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Optimization of Vapour Compression Refrigeration Systems using Mixing of Nanomaterials

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ABSTRACT

This paper mainly deals with energy exergy analysis for finding irreversibilities in the brine cooled evaporator couped vapour compression refrigeration system using R134a ecofriendly refrigeration for reducing ozone depletion and global warming. The numerical computation was carried out using EES software on utilization of three nano particles (i.e. CuO, Al_2O_3 and TiO_2) and it was observed that thre is a improvement in the refrigerating effect, first law efficiency and second law efficiency and reduction in the the system exergety destruction ratio.

Keywords: *Vapour Compression Refrigeration Systems; Energy and Exergy Analysis; First and Second Law Analysis; Irreversibility Analysis; Efficiency Improvement; Nano Materials.*

1.0 Introduction

The methods for finding the first law and second law efficiency of vapour compression and vapour absorption refrigeration systems are well defined in Literature [1].However highest COP indicating the better performance of the vapour compression refrigeration system. The COP of system can be enhanced either by decreasing the work of compressor by introduction of multi stages compressors or increasing the refrigeration effect. It is also possible to reduce the compressor work to considerable extent by compressing the refrigerant very close to the saturation line this can be achieved by compressing the refrigerants in more stages with intermediate inter-cooler. The refrigeration effect can be increase by maintaining the condition of refrigerants in more liquid stage at the entrance of evaporator which can be achieved by expanding the refrigerant very close to the liquid line. The expansion can be brought close to the liquid line by sub-cooling the refrigerant and removing the flashed vapours by incorporating the flash chamber in the working cycle. The evaporator size can be reduced because an unwanted vapour formed is removed before the liquid refrigerant enters in the evaporator. The use of nano particles mixing with R718 in the secondary evaporator enhances the first and second law performances in the vapour compression refrigeration systems.

2.0 Vapour Compression Refrigeration Refrigeration System Using Mixing Of Nano Materials

The utility of second law analysis on vapour compression refrigeration systems is well defined because it gives the idea for improvements in efficiency due to modifications in existing design in terms of reducing exergy destructions in the components. Due to effect of global warming and ozone depletion the comparison and impact of environmental friendly refrigerants (R507a, R410a, R290, R600, R600a, R1234yf, R404a, R125, R717, R152a and R407C) on vapour compression refrigeration system is important for calculating first law and second law performance on the basis of energetic and exergetic approach. Comparison was done for different nano materials in terms of coefficient of performance, rational efficiency and exergy destruction ratio, exergy input and exergy of product with variation of brine flow rate of water in the system. It was observed that for all considered nano materials energetic efficiency (first law efficiency) & second law efficiency (rational efficiency), and system exergy destruction and

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rational exergy destruction ratio of system shows minimum performance using nano copper materials.

3.0 Literature Review

Now a day's most of the energy utilize in cooling and air conditioning in industrial as well as for domestic applications. In addition with energy consumption, using of refrigerants in cooling and air conditioning having high GWP and ODP are responsible for global warming and ozone depletion. The primary requirements of ideal refrigerants is having good physical and chemical properties, due to good physical and chemical properties such as non-corrosiveness, non-toxicity, non- flammability, low boiling point, Chlorofluorocarbons (CFCs) have been used over the last many decades. But hydro-chloro-fluoro-carbons (HCFCs) and Chlorofluorocarbons (CFCs) having large amount of chlorine content as well as high GWP and ODP, so after 90s refrigerants under these categories are almost prohibited [1] Most of the study has been carried out for the performance evaluation of vapour compression refrigeration system using energetic analysis. But with the help of first law analysis irreversibility destruction or losses in components of system unable to determined [2], so exergetic or second law analysis is the advanced approach for thermodynamic analysis which give a additional practical view of the processes [3] In addition to this second law analysis also provides new thought for development in the existing system [4]

