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Role of Nano-technology for improving of thermal performances of vapour compression refrigeration system (VCRS): An Overview

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Abstract

The thermodynamics analysis of modified vapour compression refrigeration system using ecofriendly refrigerants have been presented based on energy and exergy concepts. The modified vapour compression refrigeration system having heat exchanger between two simple vapour compression cycle and this heat exchanger act as super heater for first cycle and condenser for secondary cycle. Numerical computations have been carried out using energy and exergy equations to calculate different parameters for evaluating the system performance of cycle using R134a ecofriendly refrigerant using three types of nano particles mixed with brine water flowing in the evaporator. From simulation results of modified vapour compression refrigeration systems using different ecofriendly refrigerants gives better thermal performance comparison of these refrigerants when used without nano particles in modified vapour compression refrigeration system. It was observed that first law efficiency is decreasing as compressor speed increasing and maximum thermal efficiency around 12% to 22% higher by using copper nano particles mixed in the brine water in the evaporator and minimum (8% to 15% higher) by using TiO_2 nano particles of size 0.00001m mixed in the brine water in the evaporator as without mixing nano particles.

Key words: Nano-Technology, VCRS, Thermal first & second law Performance, Eco-friendly refrigerants

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

The use of nano particles improves the first law and second law performance significantly. The best performance is found using R152a and worst performance is observed using R410a. Due to flammable nature of R290, R600, R600a and R152a.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 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. The refrigeration effect can also be increased using nano particles mixed with R718 in the secondary evaporator circuit and R134a in the primary evaporator circuit. The evaporator overall heat transfer coefficient is also increases which enhanced refrigeration effect due to nano particles mixed with R718 in the secondary evaporator circuit and R134a in the primary evaporator circuit. Vapour compression refrigeration system based applications

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make use of refrigerants which are responsible for greenhouse gases, global warming and ozone layer depletion. Montreal protocol was signed on the issue of substances that are responsible for depleting Ozone layer and discovered how much consumption and production of ozone depletion substances took place during certain time period for both developed and developing countries. Another protocol named as Kyoto aimed to control emission of greenhouse gases in 1997. The relationship between ozone depletion potential and global warming potential is the major concern in the field of GRT (green refrigeration technology) so Kyoto proposed new refrigerants having lower value of ODP and GWP. Internationally a program being pursued to phase out refrigerants having high chlorine content for the sake of global environmental problems. Due to presence of high chlorine content high global warming potential and ozone depletion potential after 90.s CFC and HCFC refrigerants have been restricted. Thus, HFC refrigerants are used nowadays, showing much lower global warming potential value, but still high with respect to non-fluorine refrigerants. Lots of research work has been done for replacing old refrigerants with new refrigerants.

