Energy-Exergy Performance Comparison of Vapour Compression Refrigeration Systems using three NANO Materials Mixed in R718 as secondry Fluid and R-1234yf and R-1234ze Ecofriendly Refrigerants in the Primary Circuit

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Abstract

The global warming and ozone depletion are serious issues and search for new and ecofriendly refrigerants for reducing global warming. The methods for improving first law and second law efficiency have been considered by mixing nano particles mixed in secondary evaporator circuit with R718 and newely developed ecofriendly refrigerants of low global warming potentials is proposed in this paper. Detailed energy and exergy analysis of vapour compression refrigeration systems have been carried out using R1234yf (of GWP=4) and R1234ze (of GWP=6) in terms of performance parameter for various ecofriendly refrigerants for replacing R134a and other refrigerants after 2030.

The numerical computations have been carried out for variable compressor speed vapour compression refrigeration systems. It was observed that first law and second law efficiency improved by 25% by mixing Copper nano particles in the R-1234yf and 18% using R1234ze ecofriendly refrigerants in the primary circuit of vapour compression refrigeration systems.

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)
δ	efficiency defect (non-dimensional)
ΔT_{sc}	degree of subcooling
EP	exergy rate of product (kW)
EV	Expansion Valve
EP	Evaporator

Subscript

e	evaporator
comp	compressor
h	specific enthalpy (kJ/kg)
P	pressure (kPa)
IR	irreversibility (kW)
E_x	exergy rate of fluid (kW)
m	mass flow rate (kg/s)
s	specific entropy (kJ/kgK)
EF	exergy rate of fuel (kW)
EL	exergy loss rate (kW)
η	efficiency (non-dimensional)
r	refrigerant, space to be cooled
ex	exergetic
ev	expansion valve
c	condenser
sc	subcooler
k	kth component

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1. Introduction

Refrigeration is a technology which absorbs heat at low temperature and provides temperature below the surrounding by rejecting heat to the surrounding at higher temperature. Simple 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 first law and second law performances of system.

Performance of systems based on vapour compression refrigeration technology can be improved by following:

- 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 with flash chamber where the flash vapours is removed after each stage of expansion as a consequence there will be increase in cooling capacity and reduce the size of the evaporator.
- Work input can also be reduced by replacing multi-stage compression or compound compression with single stage compression.
- Refrigeration effect can also be increased by passing the refrigerant through subcooler after condenser to evaporator.
- Use of nano particles mixed with R718 in the secondary evaporator circuit
- Use of nano particles directly mixed with ecofriendly refrigerants in the primary circuit
- Use of nano particles coating in the VCR condenser tubes

2. Literature Review

Vapour compression refrigeration system based applications 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 green house 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 [1].

Reddy et al. [2] carried out 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 subcooling 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 R407C has poor performance in all respect.

Selladurai et.al.[3] 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 obtained in the compressor compare to condenser, expansion valve and evaporator. **Nikolaidis et.al. [4]** studied the change in evaporator and condenser temperatures of two stage vapour compression refrigeration plant using R22 add considerable effect on plant irreversibility. They suggested that there is need for optimizing the conditions imposed upon the condenser and evaporator. **Kumar et. al. [5]** carried out energy and exergy analysis of vapour compression refrigeration system by the use of exergy-enthalpy diagram. They did first law analysis (energy analysis) for calculating the coefficient of performance and exergy analysis (second law analysis) for evaluation of various losses occurred in different components of vapour compression cycle using R11 and R12 as refrigerants. **Mastani Joybari et al.[6]** conducted experimental measurements on a domestic refrigerator originally manufactured to use of 145g of R134a and concluded the exergetic defect occurred in compressor was highest as compare to other components and through their analysis it has been found that instead of 145g of R134a if 60g of R600a is used in the considered system gave same performance which ultimately result into economical advantages and reduce the risk of flammability of hydrocarbon refrigerants. **Ahamed et al.[7]** performed experimental measurements of domestic refrigerator with hydrocarbons (isobutene and butane) by energy and exergy analysis. They reached to the results that energy efficiency ratio of hydrocarbons comparable with R134a but exergy efficiency and sustainability index of hydrocarbons much higher than that of R134a at considered evaporator temperature. It was also found that compressors shows highest system defect (69%) among components of considered in the system. **Bolaji et al. [8]** did experimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator and concluded that R32 shows lowest performance whereas R134a and R152a showing nearly same performance but best performance was obtained of system using R152a. **Yumrutas et al. [9]** studied the exergy analysis based investigation of effect of condensing and evaporating temperature on vapour compression refrigeration cycle in terms of pressure losses, COP, second law efficiency and exergy losses. Variation in temperature of condenser as well as have negligible effect on exergy losses of compressor and expansion valve, also first law efficiency and exergy efficiency increase but total exergy losses of system decrease with increase in evaporator and condenser temperature. **Padilla et al. [10]** did exergy analysis **Getu and Bansal [11]** had optimized the design & operating parameters of like condensing temperature, subcooling temperature, evaporating temperature, superheating temperature and temperature difference in cascade heat exchanger R744-R717 cascade refrigeration system. A regression analysis was also done to obtain optimum thermodynamic parameters of same system. **Spatz and**

