Replacement of R22 to manage lifetime operation of HCFC based equipments

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Abstract

R22 is a Hydrochlorofluorocarbon (HCFC) commonly used in air conditioning, process chiller and industrial refrigeration plant applications. Because of worldwide discussion and reaction on global warming and ozone depletion, it is necessary to replace refrigerants having lower or zero ozone depletion and global warming potential. R22 will soon be phased out due to ozone depletion potential. It is an opportunity for improved environmental performance include the wider acceptance of refrigerants other than R22 which is used as alongside the highly ozone depleting (ODP) CFC's, but has a relatively low ozone depletion potential. However, even this lower ODP is no longer considered acceptable. Users of refrigeration are facing new choices with regard to selection of refrigerants because CFC and HCFC refrigerants are being phased out to protect the ozone layer. There is considerable confusion and controversy regarding the best choices, particularly when the environmental issue of global warming is taken into account. This paper considers the choice and availability of different refrigerants as substitute of R22, to avoid losing lifetime operation of designed and manufactured equipments for R22 like bottle cooler, chillers, vapour source heat pump, air conditioner etc.

Keywords: R22, GWP, ODP, refrigerant, Phase-out, CFC, HCFC, HFC, R22, R407C, R410A, R134a, Ozone depletion, Zeotropic refrigerant mixture

1. Introduction

In the 1980s, the depletion of stratospheric ozone, a compound which absorbs harmful UV-B radiation was discovered; the root cause of the problem was determined to be atmospheric halogen gases. Atmospheric ozone (O_3) is created when oxygen molecules (O_2) collide with free oxygen atoms (O); however, upon exposure to solar radiation, halogen gases create compounds that are highly reactive with ozone molecules, breaking them apart, and leaving oxygen (O_2). One of the halogen atoms principally responsible for depleting ozone in this manner is chlorine (Cl), commonly used in so called Chlorofluorocarbon (CFC) and Hydrochlorofluorocarbon (HCFC) refrigerants.

The Montreal Protocol, modified by the EU enforces the end of supply of (HCFCs) from 2015, including the ozone-depleting refrigerant gas R22, in refrigeration, heat pump and air conditioning (AC) systems [6]. R22 is commonly used in AC systems pre-dating 2004 and so its ban will have a major effect on air-conditioning costs. There are a range of possibilities when considering changing from R22 to an alternative refrigerant with low GWP & ODP. Delaying equipment replacement may buy time to allow alternative technology to become more readily available and established. The choice between competing refrigerants has always been complex. Nevertheless, there used to be fairly clear divisions between different types of refrigerant. CFCs and HCFCs were the refrigerant of choice for the vast majority of small, medium and many large sized refrigeration systems. This was because of their excellent safety characteristics (non-toxic and non-flammable) and good materials compatibility (allowing use of copper components).

R22 has been commonly used in residential heat pump, air conditioning and refrigeration systems since the 1990s following the phase out of chlorofluorocarbons (CFCs) in developed countries in 2000. The demand for R22 equipment has been increasing, especially in developing country markets. Of particularly high demand are refrigerated appliances for small and mid size shops and restaurants at affordable costs. The appliances are mostly factory made plug-in units with hermetic refrigerant circuits—such as bottle coolers, ice cream freezers, commercial freezers / refrigerators, beer coolers. The companies manufacturing these appliances are often small compared to household appliance manufacturers, so existing equipment and personnel knowledge about refrigeration and safety standards are not always adequate. R22 is a well performing refrigerant in use in small refrigerated appliances, with the exception of applications with high discharge temperatures at low evaporation temperatures in freezers.

Table 1. Applications of refrigerant R22 [7]

Residential Uses	Commercial and Industrial uses
Window and split air-conditioning units	Packaged air conditioners and heat pumps
Dehumidifiers	Chillers
Central air conditioners	Retail food refrigeration
Air-to-air heat pumps	Cold storage warehouses
Ground-source heat pumps	Industrial process refrigeration
Ductless air conditioners	Transport refrigeration

2. Replacement of R22 in different applications

The necessity for non-chlorinated refrigerants pursuant to the new regulations resulted in the investigation of HCFC-22 replacements. in the 1990s. Several refrigerant alternatives emerged from these studies, with none being a perfect replacement in the sense that it mimics the performance of R22 in all applications. Those refrigerants that have shown the greatest potential as R22 replacements are known as hydrofluorocarbons (HFCs), compounds that contain no chlorine atoms and so have very little or no ozone depletion potential. Of these alternatives, the most commonly considered to be candidates to replace R22 are HFC refrigerants R410A, R134a, and R407C. R410A and R407C are blends, while R134a is composed of a single constituent. R410A is composed of a 50/50 mixture of R-32 and R-125, while R407C is composed of 23% R-32, 25% R-125, and 52% R134a by weight. When considering alternative refrigerants, the advantages and disadvantages of each (including R22) must be carefully considered.

