International Journal of Advance Research and Innovation
Vol. 2(3), Jul-Sept 2014, pp. 60-67
Doi: 10.51976/ijari.231411
www.gla.ac.in/journals/ijari

Article Info

Received: 22 Jul 2014 | Revised Submission: 20 Aug 2014 | Accepted: 30 Aug 2014 | Available Online: 15 Sept 2014

Appropriate Vapour Compression Refrigeration Technologies for Sustainable Development

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ABSTRACT

This paper mainly focuses on CFCs and their alternatives to their use. The main critical issue in the field of green technologies is to develop the relationship between ODP and GWP and suggest new and alternative refrigerants which do not damage ozone layer and not to increase global warming. The first and second law thermodynamic analysis of vapor refrigeration system of 1.5 ton capacity for seven eco-friendly refrigerants such as (R-134a, R-404a, R-407C, R-502, propane(R-290), isobutene(R-600a), butane (R-600)) have been carried out in terms of performance parameters such as COP, EDR, Exegetic efficiency, ratio of exergy destruction in components such as condenser, compressor, throttle valve and evaporator. These performance parameters have been evaluated by varying condenser temperatures in the range from 303 K to 333K and evaporator temperatures in the range from 253 K to 278K. It was observed that R-290 and R-600 (butane) and R-600a (isobutene) of zero ODP and zero GWP is best alternatives if its flammable problem will mitigate and R-134a (of zero ODP and 1300 GWP), R-407c, R-404a and R-410a are the next option of R-22 refrigerant but it needs larger size of compressors which increases the cost of the system.

Keywords: *Sustainable Refrigeration Technologies; Green Vapour Compression Technologies; Energy and Exergy Analysis, Sustainable Development; Eco Friendly Refrigerants; First and Second Law Analysis.*

1.0 Introduction

An eminent philosopher has defined Science as “TAPASAYA” and Technology as “Bhog” where as science is pure selfless and open to all search for truth where as technology is the exploitation of scientific knowledge for selfish purposes and profit motive and hence it tends to be secretive in this competitive world of today with a throat cutting environment. Sustainable Development is a process in which development can be sustained for generations. It also focuses attention on inter generational fairness in the exploitation of development opportunities while social development is a function of technological advancement, and also the technological advancement, in turn is a function of scientific know how for a streamlined development of the society. Technology is one of the crucial determinants of sustainable development. Technological import through collaborations has been one of the most important sources of technological inputs for Indian conditions.

The use of technologies originating in rich countries often ten to create many social, ecological and resource problems in poor countries. The exploitation of the vast natural resources through progressive development of science, engineering and technology that has brought about the vast changes in the civilization and society from the stone age to the present high technology era. In facts, the mad race for industrialization and economic development has resulted in over exploitation of natural resources, leading to a situation where the two worlds of mankind- the biosphere, lithosphere and hydrosphere of his inheritance and the techno sphere of his creation, are out of balance with each other, indeed on a collision path.

To facilitate optimal utilization of finite natural resources for ensuring a sustainable benefit steam for better quality of life on the one hand and to simultaneously keep in mind the conservation of natural resources on the other hand, it is essential that the technology conservation process must be made as efficient as possible. Therefore sustainable economic development depends on the careful choice of technologies and judicious management of resources for productive activities to satisfy the changing human needs without degrading the environment or depleting the natural resources base.

2.0 Application of Ecofriendly Refrigerants in the Vapour Compression Refrigeration Systems/ Heat Pumps

The efforts under the Montreal protocol to protest the OZONE layer, the alternative refrigerants have been proposed as a substitute for ozone

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depleting substances. HFCs (Hydrofluoro carbons) PFCs (Perfluro carbons) have zero ODP potential but they are producer of green house gases and are subjected to limitation and reduction commitments under UNFCC(United Nations Framework Convention on Climate change). With the entry into force of Kyoto protocol on 16th February 2005 developed countries have already planning and implementing rational measures intended to contribute towards meeting green house gas reduction targets during the first commitment period of Kyoto protocol (2008-2012). The countries have also started together with developing countries to size up projects that qualify under Kyoto clean development mechanism. As what lies beyond 2012 all Governments will work together over next few years to decide on future intergovernmental action on the climate change. In this light, it is vital that there should be continuous work on the replacement options for ozone depleting substances in way that serve the aim of the Montreal protocol and UNFCC alike. In the developing countries the conversion of CFCs to alternate is still a major issue. In this paper the first law and second law analysis of various eco friendly refrigerants have been carried out which will help in deciding about the path to be followed to satisfy Montreal and Kyoto protocol. On the basis of theoretical analysis, an extensive experiments have been conducted in the Advanced centre for studies and research in green energy technologies at DCE and It was observed that R-134a refrigerant is the best alternative.