Motta [12] had mainly focused on replacement of R12 with R410a through experimental investigation of medium temperature vapour compression refrigeration cycles. In terms of thermodynamic analysis, comparison of heat transfer and pressure drop characteristics, R410a gives best performance among R12, R404a and R290a.. **Han et al. [13] carried out** experimental tests under different working conditions experimental results revealed that there could be replacement of R407C in vapour compression refrigeration system having rotor compressor with mixture of R32/R125/R161 showing higher COP, less pressure ratio and slightly high discharge compressor temperature without any modification in the same system. **Halimic et al. [14] had** compared performance of R401A, R290 and R134A with R12 by using in vapour compression refrigeration system, which is originally designed for R12.Due to similar performance of R134a in comparison with R12, R134A can be replaced in the same system without any medication in the system components. But in reference to green house impact R290 presented best results. **Xuan and Chen [15]** suggested the replacement of R502 by mixture of HFC-161 in vapour compression refrigeration system and conducted experimental study it was found that mixture of HFC-161 gives same and higher performance than R404A at lower and higher evaporative temperature respectively on the vapour compression refrigeration system designed for R404A. **Cabello et al. [16]** had analyzed the effect of operating parameters on first law efficiency (COP), work input and cooling capacity of single-stage vapour compression refrigeration system. There is great influence on energetic parameters due change in suction pressure, condensing and evaporating temperatures. **Cabello et al. [17] observed the** effect of condensing pressure, evaporating pressure and degree of superheating was experimentally investigated on single stage vapour compression refrigeration system using R22, R134a and R407C.It was observed that mass flow rate is greatly affected by change in suction conditions of compressor in results on refrigeration capacity because refrigeration capacity depended on mass flow rate through evaporator. It was also found that for higher compression ratio R22 gives lower COP than R407C.. Mishra [18] Simple VCR with liquid vapour heat exchanger, flash intercooler, flash chamber, water intercooler, liquid subcooler and stages in compression(double stage and triple stage) Mishra [19] conducted detailed analysis of vapour compression refrigeration systems using thirteen ecofriendly refrigerants Mishra [22] observed that there is a 12% to 19% improvement in the first law efficiency using nano particles mixed with R718 in the secondary evaporator circuit of VCR and suggested that higher improvement occurs using copper particles mixed with R718 and low improvement occurs using TiO2 in R134a Mishra [19] also observed the improvement in the second law thermal performance of vapour compression refrigeration system by mixing Al_2O_3 in R718 in secondary evaporator circuit and various ecofriendly refrigerants in the primary evaporator circuit. The lowest performance was observed by using R410a in the primary evaporator circuit 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. Researchers did not go through the nano mixed ecofriendly refrigerant in the secondary evaporator and R1234yf and R1234ze used in the primary circuit of evaporator in terms of improving first and second law efficiency of vapour compression refrigeration systems

3. Results and Discussions

Table: (1—3) gives the variation of first law efficiency in terms of coefficient of performance and second law efficiency using R1234ze refrigerant in the primary circuit and R-718 with nano mixed refrigerant in the evaporator circuit . It was observed that performance of R1234yf and R1234ze is acceptable as compared with R1234a. Even then mixing circuit, the performance of R1234yf gives better performance than R1234ze and R1234a. The worst performance is observed using R410a

Table: 1. performance evaluation of vapour compression refrigeration system using R1234 ze ecofriendly refrigerants in primary circuit and following nano materials mixed with R718 in the secondary circuit

Nano materials	**COP**	**EDR**	**ETA_II**
Copper	5.093	0.5199	0.4801
Al oxide sapphire	4.34	0.6239	0.3761
TiO2	3.823	0.644	0.356

Table: 2. performance evaluation of vapour compression refrigeration system using R1234 yf ecofriendly refrigerants in primary circuit and following nano materials mixed with R718 in the secondary circuit

Nano materials	**COP**	**EDR**	**ETA_II**
Copper	5.293	0.5071	0.4929
Al oxide sapphire	4.36	0.5666	0.4334
TiO2	3.832	0.6721	0.3279

Table: 3. performance evaluation of vapour compression refrigeration system using R134 a ecofriendly refrigerants in primary circuit and following nano materials mixed with R718 in the secondary circuit

Nano materials	**COP**	**EDR**	**ETA_II**
Copper	5.193	0.5194	0.4806
Al oxide sapphire	4.35	0.6239	0.3761
TiO2	3.82	0.654	0.346

Similarly the effect of nucleate heat transfer in terms of enhancement factor is showing the percentage improvement in the first law efficiency as shown in Table-4-5 respectively**.** The effect of computed nano refrigerant property for enhancement factor and first law efficiency is shown in Table-5. It was observed the best performance is achieved using R1234yf which can replace R134a for low temperature and R1234ze for higher temperature applications

Table: 4. Nucleate heat transfer coefficient enhancement factor and First law improvement (COP enhancement) based on nanoparticle used in R718 and ecofriendly refrigerants in primary circuit

