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ORIGINAL ARTICLE

Thermodynamic performances improvement of vapour compression system using ecofriendly HFO refrigerants

R. S. Mishra

Department of Mechanical Engineering, Delhi Technological University Delhi, India

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Abstract

Vapour compression refrigeration systems are widely used in the areas which experience hot climatic conditions. Performance improvement of vapour compression refrigeration system has been done before by using methods. But due to advancement in nanotechnology, these days, the nanofluids are considered as the most effective heat transfer fluids, having better heat transfer properties than the conventional HFC/HFO/HCFO refrigerants. In this paper, performance improvement of the vapour compression refrigeration system has been done by using copper (Cu), Al_2O_3 and TiO_2 in the brine water in the secondary circuit of evaporator and ecofriendly R1234ze(Z), R1224yd(Z) R1233zd(E), R1234ze(E), R1243zf & R1234yf, in the primary circuit of evaporator have been investigated. The numerical computation was carried out by developing computer code and it was found that the thermodynamic performances using R1225ye(Z), and R1234ze(E) are nearly similar with minor variations in R1225ye(Z) while R1233mzz(Z) are nearly similar with using R1224yd(Z) with slight variations.
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1. Introduction

Refrigeration is that branch of science that deals with the study of heat absorbed at low temperature and provides temperature below the surrounding by rejection of heat to the surrounding at higher temperature and the refrigeration and air conditioning are needed for domestic and industrial comfort and preservation purposes. The vapour compression system which consists of four major components compressor, expansion valve, condenser and evaporator in which total cooling load is carried at one temperature by single evaporator but in many applications like large hotels, food storage and food processing plants, food items are stored in different compartment and at different temperatures. Therefore, there is need of multi evaporator vapour compression refrigeration system. Although refrigeration, air conditioning and heat pump appliances require significant amounts of energy for their operation. Due to this energy challenge, several investigators are finding various means to improve performance and energy efficiency of refrigeration and air conditioning system. Although, some researchers have tried to improve the performance of refrigeration system. [1]. The performance of refrigerator is evaluated in term of COP which is the ratio of refrigeration effect to the net work input given to the system. The COP of vapour compression refrigeration system can be improved either by increasing refrigeration effect or by reducing work input given to the system. It is well known that throttling process in VCR is an irreversible expansion process. Expansion process is one of the main factors responsible for exergy loss in cycle performance because of entering the

Corresponding author: R.S. Mishra
Email Address: hod.mechanical.rsm@dtu.ac.in
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portion of the refrigerant flashing to vapour in evaporator which will not only reduce the cooling capacity but also increase the size of evaporator. This problem can be eliminated by adopting multi-stage expansion 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 [2].

1.1 Use of nano materials in the ecofriendly refrigerants

Refrigeration systems have become one of the most important utilities for people's daily lives. With the advancement and technological developments in the field of refrigeration new methods are developed to increase the COP of the systems.The systems under vapour compression technology consume huge amount of electricity,this problem can be solved by improving performance of system.

The conventional methods for exchanging heat from the system involves increment in the surface area but this leads to the increase in the size of the system, so there was need of some efficient way that can enhance the heat transfer. The inventive idea of using nanofluids, fluids which consist of suspended nanoparticles are used to remove such kind of barriers. The use of nano particles improves the first law and second law performance significantly. Nano particles of Al_2O_3, TiO_2 and CuO are used due to their higher thermal conductivity to achieve better efficiency. The best performance is found using R152a and worst performance is observed using R410a. Due to flammable nature of R290, R600, R600a and R152a [4]

R S Mishra and Jaiswal R K [5] experimentally evaluated the performance of a vapour compression refrigeration system by using Cu, Al_2O_3, CuO and TiO_2 based nano refrigerants in the primary circuit. The experimental results showed that the C.O.P of the system using Al_2O_3/R134a nano refrigerant was enhanced by 35% which was highest among all other Nano refrigerants. Shengshan Bi et al. [6] tested on a domestic refrigerator in which they mixed mineral oil TiO_2 as the lubricant with refrigerant R600a. They found that the system when operated with the nano refrigerant, it worked efficiently and the performance of the system was improved when it was compared to a system that uses only R600a.

Subramani & Prakash [7] used Al2O3 at 0.06% weight in the mineral oil.They concluded that there was the reduction in power consumption upto 25% when POE oil is replaced by a mixture of mineral oil and alumina nanoparticles.

Kumar et al. [8] examined heat transfer enhancement using nanofluid Al_2O_3 & R600a/mineral oil as working fluid in a domestic refrigerator, their result showed an increase in COP by 19.6% and reduction in power consumption by 11.5%.

Abbas et al. [9] performed the analysis of an air conditioning system by using a concentration of 0.01-0.1wt% of CNT Polyester oil with refrigerant R134a. The results concluded that usage of CNT particles concentration of 0.1% by weight results in highest heat transfer and the COP was enhanced by 4.2%. Sabareesh et al. [10] investigated experimentally the effects of using nanofluids in VCRS as a lubricant additive, the nanoparticle used in the experiment was TiO2. The results of the experiment showed that the when nanofluid used in 0.01% by volume concentration the heat transfer of the system was enhanced by 3.6% that leads to the increase in COP by 17%.

Taliv Hussain, et.al. [11] conducted experiment on vapour compression refrigeration system using Al_2O_3 as nano materials in R134a and found that at 28°C the COP of the VCRS using Al2O3 nanofluid was enhanced by 25.7%, 17.46% and 11.74% for 0.01%, 0.005% and 0.001% by wt. of Al_2O_3 respectively as compared to the conventional system.

