 1234ze(Z) gives better thermodynamic performances than using HFC-134a. However lowest thermodynamic performances were found using HFO-1234yf by using brine fluid flow in secondary circuit of evaporator and water flow in the secondary circuit of condenser water.

(ii) The detailed thermal performances of the VCR system with HFC-152a refrigerants in the primary circuit and brine-based fluid in the secondary circuit of the evaporator and wtater flow in the condenser have been evaluated and it was found that three factors (mass flow rate of brine, compressor speed and water flow rate in the condenser strongly affecting system thermodynamic performances.

(iii) By increasing compressor speed, the first law efficiency (COP) decreasing while exergy efficiency is increased because increase in compressor speed helps decrease the heater surface temperature, which is good for cooling and the power required by the compressor is increasing

(iv) By changing mass flow rate of water in the secondary circuit and it was found that by increasing compressor speed, the first law efficiency (COP) increasing while exergy efficiency is also increased while electrical energy consumption is reduced as mass flow of water in the condenser is increased.

References

[1] K. Chopra, V. Sahni, and R. S. Mishra, "Thermodynamic analyses of multiple evaporators vapour compression refrigeration systems with R410A, R290, R1234YF, R502, R404A and R152A," *Int. J. Air-Conditioning and Refrigeration*, vol. 21, no. 1, pp. 1–14, 2014.

[2] R. S. Mishra, "Thermodynamic performance evaluation of multiple evaporators, single compressor, single expansion valve and liquid vapour heat exchanger in vapour compression refrigeration systems using thirteen ecofriendly refrigerants for reducing global warming and ozone depletion," *Int. Res. J. Sustainable Sci. & Eng.*, vol. 2, no. 3, pp. 1–10, 2014.

[3] R. S. Mishra, "Comparison of six modified VCR systems at different evaporator temperatures using single and multiple compressors expansion valves with seven ultra-low GWP ecofriendly refrigerants," *Int. J. Res. Eng. Innov.*, vol. 8, no. 3, pp. 120–127, 2024.

[4] R. S. Mishra, "Methods for improving thermal performance of VCR system using twelve ecofriendly refrigerants in primary circuit and nanofluid (water-nano particles based) in secondary circuit," *Int. J. Emerging Technol. Adv. Eng.*, vol. 4, no. 6, pp. 1–7, Jun. 2014.

[5] R. S. Mishra and R. K. Jaiswal, "Thermal performance improvements of VCR system using ecofriendly-based nanorefrigerants in primary circuit," *Int. J. Advance Res. Innov.*, vol. 3, no. 3, pp. 524–535, 2019.

[6] Z. Said, S. Rahman, and M. Sohail, "Nano-refrigerants and nano-lubricants in refrigeration: Synthesis, mechanisms, applications, and challenges," *Appl. Therm. Eng.*, vol. 233, p. 121211, Oct. 2023.

[7] I. M. Mahbubul, R. Saidur, and M. A. Amalina, "Investigation of viscosity of R123-TiO2 nanorefrigerant," *Int. J. Mech. Mater. Eng.*, vol. 7, no. 2, pp. 146–151, 2012.

[8] I. M. Mahbubul, S. A. Fadhilah, R. Saidur, K. Y. Leong, and M. A. Amalina, "Thermophysical properties and heat transfer performance of Al2O3/R-134a nanorefrigerants," *Int. J. Heat Mass Transf.*, vol. 57, pp. 100–108, 2013.

[9] R. S. Mishra and R. Jaiswal, "Thermophysical property of nanorefrigerant: Preparation, thermal characteristics, and applications," *Int. J. Res. Eng. Innov.*, vol. 3, no. 3, pp. 163–170, 2017.

[10] S. Alagarsamy, "Experimental investigation of ZnO/SiO2 hybrid nano-lubricant in R600a VCR system," *Mater. Today: Proc.*, vol. 45, no. 2, 2020, doi: 10.1016/j.matpr.2020.10.180.

[11] A. Baskaran, N. Manikandan, J. L. Tesfaye, and N. Nagaprasad, "Investigation on the performance of domestic refrigerator with zirconium oxide-R134a nanorefrigerant," *J. Nanomater.*, vol. 2022, Art. no. 3668458, Mar. 2022, doi: 10.1155/2022/3668458.

[12] S. Venkataiah and G. Sthithapragna, "Comprehensive evaluation of nanorefrigerants: A review," *Mater. Today: Proc.*, vol. 72, no. 5, Sep. 2022, doi: 10.1016/j.matpr.2022.09.094.

[13] S. Gobane, T. Dama, N. Hasan, and E. Yanmaz, "Characterization of copper oxide–jatropha oil nanofluid as a secondary refrigerant," *J. Nanomater.*, vol. 2023, Art. no. 7612959, 2023, doi: 10.1155/2023/7612959.

[14] O. A. Alawi, N. A. C. Sidik, and H. A. Mohammed, "A comprehensive review of fundamentals, preparation and applications of nanorefrigerants," *Int. Commun. Heat Mass Transf.*, vol. 103, pp. 54–61, Mar. 2019.

[15] R. S. Mishra, "Methods for enhancing energetic-exergetic performances of VCR system using HFO-1336mzz(Z) refrigerant through nanomaterials mixed with R-718 fluid in secondary circuit of evaporator," *Int. J. Advance Res. Innov.*, vol. 4, no. 3, pp. 143–148, 2020.

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