Refrigerant	**Enhancement factor**	**COP_enhance ment**
R1234yf	3.54	23 %

R1234ze	2.38	18%
R134a	2.3	19%

Table: 5. Effect of Computed nanorefrigerents property in terms of enhancement factor on first law improvement

Refrigerant	Enhancement factor	COPenhance ment
R1234 yf	2.04	23 %
R 1234ze	1.7	19%
R134a	2.24	21 %

4. Conclusions and Recommendations

The following conclusions have been drawn

a) Even in mixing of nano particles mixed with R718 in the secondary circuit and R1234yf for low temperature applications gives better first law and second law performance as compared to R134arefrigerant
b) Although the performance of R134a is better than R134a using nano particles mixing in R718 but R1234ze can replace R134a for higher temperature applications.
c) The best first law and second law performances have been found using copper nano materials mixed with R718 in secondary evaporator circuit as compared to TiO2 nano particles.

References

[1] Johnson. E. Global warming from HFC. Environ. Impact Asses.1998, 18, 485-492
[2] V. Siva Reddy, N. L Panwar, S. C. Kaushik, Exergy analysis of a vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A. Clean Techn Environ Policy.2012, 14:47-53
[3] R. Saravanakumar, V. Selladurai, Exergy analysis of a domestic refrigerator using eco-friendly R290/R600a refrigerant mixture as an alternative to R134a.Int J Therm Anal Calorim.2013
[4] C. Nikolaidis, D. Probert, Exergy method analysis of a two-stage vapour-compression refrigeration-plants performance. Int J Applied Thermal Engineering, 1998, 60:241-256
[5] S. Kumar, M. Prevost, R. Bugarel, Exergy analysis of a vapour compression refrigeration system. Heat Recovery Systems & CHP.1989, 9, 151-157
[6] Mahmood Mastani Joybari, Mohammad Sadegh Hatamipour, Amir Rahimi, Fatemeh Ghadiri Modarres-Exergy analysis and optimization of R600a as a replacement of R134a in a domestic refrigerator system. International Journal of refrigeration, 2013, 36, 1233-1242.
[7] J. U. Ahamed, R. Saidur, H. H Masjuki, M.A Sattar-An analysis of energy, exergy and sustainable development of a vapour compression refrigeration system using hydrocarbon, International journal of Green energy, 2012, 9, 707-717.
[8] B. O. Bolaji, M. A. Akintunde, T. O. Falade. Comparative analysis of performance of three ozone-friends HFC refrigerants in a vapor compression refrigerator. Int J Sustainable Energy & Environment, 2011, 2, 61-64.
[9] RecepYumrutas, Mehmet Kunduz, Mehmet Kanoglu-Exergy analysis of vapor compression refrigeration systems. Exergy, An International Journal, 2002, 2, 266-272.
[10] M. Padilla, R. Revellin, J. Bonjour. Exergy analysis of R413A as replacement of R12 in a domestic refrigeration system. Int J Energy Conversion and Management, 2010, 51, 2195-2201.
[11] H. M Getu, P. K Bansal. Thermodynamic analysis of an R744-R717 cascade refrigeration system. Int J Refrigeration, 2008, 31, 45-54
[12] Mark W. Spatz, Samuel F. Yana Motta. An evaluation of options for replacing HCFC-22 in medium temperature refrigeration systems. Int J Refrigeration, 2004, 27, 475-483.
[13] X. H. Han, Q. Wang, Z. W. Zhu, G. M. Chen. Cycle performance study on R32/R125/R161 as an alternative refrigerant to R407C. Int J Applied Thermal Engineering, 2007, 27, 2559-2565
[14] E. Halimic, D. Ross, B. Agnew, A. Anderson, I. Potts. A comparison of the operating performance of alternative refrigerants. Int J Applied Thermal Engineering, 2003, 23, 1441-1451
[15] Yongmei Xuan, Guangming Chen. Experimental study on HFC-161 mixture as an alternative refrigerant to R502. Int J Refrigeration. Article in Press.
[16] R. Cabello, J. Navarro-Esbrı, R. Llopis, E. Torrella. Analysis of the variation mechanism in the main energetic parameters in a single-stage vapour compression plant. Int J Applied Thermal Engineering, 2007, 27, 167-176
[17] R. Cabello, E. Torrella, J. Navarro-Esbr, Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids. Int J Applied Thermal Engineering, 2004, 24, 1905-1917
[18] R. S. Mishra, R. K. Jaiswal, Methods for Improving Thermodynamic Performance of Variable Speed Vapour Compression Refrigeration Systems Using Nanorefrigerent in Primary Circuit, Nature & Environment, 20(2), 2015, 26-47
[19] R. S. Mishra, Kapil Chopra, V. Sahni, Irreversibility Optimization Using Energy-Exergy Analysis of Three Stage Vapour Compression Refrigeration Systems with Flash-Intercooler Using Ecofriendly Refrigerants (R410a, R290, R600, R600a, R1234yf, R125, R717 And R134A) for Reducing Global Warming and Ozone Depletion, Nature & Environment, 20(2), 2015, 73-89