2. Literature Review

Mishra et al. [1-3] performed numerical analysis of vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A, and discussed the effect of evaporator temperature, degree of sub cooling at condenser outlet, superheating of evaporator outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature on COP and exergetic efficiency. They reported that evaporator and condenser temperature have significant effect on both COP and exergetic efficiency and also found that R134a has the better performance while R404a has poor performance in all respect. Mishra et al.[4] compared the performance between R134a and R290/R600a mixture on a domestic refrigerator which is originally designed to work with R134a and found that R290/R600a hydrocarbon mixture showed higher COP and exergetic efficiency than R134a. In their analysis highest irreversibility is obtained in compressor. 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 with single evaporator. It was found that nano particles (TiO_2 and Al2O3) mixed with R718 refrigerants was 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. Mishra et al. [5] Using Engineering Equation Solver software a numerical model has been developed for comparison of performance parameters of systems (system 1 & system-2). Thermodynamic analysis in terms of energy and exergy analysis of multiple evaporators and compressors with individual expansion valves (system-1) and multiple evaporators and compressors with multiple expansion valves (system-2) have been carried out and following conclusions was drawn from present investigation. For same degree of sub cooling, fixed evaporators and condenser temperatures system-2 is the best system with comparisons of system-1. R600, R600a and R152A show better performances than other refrigerants for both systems (system-1 & system-2) but due to inflammable property of R600 and R600a, R134a is preferred for both systems. First law efficiency and second law efficiency of system-2 is 3%-6% higher than System-1. Mishra et al. [6] performed thermal modeling of Vapor Compression Refrigeration System using R134a in primary circuit and Al2O3-Water based nano-fluids in secondary circuit. The performances of vapour compression have been studies in details and conclusions were made that the optimum temperature of evaporator is found to be -50C. Similarly exergy destruction ratio is also decreases up to 273K and then increases. The optimum evaporator temperature to be found to be 273K for optimum EDR condenser temperature with performance parameters. Also found that as condenser temperature increases, the first law efficiency of vapour compression refrigeration system is decreases. Also second law efficiency is also decreases. Similarly exergy destruction ratio is also decreases. Use of nano particle suspended in the water used as refrigerant in the secondary circuit in the evaporator greatly affecting its first law performance. As evaporator temperature is increases, the first law efficiency and second law efficiency increases. The increasing condenser temperature the First law and second law performance decreases. Mishra et al. [7]investigates Thermodynamic analysis in terms of energy and exergy analysis of multiple evaporators and compressors with individual expansion valves (system-1) and multiple evaporators and compressors with multiple expansion valves (system-2) have been carried out that R134a, R407c, show better performances than other refrigerants in Vapour compression refrigeration system. Due to flammable property of R290 and R600a, R134a is preferred for vapour compression refrigeration systems and gives first law efficiency and second law efficiency of Vapour compression using R407c is -2 is 3%-6% higher than R134a.

Mishra et al. [8] performed first law and second law analysis of vapour compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with ecofriendly refrigerants in the system and R718 (water used in secondary circuit with and without nano particles mixed with water used as refrigerant) have been presented. He found that the First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using R718 mixed with nano particles gives better performance is than without nano particles used in the secondary circuit of water cooled evaporator for above mentioned ecofriendly refrigerants. Also refrigeration systems using R152a refrigerant is higher but is has flammable nature similar to hydrocarbons then safety measures to be taken while using R152a or hydrocarbons (R290, R600 and R600a) it improved by using TiO_2 in the secondary evaporator circuit as compared to Al_2O_3 in the secondary circuit he found efficiency for R507a and R134a are nearly matching the same values are better than that for R125.For practical applications R-407c, R134a and R404a, R125 can be used instead of R-152a which was not applicable for commercial applications due to flammable nature and R717 is also toxic nature. Efficiency improved by using TiO_2 is better than using Al_2O_3 with R718 refrigerant in the secondary evaporator circuit. Mishra et al. [9] Investigates energy and exergy analysis of vapour compression refrigeration systems using R134a ecofriendly refrigerant in primary circuit and three nano particles mixed with R718 in the secondary evaporator is presented and found that copper oxide gives performance improvements in the range 11.23% to 18% without nano particles and better performance was found using copper oxide nano material in efficiency. The COP improvement is 18.35% and second law efficiency improvement is 18.31% observed using Al_2O_3 nano materials mixed with R718 in secondary circuit as compared to without nano refrigerants. Similarly, 17.72% and 17.685% second law efficiency. Mishra et al [10] Analyze, first law and second law analysis of vapour compression refrigeration system with and without nano particles using ecofriendly refrigerants (R134a, R1234yf, and R1234ze) and found that withoutAl_2O_3 nano particles mixed in R718 in the secondary evaporator circuit and ecofriendly refrigerants in the primary circuit (i.e. R134a and R1234ze) are matching the same values, both are better than that for R123yf which has low GWP (i.e. GWP =4) is showing 2–6% higher value of first law efficiency i.e. (COP) and second law efficiency i.e. (Exergetic efficiency) in comparison to R123yf.It was found that energetic and exergetic efficiency greatly affected by changes in evaporator and condenser temperature. R1234ze is the best among considered refrigerant since it has 218 times lower GWP values than R134a and R1234ze is ecofriendly has both ODP and GWP are lowest. The R1234yf and R1234ze can replace R-134a after 2030 due to low global warming potential. Mishra et al[11] Performed first law and second law analysis of vapour compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with thirteen ecofriendly refrigerants have been presented and found that First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using R717 refrigerant is higher but is has toxic nature can be used by using safety measure for industrial applications also efficiency for R152a and R600 are nearly matching the same values are better than that for R125 at 313K condenser temperature and showing higher value of COP and exergetic efficiency in comparison to R125.For practical applications R-134a is recommended because it is easily available in the market has second law efficiency slightly lesser than R-152a which was not applicable for commercial applications. The worst component from the viewpoint of irreversibility is expansion valve followed by condenser, compressor and evaporators, respectively. The most efficient component found to be sub-cooler. The R-152a has least efficiency defects for 313K condenser temperature. 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 R134a and 18% when using R407c in the primary circuit. Performance evaluation of vapour compression refrigeration system when calculated nano-refrigerant property implement into the program based on Al_2O_3 nanoparticle mixed in the R134a ecofriendly refrigerant is 13% and Al_2O_3nanoparticle mixed in the R407c is 9%. The thermal performance evaluation of vapour compression refrigeration system when nanoparticle into refrigerant oil nanoparticle based on Al_2O_3 nanoparticle mixed in the ecofriendly R134a 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 R407c and improvement in the first law performance is 28% using R134a 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 2.64% when Al_2O_3 directly mixed with R407c, mixed with compressor oil and then used as refrigerant the primary circuit.