Table 2. Properties of refrigerant R22and its replacement [5]

Refrigerant	Atmospheric lifetime (Years)	ODP	GWP (100 Years)
R22	12	0.034	1780
R134a	14	~ 0.0	1320
R407C	a	~ 0.0	1700
R410 A	a	~ 0.0	2000
R290	b	0.0	~ 20
a. Atmospheric lifetimes are not given for blends b. Unknown			

2.1. Replacement of R22 in Scroll Chillers [6]

For scroll chillers, the most popular R22 replacement options include:

- R410A a zeotropic mixture of 50% HFC-32 and 50% HFC-125
- R407C a zeotropic mixture of 23% HFC-32, 25% HFC-125, and 52% HFC-134a.

R407C requires the least changes for component and system manufacturers, as well as installation and service contractors. The safety classification and handling characteristics are similar to R22 (non-flammable, low toxicity). R410A requires significant changes for component and system manufacturers but has offsetting benefits. The safety classification is the same as R22.

2.1.1. Transition from R22 to R407C

R407C has capacity and pressure close to R22. In fact, its operating characteristics are so similar to HCFC22 that it can be used in either existing R22 systems (requires some changes such as the oil) or in new systems that were originally designed for R22. Unlike R410A, the system efficiency of R407C is somewhat lower than R22 (~5% lower), especially in systems that were originally designed for R22. R407C is a zeotropic blend, meaning the resulting mixture does not act as a single compound. At a given pressure, it evaporates over a range of temperatures, rather than at a single temperature.

R407C has been used considerably in Europe, where the phase out of ozone depleting refrigerants (including R22) was accelerated, and manufacturers did not have time to re-design systems for higher pressure R410A refrigerant. In systems in which glide is acceptable, R407C has become a popular option for manufacturers who want to move quickly to an HFC alternative. In the long run, however, the lower-efficiency performance of this refrigerant may make it a less attractive alternative compared to R410A for medium and high-temperature applications. R407C has an ODP of zero and no scheduled phase out date. It has been designated an A1 refrigerant in ASHRAE Standard 34 – Designation and Safety Classification of Refrigerants.

2.1.2. Transition from R22 to R410A

Operating pressures in a R410A refrigerant system are about 50% higher than a comparable R22 system. As a result, R410A cannot be used as a direct, functional replacement in R22 systems. R410A equipment has been specifically designed to operate at higher pressure, with a thicker compressor shell, heavier wall tubing and superior control and protections. The more robust materials, in turn, enable manufacturers to create heavier, better welds at joints, helping to improve their resistance to abuse. In addition, consistent field experience indicates that R410A offers greater compressor sound reduction than those units using R22. Another property that reduces the required amount of refrigerant is the lower liquid density of the refrigerant. This leads to a 12% reduction in the mass of the refrigerant required. The total of these effects is an overall reduction of 25% to 30% charge reduction in fully optimized R410A systems. Field-testing and the product history to date for R410A equipment suggest that these units are more reliable than R22 units. For residential and light-commercial to commercial AC, the overwhelming choice is R410A. But this refrigerant, a blend of R32 and R125 with very low glide (less than -17.22 ℃), has very different characteristics from R22; in particular, its operating pressure and volumetric capacity are significantly higher. This implies a major equipment redesign instead of simple component changes. For larger equipment, R410A will play a role.

2.2. Replacement of R22 in Commercial Appliances like Freezer and Bottle Cooler [4]

Propane (R290) can be introduced in many of today's R22 applications. No other single component refrigerant has such similar thermodynamic behaviour to R22. In climates characterized by high ambient temperatures, R290 provides improved performance in terms of discharge temperature and pressure. The experience built up over several years of production, mainly with commercial refrigerated appliances (ice cream freezers, commercial freezers/ refrigerators, ...), demonstrates that R290 is a promising alternative for R22, as components (e.g. compressors) are available in the market and R290 is compatible to the most commonly used heat exchangers and materials. However, application possibilities have been limited due to safety concerns. Safety standards for appliances are available, covering refrigerant charges up to 150 grams (g) per system. Appliance producers manufacturing R290 systems must be equipped accordingly, and service technicians must be trained in safe handling procedures.

Table 2. Thermodynamic Comparison of R290 to Other Refrigerants [4]

Parameters	R22	R290	R134a
Pressure	**	**	↑↑
Pressure ratio low back pressure (LBP)	**	↑↑	↓↓
Discharge temperature	↓↓	↑↑	↑↑
Volumetric capacity	↑↑	↑↑	↓↓
Capacity loss	**	**	**
COP	**	**	**

Legend: ** = acceptable; ↑↑ = good; ↓↓ = problematic

Refrigerants taken into the comparison are R22, R290, R134a, R404A and R600a. For the comparison two conditions were chosen, which represent operation of a commercial freezer display case and a bottle cooler at high ambient temperature.