Based on the literature it was observed that researchers have gone through detailed first law analysis in terms of coefficient of performance and second law analysis in term of exergetic efficiency of simple vapour compression refrigeration system using R-134a, R407C, R404a, and found performance improvement theoretically and experimentally. Very less work have been done using HFO R-1225ye(Z) & R1336mzz(Z) [11,12, 13,14,15]

This paper mainly deals with effect ofHFO refrigerants with nano particles (Copper, TiO_2 and Al_2O_3) mixed with R718 and R1234ze(Z), R1224yd(Z), R1233zd(E) & R1243zf refrigerants used in the water cooled evaporator for improving thermal performance of vapour compression refrigeration systems.

2. Results and Discussion

Application of Nano particles in refrigerants has been identified as a way of enhancing the performance of the vapour compression refrigeration system (VCRS) without modifying the system components. When Nano particles are dispersed in a refrigerant or lubricant, they are regarded as Nano refrigerants. The improvement in heat transfer and tribology are responsible for the enhancement of VCRS performance. The effect of HFO refrigerants with nano particles (Copper , TiO_2 and Al_2O_3) mixed with R718 and R1234ze(Z), R1224yd(Z), R1233zd(E) & R1243zf refrigerants used in the water cooled evaporator for improving thermal performance of vapour compression refrigeration systems for keeping evaporator size constant due to enhancing heat transfer coefficient in the evaporator and condensers with effect increase in evaporator temperature which worked as effect of superheating due to nano effect which enhanced the thermodynamic performance, it was also observed that by increasing brine mass flow rate , the first law performance was increased due to overall effective heat transfer coefficient was increased sharply similarly refrigeration effect was also enhanced and heat rejected rate from condenser is alos increased. The thermophysical properties of nano fluid was computed and shown in Table-1.

Table-1 physical properties of nano fluid using R1233zd(E)

Effective Properties of Nano fluids	CuO	Al_2O_3	TiO_2
Effective Mixture density	1394	1146	1155
Effective Mixture Conductivity	31.19	16.78	9.691
Effective Mixture specific Heat	2966	3590	3558
Effective Mixture viscosity	0.00382	0.00381	0.0038
Effective Mixture Prandtl Number	0.3633	0.8176	1.402

2.1 Effect of ecofriendly refrigerants without nano materials

Table-2(a) show the effect of brine flow rate in the secondary circuit of evaporator on the thermodynamic performances using R1233zd(E) and it was found that as brine flow rate in increases, the first and second law performances were increased. Similarly, evaporator heat transfer coefficient increaely significantly as brine flow rate is increasing but condenser heat transfer coefficient is increasing slowly as brine flow rate is increasing. Table-2(b) shows the effect of brine flow rate in the secondary circuit of evaporator on the thermodynamic performances using R1224yd(Z) and the first and second law performances are increases as brine flow rate is increasing. It was also found that R-1233zd(E) gives better thermodynamic performances than using R1224yd(Z). the lowest thermodynamic performances were found using R1234yf. The thermodynamic performances using R1225ye(Z), R1243zf and R1234ze(E) are nearly similar with minor variations. Performance evaluation of vapour compression refrigeration system when calculated nucleate heat transfer coefficient enhancement factor based on Al_2O_3 nanoparticle mixed in the ecofriendly refrigerant and implement into the program results is to be found as 23% using R1234zf and 18% when using R1243zf in the primary circuit. Performance evaluation of vapour compression refrigeration system when calculated nano-refrigerent property implement into the program based on Al_2O_3 nanoparticle mixed in the R1243zf ecofriendly refrigerant is 13% and Al_2O_3 nanoparticle mixed in the R1243zf is 9%. Performance evaluation of vapour compression refrigeration system when nanoparticle into refrigerant oil nanoparticle based on Al_2O_3nanoparticle mixed in the ecofriendly R1243zf refrigerant is 11%

The performance of vapour compression refrigeration systems using Al_2O_3 particles direct mixed in the R134a gives better first law performance than R1243zfand improvement in the first law performance is 18% using R1243zf and Al_2O_3 nano particles mixed with compressor oil and then used is 18.8% and 8% as heat transfer enhancement factor and implement into the refrigerant property and lowest improvement 2.65% when Al_2O_3 directly mixed with R1243zf, mixed with compressor oil and then used as refrigerant the primary circuit.
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*Table-2(a) Effect of brine flow rate in evaporator without nano particles on the thermodynamic performances of vapour compression refrigeration system using R1233zd(E)*for mw=0.008 kg/sec)

Brine flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	2.96	3.025	3.081	3.13
Exergy of Fuel ($W_{\_comp}$) in Watt	102.0	102.8	103.4	103.9
Irreversiblity Ratio	2.439	2.478	2.509	2.540
Second law Effectiveness	0.2908	0.2877	0.2850	0.2825
Exergy Destruction Ratio(EDR)	2.022	1.9533	1.898	1.8547
Exergetic Efficiency	0.3309	0.3386	0.3450	0.3503
Isentropic efficiency of compressor	0.7273	0.7353	0.7419	0.7477
Volumetric efficiency of compressor	0.6148	0.6169	0.6186	0.6201
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	664.62	691.04	714.49	735.56
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	644.56	653.31	660.71	667.8
Exergy of Product in Watt	29.65	29.58	29.46	29.36
Evaporator temperature (K)	271.5	272.3	272.9	273.3
Condenser temperature (K)	321.3	321.7	322	322.3
Evaporator pressure (Bar)	2.758	2.838	2.906	2.965
Condenser pressure (Bar)	12.58	12.70	12.81	12.91
LMTD of Evaporator(K)	21.09	20.89	20.71	20.54
LMTD of Condenser (K)	33.32	33.09	32.01	32.77
LMTD of Condenser vapour (K)	18.2	18.06	17.95	17.85
Reynold number in condenser	200375	1999874	199543	199324
Reynold number in capillary tube	18309	19072	19732	20311
Reynold number in brine	378	438.4	498.2	558.1
Refrigerating effect (Watts)	301.8	310.9	318.6	325.3
Heat Rejected by Condenser	399.8	409.7	418.9	425.4
Compressor work (Watts)	102.0	102.8	103.4	103.9
Brine outlet temperature(^oC)	14.69	15.71	16.54	17.22
Condenser water outlet temperature (^oC)	36.95	37.27	37.5	37.71

