Volume 2, Issue 4 (2014) 784-789 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

Methods for Improving Thermodynamic Performance of Vapour Compression Refrigeration Systems Using R134a Ecofriendly Refrigerant in Primary Circuit and Three Nano Particles Mixed with R718 used in Secondary Evaporator Circuit for Reducing Global Warming and Ozone Depletion

R. S. Mishra
Department of Mechanical Engineering, Delhi Technological University, New Delhi, India

Article Info

Article history:
Received 30 September 2014
Received in revised form
20 October 2014
Accepted 20 November 2014
Available online 15 December 2014

Keywords

Vapour Compression Refrigeration Systems,
Energy and Exergy Analysis,
First and Second Law Analysis,,
Irreversibility Analysis,
Efficiency Improvement using Nano Particles

Abstract

The methods for improving first law and second law efficiency have been considered in this paper by using three nano particles mixed with R718 refrigerants mixed in the secondary circuit and R134a in primary circuit is investigated in this paper. Detailed energy and exergy analysis for calculating performance parameters in the vapour compression refrigeration systems have been carried out. The numerical computations using three nano particles (i.e. CuO, Al_2O_3 and TiO_2) have been carried and it was observed that first law and second law efficiency improved from 15% to 18% and improvements in overall heat transfer coefficient in evaporator is ranging 79.58% to 91.41% using nano materials as compared to without nano particles.

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 Sub cooling
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)
H	Efficiency (Non-Dimensional)
R	Refrigerant, Space to be Cooled
ex	Exergetic
ev	Expansion Valve
C	Condenser
sc	Subcooler
K	kth Component

Corresponding Author,
E-mail address: professor_rsmishra@yahoo.co.in

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 performance of system.

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

- Refrigeration effect can also be increased using nano particles mixed with R718 in the secondary evaporator circuit and R134a in the primary evaporator circuit
- 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 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[1]. 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 [2].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 [3-8]and 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 irreversibility analysis (second law analysis) of followings: Simple VCR with liquid vapour heat exchanger , flash intercooler, flash chamber, water intercooler, liquid subcooler and stages in compression(double stage and triple stage)multiple evaporators systems with multi-stage expansion and compound compression in vapour compression refrigeration systems detailed analysis of vapour compression refrigeration systems using several new ecofriendly refrigerants is required. For improving thermal performance of vapour compression refrigeration systems both multiple evaporator system by using liquid vapour heat exchanger for improving: First law efficiency (COP) , second law efficiency (Exergetic efficiency) and Reduction of system defect in components of system in terms of exergy destruction ratio which results into reduction of work inputis also required (30).

