Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 109 (2017) 4 – 10

Energy Procedia

International Conference on Recent Advancement in Air conditioning and Refrigeration

RAAR 2016

Performance of R407C as an Alternate to R22: A Review

Shailendra Kasera[a*], Prof. Shishir Chandra Bhaduri[b]

[a]*Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, India*

[b]*Department of Mechanical Engineering, JK Lakshmipat University, Jaipur, India*

Abstract

The outcome of R407C as a drop in replacement of R22 has been reviewed in this paper. As per Montreal Protocol, R22 is going to be phase out due to its unfavourable impacts related to environment e.g. ozone depletion potential (ODP) and global warming potential (GWP). R407C has zero ODP and considerably GWP as compared to R22. The releasing of refrigerants in the surroundings becomes the cause of issues pertinent in environment. A detailed review about the experimental studies associated with the performance of R407C is provided. The aim is to put together all the diversified information about the R407C in a single paper. It is found after the careful observation that R22 performs somewhat better than R407C in many aspects i.e. COP, Cooling Capacity, Energy Consumption, and Exergetic Analysis but retrofitting point of view, it is best suitable refrigerant and R410A is suitable for new design.

Peer-review under responsibility of the organizing committee of RAAR 2016.

Keywords: R22 Phaseout ; Ozone deletion potential; Global warming potential; R407C

1. Introduction

Refrigeration technology has a prominent role in current scenario. It makes the life convenient and helps in preservation of food. It provides not only contented and hygienic environment but makes life more efficient also. These technological advancements, which contribute to human comforts, are affecting the environment also through global warming and ozone depletion.

* Corresponding author. Tel.: +91-998-314-4773, +91-941-406-4784
E-mail address: shailendrakasera@poornima.org, scbhaduri@jklu.edu.in

Peer-review under responsibility of the organizing committee of RAAR 2016.
doi:10.1016/j.egypro.2017.03.032

Nomenclature

COP	coefficient of performance
GWP	global warming potential
NBP	normal boiling point
ODP	ozone depletion potential
P	pressure
T	temperature
TEWI	total equivalent warming impact

Subscripts

a	air
CO	Condenser
CR	Critical
db	Dry bulb
wb	Wet bulb

Ozone Depletion and Global Warming has always been prime environmental alarming factor with major repercussion. Ozone layer is quite helpful in cleaning all the harmful ultraviolet rays of the sun through the absorbing maximum of the damaging ultraviolet B radiation. Contacting the increased ultraviolet B radiation results in diseases of skin cancer, eye damage, diminishing rates of growth of vegetation, disturbance in ecosystem, and it instigates the risk of disease. Halocarbon is such a group of compounds which has combination of one of the halogens and carbon. Halocarbons include fluorine, chlorine, iodine and bromine. These are responsible for Ozone depletion. It is known that 100,000 ozone molecules can be destroyed by one chlorine atom. ODP is based upon the ODP of CFC-11 assigned with a value of unity. The definition of ODP is that it is defined as the ratio for any given substance between the ozone consumption per unit mass discharge in the atmosphere and which is consumed by R11; this is accountable for such effects. The absorption of infrared emissions from the earth causing an increase in global earth surface temperature makes GWP as the pivot environmental issue of next level. It is this GWP which has amount of infrared radiation which can be absorbed by gas related to carbon dioxide with assigning of 1 to GWP, integrated over a period of 100 years.

Aprea et al. (8) explained the concept of indirect global warming potential. The combined effect of direct and indirect is known as TEWI (Total Equivalent Warming Impact).
Two major environmental issues have given rise to a series of international treaties i.e. Montreal Protocol 1989 demanding a gradual phase out of halogenated fluids. The most environmentally unsafe refrigerants, such as CFCs are already banned. HCFC will be phased out by developed countries in 2020 and for developing countries in 2030. R22 is accepted as the most suitable refrigerant but it will be phased out as per the schedule. [1-7]

2. Alternatives to R22

Suggestive alternatives to R22 are R134a, R290 (Propane), R407C and R410A. R407C and R410A are a zeotropic blend of R32/R125/R134a (23/25/52 by wt %) and R32/R125 (50/50 by wt %) respectively. It is suggested that acid and poisonous substances may be formed if R134a is decomposed by the sunlight in the troposphere and the world may face another catastrophe due to this which is worse than the CFC experience [1]. R134a required larger compressor and inapt for most of the refrigeration application. Flammability is the major disadvantage of R290. It shows unsuitability for adopting it as per an alternative to R22 due to safety issues. As per the literature survey, R407C is looking the best candidate as a drop in substitute for R22. A list of the most potential alternative is given in Table 1. It also includes safety group as per ASHRAE standard 34 [9].