Table-2(b) Effect of Water flow rate in evaporator without nano particles on the thermodynamic performances of vapour compression refrigeration system using R1224yd(Z) for mb=0.008 kg/sec)

Brine flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	2.957	3.025	3.082	3.129
Exergy of Fuel ($W_{\_comp}$) in Watt	104.1	102.8	101.7	100.8
Irreversiblity Ratio	2.604	2.476	2.379	2.304
Second law Effectiveness	0.2775	0.2877	0.2959	0.3027
Exergy Destruction Ratio(EDR)	2.022	1.9533	1.898	1.8547
Exergetic Efficiency	0.3309	0.3386	0.3450	0.3503
Isentropic efficiency of compressor	0.740	0.7352	0.7316	0.7288
Volumetric efficiency of compressor	0.6123	0.6169	0.6199	0.6223
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	692.05	691.04	690.57	690.41
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	636.47	653.31	667.1	678.6
Exergy of Product in Watt	28.87	29.56	30.09	30.52
Evaporator temperature (K)	272.6	272.3	272.0	271.9
Condenser temperature (K)	323.0	321.7	320.6	319.8
Evaporator pressure (Bar)	2.870	2.838	2.815	2.976
Condenser pressure (Bar)	13.15	12.71	12.38	12.11
LMTD of Evaporator(K)	20.64	20.89	21.08	21.22
LMTD of Condenser (K)	34.28	33.09	32.14	31.38
LMTD of vapour (K)	17.75	18.06	13.31	13.51
Reynold number in condenser	203992	199874	196638	194030
Reynold number in capillary tube	26312	26110	25963	25849
Reynold number in brine	438.9	438.4	438.0	437.6
Refrigerating effect (Watts)	307.6	310.9	313.4	315.5
Heat Rejected by Condenser	407.5	409.7	411.4	412.7
Compressor work (Watts)	104.1	102.8	101.7	100.8
Brine outlet temperature(°C)	15.81	15.71	15.63	15.57
Condenser water outlet temperature (°C)	38.92	37.24	35.93	34.3

2.2 Effect of ecofriendly refrigerants with copper material

All the above results show that the performance of a refrigeration system can be improved by adding the nanoparticles in the refrigerant (up to a certain limit). This is due to the fact that the addition of nanoparticles causes an improvement in the heat transfer characteristics of the base refrigerant, which thereby affects the COP of the refrigeration system as shown in Table-3(a) to Table-3(c) respectively.
Thus, the performance of the refrigeration system (COP) has been improved significantly using 0.5% Al2O3 (wt) nanoparticles in R134a, whereas with 1% Al2O3 (wt) it actually decreases Similarly, in the same case, the temperature at the outlet of the evaporator is also found to be increased due to improved heat transfer characteristics of Nano refrigerants. A significant improvement in the refrigeration effect is observed. This has also led to the superheating of the vapor at the exit of the evaporator. Moreover, the COP of the refrigeration system is observed to be higher at lower ambient temperatures and decreases with an increase in the ambient temperature

Table-3(a)to Table-3(f) show the effect of brine flow rate in the secondary circuit of evaporator on the thermodynamic performances using HFO refrigerants and it was found that as brine flow rate in increases, the first and second law performances were increased. Similarly, evaporator heat transfer coefficient increasingly significantly as brine flow rate is increasing but condenser heat transfer coefficient is increasing slowly as brine flow rate is increasing.

2.3 Effect of ecofriendly refrigerants on thermal performances with Nano materials.

Table-4(a) show the effect of brine flow rate in the secondary circuit of evaporator on the thermodynamic performances using R1233zd(E) and it was found that as brine flow rate in increases, the first and second law performances were increased. Similarly, evaporator heat transfer coefficient increasingly significantly as brine flow rate is increasing but condenser heat transfer coefficient is increasing slowly as brine flow rate is increasing.

Table-3(a) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(Z)

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.519	3.591	3.549	3.698
Exergy of Fuel ($W_{\_comp}$) in Watt	107.8	108.4	108.9	109.3
Irreversiblity Ratio	2.84	2.91	2.97	3.023
Second law Effectiveness	0.2604	0.2558	0.2519	0.2486
Exergy Destruction Ratio(EDR)	1.539	1.488	1.448	1.416
Exergetic Efficiency	0.3939	0.4020	0.4085	0.4139
Isentropic efficiency of compressor	0.7939	0.8024	0.8094	0.8152
Volumetric efficiency of compressor	0.6323	0.6346	0.6364	0.6379
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1334.09	1374.22	1390.63	1404.55
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	716.08	724.74	731.66	737.33
Evaporator temperature (K)	277.6	278.3	278.9	279.4
Condenser temperature (K)	325.6	325.0	324.6	324.2
Evaporator pressure (Bar)	3.435	3.522	3.593	3.651
Condenser pressure (Bar)	13.66	13.80	13.91	14.0
LMTD of Evaporator(K)	13.0	13.5	13.27	13.36
LMTD of Condenser (K)	32.06	32.01	31.97	31.95
LMTD of Condenser vapour (K)	16.74	17.06	17.33	17.57
Reynold number in condenser	199517	199844	200250	200598
Reynold number in capillary tube	25160	26110	26890	27545
Reynold number in brine	99.75	114.05	128.2	142.5
Refrigerating effect (Watts)	379.2	389.2	397.4	404.1
Heat Rejected by Condenser	483.2	493.9	502.5	509.7
Compressor work (Watts)	107.8	108.4	108.9	109.3
Brine outlet temperature(^oC)	12.05	13.37	14.47	15.34
Condenser water outlet temperature (^oC)	39.44	39.76	40.02	40.23

