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ORIGINAL ARTICLE

Comparison of thermodynamic (energy-exergy) performances VCR systems using low GWP HFC refrigerants and HFO blends in primary and nano mixed brine /glycol flow in secondary circuit evaporator

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Abstract

This paper mainly deals with the low global warming potential HFC refrigerants along with another three HFO+HFC blended refrigerants in the primary circuit of the evaporator and comparison for using brine flow with nano materials and glycol-based fluid mixed with nano materials flow and without nano materials in the secondary circuit of the evaporator. Numerical computation was carried out for effect of performance parameters (mass flow rate of water in condenser, and brine /glycol-based fluid flow in the secondary circuit of evaporator) on first and second law thermal performances by using developed model for VCR system. The developed thermal model computes volumetric efficiency, isentropic efficiency, effective thermal conductivity, viscosity , specific heat and density of nano fluids and found that by using HFC-245fa refrigerant the thermodynamic first law(energy) performances (COP) enhanced up to 23.26%, 22.935%, and 18.82% respectively by using CuO, Al2O3and TiO2 nanomaterials in brine fluid and 21.205%, 19.99% &17.32%, by using glycol based nano fluids respectively in the secondary circuit of the evaporator. Similarly, its thermodynamic second law performances using HFC+HFO blended refrigerant the thermodynamic second law(exergy) performances enhanced up to 25.6%, 22.4% and 20.24% respectively by using CuO, Al2O3and TiO2 mixed nanomaterials in brine water and 20. %, 19.87%, and 14.937% respectively using glycol solution primary circuit.
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1. Introduction

Technology is based on the rejection of heat to the surrounding at higher temperatures and absorption of heat at low temperatures, evaporator, expansion valve, condenser and compressor are the four main components of the single-stage vapour compression system. VCR systems consume a large amount of electricity. This difficulty can be removed by improving the performance parameters of the system. Therefore, the thermodynamic performances of techniques based on VCR system technology can be improved by following. First law efficiency (Coefficient of performance) and second law performance (exergy efficiency) are the main two parameters to calculate the performance of refrigeration systems. The Coefficient of performance can be enhanced by minimizing the compressor's power consumption or increasing the refrigeration effect. The adoption of multi-stage throttling can increase the refrigeration effect. On the other hand, compressor power consumption can be enhanced by incorporating multi-stage compression and flash chamber.

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1.1 Thermodynamic analysis of VCR systems

The Coefficient of performance is commonly used to calculate the performance of vapour compression system but COP provides no information regarding thermodynamic losses in the system components, one can quantify the exergy losses in VCR systems using exergy analysis. Exergy losses increase with increasing of the temperature difference between systems and surroundings. Exergy is the available or useful energy and loss of energy means loss of exergy in the system. Exergy losses are useful to improve the performance of the system and better utilization of energy input given to the system, which is beneficial for environmental conditions and economics of energy technologies.

The systems under vapour compression technology consume an enormous amount of electricity, this problem can be solved by improving performance of system.

- R450A is a HFO blend, used a replacement for R134a. It offered similar performance with a much lower Global Warming Potential (GWP) than HFC-134a. R450A is mainly used in medium and high-temperature refrigeration applications.
- R513A has the potential to replace R134a in current refrigerators, especially in small-capacity home air conditioning units.
- The refrigerant R515A are the drop-in replacement for R134a.
- Refrigerant R454b is a mildly flammable low global warming potential (GWP) hydrofluoroolefin (HFO) based refrigerant to replace R410a in new equipment designs. It offers the optimal balance of properties to replace R410a in direct expansion air conditioning, chiller, and heat pump applications.
- R454C is a mildly flammable refrigerant with a GWP less than 150. It is used as a replacement of R404A and R22 in new equipment designs in positive displacement, direct expansion low and medium temperature commercial and industrial applications. The thermal and environmental properties of HFO and HFO blends are shown in table-1(a) respectively.