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 [3,4,5]. In addition to this second law analysis also provides new thought for development in the existing system [6].

These scientists did not gone through second law analysis in terms of system defect defined as irreversibility calculations in various components of vapour compression refrigeration Therefore objective of the present investigations to find out irreversibility's 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.

3.0 Utility of Energy and Exergy Analysis in Vapour Compression Refrigeration Systems

The first law analysis using for evaluation of coefficient of performance having values greater than unity for certain processes.

The first law of thermodynamics is concerned only with the conservation of energy, and it gives no information on how, where, and how much the system performance is degraded, exergy analysis is a powerful tool in the design, optimization, and performance evaluation of energy systems [1].

Exergy analysis (second law analysis) helps in identifying the thermal losses and energy transfer for the processes [2-5].

After 90's CFC and HCFC refrigerants have been restricted due to presence of chlorine content and their high ODP and GWP. Thus, HFC refrigerants are used nowadays, showing much lower global warming potential value, but still high with respect to non-fluorine refrigerants. Many researchers have been done for replacing of "old" refrigerants with "new" refrigerants [6-12].

4.0 Summary of Literature Review and Research Gaps Identified

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

Thermodynamic analysis of different refrigeration systems have been carried out using various combinations.

Performance analyses have been done also employing different refrigerants and alternative refrigerants.

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

5.0 Research Objectives in VCR

1. Thermodynamic analysis of simple modified vapour compression system using alternative refrigerants.
2. Thermodynamic analysis of combined vapour compression system (using alternative refrigerants) and vapour absorption systems.
3. Thermodynamic analysis of novel hybrid refrigeration systems.
4. Thermodynamic analysis of vapour compression using alternative refrigerants and hybrid refrigeration systems using performance enhancing devices.

6.0 Research Methodology

The study provides the input on the usage of a particular type of refrigeration system, combination of refrigeration systems which could be suitable from the view point of its thermal performances, economy and need as per the given objectives and conditions. It will also give an idea about the suitable selecting eco friendly refrigerants for reducing global warming and ozone depletion as an alternative to be used in future for residential, industrial and medical applications by incorporating these vapour refrigeration systems. In this paper great emphasis put on saving of energy and using of ecofriendly refrigerants due to increase of energy crises, global warming and depletion of ozone layer. In this investigation the work input required running the vapour compression refrigeration system reduced by using compound compression and work input further decrease by flash inter cooling between two compressors using of eco-friendly refrigerants. The performance will be evaluated using Energy equation based on first law of thermodynamics and a computer programmes have developed using the EES software for the thermal performance evaluation. Results are to be obtained for calculating first law efficiency in terms of coefficient of performance on vapour compression refrigeration systems by varying condenser and evaporator temperatures. Similarly exergy equation based on second law of thermodynamics is formulated for these systems and same steps will be followed with conclusions.

7.0 Eco Friendly Refrigerants used in Vapour Refrigeration Systems

The performance of Vapour compression refrigeration systems of 1.5 tons refrigerating capacity are given using following ecofriendly refrigerants.

R-410a: is a azeotropic mixture of HFC-32 and HFC-125 in the proportions 50%, 50% by weight with 2% tolerance allowed for each of the components. It has very low temperature glide around 0.1K and its vapor pressure is roughly 50% higher than that of HCFC22.

R-32/124a: R-32 is a near azeotropic mixture of HFC-32 (Difluromethane) and R-124a in the proportions of 30% and 70% by weight.