Table-3(b) Effect of brine flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1233zd(E)

Brine flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.518	3.519	3.649	3.698
Exergy of Fuel ($W_{\_comp}$) in Watt	107.8	108.8	108.9	109.3
Irreversiblity Ratio	2.604	2.91	2.97	3.023
Second law Effectiveness	0.2489	0.2550	0.2519	0.2486
Exergy Destruction Ratio(EDR)	1.615	1.539	1.448	1.4160
Exergetic Efficiency	0.3824	0.3939	0.4085	0.4139
Isentropic efficiency of compressor	0.7999	0.8024	0.8094	0.8152
Volumetric efficiency of compressor	0.6275	0.6346	0.6364	0.6379
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1354.51	1374.22	1390.63	1404.55
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	717.08	724.74	731.66	737.33
Exergy of Product in Watt	28.06	27.72	27.42	27.16
Evaporator temperature (K)	277.6	278.3	278.9	279.4
Condenser temperature (K)	326.1	325.0	325.3	325.6
Evaporator pressure (Bar)	3.475	3.435	3.593	3.651
Condenser pressure (Bar)	14.2	13.66	13.91	14.0
LMTD of Evaporator(K)	12.77	13.37	13.27	13.36
LMTD of Condenser (K)	33.52	32.01	31.97	31.95
LMTD of Condenser vapour (K)	16.81	13.15	16.98	16.91
Reynold number in condenser	199517	26110	200250	200598
Reynold number in capillary tube	25358	25164	26890	27545
Reynold number in brine	99.75	114.1	128.0	142.4
Refrigerating effect (Watts)	373.7	379.2	397.4	404.1
Heat Rejected by Condenser	479.2	483.2	502.5	509.7
Compressor work (Watts)	109.4	108.4	108.9	109.3
Brine outlet temperature(^oC)	12.24	13.57	14.45	15.34
Condenser water outlet temperature (^oC)	39.44	39.76	40.02	40.23

Table-3(c) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1224yd(Z)

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.498	3.569	3.626	3.673
Exergy of Fuel ($W_{\_comp}$) in Watt	107.6	108.2	108.7	109.1
Irreversiblity Ratio	2.821	2.888	2.946	2.996
Second law Effectiveness	0.2617	0.2572	0.2535	0.2503
Exergy Destruction Ratio(EDR)	1.554	1.503	1.464	1.432
Exergetic Efficiency	0.3916	0.3995	0.4059	0.4112
Isentropic efficiency of compressor	0.7914	0.7998	0.8066	0.8122
Volumetric efficiency of compressor	0.6317	0.6339	0.6357	0.6372
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1351.3	1370.77	1386.97	1400.72
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	713.53	722.05	728.87	738.45
Evaporator temperature (K)	277.4	278.1	278.7	279.1
Condenser temperature (K)	324.4	324.8	325.2	325.4
Evaporator pressure (Bar)	3.410	3.495	3.564	3.621
Condenser pressure (Bar)	13.62	13.75	13.86	13.95
LMTD of Evaporator(K)	13.30	13.45	13.57	13.66
LMTD of Condenser (K)	32.09	32.02	31.98	31.95
LMTD of Condenser vapour (K)	17.21	17.10	17.01	16.95
Reynold number in condenser	199427	199760	200095	200416
Reynold number in capillary tube	24891	25813	26573	27210
Reynold number in brine	99.75	114.05	128.2	142.5
Refrigerating effect (Watts)	376.3	386.3	394.1	400.7
Heat Rejected by Condenser	480.1	490.5	499.0	506.0
Compressor work (Watts)	107.6	108.2	108.7	109.1
Brine outlet temperature(^oC)	12.15	13.46	14.53	15.42
Condenser water outlet temperature (^oC)	39.35	39.66	39.91	40.12

Table-3(d) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1243zf

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.483	3.591	3.681	3.76
Exergy of Fuel ($W_{\_comp}$) in Watt	110.1	108.4	107	105.8
Irreversiblity Ratio	3.106	2.91	2.764	2.645
Second law Effectiveness	0.2436	0.2558	0.2657	0.2744
Exergy Destruction Ratio(EDR)	1.565	1.4876	1.4272	1.3759
Exergetic Efficiency	0.3899	0.4020	0.4120	0.4209
Isentropic efficiency of compressor	0.8086	0.8024	0.7978	0.7940
Volumetric efficiency of compressor	0.6296	0.6346	0.6385	0.6416
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1379.09	1374.22	1372.12	1371.60
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	702.83	724.74	742.81	758.66
Exergy of Product in Watt	26.81	27.72	28.43	29.02
Evaporator temperature (K)	278.7	278.3	278.0	277.9
Condenser temperature (K)	326.6	325.0	323.7	322.7
Evaporator pressure (Bar)	3.563	3.522	3.491	3.467
Condenser pressure (Bar)	14.35	13.80	13.37	13.02
LMTD of Evaporator(K)	12.91	13.15	13.33	13.46
LMTD of Condenser (K)	33.5	32.01	30.82	29.82
LMTD of Condenser vapour (K)	16.74	17.06	17.33	17.57
Reynold number in condenser	205062	199844	195813	192386
Reynold number in capillary tube	26312	26111	25963	25849
Reynold number in brine	114.0	114.0	114.0	114.0
Refrigerating effect (Watts)	383.4	389.2	398.3	397.7
Heat Rejected by Condenser	489.5	493.9	497.2	500.0
Compressor work (Watts)	110.1	108.4	107.0	105.8
Brine outlet temperature(^oC)	13.54	13.37	13.23	13.12
Condenser water outlet temperature (^oC)	41.72	39.76	38.21	36.89