Table 1(a): Thermodynamic and environmental Properties of HFC-134a, HFO-1234yf & HFO Blends

Thermodynamic Property	R134a	R1234yf	R450A	R513A	R515A	R454B	R454C
HFO+HFC Blends	–	–	42% R134A+ 58% R1234ze	R134a+ R1234yf	88% R1234ze+ 12%R227ea	68.9% R32+31.1% R1234yf	21.5% R32+78.5% R1234yf
Molar Mass (kg/kmol)	102.3	114.04	108.6	108.4	118.73	62.6	90.78
Boiling Point at 1 atm (K)	247.08	243.70	-23.5+273.15	-29.2+273.15	50 K at 1 atm	-50.9+273.15	-45.6+273.15
Critical Temperature (K)	374.21	367.85	105.87+273.15	96.5+273.15	97.7+273.15	77+273.15	(82.4+273.15) K
Critical Pressure (MPa)	4.06	3.380	3.814	3.7657	35.8 bar	52.669 bar	43.188 bar
Critical Density (kg/m^3)	511.90	478.01	492.2 .	1185.7	1258.4	443.0	461.6
GWP	1300	4	547	570/573	387/402	466/467	<150(148/146)
ODP	0	0	0	0	0	0	0
Safety Class (ASHRAE)	A1	A2L	A1	A1	A1	A2L	A2L

Adrián Mota-Babiloni [3] carried out analysis of the feasibility of R454C and R455A, two new low global warming potential (GWP of 148) refrigerants, in VCR systems as alternatives to R404A for warm countries and found that the R454C and R455A will be the most viable low GWP options to perform a direct replacement of R404A due to similar uniqueness and found experimental results show that the cooling capacity of the reserves is slightly lower than R404A, being the Coefficient of Performance (COP) of the new mixtures 10–15% higher than that of R404A, especially at more increased condensation. The utilization of green energy can be increased by this method. Mishra [5] computed the first law and second law analysis of VCR systems with and without nanoparticles using eco-friendly refrigerants (R134a, R407c, R404a, R1234yf, and R1234ze) and suggested the blends of HFOs with nanoparticles with has a promising future.

1.2 Use of Nano refrigerants in VCR systems

Nano refrigerant fluid used in a refrigeration system in which suspended nanoparticles are well-dispersed in a continuous base refrigerant. It has a very long history that has contributed to developing and enhancing modern refrigeration system due to enhancement in the thermodynamic energy and exergy performances. Many essential research investigations have been conducted on studying the thermal conductivity of water-based nano-fluids and nano-refrigerants. The thermal conductivity of CNT-based nano-refrigerants is enhanced compared to the base refrigerants fluid (W. Jiang et al. [1]). K. Henderson, et al., [2] also performed an R-134a-CuO combination in the same horizontal tubes with POE as a lubricant and observed 100 % enhancement in heat transfer coefficient. Mishra [4] pointed out that the conductivity ratio of pure refrigerant to nano refrigerant increases with the concentration of nanoparticles in the host refrigerant. In contrast, Cu 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 copper oxide as nanoparticle have the highest Effectiveness factor approx. 3.2 at 5 vol %. The effectiveness factor increases with an increasing percentage of volume (vol %), and the copper nanoparticle-based nano refrigerant has the highest convective heat transfer coefficient ratio than other nanoparticles mixed in brine water in the secondary circuit of the evaporator. In response to various environmental conventions, more environmentally friendly refrigeration systems have been investigated in recent years. Two aspects are of particular concern: ecological refrigerants and energy consumption.

Nano refrigerants have potential to replace R134a and Mishra [5] found worst thermal performance in terms of first law efficiency, second-law efficiency and exergy efficiency By using nano in the HFC-410a and concluded that that the best thermal performance in terms of first-law efficiency is found by using R1234ze(Z). The effect of HFC refrigerants' and HFC+HFO blended of low GWP on their first and second law performances. The Comparison has been done for using low global warming potential three HFC refrigerants and also three HFO+HFC blended refrigerants in the primary circuit of the evaporator and brine flow with nano materials and without nano materials in the secondary circuit of the evaporator.

2. Results and Discussion

The following input parameters have been taken.