Mishra et al [12], the computation modeling of vapor compression refrigeration systems was carried out with the help of engineering equation solver of Hon'ble Dr. S.A. Klein (2002) for first and second law analysis in terms of energetic analysis i.e. COP (First law analysis) and exegetic analysis in terms of exergetic efficiency, exergy destruction ratio (EDR) and percentage exergetic destruction in each component (second law analysis). In this analysis, we assumed negligible pressure losses and heat losses. The comparative performance of 4.75 KW window air conditioner is evaluated for condenser temperature varying between 300K to 327K with increment of 3 and evaporator temperature is varying from 274K to 278 K with increment of 1. The energy and exergy change in vapour compression refrigeration cycle have been calculated for various ecofriendly refrigerants such as R-1234yf, R-1234ze, R404a, R-290 (propane), R600 (butane), R-600a (isobutene) for environmental temperature of 298K. The variation of fist law efficiency in terms of cop and second law efficiency in terms of exegetic efficiency. As condenser temperature increases the first law efficiency decreases while second law efficiency decreases. Similarly, with increasing evaporator temperature, the first law efficiency increases while second law efficiency decreases.

Mishra et al [13]analyze that first law and second law analysis of vapor compression refrigeration systems using multiple evaporators and single compressor and single expansion valve with eco-friendly refrigerants in the system and R718 (water used in secondary circuit with and without nano particles mixed with water used as refrigerant) have been presented. He found that R718 mixed with nano particles gives better performance is than without nano particles used in the secondary circuit of water cooled evaporator for above mentioned eco-friendly refrigerants he also found that R152a refrigerant is higher but is has flammable nature similar to hydrocarbons then safety measures to be taken while using

R152a or hydrocarbons (R290, R600 and R600a) efficiency improved by using TiO_2 in the secondary evaporator circuit as compared to Al_2O_3 in the secondary circuit .