Table-3(e) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(E)

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.468	3.538	3.598	3.642
Exergy of Fuel ($W_{\_comp}$) in Watt	107.3	107.9	108.4	108.8
Irreversiblity Ratio	2.794	2.858	2.914	2.963
Second law Effectiveness	0.2636	0.2592	0.2555	0.2524
Exergy Destruction Ratio(EDR)	1.576	1.525	1.485	1.453
Exergetic Efficiency	0.3882	0.3960	0.4024	0.4077
Isentropic efficiency of compressor	0.7878	0.7961	0.8029	0.8085
Volumetric efficiency of compressor	0.6307	0.6329	0.6347	0.6362
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1294.42	1315.42	1333.05	1348.13
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	709.85	718.36	725.2	730.81
Evaporator temperature (K)	277.1	277.8	278.4	278.8
Condenser temperature (K)	324.3	324.7	325.0	325.2
Evaporator pressure (Bar)	3.373	3.458	3.527	3.584
Condenser pressure (Bar)	13.56	13.69	13.80	13.89
LMTD of Evaporator(K)	13.73	13.86	13.96	14.04
LMTD of Condenser (K)	32.12	32.05	32.0	31.98
LMTD of Condenser vapour (K)	17.25	17.14	17.06	16.99
Reynold number in condenser	199314	199604	199907	200202
Reynold number in capillary tube	24502	25410	26161	26793
Reynold number in brine	99.75	114.05	128.2	142.5
Refrigerating effect (Watts)	372.1	381.8	389.7	396.4
Heat Rejected by Condenser	475.6	486.0	494.4	501.4
Compressor work (Watts)	107.3	107.9	108.4	108.8
Brine outlet temperature(^oC)	12.29	13.59	14.65	15.53
Condenser water outlet temperature (^oC)	39.21	39.52	39.78	39.99

Table-3(f) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234yf

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.423	3.501	3.549	3.596
Exergy of Fuel ($W_{\_comp}$) in Watt	106.9	107.6	108.0	108.4
Irreversiblity Ratio	2.756	2.830	2.869	2.916
Second law Effectiveness	0.2663	0.2635	0.2586	0.2554
Exergy Destruction Ratio(EDR)	1.61	1.549	1.517	1.484
Exergetic Efficiency	0.3832	0.3923	0.3973	0.4026
Isentropic efficiency of compressor	0.7825	0.7912	0.7975	0.8031
Volumetric efficiency of compressor	0.6293	0.6315	0.6333	0.6348
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1216.6	1243.65	1258.73	1275.4
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	704.36	714.28	719.72	725.39
Evaporator temperature (K)	276.6	277.2	277.9	278.4
Condenser temperature (K)	324.0	324.5	324.7	325.0
Evaporator pressure (Bar)	3.319	3.417	3.471	3.529
Condenser pressure (Bar)	13.47	13.62	13.71	13.81
LMTD of Evaporator(K)	14.36	14.48	14.55	14.60
LMTD of Condenser (K)	32.17	32.08	32.04	32.0
LMTD of Condenser vapour (K)	17.33	17.20	17.13	17.06
Reynold number in condenser	199177	199459	199659	199916
Reynold number in capillary tube	23931	24975	25559	26183
Reynold number in brine	99.75	114.05	128.2	142.5
Refrigerating effect (Watts)	365.9	377.15	380.4	390.0
Heat Rejected by Condenser	469.0	481.0	487.7	494.7
Compressor work (Watts)	106.9	107.6	108.0	108.4
Brine outlet temperature(^oC)	12.51	14.0	14.82	15.68
Condenser water outlet temperature (^oC)	39.02	39.37	39.57	39.78

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Table-4(a) Effect of Water flow rate in evaporator by mixing copper (Cu) nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(Z)

Water flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.519	3.563	3.609	3.698
Exergy of Fuel ($W_{\_comp}$) in Watt	107.8	108.4	108.9	109.3
Irreversiblity Ratio	2.84	2.91	2.97	3.023
Second law Effectiveness	0.2604	0.2558	0.2519	0.2486
Exergy Destruction Ratio(EDR)	1.539	1.488	1.448	1.416
Exergetic Efficiency	0.3939	0.4020	0.4085	0.4139
Isentropic efficiency of compressor	0.7939	0.8024	0.8094	0.8152
Volumetric efficiency of compressor	0.6323	0.6346	0.6364	0.6379
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1334.09	1374.22	1390.63	1404.55
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	716.08	724.74	731.66	737.33
Evaporator temperature (K)	277.6	278.3	278.9	279.4
Condenser temperature (K)	325.6	325.0	324.6	324.2
Evaporator pressure (Bar)	3.435	3.522	3.593	3.651
Condenser pressure (Bar)	13.66	13.80	13.91	14.0
LMTD of Evaporator(K)	13.0	13.5	13.27	13.36
LMTD of Condenser (K)	32.06	32.01	31.97	31.95
LMTD of Condenser vapour (K)	16.74	17.06	17.33	17.57
Reynold number in condenser	199517	199844	200250	200598
Reynold number in capillary tube	25160	26110	26890	27545
Reynold number in brine	99.75	114.05	128.2	142.5
Refrigerating effect (Watts)	379.2	389.2	397.4	404.1
Heat Rejected by Condenser	483.2	493.9	502.5	509.7
Compressor work (Watts)	107.8	108.4	108.9	109.3
Brine outlet temperature(^oC)	12.05	13.37	14.47	15.34
Condenser water outlet temperature (^oC)	39.44	39.76	40.02	40.23