R-134a: is a member of the family of HFC refrigerants. The HFC refrigerants are similar composition to CFCs and HCFCs and they have become the primary focus of the refrigeration and air conditioning industries as a long term substitute for traditional refrigerants. HFCs are not miscible with traditional mineral oil so alternative synthetic lubricants are recommended synthetic polyester either alkyl benzene or polyalkylen glycol

R-407c: is a mixed zoetrope refrigerant consisting of three HFC components such as R-32, R-125 and R-134a in the proportions 23%, 25% and 52% by a weight +_ 2% tolerances allowed for each of the components. R-407c has properties very similar to R-22 which was replaced in air conditioning applications in terms of both its operating pressures and its performance in dry expansion air conditioning systems**.**

R-404: can be used as ecofriendly refrigeration systems. The tables (5-6) showing the variation of condenser temperature and evaporator temperature with performance parameters of VCR_**Propane (R-290)** can be used as substitute for R-11, R12 and R22 because of zero ODP and GWP. The pressure levels and refrigerating capacity are similar to R-22 and R-502 along with its temperature behavior is as favourable as with R-22 & R-502. There is no material problems in compressor of hermetic and semi hermetic types in air conditioning units and heat pumps. The first law and second law performances in terms of variation of condenser and evaporator temperatures with COP, Exergy Destruction Ratio(EDR), exegetic efficiency, exergy destruction in each components of vapor compression refrigeration system of 1.5 tons capacity using R-290 refrigerant for 298K of ambient temperature are shown in Table-7 -8 respectively.

R600: can be used as substitute for R-11,R12 and R22 because of zero ODP and GWP. The pressure levels and refrigerating capacity are similar to R-22 and R-502 along with its temperature behavior is as favourable as with R-22 & R-502. There is no material problems in compressor of hermetic and semi hermetic types in air conditioning units and heat pumps. The first law and second law performances in terms of variation of condenser and evaporator temperatures with COP, Exergy Destruction Ratio(EDR), exegetic efficiency, exergy destruction in each components of vapor compression refrigeration system of 1.5 tons capacity using R-600a refrigerant for 298K of ambient temperature are shown in Table-10 -11 respectively.

8.0 Thermal Performance of Vapour Compression Refrigeration Systems using Ecofriendly Refrigerants

The major disadvantage of hydrocarbon refrigerants is their inflammability therefore system must be designed by consideration of flame proof regulations however with open compressors additional safety devices may be required. For practically mass flow rate of refrigerant may be low as 55% to 60% approximately as compared to R-22 and internal heat exchanger between the suction and liquid line is improved the refrigeration capacity along with COP. Due to good solubility with mineral oils, it may be necessary to use an oil it lower mixing characteristics or increasing viscosity for higher suction pressure, the use of internal heat exchanger is advantageous because it leads to higher oil temperatures to lower solubility improves its viscosity. Due to favorable temperature behavior of R-290, the single stage compressor is used down to approximately 233K evaporator temperature respectively and can also be considered as a direct substitute for R-502. Propylene (R-1270) can be used as substitute because of good refrigerant by higher volumetric refrigeration capacity and low boiling temperature however higher pressure level and discharge gas temperature have to be taken into consideration which restricting the possible application range. R-1270 is also easily inflammable and due to chemical double linkage it is relatively reaction friendly and there is a danger of polymerization at higher pressure and temperature levels. The component dimensions have to be altered when using R-1270 refrigerant due to higher volumetric refrigeration capacity along with lower compressor displacement. Because of higher vapor density, the mass flow rate is almost the same as for R-290 and liquid density is nearly identical for the liquid volume in circulation.

9.0 Numerical Computations

The computation modeling of vapor compression refrigeration systems was carried out with the help of engineering equation solver of Klein [13]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 components (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 303K to 333K with increment of 5 and evaporator temperature is varying from 253K to 278 K with increment of 5. The energy and exergy change in vapour compression refrigeration cycle have been calculated for various eco friendly refrigerants such as R-134a, R404a, R410a, R407c R-290 (propane), R600 (butane), R-600a (isobutene) for environmental temperature of 298K. and results are shown in Table(1) to 12 respectively.