2. Literature Review

Reddy et al. [9] conducted numerical experiments on vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 and R507A , and find out 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 observed that 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 and Saravana kumar [10]** had compared the first law performance between R134a and R290/R600a mixture on a domestic refrigerator which is originally and observed that that R290/R600a hydrocarbon mixture gives higher first law efficiency (COP) and second law efficiency (exergetic efficiency) as compared with R134a. They observed in the vapour compression refrigeration system, that highest irreversibility obtained in the compressor as compared to condenser, expansion valve and evaporator. **Nikolaidis and Probert [11]** also observed analytically that change in evaporator and condenser temperatures in the two stage vapour compression refrigeration system using R22 adding considerable effect on system irreversibility. They reported that there is need for optimizing the conditions imposed upon the condenser and evaporator. **Kumar et al. [12]** conducted energy and exergy analysis of vapour compression refrigeration system by the use of exergy-enthalpy diagram. They analysized 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.[13]** conducted experimental studies on a domestic refrigerator originally manufactured to use of 145g of R134a.They concluded that 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. **Anand and Tyagi [14]** conducted detailed exergy analysis of two ton of refrigeration capacity window air conditioning test rig using R22 as working refrigerantand found, that irreversibility in system components will be highest when the system is 100% charged and lowest when 25% charged and irreversibility in compressor is highest among system components. **Arora and Kaushik [7]** developed numerical model of actual vapour compression refrigeration system with liquid vapour heat exchanger and did energy and exergy analysis on the same in the specific temperature range of evaporator and condenser and concluded that R502 is the best refrigerant compared to R404A and R507A and compressor is the worst component and liquid vapour heat exchanger is best component of the system in case of exergy transfer. **Ahamed et al. [17]** had performed experiments on domestic refrigerator with hydrocarbons (isobutene and butane) and analysed thermal performance using energy and exergy analysis and observed that 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. They found that compressor is showing highest system defect (69%) among components of in the considered vapour compression refrigeration system. **Ahamed et al. [15]** also used of hydrocarbons and mixture in the vapour compression system and found that compressor shows much higher exergy destruction as compared to rest of components in the vapour compression refrigeration system and this exergy destruction can be minimized by using of nanofluid and nanolubricants in compressor. **Bolaji et al. [18]** had conducted experimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator and found that R32 showing lowest thermal performance whereas R134a and R152a showing nearly same thermal performance and excellent performance was obtained using R152a. **Yumrutas et al. [19]**carried out exergy analysis based on effect of condensing and evaporating temperatures in the 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. [20] carried out** exergy analysis of domestic vapour compression refrigeration system with R12 and R413A was done. They concluded that performance in terms of power consumption, irreversibility and exergy efficiency of R413A is better than R12, so R12 can be replaced with R413A in domestic vapour compression refrigeration system due to global warming. **Getu and Bansal [21]** had optimized the design and operating parameters of like condensing temperature, subcooling temperature, evaporating temperature, superheating temperature and temperature difference in cascade heat exchanger R744-R717 cascade refrigeration system. They carried out regression analysis to obtain optimum thermodynamic parameters of same system. **Spatz and Motta [22]** had mainly focused on replacement of R12 using 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. **Mohanraj et al. [23]** observed through experimental investigation in the domestic refrigerator and concluded COP variation with different environmental temperatures of system using mixture of R290 and R600a in the ratio of 45.2: 54.8 by weight showing up to 3.6% greater than same system using R134a, also discharge temperature of compressor with mixture of R290 and R600a is lower in the range of 8.5-13.4K than same compressor with R134a. **Han et al. [24]** considered different working conditions and experimental results revealed that there could be replacement of R12 by eco-friendly 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. [25]** had studied thermal first law performance of vapour compression refrigeration system using eco-friendly R401A, R290 and R134A refrigerants with R12 for replacing R12 because R12 gives more ozone depletion and global warming 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 [26]** studied vapour compression refrigeration by mixture of HFC-161 for replacing of R502 and conducted experiments. They 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. [27]** had evaluated 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. [28]** observed that 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. **Stanciu et al. [29]** also conducted numerical and graphical investigation on single stage vapour compression refrigeration system using R22, R134a, R717, R507a, R404a refrigerants in terms of first law efficiency (COP), compressor work, second law efficiency (exergetic efficiency) and refrigeration effect, effect of subcooling, superheating and compression ratio and did system optimization working with specific refrigerant in the vapour compression refrigeration system.

3. Summary of Literature Review and Research Gaps Identified

The study of above literatures and many other authors have not mentioned in the description presents in terms of following points-

Thermodynamic analysis of different vapour refrigeration systems have been carried out using various combinations. and thermal performance analysis have been done by employing different ecofriendly and new alternative refrigerants.

It has been concluded that different kinds of nano-particles such as Al_2O_3, TiO_2, CuO and Cu can be mixed with the new ecofriendly refrigerants for enhance performance enhancement.

But still a very vast area is available for exploration for using various combination/ modification/ hybrid systems and these systems could be tested with alternative and newer ecofriendly refrigerants which have low GWP values. Such as R1234yf and R1234ze

The following research objectives to be considered in the vapour compression refrigeration systems.

4. Research Objectives

- Thermodynamic first law analysis in terms of coefficiency of vapour compression system using alternative ecofriendly refrigerants in the primary evaporator circuit and nano particles mixed with R718 in the secondary evaporator circuit
- Thermodynamic second law analysis in terms of exergetic efficiency of vapour compression system using alternative ecofriendly refrigerants in the primary evaporator circuit and nano particles mixed with R718 in the secondary evaporator circuit

5. Research Methodology

The thermodynamic performance for the vapour compression refrigeration refrigeration is evaluated using Energy –exergy balance equations is based on the first law of thermodynamics. A numerical computer programme was developed for three nano particles mixed in R718 in the secondary evaporator circuit and R134a in the primary evapor circuit systems using EES software for finding the first law in terms of coefficient of performance (COP) and second law efficiency in terms of exergetic efficiency and irreversibility in the system in terms of exergy Destruction ratio (EDR) which is a total irreversibility in the system in terms of total losses in the system to the exergety output evaluation and results are obtained on vapour compression refrigeration system by varying condenser and evaporator temperatures.

