International Journal of Advance Research and Innovation
Vol. 3(4), Oct-Dec 2015, pp. 62-66
Doi: 10.51976/ijari.341511

Article Info
Received: 25 Sept 2015 | Revised Submission: 20 Oct 2015 | Accepted: 28 Nov 2015 | Available Online: 15 Dec 2015

Energy-Exergy Performance Comparison of Vapour Compression Refrigeration Systems using Three NANO Materials Mixed in R718 assecondry Fluid and R-1234yf and R-1234ze Ecofriendly Refrigerants inthe Primary Circuit

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ABSTRACT

The global warming and ozone depletion are serious issues and search for newand ecofriendly refrigerants for reducing global warming. The methods forimproving first law and second law efficiency have been considered by mixingnano particles mixed in secondary evaporator circuit with R718 and newlydeveloped ecofriendly refrigerants of low global warming potentials isproposed in this paper. Detailed energy and exergy analysis of vapourcompression refrigeration systems have been carried out using R1234yf (of GWP=4) and R1234ze (of GWP=6) in terms of performance parameter forvarious ecofriendly refrigerants for replacing R134a and otherrefrigerants after 2030.

The numerical computations have been carried out for variablecompressor speed vapour compression refrigeration systems. It wasobserved that first law and second law efficiency improved by 25% bymixing Copper nano particles in the R-1234yf and 18% using R1234zeecofriendly refrigerants in the primary circuit of vapour compressionrefrigeration systems.

Keywords: *Vapour Compression Refrigeration Systems; Energy and Exergy Analysis; First and Second Law Analysis; Irreversibility Analysis; VCR with Direct nano Particles Mixed Refrigerants.*

1.0 Introduction

Refrigeration is a technology which absorbs heat at lowtemperature and provides temperature below the surroundingby rejecting heat to the surrounding at higher temperature.

Simple vapour compression system which consists of fourmajor components compressor, expansion valve, condenserand evaporator in which total cooling load is carried at onetemperature by single evaporator but in many applications likelarge hotels, food storage and food processing plants, fooditems are stored in different compartment and at differenttemperatures. Therefore there is need of multi evaporatorvapour compression refrigeration system. The systems undervapour compression technology consume huge amount ofelectricity, this problem can be solved by improving first lawand second law performances of system. Performance of systems based on vapour compressionrefrigeration 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 network input given to the system. The COP of vapourcompression refrigeration system can be improvedeither by increasing refrigeration effect or by reducingwork input given to the system.
- It is well known that throttling process in VCR is anirreversible expansion process. Expansion process isone of the main factors responsible for exergy loss incycle performance because of entering the portion of the
- refrigerant flashing to vapour in evaporator which willnot only reduce the cooling capacity but also increasethe size of evaporator. This problem can be eliminatedby adopting multi-stage expansion with flash chamberwhere the flash vapours is removed after each stage ofexpansion as a consequence there will be increase incooling capacity and reduce the size of the evaporator.
- Work input can also be reduced by replacing multistagecompression or compound compression withsingle stage compression.
- Refrigeration effect can also be increased by passingthe refrigerant through subcooler after condenser toevaporator.

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- Use of nano particles mixed with R718 in thesecondary evaporator circuit
- Use of nano particles directly mixed with ecofriendlyrefrigerants in the primary circuit
- Use of nano particles coating in the VCR condensertubes

2.0 Literature Review

Vapour compression refrigeration system basedapplications make use of refrigerants which are responsiblefor greenhouse gases, global warming and ozone layerdepletion. Montreal protocol was signed on the issue ofsubstances that are responsible for depleting Ozone layerand discovered how much consumption and production ofozone depletion substances took place during certain timeperiod for both developed and developing countries. Another protocol named as Kyoto aimed to control emissionof green house gases in 1997. The relationship betweenozone depletion potential and global warming potential isthe major concern in the field of GRT (green refrigerationtechnology) so Kyoto proposed new refrigerants havinglower value of ODP and GWP. Internationally a programbeing pursued to phase out refrigerants having high chlorinecontent for the sake of global environmental problems .Dueto presence of high chlorine content ,high global warmingpotential and ozone depletion potential after 90's CFC and HCFC refrigerants have been restricted. Thus, HFC refrigerants are used nowadays, showing much lower globalwarming potential value, but still high with respect to nonfluorinerefrigerants. Lots of research work has been donefor replacing "old" refrigerants with "new" refrigerants [1].