Table 1. Properties of Few Alternatives to R22

Refrigerant	Molecular weight (kg/kmol)	NBP (^{0}C)	T_{CR}(^{0}C)	P_{CR}(MPa)	ODP	GWP (100 years)	Safety Group
R22	86.47	-40.8	96.20	4.99	0.055	1700	A1
R134a	102.03	-26.1	101.1	4.06	0	1300	A1
R290	44.10	-42.1	96.8	4.25	0	11	A3
R407C	86.2	-43.6	86.1	4.62	0	1530	A1/A1
R410A	72.56	-50.5	72.5	4.96	0	1730	A1/A1

3. Retrofitting

Following process for retrofitting is adopted.

- The compressor is removed from air conditioner and recovering of R22 can be possible along with mineral oil. The quantity of mineral oil is measured further.
- A small quantity of fresh polyol ester oil is charged in compressor and it is run dry.
- The oil was drained and same is repeated at least twice.
- The compressor is reinstalled in the system and the filter-drier is replaced by a solid core filter-drier.
- The system is checked for leaks with dry nitrogen and kept for evacuation for an hour.
- Fresh charges of polyol ester oil same as the mineral oil is charged.
- The system is evacuated to a vacuum of 500 microns.
- R-407C is filled into the system. R-407C is 95% of the original R22 charge [10].

4. Experimental Studies

There are large numbers of experimental studies which are found in literature related to alternative refrigerants. A brief summary is given below.

4.1 Coefficient of Performance

Devotta et al. (10) performed the experiment to know the performance of R-407C as a drop in substitute to R-22 regarding 1.5 TR Window Air Conditioner. He showed the variation of COP for both R-22 and R-407C in concern of outdoor conditions. COP of R-22 was 2.57 and 1.84 in case of lower outdoor condition (T_{db}=35 ^{0}C, T_{wb}=30 ^{0}C) and higher outdoor conditions (T_{db}=46 ^{0}C, T_{wb}=27 ^{0}C) respectively. Similarly the value for R-407C was 2.36 and 1.59 respectively. The cooling efficiency of R-407C was 7.9% which got decreased for the lower outdoor conditions and 13.47% lower for the higher outdoor conditions.

Joudi et al. (11) calculated the COP for four refrigerants R290, R22, R407C and R410A. They selected 1 TR system for R290, R407C, and R410A with optimum charge of 500 g, 1100 g and 1600 g, respectively. Similarly, the optimum charge for R290, R407C, and R410A were 900 g, 1900 g and 2800 g respectively for the 2 TR systems. The COP of R290 is 18.4% higher than R22, 24.8% than R407C and 14% than R410A for 1 TR system whereas; it is 7.9% larger than R22, 15.7% than R407C and 12.95% than R410A for 2 TR systems. The COP for R290 is the maximum among all the four refrigerants tested due to its best thermo physical properties. Because of lower thermo physical properties as compared to the others, R407C has the low value of COP. These revealed that as the ambient temperature increased, the COP values got decreased for all the refrigerants. The COP of R407C was similar to R22 being maximum for R290 and minimum for R410A.

Devotta et al. (9) had experimentally shown the COP for R-22 and alternative refrigerants i.e R134a, R290, R407C, R410A for various evaporating temperatures for T_{CO} = 55°C. R134a had the highest amount of COP while R-410A had the lowest COP. R407C had 1.76 % lesser COP than R22 and R290 had COP which was marginally higher than R22. Cabello et al. (12) worked on three different working fluids, R134a, R407C and R22. They mentioned that the refrigeration plant working with R22 showed a larger COP during the use of R407C for low compression ratios. But, when the compression ratio grew over 6 the COP presented by the setup working with R407C and it was greater than the obtained one with R22.

Fatouh et al. (13) accomplished experimental investigation of a direct expansion air conditioner running with R407C as an R22 alternative. They added that when the evaporator air inlet temperature was increased from 20 to 32 ^{0}C, actual COP increased by 29.4% for R22 and 23.7% for R407C. It might be due to the rate of increasing evaporating pressure which was greater than the condensing pressure. Similarly, the average COP for R22 and R407C got increased by 30.1% and 24.1%, respectively when the humidity ratio rose from 9 to 14.5 g_{wv}/kg_a. It was due to the rate of enhancement of cooling capacity with humidity ratio being larger than the rate of increase of compressor power. COP increased with raised air volume flow rate. The volume flow rate altered considerably the actual cooling load leading directly to the increase in COP. The COP surged by 29% and 33% for R22 and R407C, respectively when the evaporator volume flow rate got enhanced from 300 m^3/h to 700 m^3/h due to augmentation in cooling capacity.