Table-1(c): Input data used in VCR system

S.No.	Description	Value with unit
1	Length of evaporator tube	10.m
2	Length of condenser tube	16.6m
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
7.	Compressor speed	2900 rpm

Table-2(a) Thermodynamic energy performance (COP) (COP) of VCR system using CuO mixed in brine water solution

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	3.785	2.965	27.656
R-152a	3.783	2.964	27.588
R32	3.578	2.845	25.7645

Table-2(b) Thermodynamic first law performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	3.586	2.965	20.944
R-152a	3.576	2.964	20.648
R32	3.375	2.845	18.629

2.1 Thermodynamic performance of VCR system using low GWP HFC refrigerants using brine water solution in the secondary circuit of evaporator

The thermodynamic energy performance (COP)of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic first law (energy) performance improvement along with refrigerants are shown in Table-2(a) and second law (exergy) performance using copper oxide (CuO) nano material shown in Table-2(c) respectively.

Table-2(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	3.565	2.965	20.23
R-152a	3.560	2.964	20.108
R32	3.247	2.845	14.130

2.2 Thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC +HFO Blended refrigerants

The thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol solution was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in table-3(a) to table-3(c) respectively.

2.3 Thermodynamic energy performance of VCR system using low GWP HFC refrigerants using glycol solution in the secondary circuit of evaporator

The thermodynamic energy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol solution was flowing in the secondary circuit of evaporator and COP improvement using low GWP HFC refrigerants are shown in table-4(a) to table-4(c) respectively.

Table-3(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With nano	Without Nano	% enhancement
R245fa	0.3653	0.2845	28.40
R-152a	0.3647	0.2842	28.325
R32	0.3526	0.2885	22.218

Table-3(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3557	0.2845	25.026
R-152a	0.3545	0.2842	24.736
R32	0.3375	0.2825	19.469

Table-3(c) Thermodynamic Second law performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhanceme nt
R245fa	0.3435	0.2870	19.686
R-152a	0.3367	0.2857	17.851
R32	0.3175	0.2785	14.00

Table-4(a) Thermodynamic energy performance (COP) of VCR system using CuO mixed in glycol solution

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	3.275	2.657	23.259
R-152a	3.235	2.625	23.238
R32	3.057	2.537	20.497

Table-4(b) Thermodynamic first law (energy) performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	3.265	2.657	22.935
R-152a	3.165	2.625	20.571
R32	3.001	2.537	18.289

Table-4(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% Enhancement
R245fa	3.157	2.657	18.82
R-152a	3.067	2.625	16.838
R32	2.875	2.537	13.323

2.4 Thermodynamic exergy performance of VCR system using low GWP HFC +HFO Blended refrigerants

The thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol solution was flowing in the secondary circuit of evaporator and COP improvement using low GWP HFC refrigerants are shown in Table below.

Table-5(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3625	0.2870	26.307
R-152a	0.3537	0.2857	23.801
R32	0.3425	0.2785	22.980

Table-5(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3525	0.2870	22.822
R-152a	0.3457	0.2857	21.0
R32	0.3265	0.2785	17.235

Table-5(c) Thermodynamic Second law performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3365	0.2845	18.278
R-152a	0.3357	0.2842	18.121
R32	0.3275	0.2825	15.930

2.5 Thermodynamic performance of VCR system using low GWP HFC +HFO Blended refrigerants

The thermodynamic energy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in Table.

Table-6(a) Thermodynamic energy performance (COP) of VCR system using CuO mixed in brine water solution

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.527	2.855	23.537
R-513a	3.503	2.857	25.264
R450a	3.467	2.845	21.863

Table-6(b) Thermodynamic first law (energy) performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without	% enhancement
R 515a	3.629	2.965	22.395
R-513a	3.456	2.958	16.835
R450a	3.27	2.845	14.93

Table-6(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With nano	Without	% enhancement
R 515a	3.465	2.965	16.863
R-513a	3.466	2.966	16.858
R450a	3.265	2.845	11.248

Table-7(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3735	0.2976	25.504
R-513a	0.3527	0.2935	20.170
R450a	0.3326	0.2885	15.286

Table-7(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3625	0.2976	21.80
R-513a	0.3435	0.2935	17.036
R450a	0.3255	0.2885	12.82

Table-7(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3472	0.2976	16.67
R-513a	0.3367	0.2935	14.72
R450a	0.3073	0.2885	6.516

Table-7(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3472	0.2976	16.67
R-513a	0.3367	0.2935	14.72
R450a	0.3073	0.2885	6.516

2.6 Thermodynamic performance of VCR system using low GWP HFC+HFO blended refrigerants using glycol solution in the secondary circuit of evaporator

The thermodynamic energy performance of VCR systems has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in Table-8(a) and second law (exergy) performance using TiO_2 nano material shown in Table-9(c) respectively.