Table-4(b) Effect of brine flow rate in evaporator by mixing Al_2O_3 nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(Z))

Brine flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.489	3.561	3.619	3.667
Exergy of Fuel ($W_{\_comp}$) in Watt	107.5	108.1	108.6	109.0
Irreversiblity Ratio	2.813	2.88	2.938	2.99
Second law Effectiveness	0.2622	0.2577	0.2539	0.2507
Exergy Destruction Ratio(EDR)	1.56	1.509	1.469	1.436
Exergetic Efficiency	0.3906	0.3986	0.4051	0.4105
Isentropic efficiency of compressor	0.7904	0.7988	0.8058	0.8115
Volumetric efficiency of compressor	0.6314	0.6337	0.6355	0.6370
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1297.47	1318.7	1336.52	1351.76
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	712.47	721.11	728.06	733.75
Evaporator temperature (K)	277.3	278.0	278.6	279.1
Condenser temperature (K)	324.4	324.8	325.1	325.4
Evaporator pressure (Bar)	3.399	3.485	3.556	3.614
Condenser pressure (Bar)	13.6	13.74	13.85	13.94
LMTD of Evaporator(K)	13.42	13.56	13.66	13.74
LMTD of Condenser (K)	32.09	32.03	31.99	31.96
LMTD of Condenser vapour (K)	17.22	17.11	17.02	16.95
Reynold number in condenser	199393	199718	200052	200374
Reynold number in capillary tube	24779	25711	25481	27130
Reynold number in brine	99.75	114.0	128.2	142.5
Refrigerating effect (Watts)	375.1	385..0	393.1	399.8
Heat Rejected by Condenser	478.8	489.4	498.0	505.2
Compressor work (Watts)	107.5	108.1	108.6	109.0
Brine outlet temperature(^oC)	12.19	13.5	14.56	15.44
Condenser water outlet temperature (^oC)	39.31	39.62	39.88	40.10

Table-4(c) Effect of brine flow rate in evaporator by mixing TiO_2 nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(Z)

Brine flow rate (kg/sec)	0.007	0.008	0.009	0.010
First Law Efficiency (COP)	3.445	3.516	3.574	3.622
Exergy of Fuel ($W_{\_comp}$) in Watt	107.1	107.7	108.2	108.6
Irreversiblity Ratio	2.774	2.839	2.893	2.942
Second law Effectiveness	0.2649	0.2606	0.2569	0.2537
Exergy Destruction Ratio(EDR)	1.593	1.541	1.50	1.466
Exergetic Efficiency	0.3857	0.3936	0.40	0.4055
Isentropic efficiency of compressor	0.7851	0.7935	0.8004	0.8061
Volumetric efficiency of compressor	0.630	0.6322	0.6341	0.6356
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1219.42	1242.43	1261.94	1278.77
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	707.09	715.71	722.68	728.43
Evaporator temperature (K)	276.9	277.6	278.2	278.6
Condenser temperature (K)	324.1	324.50	324.9	325.1
Evaporator pressure (Bar)	3.345	3.431	3.501	3.559
Condenser pressure (Bar)	13.52	13.65	13.76	13.85
LMTD of Evaporator(K)	14.05	14.16	14.23	14.29
LMTD of Condenser (K)	32.15	32.07	32.02	31.99
LMTD of Condenser vapour (K)	17.29	17.18	17.09	17.02
Reynold number in condenser	199240	199503	199788	200071
Reynold number in capillary tube	24213	25125	25882	26523
Reynold number in brine	99.75	114.0	128.2	142.5
Refrigerating effect (Watts)	369.0	378.8	386.8	393.5
Heat Rejected by Condenser	472.3	482.7	491.3	498.5
Compressor work (Watts)	107.1	107.7	108.2	108.6
Brine outlet temperature(^oC)	12.40	13.68	14.73	15.59
Condenser water outlet temperature (^oC)	39.11	39.43	39.68	39.90

Table-5(a) Effect of Compressor speed (rpm)on the thermodynamic performances of vapour compression refrigeration system by mixing copper nano particles in brine flowand R1234ze(E) in primary circuit of evaporator

Compressor speed (rpm)	2500	2600	2700	2800	2900	3000
First Law Efficiency (COP)	3.566	3.607	3.565	3.529	3.498	3.472
Exergy Destruction Ratio(EDR)	1.443	1.476	1.506	1.531	1.554	1.573
Exergetic Efficiency	0.4093	0.4038	0.399	0.395	0.3916	0.3886
Isentropic efficiency of compressor	0.765	0.7712	0.7777	0.7844	0.7916	0.7985
Volumetric efficiency of compressor	0.6560	0.6497	0.6435	0.6375	0.6317	0.620
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1359.43	1353.58	1350.57	1349.93	1351.3	1354.34
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	707.76	708.53	709.84	711.50	713.53	715.88
Reynold number in condenser	199503	199788	200071	199240	199503	199788
Reynold number in capillary tube	25125	25882	26523	24213	25125	25882