4.2 Cooling Capacity

Cooling capacity should be corresponding with the base line data otherwise compressor has to be redesigned. If an alternative refrigerant gives closer cooler capacity, it is, than only, be considered for retrofitting. Devotta et al. (10) showed that R22 gave a cooling capacity of 5.466 kW and 4.211 kW for lower outdoor and higher outdoor conditions respectively and R407C had a lower cooling capacity of 2.1% for the lower outdoor conditions and 7.93% lower for the higher outdoor conditions with respect R22. They experimentally showed that capacities of R22 and R407C were lower for the higher outdoor conditions with a similar trend.

Joudi et al. (11) presented that the cooling capacity got decreased as the ambient air temperature increased. It was due to the decrease in the enthalpy change in the evaporator. Both for 1 & 2 TR systems average cooling capacity at operational temperatures using R407C was lower by 1.4 % than R22. At the standard test condition, the cooling capacity of R410A had a higher value, due to the upper volumetric refrigerating capacity.

Fatouh et al. (13) reported that for two refrigerants R22 & R407C, more than 36% increasing in the average cooling capacity was observed when the evaporator air inlet temperature rose up from 20 to 32^{0}C. When the humidity ratio increased from 9 g_{wv}/kg_a to 14.5 g_{wv}/kg_a, the average cooling capacities of R22 and R407C also got increased by 29.4% and 38.5%, respectively. They revealed that the actual cooling capacity increased with the enhancement in the evaporator air flow rate. The average cooling capacity of R22 was higher than that for R407C by 12% at the same situation of evaporator air volume flow rate.

Lee et al. (14) carried out experimental investigation on R407C as a substitute for R22 in a screw chiller. They also reported that the cooling capacity was observed with a decrease while changing the refrigerant from R22 to R407C. Compressor work also got more in amount resulting in a substantial COP decrease.

4.3 Energy Consumption

Devotta et al. (10) reported that for all the outdoor conditions, energy consumed by the system with R-407C, by 2.13 to 2.29 kW, was higher than R22. The power consumed with R-407C was high by 6 to 7%. They informed that the power consumed by the system retrofitted with R-407C was higher with 65 W than the prescribed limit as per IS 1391(1992).

Joudi et al. (11) informed that R290 needed the lower power consumption because of the lower charge and lower vapor viscosity which reduced compressor load and power consumption. R410A required the highest power consumption when compared with R22. For 1 TR system, the power consumed by R407C was in range of 1.26-1.43 kW for 35- 55 ^{0}C ambient air temperature and 1.22-1.34 kW power consumed by R22 for the same temperature range. Similar results were shown by Devotta et al. (9). R-410A required the highest compressor power whereas the HFC-134a needed the lowest compressor power. R407C consumes 1.75% more power than R22.

Fatouh et al. (13) explained the effect of evaporator air inlet humidity ratio and evaporator air volume flow rate on compressor electric power. When the humidity ratio increases from 9 to 14.5 g_{wv}/kg_a, the average compressor power of R22 increases by 10% whereas it increases by 11.6% for R407C. They reported that the compressor power somewhat increases as soon as the evaporator air volume flow rate increases. This trend of actual compressor power is accepted by the increase in bandwidth between the condenser and the evaporator heat loads with the evaporator air volume flow rate.

Aprea et al. (16) determined the compressor performance using R407C in comparison to R22. Their investigation unveiled that R22 performed better than R407C by 8-14% mainly because of a better compression process. The volumetric and isentropic efficiencies of the semi-hermetic compressor got enhanced by 3-7% & 6-14 % respectively than R407C.

4.4 Discharge Pressure

Devotta et al. (10) informed that R407C had higher pressures than R22 with discharge pressure of R22 being at 2193 kPa for the lower outdoor conditions and 2784 kPa for the higher outdoor conditions. For all operating conditions, the discharge pressure of R-407C is varied in the range 11-13% higher than R22. Similarly Joudi et al. (11) noted that the discharge pressure of R407C was higher by 1.385 bar for 1 TR system and 2.3 bar for 2 TR system than that of R22.

4.5 Pressure Ratio

Devotta et al. (9) calculated the pressure ratio for R22 and alternative refrigerants. In case of R134a, the pressure ratios were the highest and the lowest for R290 related to the entire range of Evaporating temperature (-4 to 12^0C). R407C has 6.60 % more pressure ratio than R22. Lower pressure ratio was suggested for higher compressor efficiency. Joudi et al. (11) showed that the average compression ratio of R407C is higher by 3.7% & 5.6% for 1 TR and 2 TR system respectively than that of R22.