Now a day, the emphasis put on saving of energy and using of ecofriendly refrigerants due to increase of energy crises, global warming and depletion of ozone layer [5] The work input required running the vapour compression refrigeration system reduced by using compound compression and work input further decrease by flash intercooling between two compressors using of eco-friendly refrigerants[6] These scientists did not gone through second law analysis in terms of system exergy destruction ratio used defining irreversibility calculations in various components of vapour compression system [7] Therefore objective of the present investigations to find out the system exergy destruction ratio for finding irreversibility occurred in the components of vapour compression refrigeration systems because second law analysis is very useful for finding the irreversibility in components as well as in whole system it is a powerful tool for designing and analyzing of air conditioning and refrigeration systems

4.0 Summary of Literature Review and Gaps Inentified

The study of above literatures and many others not mentioned in the description presents following points-

(i) Thermodynamic analyses of different vapour compression refrigeration systems using different nano refrigerants for enhancing first and second law efficiencies.

(ii) Performance analysis for enhancing overall evaporator heat transfer coefficient, enhancing refrigerating effect, enhancing condenser overall heat transfer coefficients using alternative refrigerants of low GWP and ODP values.

(iii) The different kinds of nanoparticles are used or mixed with the refrigerants for enhancing COP and exergetic efficiency and reduction of exergy destruction ratio.

5.0 Research Objectives

(i) Thermodynamic analysis of simple modified vapour compression system using alternative refrigerants in the primary circuit and nano refrigerants mixed with R717 for reducing the size of evaporator by enhancing evaporator overall heat transfer coefficient, for reducing cost.

(ii) Thermodynamic analysis of vapour compression system (using alternative refrigerants) for enhancing refrigerating effect, and condenser overall heat transfer coefficient

(iii) Comparative analysis of different nano materials for enghancing first and second law performances and reducing exergy destruction ratio in the system for improving design analysis of vapour compression using alternative refrigerants and hybrid refrigeration systems using performance enhancing devices.

6.0 Results and Discussions

The study provides the input on the usage of nano particles mixed in R718 in the secondary evaporator circuit for a vapour compression refrigeration system, using R134a ecofriendly refrigerant in the water cooled evaporator-condenser for residential, industrial and medical applications incorporating these refrigeration systems.

Table 1-a: Variation of Exergey of Fuel (Total Work Input) with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	Exergy_Fuel (Watts) with Copper	Exergy_Fuel (Watts) with TiO2	Exergy_Fuel (Watts) with Al2O3	Exergy_Fuel (Watts) without nano
0.007	111.0	110.3	110.70	105.10
0.008	111.7	111.0	111.4	105.9
0.009	112.2	111.5	11.90	106.6
0.010	112.6	111.9	112.3	107.10
0.011	113	112.3	112.7	107.6

From table-la, As brine flow rate is increasing, exergy input is increasing with using mixed nano-materials R718 refrigerant in the secondary evaporator circuit as compared without nano-materials mixed with R718 maximum exergy of fuel is obtained at 0.011 brine mass flow rate. Similarly exergy of product is decreasing as increasing brine mass flow rate.as shown in Table-lb. as brine mass flow rate is increasing the refrigerating effect is increasing in the all most nano mixed R718 used in the secondary circuit of the system.

Table 1-b: Variation of Exergey of Product with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	Exergy_product (Watts) Copper	Exergy_product (Watts) TiO2	Exergy_product (Watts) Al2O3	Exergy_product (Watts) Without nano
0.007	26.28	26.68	26.45	28.49
0.008	25.86	26.30	26.04	28.29
0.009	25.49	25.96	25.68	28.13
0.010	25.17	25.66	25.37	27.99
0.011	24.88	25.4	25.1	27.84

Table 1-c: Variation of Refrigerating Effect with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	RE_copper	RE_TiO_2	RE_$Al2O_3$	RE_without nanomaterials
0.007	389.2	378.6	384.9	309.6
0.008	399.7	388.8	395.3	319
0.009	408.3	397.2	403.8	327
0.010	415	404.3	410.9	334
0.011	421.4	410.3	416.9	340.10

Table-2a shws the variation of condenser heat rejected with brine flow rate in the secondary circuit of evaporator and it was observed that by increasing brine mass flow rate, the heat rejected rate in the condenser is increases and similarly overall evaporator heat transfer coefficient is also increase in the larger rate and similar trends was also observed with lesser variation in the condenser overall heat transfer coefficient.as shown in Table-2(b) and Table-2(c) respectively.