6. Numerical Computations

The study will provide the input on the usage of nano particles mixed with R718 in the secondary evaporator circuit which enhances evaporator heat transfer coefficient and increases refrigeration effect for a particular type of vapour compression refrigeration system, which could be suitable from the view point of its economic performance, and need as per the given objectives and conditions. It will also give an idea about the suitable nano materials mixed in R718 refrigerant effecting first law performance Similarly exergy equation based on second law of thermodynamics is to be formulated for these systems and second law effectiveness (exergetic efficiency) along with system exergy destruction ratio (EDR) for finding irreversibility occurred in the system components and as a whole system and suitable measures for removing irreversibilities in the components for enhances system performances in the refrigeration systems. as used in future for residential, industrial and medical applications.

7. Results and Discussions

Table: 1. Percentage First Law Performance Improvement (in terms of coefficient of performance) of vapour compression refrigeration system using three nano particles mixed with R718 in the Secondary Evaporator Circuit

Nano-particles	First law efficiency (COP)	% Improvement
Copper oxide	3.589	18.35
Copper	3.58	18.347
Al2O3	3.561	17.72
TiO2	3.516	11.23
Without Nano particles	3.025	______

Table-1 shows the first law performance in terms of COP of vapour compression refrigeration system using three nano particles mixed with R718 refrigerant and it bwas observed that the first law performance improved using nano refrigerants from 11.23% to 18.35% as compared with without nano refrigerants in secondary circuit.

Table: 2. Percentage Second Law Performance Improvement (in terms of exergetic efficiency) of Vapour Compression refrigeration system using three nano Particles mixed with R718 in the Secondary Evaporator Circuit

Nano particles	Second law Efficiency	% improvement
Copper oxide	0.40071	18.31
Copper	0.4007	18.30
Al2O3	0.3986	17.6853
TiO2	0.3936	16.209
Without Nano Particles	0.3387	_____

Table-2 shows the second law performance in terms of exergetic efficiency of vapour compression refrigeration system using three nano particles mixed with R718 refrigerant and it bwas observed that the first law performance improved using nano refrigerants from 16.206% to 18.31% as compared with without nano refrigerants in secondary circuit.. Similarly the performance of vapour compression refrigeration is also compared using different eco-friendly refrigerants in the primary evaporator circuit without nano particles mixed in R718 in secondary evaporator circuit and it was observed that R 134a gives better first law and second law performance than R404a and R407c. The performance using R1234ze and R1234yf gives lesser thermodynamic first and second law performance as compared with R134a , but these refrigerants have low global warming potential (GWP) and zero ozone depletion potential (ODP) as compared to R134a.

Table: 3. Performance Parameters of Vapour Compression Refrigeration System using Ecofriendly Refrigerants and without Nano Materials

Refrigerants	COP	ED_Ratio	ETA_Second
R134a	2.973	2.447	0.2901
R404a	2.705	3.158	0.2717
R407c	2,754	2.333	0.30

Table: 4.a and Table-4.b gives the improvements in overall heat transfer coefficient using nano particles mixed with R718 in secondary evaporator circuit as compared without nano particles and significant improvement was observed. The variation of difference in temperatures in the evaporator and condenser is also increasing as compared to without nano prefrigerants in the secondary circuit.

Table: 4a. Effect of Overall Evaporator Heat Transfer Coefficient Using Different Nano Particles Mixed With R718 in the Secondary Evaporator Circuit and R134a in Primary Circuit

Nano particles	Overall heat transfer Coefficient (U_e)	Difference in water temperature (^oC)	Difference in Brine temperature (^oC)
Copper oxide	1372.14	15.71	11.58
Copper	1367.18	14.55	11.44
Al_2O_3	1318.0	14.62	11.5
TiO2	1242.43	14.43	11.32
Without Nano particles	691.04	12.24	9.29

Table: 4b. Effect of Overall Evaporator Heat Transfer Coefficient using Different Nano Particles Mixed with R718 in the Secondary Evaporator Circuit and R134a in Primary Circuit

Nano Particles	Overall heat transfer Coefficient (U_e)	% improvement
Copper oxide	1325.7	91.41
Copper	1324.25	91.4099
Al2O3	1318.70	90.6077
TiO2	1242.43	79.6
Without Nano particles	691.65	_____

8. Conclusions

In this paper, 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 following conclusions from the present analysis are summarized below:

1. The First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of vapour compression refrigeration systems using three nano materials have been compared and 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
2. The First law efficiency (COP) and Second law efficiency (Exergetic efficiency) of using R134a eco-friendly refrigerant in primary evaporator circuit and Copper oxide mixed with R718 in the secondary evaporator circuit gives better first law efficiency (COP) and second law efficiency (Exergetic efficiency) as compared to TiO_2 nano particles mixed with R718
3. The COP improvement 18.35% and second law efficiency improvement is 18.31% observed using Al2O3 nano materials mixed with R718 in secondary circuit as compared to without nano refrigerants. Similarly 17.72% and 17.685% second law efficiency.