4.6 Discharge Temperature

Devotta et al. (10) explained that R407C had lower discharge temperature than R22. Lower discharge temperature was recommended for better lubricant and refrigerant stability. Many reactions at lower temperatures started due to the compatibility problems among lubricant, refrigerant and materials of the system and compressor was prone to be slower. This implied that the reliable life of the compressor was liable to be longer.

4.7 Specific Compressor Displacement

Devotta et al. (10) reported that specific compressor displacement is same for both R22 & R407C and it is possible to retrofit R22 compressors with R407C compressors.

4.8 Environmental Impact

Aprea et al. (8) evaluated the values of TEWI for R22 and R407C. It offers quantitative information on greenhouse effects of refrigerants. It is characterized as the aggregate of the direct chemical greenhouse gas emission and of the indirect energy linked to carbon dioxide emissions of the systems in which they are utilized.

The emission of refrigerants and other pollutants are at the root of the direct global-warming potential. The indirect global-warming potential results from the emission of carbon dioxide due to the consumption of fossil fuels (oil, natural gas, and coal).

On the basis of the experimental plant Aprea et al. (8) reported that the direct contributions to the greenhouse effect relating to R22 and to R407C amid the useful life of plant corresponded to the equal impact on global warming as the releasing of 6375 and 5400 kg of carbon dioxide, respectively. The direct contribution of R22 was 15% greater than the R407C. Coefficient of performance of R407C was lower than that of pertaining to R22. In this manner, the circuitous contribution to the greenhouse effect of R407C was constantly higher than that of R22.

Joudi et al. (11) calculated the TEWI for 1 TR and 2 TR systems. They concluded that under the standard conditions, the performance of the 1 TR split system was environmentally better than the 2 TR split system. This occurred because of lower refrigerant charged and lower electricity used. Therefore, the type of refrigerant and refrigeration capacity both influences the environment.

4.9 Exergetic Analysis

Aprea et al. (15) calculated the exergy for both R22 and R407C vapour compression plant and they reported that the overall exergetic performance of R22 was significantly better by maximum of 45% to a minimum of 7%. Exergy destroyed in the overall plant for R407C is greater than R22. To know the contribution of each device, they calculated the exergy flow destroyed separately. Exergy flow destroyed in the compressor is always greater for R407C in the range of 4-13 % due to higher power consumption or irreversibility. The exergy flow destroyed in the evaporator and condenser working with R407C was always higher than R22 in the range of 4-10% and 2-19% respectively. This was a straight outcome of greater temperature difference between the refrigerant fluid and the secondary fluid of both the heat exchangers. The contribution of expansion valve to overall irreversibility was marginal. They concluded that the evaporator and compressor must be optimized in order to improve the overall plant performance.

4.10 Other Parameters

Youbi-Idrissi et al. (17) had experimentally explained the concept of impact of refrigerant – oil solubility on evaporator performances working with R407C. They selected two POE oils of the same viscosity grade i.e. Oil I: an Emery 2968A/R407C mixture, Oil II: a commercial oil/R407C mixture. Both oils were supposed to be miscible with R407C for temperatures ranging from the level -10 to 60^0C and refrigerant was more soluble in oil I than in oil II. They revealed that at the outlet side of the evaporator, the non-evaporated quantity of refrigerants could be high. They further added that the there had been an important contribution of the latent heat inducing a higher enthalpy ratio as well as a smaller non-evaporated quantity of the refrigerant at the compressor suction.

Vaisman (18) did a computational comparison of R22 and R407C air conditioners with rotary vane compressors. He reported that R407C was compatible with R22 in terms of performance and optimal design. However, optimal design for R22 system was not necessarily optimal for R407C. This factor should be taken into notice while developing new air conditioner.

Aprea et al. (19) experimentally evaluated the energetic performances of electronic and thermodynamic expansion valves using R22 and R407C refrigerants in steady and transient modes. They reported that performance of both the valves is equal in terms of COP for steady state but in the transient tests for both refrigerants, the electronic valve shows a better performance.

Zhiqiang et al. (20) calculated the performance characteristics using R22 and R407C for air source heat pump during frosting and defrosting. Both refrigerants had similar performance characteristics in heating mode. Simulation results showed that the performances of the R407C system got declined faster than those of the R22 system under frosting. R407C system attained its steady state conditions which were quicker than that of the R22 system after defrosting.