Table 2-a: Variation of Condenser Heat Rejected with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	Qcond Copper (Watts)	Qcond TiO2 (Watts)	Qcond Al2O3 (Watts)	Qcond (Watts) without nano
0.007	496.2	484.83	491.6	410.5
0.008	507.4	495.8	507.7	420.8
0.009	516.5	504.7	511.7	429
0.010	524	512.2	519.2	437
0.011	530.3	518.6	525.6	443.6

Table 2-b: Variation of Evaporator Overall Heat Transfer Coefficient with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	Ue _copper ($w/m^{2o}C$)	Ue TiO2 ($w/m^{2o}C$)	Ue $Al2O_3$ ($w/m^{2o}C$)	Ue_ without nano Material ($w/m^{2o}C$)
0.007	1380	1239	1320.0	673.45
0.008	1401	1263.34	1342.87	700.47
0.009	1418	1284.03	1361.93	724.47
0.010	1433	1301.9	1378.26	746.05
0.011	1446	1317.55	1392.44	765.63

Table 2-c: Variation of Condenser Overall Heat Transfer Coefficient with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	Uk _ copper ($w/m^{2o}C$)	Uk TiO2 ($w/m^{2o}C$)	Uk $Al2O_3$ ($w/m^{2o}C$)	Uk_ Without nano ($w/m^{2o}C$)
0.007	717.61	708.14	714.01	646.31
0.008	726.24	717.26	722.63	655.21
0.009	733.12	724.2	729.54	662.72
0.010	738.74	729.9	735.9	669.16
0.011	743.4	734.7	739.9	674.78

Table 3-a: Variation of COP with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	COP_ Copper	COP_ Al_2O_3	COP_ TiO_2	COP_ without nano
0.007	3.507	3.432	3.477	2.946
0.008	3.58	3.504	3.549	3.013
0.009	3.64	3.563	3.609	3.069
0.010	3.689	3.612	3.658	3.119
0.011	3.731	3.653	3.699	3.162

Table3a. Shows the variation of exergy Destruction ratio based on exergy output in the vapour compression refrigeration system with varying brine mass flow rate of using three nano particles mixed with R718 refrigerant and it was observed that the EDR decrease with increasing brine mass flow rate. Similar trend was observed in the rational exergey destruction which is a ratio of exergety losses in the system to the exergy of fuel, as shown in the Table-3d.

Table 3-b: Variation of Exergetic Efficiency with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

Mb (Kg/sec)	ETA-II copper	ETA-II Al_2O_3	ETA-II TiO_2	ETA-II Without nano
0.007	0.3842	0.3842	o.3892	0.3298
0.008	0.4008	0.3922	0.3913	0.3372
0.009	0.4074	0.3988	0.4039	0.3436
0.010	0.4129	0.4043	0.4094	0.3491
0.011	0.4176	0.4090	0.4141	0.3540

Table 3-c: Variation of exergy Destruction Ratio (EDR_System) with Brine Mass Flow Rates of Vapour Compression Refrigeration

Mb (Kg/sec)	EDR_ System copper	EDR_ System Al_2O_3	EDR_ System TiO_2	EDR_ System without nano
0.007	1.603	1.603	1.569	2.032
0.008	1.495	1.55	1.517	1.965
0.009	1.454	1.507	1.476	1.91
0.010	1.422	1.473	1.442	1.864
0.011	1.395	1.445	1.415	1.825