Reddy et al. [2] carried out numerical analysis ofvapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A , anddiscussed the effect of evaporator temperature, degree ofsubcooling at condenser outlet, superheating of evaporatoroutlet, vapour liquid heat exchanger effectiveness anddegree of condenser temperature on COP and exergeticefficiency. They reported that evaporator and condensertemperature have significant effect on both COP andexergetic efficiency and also found that R134a has the betterperformance while R407C has poor performance in allrespect.

Selladurai et.al.[3] compared the performancebetween R134a and R290/R600a mixture on a domesticrefrigerator which is originally designed to work with R134a and found that R290/R600a hydrocarbon mixtureshowed higher COP and exergetic efficiency than R134a. Intheir analysis highest irreversibility obtained in thecompressor compare to condenser, expansion valve andevaporator.

Nikolaidis et.al. [4] studied the change inevaporator and condenser temperatures of two stage vapourcompression refrigeration plant using R22 add considerableeffect on plant irreversibility. They suggested that there isneed for optimizing the conditions imposed upon thecondenser and evaporator. **Kumar et. al. [5]** carried outenergy and exergy analysis of vapour compressionrefrigeration system by the use of exergy-enthalpy diagram. They did first law analysis (energy analysis) for calculatingthe coefficient of performance and exergy analysis (secondlaw analysis) for evaluation of various losses occurred indifferent components of vapour compression cycle using R11 and R12 as refrigerants.

Mastani joybari et al.[6] conducted experimental measurements on a domesticrefrigerator originally manufactured to use of 145g of R134a and concluded the exergetic defect occurred incompressor was highest as compare to other componentsand through their analysis it has been found that instead of 145g of R134a if 60g of R600a is used in the consideredsystem gave same performance which ultimately result intoeconomical advantages and reduce the risk of flammabilityof hydrocarbon refrigerants.

Ahamed et al.[7] performedexperimental measurements of domestic refrigerator withhydrocarbons (isobutene and butane) by energy and exergyanalysis. They reached to the results that energy efficiencyratio of hydrocarbons comparable with R134a but exergyefficiency and sustainability index of hydrocarbons muchhigher than that of R134a at considered evaporatortemperature. It was also found that compressors showshighest system defect (69%) among components ofconsidered in the system.

Bolaji et al. [8] didexperimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator andconcluded that R32 shows lowest performance whereas R134a and R152a showing nearly same performance butbest performance was obtained of system using R152a.

Yumrutas et al. [9] studied the exergy analysis basedinvestigation of effect of condensing and evaporatingtemperature on vapour compression refrigeration cycle interms of pressure losses, COP, second law efficiency andexergy losses. Variation in temperature of condenser as wellas have negligible effect on exergy losses of compressor andexpansion valve, also first law efficiency and exergyefficiency increase but total exergy losses of systemdecrease with increase in evaporator and condensertemperature.

Padilla et al. [10] did exergy analysis

Getuand Bansal [11] had optimized the design & operatingparameters of like condensing temperature, subcoolingtemperature, evaporating temperature, superheatingtemperature and temperature difference in cascade heatexchanger R744-R717 cascade refrigeration system. A regression analysis was also done to obtain optimumthermodynamic parameters of same system.

Spatz and Motta [12] had mainly focused on replacement of R12 with R410a through experimental investigation of mediumtemperature vapour compression refrigeration cycles. Interms of thermodynamic analysis, comparison of heattransfer and pressure drop characteristics, R410a gives bestperformance among R12, R404a and R290a..

Han et al. [13] carried out experimental tests under different workingconditions experimental results revealed that there could bereplacement of R407C in vapour compression refrigerationsystem having rotor compressor with mixture of R32/R125/R161 showing higher COP, less pressure ratioand slightly high discharge compressor temperature withoutany modification in the same system.