Table: 1. Performance of vapour compression refrigeration systems using eco friendly refrigerants (R-134a), Evaporator temperature = 253K, Ambient temperature = 298K, Load= 4.75KW' Tr = 280K

Cond Temp(k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
303	3.407	3.566	21.9	10.27	17.17	23.04	49.52
308	2.962	4.251	19.04	16.86	17.08	24.52	41.54
313	2.59	5.007	16.65	21.62	17	26.11	35.27
318	2.272	5.848	14.6	25.09	16.92	27.79	30.19
323	1.996	6.795	12.83	27.6	16.84	29.56	25.99
328	1.753	7.874	11.27	29.41	16.73	31.44	22.42
333	1.536	9.124	9.877	30.63	16.61	33.4	19.35

Table: 2. Performance of vapour compression refrigeration systems using eco friendly refrigerants (R-134a), condenser temperature = 313K, Ambient temperature = 298K, Load = 4.75KW Tr = 280K Tc = 313K

Eva Temp(k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
253	2.59	5.007	16.65	17	21.62	26.11	35.27
258	2.938	4.294	18.89	18.24	24.17	24.74	32.85
263	3.361	3.628	21.61	19.56	27.49	23.49	29.46
268	3.882	3.007	24.96	21.05	31.94	22.39	24.61
273	4.539	2.427	29.18	22.86	38.2	21.5	17.44
278	5.391	1.886	34.66	25.26	47.54	20.94	6.252

Table: 3. Performance of vapour compression refrigeration systems using eco friendly refrigerants(R-407c), condenser temperature = 313K, Ambient temperature = 298K, Load = 4.75K Tc=313K Tr = 280K

Eva Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
253	2.617	4.944	16.82	22.34	4.237	31.95	41.48
258	2.969	4.239	19.09	24.91	5.165	30.01	39.91
263	3.397	3.58	21.84	28.27	5.987	28.09	37.65
268	3.926	2.962	25.24	32.81	6.73	26.15	34.31
273	4.595	2.385	29.54	39.23	7.432	24.11	29.23
278	5.465	1.846	35.13	48.89	8.163	21.84	21.1

Table: 4. Performance of vapour compression refrigeration systems using eco friendly refrigerants(R-407c), Evaporator temperature = 253K, Ambient temperature = 298K, Load = 4.75K Te = 253K Tr = 280K

Cond Temp(k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
303	3.504	3.439	22.53	10.93	3.175	25.21	60.69
308	3.023	4.146	19.43	17.62	3.767	28.71	49.9
313	2.617	4.944	16.82	22.34	4.237	31.95	41.48
318	2.269	5.855	14.69	25.67	4.607	35.03	34.7
323	1.965	6.914	12.64	27.97	4.895	38.02	29.2
328	1.696	8.173	10.9	29.49	5.116	41.02	24.38
333	1.452	9.713	9.334	30.37	5.282	44.05	20.29

Table: 5. Performance of vapour compression refrigeration systems using eco friendly refrigerants (R-404a), Evaporator temperature = 253K, Ambient temperature = 298K, Load = 4.75KW. Te = 253K Tr = 280K

Cond Temp(k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
303	2.94	4.29	18.9	8.843	20.5	28.82	41.83
308	2.516	5.184	16.17	14.47	19.82	31.13	34.58
313	2.154	6.223	13.84	18.44	19.2	33.59	28.77
318	1.838	7.464	11.81	21.18	18.62	36.24	23.96
323	1.556	8.996	10	22.99	18.06	39.1	19.85
328	1.298	10.98	8.347	24.02	17.51	42.23	16.24
333	1.054	13.75	6.778	24.34	16.96	45.75	12.95

Table: 6. Performance of vapour compression refrigeration systems using eco friendly refrigerants (R-404a), condenser temperature = 313K, Ambient temperature = 298 K, Load = 4.75KW Tr = 280K Tc = 313

Eva Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
253	2.154	6.223	13.84	18.44	19.2	33.59	28.77
258	2.477	5.28	15.92	20.65	19.89	32.29	27.18
263	2.871	4.418	18.46	23.52	20.63	31.13	24.73
268	3.359	3.631	21.59	27.36	21.47	30.15	21.02
273	3.978	2.911	25.57	32.72	22.52	29.44	15.32
278	4.783	2.252	30.75	40.66	23.97	29.15	6.213