Table-5(b) Effect of Compressor speed (rpm) on the thermodynamic performances of vapour compression refrigeration system by mixingAl_2O_3 nano particles in brine flowand R1234ze(E) in primary circuit of evaporator

Compressor speed (rpm)	2400	2500	2600	2700	2800	2900	3000
First Law Efficiency (COP)	3.68	3.624	3.575	3.534	3.498	3.468	3.422
Exergy Destruction Ratio(EDR)	1.428	1.465	1.499	1.528	1.554	1.576	1.595
Exergetic Efficiency	0.4113	0.4056	0.4002	0.3956	0.3916	0.3882	0.3853
Isentropic efficiency of compressor	0.7556	0.7615	0.7677	0.7777	0.7742	0.7809	0.7878
Volumetric efficiency of compressor	0.6616	0.6550	0.6487	0.6435	0.6425	0.6365	0.6307
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1311.27	1302.6	1297.05	1294.10	1293.34	1294.42	1297.04
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	703.7	704.02	704.86	706.14	707.80	709.85	712.21
Reynold number in condenser	168012	174619	181052	187313	193399	199314	205057
Reynold number in capillary tube	22757	23103	23452	23802	24152	24502	24852

Table-5(c) Effect of brine flow rate in evaporator by mixingTiO_2 nano particles on the thermodynamic performances of vapour compression refrigeration system using R1234ze(E)

Compressor speed (rpm)	2500	2600	2700	2800	2900	3000
First Law Efficiency (COP)	3.575	3.528	3.490	3.453	3.422	3.398
Exergy Destruction Ratio(EDR)	1.453	1.532	1.56	1.587	1.610	1.623
Exergetic Efficiency	0.4022	0.3948	0.3902	0.3855	0.3832	0.3804
Isentropic efficiency of compressor	0.7564	0.7625	0.7691	0.7756	0.7825	0.7896
Volumetric efficiency of compressor	0.6535	0.6472	0.6412	0.6351	0.6293	0.6237
Evaporator heat Transfer Coefficient ($W/m^{2o}K$)	1224.78	1219.63	1217.77	1215.88	1216.6	1218.7
Condenser heat Transfer Coefficient ($W/m^{2o}K$)	698.45	699.32	700.82	702.31	704.36	706.13
Reynold number in condenser	174617	181022	187210	193399	199177	204878
Reynold number in capillary tube	23103	23452	23802	24152	24502	24852

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The results indicate that Al_2O_3 (0.00005m) nanoparticles in refrigerant R1233zd(E) have the potential to improve the refrigerating capacity of the vapour compression system. This is attributed to the increased heat-carrying capacity of nanoparticles-based refrigerant. However, at higher mass fractions of the nanoparticles and at higher refrigerant volume flow rates, the refrigerating capacity is found to be decreasing marginally, compared to R1233zd(E). Also, the increase in the ambient temperature has adverse effect on the refrigerating capacity of the refrigeration system, which is found to be decreasing. This can be augmented due the increased heat losses to the environment at higher condenser operating temperatures. A comparison of COP gain for vapour compression refrigeration system working with Nano refrigerant (R1233zd(E) using, copper, $Al_2O_3$and $TiO_{2)}$ is shown in table-6 (a). .it is clear that using nano particles gives a significant improvement in the COP gain of the refrigeration system. Thus, the use of nanoparticles in the R1233zd(E)has resulted in enhancement in the volumetric efficiency of compressor. Similarly, performance improvement is also seen in Table-6(b) respectively.

Table-6 (a): Thermodynamic performances using R1234ze(Z) at mass flow rate of brine=0.008 kg/sec and water flow rate in condenser=0.008 kg/sec

Performance parameters	CuO	Al_2O_3	TiO_2	Without Nano
First Law Efficiency (COP)	3.591	3.561	3.516	2.96
Exergy of Fuel (Watt)	109.4	108.1	108.3	102.0
Irreversibility Ratio	3.026	2.88	2.838	2.439
Second law effectiveness	0.2489	0.2577	0.2606	0.2908
EDR	1.487	1.509	1.541	1.9533
Exergetic Efficiency	0.4020	0.3986	0.3936	0.3386
Isentropic efficiency of compressor	0.8004	0.7999	0.7988	0.7273
Volumetric efficiency of compressor	0.6337	0.6322	0.6275	0.6148
Evaporator heat Transfer Coefficient (W/m^2K)	1358.86	1318.7	1242.43	664.62
Condenser heat Transfer Coefficient (W/m^2K)	694.81	721.11	715.71	644.56

Table-6(b): % improvement in thermodynamic performances using using R1234ze(Z) at mass flow rate of brine=0.008 kg/sec and water flow rate in condenser=0.008 kg/sec

Performance parameters	% CuO	Al_2O_3	TiO_2	Without Nano
First Law Efficiency (COP)	21.31	20.3	18.78	2.96
Exergy of Fuel (Watt)	6.863	5.9804	6.1765	102.0
Irreversiblity Ratio	24.06	18.42	16.694	2.439
Second law Effectiveness	-14.4	-11.38	-10.38	0.2908
Exergy Destruction Ratio(EDR)	-23.8	-21.11	-21.21	1.9533
Exergetic Efficiency	18.72	17.72	16.24	0.3386
Isentropic efficiency of compressor	9.982	9.82	9.731	0.7273
Volumetric efficiency of compressor	3.07	2.83	2.0657	0.6148
Evaporator heat Transfer Coefficient (W/m^2K)	104.5	98.414	86.938	664.62
Condenser heat Transfer Coefficient (W/m^2K)	12.31	11.02	10.67	644.56