3. Results and Discussions

Performance prediction of vapour compression refrigeration systems using nano particles in the brine water of evaporator circuit for following input data
Length of evaporator =0.72 m,
Length of condenser =1.2 m,
Evaporator temperature of brine water inlet = 27^0C,
Condenser temperature of water inlet = 27^0C, Pressure of brine water inlet = 2 (bar),
Pressure of condenser water inlet = 2 (bar),
Mass flow rate of brine= 0.007 (Kg/sec),
Mass flow rate of condenser water= 0.008 (Kg/sec)
From Table-1(a) to Table1(j) As compressor speed increases the first law efficiency in terms of Coefficient of performance (COP) and second law efficiency increases while exergy destruction of the system decreases. Similarly Reynold numbers of liquid portion condenser and condenser vapour portions and Reynold number of evaporation in increases. As compressor speed in increases. The LMTD of Liquid portion condenser and vapour portion condenser and LMTD of evaporator is increases. The isentropic efficiency of compressor is in increases and volumetric efficiency of compressor is decreases as compressor speed is increases.

Table-1(a): The variation of first law efficiency (COP) with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	3.631	3.582	3.058
2600	-	3.583	3.536	3.023
2700	-	3.542	3.496	2.993
2800	-	3.507	3.462	2.968
2900	3.507	3.477	3.432	2.946
3000	3.58	3.451	3.407	2.928

Table-1(b): The variation of Second law efficiency with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	0.4064	0.4010	0.3327
2600	-	0.4011	0.3958	0.3384
2700	-	0.3665	0.3914	0.3351
2800	-	0.3926	0.3889	0.3322
2900	0.3926	0.3892	0.3842	0.3298
3000	0.3896	0.3863	0.3814	0.3277

Table-1(c) :The variation of system exergy destruction ratio (EDR) with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	1.461	1.494	1.921
2600	-	1.493	1.526	1.955
2700	-	1.522	1.555	1.984
2800	-	1.547	1.581	2.01
2900	1.547	1.569	1.603	2.032
3000	1.567	1.589	1.622	2.051

Table-1(d) :The variation of Evaporator over all heat transfer coefficient (W/m²K) with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	1314.24	1234.73	677.41
26oo	-	1312.60	1233.02	675.52
2700	-	1313.30	1233.39	674.3
2800	-	1315.94	1235.47	673.64
2900	1380.0	1320.21	1239.0	673.45
3000	1386.35	1325.84	1243.72	673.65

Table-1(e) :The variation of Condenser over all heat transfer coefficient (W/m²K) with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	708.26	702.77	639.9
26oo	-	709.11	703.65	641.10
2700	-	710.38	704.95	642.46
2800	-	712.02	706.63	644.24
2900	717.61	714.01	708.64	646.31
3000	719.88	716.29	707.95	648.65

Table-1(f): The variation of volumetric efficiency of compressor with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	0.6537	0.6521	0.6350
2600	-	0.642	0.6457	0.6289
2700	-	0.6409	0.6394	0.6229
2800	-	0.6348	0.6334	0.6172
2900	0.6299	0.6289	0.6275	0.6116
3000	0.6242	0.6232	0.6217	0.6061

Table-1(g) :The variation of isentropic efficiency of compressor with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	0.7860	0.7806	0.7209
2600	-	0.7924	0.7870	0.7269
2700	-	0.7991	0.7936	0.7331
2800	-	0.8060	0.8004	0.7395
2900	0.8169	0.8131	0.8074	0.7461
3000	0.8242	0.8203	0.8146	0.7521

Table-1(h) :The variation of LMTD of condenser liquid portion with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	32.82	32.88	34.19
2600	-	33.14	33.2	34.42
2700	-	33.42	33.47	34.6
2800	-	33.67	33.71	34.74
2900	33.87	33.89	33.92	34.85
3000	34.06	34.07	34.09	34.92

Table-1(i) :The variation of LMTD of Condenser vapour portion with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	16.67	16.74	17.72
2600	-	16.83	16.9	17.58
2700	-	16.96	17.03	17.95
2800	-	17.07	17.14	18.03
2900	17.12	17.17	17.23	18.09
3000	17.20	17.24	17.30	18.13