Table: 7. Performance of vapour compression refrigeration systems using eco friendly refrigerants propane (R-290), Evaporator temperature = 253K, Ambient temperature = 298K, Load = 4.75K Te = 253K Tr = 280K

Cond Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
303	3.354	3.638	21.56	10.06	17.52	23.85	48.57
308	2.911	4.343	18.71	16.58	17.4	25.38	40.67
313	2.539	5.127	16.32	21.2	17.31	27.03	34.46
318	2.22	6.006	14.27	24.47	17.21	28.8	29.41
323	1.943	7.005	12.49	27	17.11	30.67	25.22
328	1.694	8.157	10.92	28.69	16.98	32.67	21.66
333	1.48	9.513	9.512	29.8	16.84	34.79	18.57

Table: 8. Performance of vapour compression refrigeration systems using eco friendly refrigerants propane (R-290), condenser temperature = 313K, ambient temperature = 298K, Load = 4.75K (1.5 ton), Tr = 280K' Tc = 313

Eva Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
253	2.539	5.127	16.32	21.2	17.31	27.03	34.46
258	2.88	4.401	18.51	23.67	18.49	25.77	32.07
263	3.293	3.724	21.177	26.87	19.77	24.63	28.74
268	3.802	3.091	24.44	31.16	21.21	23.65	23.98
273	4.444	2.501	28.57	37.16	22.96	22.9	16.98
278	5.275	1.949	33.91	46.09	25.28	22.51	6.12

Table: 9. Performance of vapor compression refrigeration systems using eco friendly refrigerants (isobutene (R-600a), Evaporator temperature = 253K, Ambient temperature = 298K, Load = 4.75KW) Te = 253K' Tr = 280K

Con Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
303	3.022	4.148	19.42	8.637	30.11	18.67	42.59
308	2.655	4.859	17.07	14.66	28.8	20.16	36.36
313	2.345	5.634	15.07	19.18	27.71	21.76	31.35
318	2.078	6.488	13.36	22.61	26.76	23.4	27.23
323	1.844	7.436	11.85	25.2	25.93	25.17	23.76
328	1.637	8.503	10.53	27.15	25.18	26.89	20.78

Table: 10. Performance of vapor compression refrigeration systems using eco friendly refrigerants (isobutene (R-600a), condenser temperature = 313K, Ambient temperature = 297K, Load = 4.75KW) Tc = 313K Tr = 280K

Eva Temp (k)	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
253	2.345	5.634	15.07	19.18	27.71	21.76	31.35
258	2.68	4.803	17.23	21.55	28.5	20.56	29.39
263	3.086	4.041	19.84	24.6	29.5	19.42	26.48
268	3.584	3.34	23.04	28.67	30.79	18.35	22.19
273	4.21	2.695	27.07	34.32	32.53	17.4	15.75
278	5.018	2.1	32.26	42.63	35.06	16.64	5.66

Table: 11. Performance of vapour compression refrigeration systems using six eco friendly refrigerants Evaporator temperature = 253K, condenser temperature = 313K, Ambient temperature = 298K, Load = 4.75KW' Teva = 253K Tr = 280K

Ecofriendly Refrigents	COP	EDR	Exe eff (%)	ExD COND	ExD Comp	ExD Thrott	ExD Eva
R-134a	2.59	5.007	16.6	21.62	17	26.11	35.27
iso-butane (R-600a)	2.345	5.634	15.07	19.18	27.71	21.76	31.35
Propane (R-290)	2.539	5.127	16.32	21.2	17.31	27.03	34.46
R-502	2.405	5.469	15.46	20.37	16.03	31.3	32.3
R-404a	2.154	6.223	13.84	18.44	19.2	33.59	28.77
R-407c	2.617	4.944	16.82	22.34	4.237	33.95	41.48

10.0 Conclusions

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:

1. R134a, R407c, show better performances than other refrigerants in Vapour compression refrigeration system
2. Due to flammable property of R290 and R600a , R134a is preferred for vapour compression refrigeration systems.
3. First law efficiency and second law efficiency of Vapour compression using R407c is -2 is 3%-6% higher than R134a.

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