Table3a. shows variation ot COP ot vapour compression refrigeration system with varying brine mass flow rate of using three nano particles mixed with R718 refrigerant and it was observed that the cop increases by increasing brine mass flow rate and for 0.008kg/sec improvement using nano refrigerants from 11.20% to 18.30% as compared with without nano refrigerants in secondary circuit. Table-3b

shows the variation of exergetic efficiency with varing brine mass flow rate in the evaporator in the vapour compression refrigeration system using three nano particles mixed with R718 refrigerant and it was observed that the second law performance improved by increasing brine mass flow rate and for 0.008 kg/sec mass flow rates, the optimum improvement in exergetic efficiency was found to be using nano refrigerants from 16.20% to 18.3% as compared with without nano refrigerants in secondary circuit..

Table 3-d: Variation of ED_Rational of System with Brine Mass Flow Rates of Vapour Compression Refrigeration Systems

M_b (Kg/sec)	EDR_ System copper	EDR_ System Al_2O_3	EDR_ System TiO_2	EDR_ System without nano
0.007	0.6158	0.6158	0.6108	0.6702
0.008	0.5992	0.6078	0.6087	0.6628
0.009	0.5992	0.6012	0.5961	0.6564
0.010	0.5871	0.5957	0.5906	0.6509
0.011	0.5824	0.6110	0.5859	0.6460

7.0 Conclusions

The 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 carried and following conclusions are drawn.

1. The, COP, refrigerating effect, overall evaporator heat transfer coefficient, condenser heat transfer coefficient , of vapour compression refrigeration systems is increases with increasing brine mass flow rate using three nano materials and for comparison was made for three nano materials mixed in R718 gives improvement in COP by using copper oxide in the range 11.20% to 18% without nano particles and better performance was found using copper oxide nano material
2. The Second law efficiency (Exergetic efficiency) of using R134a eco-friendly refrigerant in primary evaporator circuit increases with increase in brine mass flow rate in the evaporator secondary circuit and for O.008 kg/sec , the improvement was observed using Copper oxide mixed with R718 in the secondary evaporator circuit gives better Exergetic efficiency as compared to $Ti0_2$nano particles mixed with R718
3. The COP improvement at brine mass flow rate of 0.008 kg/sec is to be found as 18.35% and second law efficiency improvement is 18.31% using $A1_20_3$ nano materials mixed with R718 in secondary circuit as compared to without nano refrigerants. Similarly 17.72% and 17.685% improvement is observed in the second law efficiency at 0.008 kg/sec of brine mass flow rate.
4. The overall evaporator heat transfer coefficient is also increases with increasing brine mass flow rate and at 0.008 kg/sec, the is improvement 91.40% as compared with R134a ecofriendly refrigerant with copper mixed in R718as compared to without nano material and 90.57% improvement using mixed R718 with $A1_20_3$ in the secondary evaporator circuit and improvement is 79.58% observed using $Ti0_2$ nano materials mixed with R718 in secondary circuit as compared to without nano refrigerants.

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Nomenclature

COP	coefficient of performance (non-dimensional)
VCR	vapour compression refrigeration
CFC	chlorofluorocarbon
HCFC	hydrochlorofluorocarbon
Q	rate of heat transfer (kW)
W	work rate (kW)
T	temperature (K)
ED_Rational	Rational exergy destruction ratio (non-dimensional)
U_e	Evaporator Overall heat heat transfer coefficient (W/m2K)
U_k	Condenser Overall heat heat transfer coefficient (W/m2K)
E_p	exergy rate of product (W)
h	specific enthalpy (kJ/kg)
P	pressure (kPa)
IR	irreversibility (W)
E_f	exergy rate of fluid (W)
mb	Brine mass flow rate (kg/s)
s	specific entropy (kJ/kgK)
EF	exergy rate of fuel (W)
EDR	exergy Destruction Ratio non dimensional based on exergy of product
η	Exergetic efficiency (non-dimensional)
r	refrigerant, space to be cooled
ex	Exergetic