Table-1(j) :The variation of LMTD of Evaporator with compressor speed

Compressor speed (rpm)	Copper nano materials	Al_2O_3	TiO_2	Without nano
2500	-	12.91	13.52	20.29
2600	-	13.1	13.72	20.58
2700	-	13.27	13.9	20.86
2800	-	13.41	14.05	21.11
2900	13.10	13.54	14.19	21.35
3000	13.20	13.65	14.31	21.57

3.1 Effect of evaporator brine flow rate on system performance

From Table-2(a) to Table-2(m) As mass flow rate of brine in the evaporator increases the first law efficiency in terms of Coefficient of performance (COP) and second law efficiency increases while exergy destruction of the system decreases. Similarly Reynold numbers of liquid portion condenser and condenser vapor portions and Reynold number of evaporation in increases. As mass flow rate of brine in the evaporator is increases. The LMTD of Liquid portion condenser and vapor portion condenser is decreases and LMTD of evaporator is increases. The isentropic efficiency of compressor is in increases and volumetric efficiency of compressor is also increases as as mass flow rate of brine in the evaporator.

Table-2(a): The variation of first law efficiency (COP) with evaporator brine mass flow rate for m_water=0.008

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	3.507	3.477	3.432	2.946
0.008	3.580	3.549	3.504	3.013
0.009	3.640	3.609	3.563	3.069
0.01	3.689	3.658	3.612	3.119

It was observed that first law efficiency in terms of coefficient (COP) is decreasing as evaporator brine mass flow rate increasing and maximum thermal efficiency around 20% more is observed using copper materials and minimum (15% higher) by using TiO_2.

Table-2(b) :The variation of second law efficiency (Exergetic efficiency) with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	0.3926	0.3892	0.3742	0.3298
0.008	0.4008	0.3922	0.3892	0.3372
0.009	0.4074	0.4039	0.3988	0.3436
0.01	0.4129	0.4094	0.4043	0.3491

Table-2(c) :The variation of of system exergy destruction ratio (EDR) with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	1.547	1.569	1.603	2.032
0.008	1.495	1.517	1.55	1.965
0.009	1.454	1.476	1.507	1.91
0.01	1.422	1.442	1.473	1.864

Table-2(d) :The variation of evaporator overall heat transfer coefficient (W/m2K) with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	1380.0	1320.21	1239.0	675.14
0.008	1401.19	1342.82	1263.34	673.45
0.009	1418.86	1361.93	1284.03	772.42
0.01	1433.89	1378.26	1301.9	671.77

Table-2(e) :The variation of condenser overall heat transfer coefficient (W/m2K) with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	717.43	714.0	708.64	630.06
0.008	726.24	722.63	717.26	646.321
0.009	739.12	729.54	724.20	659.6
0.01	738.74	735.2	729.91	670.64

Table-2(f) :The variation of volumetric efficiency of compressor with evaporator brine mass flow rate

mass flow rate of brine (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	6299	0.6289	0.6275	0.6116
0.008	0.6323	0.6313	0.6298	0.6137
0.009	0.6343	0.6332	0.6317	0.6156
0.01	0.6359	0.6349	0.6334	0.6172

Table-2(g) :The variation of isentropic efficiency of compressor with evaporator brine mass flow rate

Evaporator mass flow rate of brine (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	0.8169	0.8131	0.8074	0.7461
0.008	0.8261	0.8222	0.8165	0.7545
0.009	0.8117	0.8297	0.8239	0.7617
0.01	0.8078	0.8360	0.8303	0.7679

Table-2(h) :The variation of LMTD of Condenser liquid portion with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/S)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	33.87	33.89	33.92	34.85
0.008	33.85	33.86	33.85	34.65
0.009	33.85	33.85	33.85	34.49
0.010	33.86	33.85	33.85	34.38

Table-2(i):The variation of LMTD of Condenser vapour portion with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	17.12	17.17	17.23	18.09
0.008	17.02	17.07	17.13	17.96
0.009	16.95	16.99	17.05	17.85
0.010	16.89	16.93	16.98	17.75