2.7 Thermodynamic exergy performance of VCR system using low GWP HFC +HFO Blended refrigerants

The thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed glycol solution was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in Tables.

Table-8(a) Thermodynamic energy performance (COP) (COP) of VCR system using CuO mixed in glycol solution

Performance Parameters	With Nano	Without -Nano	% enhancement
R 515a	3.215	2.657	20.097
R-513a	3.218	2.655	21.205
R450a	3.197	2.647	20.77

Table-8(b) Thermodynamic first law (energy) performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.185	2.657	19.872
R-513a	3.187	2.656	19.992
R450a	3.109	2.647	17.454

Table-8(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.015	2.657	13.474
R-513a	3.016	2.656	13.554
R450a	2.912	2.647	10.011

2.8 Thermodynamic exergy performance of VCR system using low GWP HFC refrigerants using glycol mixed nano material solution in the secondary circuit of evaporator

The thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and COP improvement using low GWP HFC refrigerants are shown in Table-6(a) and second law (exergy) performance using Al_2O_3 nano material shown in Table-6(b) respectively.

Table-9(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3357	0.2785	20.539
R-513a	0.3358	0.2787	20.488
R450a	0.3325	0.2785	19.39

Table-9(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3315	0.2785	19.03
R-513a	0.3318	0.2787	19.053
R450a	0.3305	0.2785	18.671

Table-9(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3101	0.2785	11.35
R-513a	0.3102	0.2787	11.302
R450a	0.3017	0.2785	8.33

Table-5(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3625	0.2870	26.307
R-152a	0.3537	0.2857	23.801
R32	0.3425	0.2785	22.980

Table-5(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3525	0.2870	22.822
R-152a	0.3457	0.2857	21.0
R32	0.3265	0.2785	17.235

Table-5(c) Thermodynamic Second law performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R245fa	0.3365	0.2845	18.278
R-152a	0.3357	0.2842	18.121
R32	0.3275	0.2825	15.930

2.9 Thermodynamic performance of VCR system using low GWP HFC +HFO Blended refrigerants

The thermodynamic energy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and COP improvement using low GWP HFC refrigerants.

Table-6(a) Thermodynamic energy performance (COP) of VCR system using CuO mixed in brine water solution

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.527	2.855	23.537
R-513a	3.503	2.857	25.264
R450a	3.467	2.845	21.863

Table-6(b) Thermodynamic first law (energy) performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without	% enhancement
R 515a	3.629	2.965	22.395
R-513a	3.456	2.958	16.835
R450a	3.27	2.845	14.93

Table-6(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With nano	Without	% enhancement
R 515a	3.465	2.965	16.863
R-513a	3.466	2.966	16.858
R450a	3.265	2.845	11.248

2.10 Thermodynamic exergy performance of VCR system using low GWP HFC refrigerants using brine water mixed nano material solution in the secondary circuit of evaporator

Table-7(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3735	0.2976	25.504
R-513a	0.3527	0.2935	20.170
R450a	0.3326	0.2885	15.286

Table-7(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3625	0.2976	21.80
R-513a	0.3435	0.2935	17.036
R450a	0.3255	0.2885	12.82

Table-7(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3472	0.2976	16.67
R-513a	0.3367	0.2935	14.72
R450a	0.3073	0.2885	6.516

Table-7(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without	% enhancement
R 515a	0.3472	0.2976	16.67
R-513a	0.3367	0.2935	14.72
R450a	0.3073	0.2885	6.516

2.11 Thermodynamic performance of VCR system using low GWP HFC+HFO blended refrigerants using glycol solution in the secondary circuit of evaporator

The thermodynamic energy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in Table-8(a) and second law (exergy) performance using TiO_2 nano material shown in Table-9(c) respectively.