References

[1] Johnson. E. Global warming from HFC. Environ. Impact Asses. 18, 1998, 485-492
[2] QiyuChen, R. C Prasad. Simulation of a vapour compression refrigeration cycles HFC134A and CFC12.Int Comm.Heat Mass Transfer. 26, 1999; 513-521
[3] 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, 51, 2010, 2195-2201
[4] H.O. Spauschus, HFC 134a as a substitute refrigerant for CFC 12. Int J of Refrigeration, 11, 1988, 389-392
[5] J. U. Ahamed, R.Saidur, H. H.Masjuki, A review on exergy analysis of vapor compression refrigeration system. Int J Renewable and sustainable energy reviews, 15, 2011, 1593-1600
[6] R. L lopis, E. Torrella, R. Cabello, D. Sánchez. Performance evaluation of R404A and R507A refrigerant mixtures in an experimental double-stage of vapour compression plant. Int J Applied Energy, 87, 2010, 1546-1553
[7] Akhilesh Arora, S. C. Kaushik, Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A. Int J Refrigeration, 31, 2008, 998-1005
[8] V. Havelsky. Investigation of refrigerating system with R12 refrigerant replacements .Int J Applied Thermal Engineering, 2000; 20:133-140
[9] 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, 14, 2012, 47-53
[10] 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
[11] C. Nikolaidis, D. Probert-Exergy method analysis of a two-stage vapour-compression refrigeration-plants performance. Int J Applied Thermal Engineering, 60, 1998, 241-256
[12] S. Kumar, M. Prevost, R. Bugarel, Exergy analysis of a vapour compression refrigeration system. Heat Recovery Systems & CHP, 9, 1989, 151-157
[13] 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, 36, 2013, 1233-1242
[14] S. Anand, S. K Tyagi, Exergy analysis and experimental study of a vapour compression refrigeration cycle.Int J Therm Anal Calorim, 110, 2012, 961-971
[15] 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, 9, 2012, 707-717
[16] Camelia Stanciu, Adina Gheorghian, Dorin Stanciu, Alexandru Dobrovicescu- Exergy analysis and refrigerant effect on the operation and performance lomits of a one stage vapour compression refrigeration system.Termotehnica, 1, 2011, 36-42
[17] J. U. Ahamed, R. Saidur, H. H. Masjuki, A review on exergy analysis of vapor compression refrigeration system. Int J Renewable and sustainable energy reviews, 15, 2011, 1593-1600
[18] 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, 2, 2011, 61-64
[19] RecepYumrutas, Mehmet Kunduz, Mehmet Kanoglu-Exergy analysis of vapor compression refrigeration systems. Exergy, An International Journal, 2, 2002, 266-272
[20] 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, 51, 2010; 2195-2201
[21] H. M Getu, P. K Bansal, Thermodynamic analysis of an R744-R717 cascade refrigeration system. Int J Refrigeration, 31, 2008, 45-54
[22] Mark W. Spatz, Samuel F. Yana Motta. An evaluation of options for replacing HCFC-22 in medium temperature refrigeration systems. Int J Refrigeration, 27, 2004, 475-483
[23] M. Mohanraj, S. Jayaraj, C. Muraleedharan, P. Chandrasekar, Experimental investigation of R290/R600a mixture as an alternative to R134a in a

domestic refrigerator. Int J Thermal Sciences, 48, 2009, 1036-1042

[24] 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, 27, 2007, 2559-2565

[25] E. Halimic, D. Ross, B. Agnew, A. Anderson, I. Potts, A comparison of the operating performance of alternative refrigerants. Int J Applied Thermal Engineering, 23, 2003, 1441-1451

[26] Yongmei Xuan, Guangming Chen. Experimental study on HFC-161 mixture as an alternative refrigerant to R502. Int J Refrigeration. Article in Press.

[27] 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, 27, 2007, 167-176

[28] 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, 24, 2004, 1905-1917

[29] S. A. Klein, F. Alvarado Engineering Equation Solver, Version 7.441. F Chart Software, Middleton, WI.2005

[30] I. Dincer. Refrigeration Systems and Applications. Wiley, UK, 26, 2003