- Low Back Pressure - Freezer evaporating/condensing/return (suction) gas at -35/50/20 ℃
- Medium Back Pressure - Bottle cooler evaporating/condensing/return (suction) gas at -10/55/20 ℃

R290 has a long history in refrigeration. It has been in use since before CFCs were developed and was re-introduced for use in heat pumps after the CFC phase out. Its thermodynamic data, efficiency, and material compatibility are well known. In some countries, appliance manufacturers and food producers began using R290 as a replacement for R404A or R134a in appliances shortly after 2000, due to environmental concerns. The energy efficiency and reliability of the appliance using R290 is expected to be equivalent to or better than that of equipment using R22. Because R290 has no ODP and a very low

GWP, assuming that R290 has the same energy efficiency as R22, the environmental impact is reduced. Based on estimated charge sizes and leak rates, emission savings are estimated to be 25 tonnes of R22 per 100,000 appliances.

2.3. Replacement of R22 in Domestic Air Conditioner

2.3.1. R290 as a replacement of R22 in Domestic Air Conditioner[3]

Performance of a domestic split type air conditioner was evaluated by using two different refrigerants, i.e., R22 and R290. The experimental investigation was conducted by using a 1 hp air conditioning unit. Power consumptions by the complete system including the evaporator as well the by the compressor alone were measured by clamp meter. Temperature was also measured at different locations by digital fluke thermometer whereas digital multi meter was used to measure the current supplied to the system. The air conditioner was run for six hours each time by setting three different set point temperatures, i.e., the cold air temperature coming out from the evaporator. From the measured information, coefficient of performance (COP), and energy efficiency ratio (ERR) were calculated for each refrigerant. The results revealed that R290 refrigerant has better COP and EER compared to R22 refrigerant. The usage of R290 refrigerant can reduce energy consumption up to 11 %. In addition to that, at the same air conditioning unit, the amount of R290 refrigerant required is relatively half of that required by R22 refrigerant. Due to R290 chemical properties, this refrigerant can easily be compressed and expanded compared to R22 refrigerant. As a result of these properties, the compressor requires less energy to compress the refrigerant which in turn increases the life span of the compressor. The only limitation of R290 is flammability. R290 refrigerant need to be handle with extra care due to its flammability properties.

2.3.2. R410A as a replacement of R22 in Domestic Air Conditioner [1]

R410A is a long-term alternative refrigerant with zero ODP (ozone-depleting-potential) for replacing R22. The performance comparison of AC included the cooling capacity, EER (energy efficiency ratio), annual power consumption of AC and the global warming impact of refrigerants adopted by the AC. It was concluded that the adoption of R410A could be helpful for AC to decrease their heat exchanger size or improve their operation efficiency for power saving. Moreover, compared to R22, R410A could in fact help alleviate its overall impact on global warming through significantly reducing the indirect global warming impact caused by operating R410A AC.

2.4. Replacement of R22 in Air Source Heat Pump [2]

The dynamic performance characteristics of the air source heat pump (ASHP) with refrigerants R22 and R407C during frosting and defrosting were studied. The results show that both refrigerant systems have similar performance characteristics, except that the performance of the R407C system deteriorated faster than that of the R22 system under frosting, and the performance of the R407C system attains its steady state faster than that of the R22 system after defrosting. R407C refrigerant can be used in either existing systems or in new systems that were originally designed for R22.

2.5. Replacement of R22 in Vapour Compression Heat Pump [6]

The performance of an air to water vapor compression heat pump has been investigated experimentally. The main purpose of study was to investigate the possibilities of using R134a as a working fluid to replace R22 for vapor compression heat pumps. Pure R22, pure R134a and some binary mixtures of R22/R134a were considered as working fluids. The performance of the system was characterized by mixture ratio, COP and evaporator air inlet temperature. Comparisons are made between the pure refrigerants and refrigerant mixtures on the basis of the COP. Experimental results show that the mixture ratio affects the COP significantly, and the COP could be improved by using pure R134a or an appropriate mixture of R134a/R22 instead of pure R22. The maximum COP occurred at a mixture ratio of around 50/50% R134a/R22. For a mass percentage of 50% of R134a, the COP was enhanced by about average 25%.

3. Conclusion

There are a range of possibilities when considering changing from R22 to an alternative refrigerant with higher performance and low global warming potential alternatives becoming more available. Delaying equipment replacement may buy time to allow alternative (zero ODP and lower GWP) technology to become more readily available and established. For scroll chillers R22 can be replaced by R407C and R410A (with 1.5% higher GWP). R410A can be used in medium and high temperature applications with higher performance in place of R22 and R407C. R290 is more efficient option for (ice cream freezers, commercial freezers/ refrigerators and domestic air conditioning unit. Since R290 is highly flammable it should be used careful consideration to safety. By R134a and mixture of R22/134a, the performance of vapour compression heat pump is improved and COP is increased about 25%.

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