Table-2(j) :The variation of LMTD of evaporator with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	13.10	13.54	14.19	21.35
0.008	13.25	13.67	14.29	21.15
0.009	13.36	13.77	14.37	20.36
0.010	13.45	13.84	14.42	20.79

Table-2(k) :The variation of Capillary Reynold number with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	27097	26671	26047	19832
0.008	28147	27703	27895	19653
0.009	29014	28559	28595	19518
0.010	29743	29281	29281	19414

Table-2(l): The variation of condenser Reynold number with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	206819	206601	206312	210116
0.008	207421	207155	206797	206080
0.009	207985	207682	207269	202919
0.010	208502	208170	208170	200356

Table-2(m): The variation of brine Reynold number with evaporator brine mass flow rate

Evaporator brine mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	104.3	104.3	104.3	334.4
0.008	119.2	119.2	119.2	396.4
0.009	134.1	134.1	134.1	396.0
0.010	149.0	149.0	149.0	395.6

3.2 Effect of condenser water flow rate on system performance

From Table-3(a) to Table3(m) As mass flow rate of water in the condenser increases the first law efficiency in terms of Coefficient of performance (COP) and second law efficiency increases while exergy destruction of the system decreases. Similarly Reynold numbers of liquid portion condenser and condenser vapour portions and Reynold number of evaporation in increases. As mass flow rate of water in the condenser is increases. The LMTD of Liquid portion condenser and vapour portion condenser is decreases and LMTD of evaporator is increases. The isentropic efficiency of compressor is in increases and volumetric efficiency of compressor is also increases as mass flow rate of water in the condenser increases.

Table-3(a) :The variation of first law efficiency (COP) with condenser water mass flow rate

Condenser water mass flow rate (Kg/s)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	3.477	3.338	2.822
0.008	3.505	3.549	3.432	2.946
0.009	3.589	3.609	3.510	2.998
0.01	3.659	3.658	3.576	3.041

Table-3(b) :The variation of second law efficiency (Exergetic efficiency) with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	0.3892	0.3736	0.3226
0.008	0.3926	0.3973	0.3842	0.3298
0.009	0.4018	0.4039	0.3929	0.3356
0.01	0.4096	0.4094	0.4003	0.3404

Table-3(c) :The variation of system exergy destruction ratio (EDR) with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	1.644	1.677	2.10
0.008	1.547	1.569	1.603	2.032
0.009	1.489	1.511	1.545	1.98
0.01	1.442	1.464	1.448	1.938

Table-3(d) :The variation of evaporator overall heat transfer coefficient (W/m^2K) with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	1372.21	1245.23.	675.14
0.008	1380.0	1342.87	1239.0	673.45
0.009	1375.15	1321.93	1235.03	672.42
0.01	1372.29	1302.0	1233.18	671.77

Table-3(e) :The variation of condenser overall heat transfer coefficient (W/m2K) with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	692.96	688.01	630.06
0.008	717.61	714.01	708.64	646.31
0.009	735.12	731.28	725.28	659.59
0.01	749.75	745.71	739.28	670.64

Table-3(f) :The variation of Volumetric efficiency of compressor with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	0.6239	0.6225	0.6075
0.008	0.6299	0.6289	0.6289	0.6116
0.009	0.6338	0.6328	0.6313	0.6146
0.01	0.6369	0.6359	0.6343	0.6171

Table-3(g) :The variation of isentropic efficiency of compressor with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	0.8198	0.8140	0.7513
0.008	0.8169	0.8131	0.8074	0.7461
0.009	0.8117	0.8080	0.8025	0.7422
0.01	0.8074	0.8041	0.7976	0.7392

Table-3(h) :The variation of LMTD of Condenser liquid portion with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	35.15	35.35	36.02
0.008	33.87	33.89	33.92	34.85
0.009	32.71	32.73	32.78	33.93
0.01	31.76	31.8	31.87	33.19