Halimic et al. [14] had compared performance of R401A, R290 and R134A with R12 by using in vapour compression refrigerationsystem, which is originally designed for R12.Due to similarperformance of R134a in comparison with R12, R134A canbe replaced in the same system without any medication inthe system components. But in reference to green houseimpact R290 presented best results.

Xuan and Chen [15] suggested the replacement of R502 by mixture of HFC-161 in vapour compression refrigeration system and conductedexperimental study it was found that mixture of HFC-161 gives same and higher performance than R404A at lowerand higher evaporative temperature respectively on thevapour compression refrigeration system designed for R404A.

Cabello et al. [16] had analyzed the effect ofoperating parameters on first law efficiency (COP), workinput and cooling capacity of single-stage vapourcompression refrigeration system. There is great influenceon 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 wasexperimentally investigated on single stage vapourcompression refrigeration system using R22, R134a and R407C.It was observed that mass flow rate is greatlyaffected by change in suction conditions of compressor inresults on refrigeration capacity because refrigerationcapacity depended on mass flow rate through evaporator. Itwas also found that for higher compression ratio R22 giveslower COP than R407C.. Mishra [18] Simple VCR withliquid vapour heat exchanger, flash intercooler, flashchamber, water intercooler, liquid subcooler and stages incompression(double stage and triple stage) Mishra [19] conducted detailed analysis of vapour compressionrefrigeration systems using thirteen ecofriendly refrigerants Mishra [22] observed that there is a 12% to 19% improvement in the first law efficiency using nano particlesmixed with R718 in the secondary evaporator circuit of VCR and suggested that higher improvement occurs usingcopper particles mixed with R718 and low improvementoccurs using TiO2 in R134a Mishra [19] also observed theimprovement in the second law thermal performance ofvapour compression refrigeration system by mixing Al2O3 in R718 in secondary evaporator circuit and variousecofriendly refrigerants in the primary evaporator circuit. The lowest performance was observed by using R410a inthe primary evaporator circuit Based on the literature it wasobserved that researchers have gone through detailed firstlaw analysis in terms of coefficient of performance andsecond law analysis in term of exergetic efficiency ofsimple vapour compression refrigeration system with singleevaporator. Researchers did not go through the nano mixedecofriendly refrigerant in the secondary evaporator and R1234yf and R1234ze used in the primary circuit ofevaporator in terms of improving first and second lawefficiency of vapour compression refrigeration systems

3.0 Results and Discussions

Table: (1—3) gives the variation of first law efficiency interms of coefficient of performance and second lawefficiency using R1234ze refrigerant in the primary circuitand R-718 with nano mixed refrigerant in the evaporatorcircuit. It was observed that performance of R1234yf and R1234ze is acceptable as compared with R1234a. Even thenmixing circuit, the performance of R1234yf gives betterperformance than R1234ze and R1234a. The worstperformance is observed using R410a

Table 1: Performance Evaluation of Vapour Compressionrefrigeration System Using R1234 Ze Ecofriendly Refrigerantsin 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 Compressionrefrigeration System Using R1234 Yf Ecofriendly Refrigerantsin 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 Compressionrefrigeration System Using R134 a Ecofriendly Refrigerants Inprimary 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 ofenhancement factor is showing the percentage improvementin the first law efficiency as shown in Table-4-5 respectively**.**

The effect of computed nano refrigerantproperty for enhancement factor and first law efficiency isshown in Table-5.

It was observed the best performance isachieved using R1234yf which can replace R134a for lowtemperature and R1234ze for higher temperatureapplications

Table: 4. Nucleate Heat Transfer Coefficient Enhancementfactor and First Law Improvement (COP Enhancement) Based on Nanoparticle Used in R718 and Ecofriendlyrefrigerants 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 Interms 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 %

4.0 Conclusions and Recommendations

The following conclusions have been drawn

a) Even in mixing of nano particles mixed with R718 inthe secondary circuit and R1234yf for low temperatureapplications gives better first law and second lawperformance 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 temperatureapplications.
c) The best first law and second law performances havebeen found using copper nano materials mixed with R718 in secondary evaporator circuit as compared to TiO2 nano particles.

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