5. Conclusions

Accelerated technological improvements in the areas of refrigeration and air conditioning have produced severed environmental problems i.e. ODP and GWP due to the use of CFC and HCFC. A large number of experimental studies of various researchers have shown in this review paper regarding performance of R407C. Performance of R407C is little low but it is the best alternative of R22 for retrofitting point of view. A brief summary is given below:

Parameter	Effect of R407C in comparison to R22
COP	Lower
Cooling Capacity	Lower
Energy Consumption	Higher
Discharge Pressure	Higher
Pressure Ratio	Higher
Discharge Temperature	Lower
Specific Compressor Displacement	Same
TEWI	Lower
Exergetic Analysis	Lower

References

1. B.O. Bolaji, Z. Huan, Ozone depletion and global warming: Case for the use of natural refrigerant – a review, Renewable and Sustainable Energy Reviews 18 (2013) 49–54.
2. James M. Calm, The next generation of refrigerants – Historical review, considerations, and outlook, International Journal of Refrigeration 31 (2008) 1123 – 1133.
3. M. Mohanraj, S. Jayaraj, C. Muraleedharan, Environment friendly alternatives to halogenated refrigerants—A review, International Journal of Greenhouse Gas Control 3 (2009) 108 – 119.
4. D.J. Wuebbles, The Role of Refrigerants in Climate Change, International Journal of Refrigeration 17(1994) 7-17.
5. C.P. Arora, Refrigeration and Air-conditioning, III Edition, Mc Graw Hill Education.

6. Mark W. Spatz, Samuel F. Yana Motta, An evaluation of options for replacing HCFC-22 in medium temperature refrigeration systems, International Journal of Refrigeration 27 (2004) 475–483.
7. M.W. Spatz, J. Zheng, R22 Alternative refrigerants: performance in unitary equipment, ASHRAE Transaction 99 (1993) 779−785.
8. C. Aprea and A. Greco, An Experimental Evaluation of the Greenhouse Effect in R22 Substitution, Energy Conservation and Management 39 (1998) 877-887.
9. S. Devotta, A.V. Waghmare, N.N. Sawant, B.M. Domkundwar, Alternatives to HCFC-22 for air conditioners, Applied Thermal Engineering 21 (2001) 703- 715.
10. S. Devotta, A.S. Padalkar, N.K. Sane, Experimental Performance Assessment of a Retrofitted Window Air Conditioner with R-407C, International Refrigeration and Air Conditioning Conference (2002).
11. K. A. Joudi, Q. R. Al-Amir, Experimental Assessment of residential split type air-conditioning systems using alternative refrigerants to R-22 at high ambient temperatures, Energy Conversion and Management 86 (2014) 496–506.
12. R Cabello, E Torrella, J Navarro-Esbrí, Experimental evaluation of a vapour compression plant performance using R134a, R407C and R22 as working fluids, Applied Thermal Engineering 24 (2004) 1905–1917.
13. M. Fatouh, T. A. Ibrahim, A. Mostafa, Performance assessment of a direct expansion air conditioner working with R407C as an R22 alternative, Applied Thermal Engineering 30 (2010) 127–133.
14. D.-Y. Lee, Y. Ahn, Y. Kim, Y. Kim, Y.-S. Chang, L. Nam, Experimental investigation on the drop-in performance of R407C as a substitute for R22 in a screw chiller with shell-and-tube heat exchangers, International Journal of Refrigeration 25 (2002) 575–585.
15. C. Aprea, A. Greco, An exergetic analysis of R22 substitution, Applied Thermal Engineering 22 (2002) 1455–1469.
16. C. Aprea, A. Greco, Performance evaluation of R22 and R407C in a vapour compression plant with reciprocating compressor, Applied Thermal Engineering 23 (2003) 215–227.
17. M. Youbi-Idrissi, J. Bonjoura, C. Marvillet, F. Meunier, Impact of refrigerant–oil solubility on an evaporator performances working with R-407C, International Journal of Refrigeration 26 (2003) 284–292.
18. I.B. Vaisman, Computational comparison of R22 and R407C air conditioners with rotary vane compressors, International Refrigeration and Air conditioning Conference 1998, paper 382.
19. C. Aprea, R. Mastrullo, Experimentally evaluation of electronic and thermostatic expansion valves performances using R22 and R407C, Applied Thermal Engineering 22 (2002) 205-218.
20. L. Zhiqiang, L. Xiaolin, W. Hanqing, P. Wangming, Performance comparison of air source heat pump with R407C and R22 under frosting and defrosting, Energy Conversion and Management 49 (2008) 232–239.