Table-3(i) :The variation of LMTD of Condenser vapour portion with condenser water mass flow rate

Condenser mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	16.82	16.85	17.76
0.008	17.12	17.17	17.23	18.09
0.009	17.40	17.45	17.51	18.35
0.01	17.64	17.68	17.75	18.57

Table-3(j) :The variation of LMTD of evaporator with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	13.27	13.92	21.08
0.008	13.10	13.54	14.19	21.35
0.009	13.29	13.74	14.33	21.55
0.01	13.44	13.89	14.54	21.71

Table-3(k) :The variation of Re_23 with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	211720	211337	206080
0.008	206819	206601	206312	205753
0.009	202749	202581	202366	205575
0.01	199474	199346	199190	205490

Table-3(l): The variation of Re_Cap with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano
0.007	-	26194	26285	19653
0.008	27097	26671	26047	20486
0.009	26914	26490	25871	21208
0.01	26774	26352	25736	21841

Table-3(m) :The variation of Re_brine with condenser water mass flow rate

Condenser water mass flow rate (Kg/sec)	Copper nano materials	Al_2O_3	TiO_2	Without nano particles
0.007	-	104.3	104.3	396.4
0.008	104.3	104.3	104.3	458.6
0.009	104.3	104.3	104.3	521.1
0.01	104.3	104.3	104.3	583.8

4. Conclusions

(i) Following conclusions were drawn from developed thermal model for vapour compression refrigeration systems using speed variable compressor Ecofriendly refrigerants HFO-1234ze can be used for high temperature application between condenser temperature ranging between 40^0C to 65^0C to the evaporator temperature range of -30^0C to 20^0C for replacing R134a and thermal performance of this refrigerant is slightly matching with R134a.

(ii) Sub-cooling of condenser improves first law efficiency in terms of coefficient of performance of vapors compression system

(iii) Super heating of evaporator outlet fluid is also improving the first law performances

(iv) For low temperature applications the HFO R1234yf gives around 3% to 5% lower thermal performance than R134a while replacing R134a

(v) Ecofriendly refrigerants HFO-1234yf can be used for medium temperature application between condenser temperature ranging between 40^0C to 50^0C to the evaporator temperature range of -50^0C to 20^0C for replacing R134a and thermal performance of this refrigerant is slightly lower than R134a.

(vi) In the secondary evaporator circuit, the evaporator heat transfer coefficient is improved (i.e. 80% to 110% more) and the condenser heat transfer coefficient is

(vii) improved (i.e. 8% to 10% more) without using nano particles mixed in R718

(viii) Best thermal performance were observed up to 22 % using copper nano materials and lowest was observed (around 7% to 10%) by mixing TiO2in the R718. While using Al_2O_3, the performances improved in the range of 12% to 19%. Similarly using silver as a nano particles, the performances, improved up to 11% to 16%

(ix) Using nano materials, the size of evaporator is reduced, hence cost is also reduced, however for same evaporator size, thermal performances also improved.

(x) Use of nano particles in the secondary circuit in the condenser, the performance of system is also improved.

(xi) The mixing of nano particles in the ecofriendly refrigerants , the thermal performance improved up 33% using copper oxide and 27% using Al2O3and lowest were found using TiO_2 up to 22%.

(xii) The first law efficiency in terms of coefficient of performance of vapour compression refrigeration system using ecofriendly R134a refrigerant is decreasing as increasing speed of compressor while second law efficiency in terms of exergetic efficiency is decreases

(xiii) The first law efficiency in terms of coefficient of performance is increasing along with increasing volumetric efficiency as increasing brine mass flow rate in the evaporator while exergetic efficiency is decreasing along with increasing isentropic compressor efficiency

(xiv) The first law efficiency in terms of coefficient of performance is increasing along with decreasing volumetric efficiency as increasing water mass flow rate in the condenser while exergetic efficiency is increasing along with decreasing isentropic compressor efficiency.

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