Similarly, the comparison of COP gain for vapour compression refrigeration system working with Nano refrigerant (R1243zf using, copper, Al_2O_3 and TiO_2 is shown in table-6 (a). .it is clear that using Nano particles gives a significant improvement in the COP gain of the refrigeration system. Thus, the use of nanoparticles in the R1233zd(E)has resulted in enhancement in the volumetric efficiency of compressor shown in Table-7b

Table-7(a): Thermodynamic performances using R1234yf at mass flow rate of brine=0.006 kg/sec and water flow rate in condenser=0.008 kg/sec by mixing copper nano materials

Performance parameters	CuO	Without Nano	% improvement
First Law Efficiency (COP)	3.416	2.96	15.405
Exergy of Fuel ($W_{\_comp}$) in Watt	109.4	102.0	6.863
Irreversiblity Ratio	3.026	2.439	24.06
Second law Effectiveness	0.2489	0.2908	-14.40
Exergy Destruction Ratio	1.4876	1.9533	-23.87
Exergetic Efficiency	0.4020	0.3386	18.72
Isentropic efficiency of compressor	0.7999	0.7273	9.982
Volumetric efficiency of compressor	0.6275	0.6148	2.0657
Evaporator heat Transfer Coefficient (W/m^{2o}K)	1358.86	664.62	104.518
Condenser heat Transfer Coefficient (W/m^{2o}K)	694.81	644.56	7.67
Exergy of Product in Watt	27.17	29.65	-8.36
Evaporator temperature (K)	278	271.5	2.394
Condenser temperature (K)	326.1	321.3	1.494
Evaporator pressure (Bar)	3.475	2.758	25.99
Condenser pressure (Bar)	14.2	12.58	13.6
LMTD of Evaporator(K)	12.77	21.09	-39.44
LMTD of Condenser (K)	33.52	33.32	0.6
LMTD of Condenser vapour (K)	16.81	18.2	-7.637
Reynold number in condenser	199517	200375	-0.4282
Reynold number in capillary tube	25358	18309	38.5
Reynold number in brine	99.75	378	-73.6
Refrigerating effect (Watts)	373.7	301.8	23.82
Heat Rejected by Condenser	479.2	399.8	19.86
Compressor work (Watts)	109.4	102.0	7.75

Table-7(b): % improvement in thermodynamic performances using R1234yf

Performance parameters	% CuO	Al_2O_3	TiO_2	Without Nano
First Law Efficiency (COP)	18.88	17.01	15.85	2.96
Exergy of Fuel (Watt)	6.863	5.998	6.13	102.0
Irreversibility Ratio	24.06	18.042	16.494	2.439
Second law Effectiveness	-14.40	-11.18	-10.18	0.2908
Exergy Destruction Ratio (EDR)	-21.21	-21.01	-21.11	1.9533
Exergetic Efficiency	16.332	17.52	16.04	0.3386
Isentropic efficiency of compressor	10.05	9.982	9.831	0.7273
Volumetric efficiency of compressor	3.074	2.83	2.80	0.6148
Evaporator heat Transfer Coefficient (W/m^{2}K)	104.518	98.114	86.438	664.62
Condenser heat Transfer Coefficient (W/m^{2}K)	11.366	11.0	10.65	644.56

3. Conclusions

Following conclusions were drawn from present investigation

- For evaluating vapour compression refrigeration system, the first law efficiency in terms of coefficient of performanceon using copper nanoparticle mixed in the ecofriendly refrigerant and implement into the program results is to be found as 21.31%, using copper 20.3%using Al_2O_3 and 18.75 using TiO_2. using R1234ze(Z) in the primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator
- For evaluating second law thermodynamic performance evaluation of vapour compression refrigeration system, the second law efficiency in terms of exergetic performances (exergetic efficiency) using copper nanoparticle mixed in the ecofriendly refrigerant is to be found as 18.72%, using copper 17.72 using Al_2O_3 and 16.24 using TiO_2 in the brine water and R1234ze(Z) in the primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator
- The evaporator overall heat transfer coefficient was increased 106.73%, using copper 98.4% using Al_2O_3 and 86.94% using TiO_2 in the brine water and R1234ze(Z) in the primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator
- The evaporator overall heat transfer coefficient was increased 104.52%, using copper 98.4% using Al_2O_3 and 86.94% using TiO_2 in the brine water and R1234yf in the primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator
- The condenser overall heat transfer coefficient was increased 12.31%, using copper 11.02% using Al_2O_3 and 10.67% using TiO_2 in the brine water and R1234ze(Z) in the primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator
- The condenser overall heat transfer coefficient was increased 11.37%, using copper 11.0% using Al_2O_3 and 10.65% using TiO_2 in the brine water and R1234yf in the

primary circuit and nano mixed brine water flowing in the secondary circuit of evaporator

- Performance evaluation of vapour compression refrigeration system when calculated nano-refrigerent property implement into the program based on Al_2O_3 nanoparticle mixed in the R1233zd(E) ecofriendly refrigerant is 13% and Al_2O_3 nanoparticle mixed in the R1243zf is 9%. Performance evaluation of vapour compression refrigeration system when nanoparticle into refrigerant oil nanoparticle based on Al_2O_3nanoparticle mixed in the ecofriendly R1224yd(Z) refrigerant is 11%
- The performance of vapour compression refrigeration systems using Al_2O_3 particles direct mixed in the brine and R1233zd(E) in the primary circuit gives better first law performance than R1243zf in primary circuit and improvement in the first law performance is 18.88% using R1234yf using copper nano material, and Al_2O_3 nano particles mixed with brine water is 17.0% and 15.85% as using R1234yf using TiO_2nano material,

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