Table-8(a) Thermodynamic energy performance (COP) (COP) of VCR system using CuO mixed in glycol solution

Performance Parameters	With Nano	Without -Nano	% enhancement
R 515a	3.215	2.657	20.097
R-513a	3.218	2.655	21.205
R450a	3.197	2.647	20.77

Table-8(b) Thermodynamic first law (energy) performance (COP) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.185	2.657	19.872
R-513a	3.187	2.656	19.992
R450a	3.109	2.647	17.454

Table-8(c) Thermodynamic first law performance (COP) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	3.015	2.657	13.474
R-513a	3.016	2.656	13.554
R450a	2.912	2.647	10.011

2.12 Thermodynamic exergy performance of VCR system using low GWP HFC refrigerants using glycol mixed nano material solution in the secondary circuit of evaporator

The thermodynamic exergy performance of VCR system has been evaluated using low GWP HFC refrigerants in the primary circuit of evaporator and nano mixed brine water was flowing in the secondary circuit of evaporator and thermodynamic energy performance (COP) improvement using low GWP HFC refrigerants are shown in Table-6(a) and second law (exergy) performance using Al_2O_3 nano material shown in Table-6(b) respectively.

Table-9(a) Thermodynamic Second law performance (Exergy efficiency) of VCR system using CuO

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3357	0.2785	20.539
R-513a	0.3358	0.2787	20.488
R450a	0.3325	0.2785	19.39

Table-9(b) Thermodynamic Second law performance (Exergy efficiency) of VCR system using Al_2O_3

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3315	0.2785	19.03
R-513a	0.3318	0.2787	19.053
R450a	0.3305	0.2785	18.671

Table-9(c) Thermodynamic Second law (exergy) performance (Exergy efficiency) of VCR system using TiO_2

Performance Parameters	With Nano	Without Nano	% enhancement
R 515a	0.3101	0.2785	11.35
R-513a	0.3102	0.2787	11.302
R450a	0.3017	0.2785	8.33

3. Conclusions

The following conclusions are made

- Thermodynamic first law (energy) performance of VCR system using eco-friendly HFC refrigerants suspended with CuO, Al_2O_3 and TiO_2 nanoparticles in the brine water of the secondary circuit of the evaporator in VCR system, it was found that the energy performance (COP) is enhanced maximum up to is about improved up to 23.26%, 22.935%, and 18.82% respectively.
- Thermodynamic second law (exergy) performance of VCR system using eco-friendly HFC refrigerants suspended with CuO, Al_2O_3 and TiO_2 nanoparticles in the brine water of the secondary circuit of the evaporator in VCR system, it was found that the energy performance (COP) is enhanced maximum upto is about improved up to 22.935%, 22.82%, and 19.686% respectively. R245fa gives the best first-law thermodynamic performance (COP) and is slightly higher than HFO- 152a
- The lower thermodynamic performances were found by using HFC-32 in the primary circuit and brine water in the secondary circuit of the evaporator of the VCR system.
- (iii) Thermodynamic first law (energy) performance of VCR system by using eco-friendly blends of HFO +HFC refrigerants with suspended CuO, Al_2O_3 and TiO_2 (titanium dioxide) nanoparticles in the brine water of the secondary circuit in the evaporator, the second law exergy performance of the system is improved in the range of 21.205%, 19.99% &17.32%, respectively.
- Thermodynamic second law (exergy) performance of VCR system using eco-friendly HFC refrigerants suspended with CuO, Al_2O_3 and TiO_2 nanoparticles in the brine water of the secondary circuit of the evaporator in VCR system, it was found that the energy performance (COP) is enhanced maximum upto is about improved up to 20.54%, 19.87%, and 14.937% respectively.
- In using HFO blends, R515a gives the best first-law thermodynamic performance (COP) and is slightly higher than R513a. The lower thermodynamic performances were found by using R450a in the primary circuit and brine water in the secondary circuit of the evaporator of the VCR system.

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