ISHRAE Position Paper on

REFRIGERANTS FOR INDIAN REFRIGERATION AND AIR CONDITIONING INDUSTRIES:

Challenges and Responsibilities

By Refrigerant Committee of ISHRAE

Introduction

Refrigeration and Air Conditioning (RAC) applications, in the current era, touch our lives in far reaching areas in a wide range of fields. They have become essential not only for food security (post-harvest vegetable, fruit and grain storage, food processing and freezing), health security (healthcare, vaccine and pharmaceutical storage and cryosurgery), financial security (industrial development including IT, pharmaceuticals, chemicals, petrochemicals and many others), but also for human comfort (air conditioning). It is well known that with comfort air conditioning, human productivity has increased. AC&R is now a backbone of our lifestyle, and plays an important role in future sustainable development.

Prior to 1930, refrigerants from known and available chemicals were used and no special fluids were developed. Safety (toxicity and flammability) issues were previously not well understood. In I928, *Midgley* (1930) discovered that CFC-12 could be used as a non-toxic and non-flammable refrigerant. This was followed by development of a series of CFCs, HCFCs and HFCs and more recently HFOs.

CFCs and HCFCs were earlier extensively used as refrigerants (CFC-11, CFC-12, HCFC-22, CFC-113, CFC-114, CFC-115, and HCFC-123). These fluids have many desirable characteristics such as thermal and chemical stability, thermodynamic suitability, non toxicity, non flammability, material compatibility, low cost, etc. Some of these fluids also are or were used as solvents, foam blowing agents, aerosol propellants, and for a few other applications.

In 1974, *Molina and Rowland* (1974) identified CFCs (including HCFCs) as the major source of chlorine in the stratosphere and discovered their link to ozone layer depletion. Stratospheric ozone layer acts as a filter to UV-B rays reaching the earth. The lethal consequences of its depletion include health hazards on human beings and living creatures and other ecological as well as environmental problems (UNEP, 2014a).

Montreal Protocol

In order to control the damage to the stratospheric ozone layer depletion, the Montreal Protocol (MP) was globally adopted in September 1987. MP specifies some control measures for the reduction and ultimately the phase-out of Ozone Depleting Substances (ODSs), including HCFCs. MP embodied 'the polluter pays' principle with committed, but differentiated, responsibility, and created the Multilateral Fund (MLF) in 1991 for the implementation of MP based on the contributions made by Non-A5 countries (developed). MP also provided 10 years grace period for A5 (developing) countries.

India ratified the Montreal Protocol on Substances that Deplete the Ozone Layer in 1992 and followed it up with further ratification of all the subsequent amendments. Indian Ozone Depleting Substances (Regulation) Rules, 2000, under Environment Protection Act (1986), came into force on 17th July 2000. Accordingly, CFCs were phased out 17 months ahead of the target date of 2010 (MoEF, 2012). HCFCs have lower ODP. As per the accelerated MP phase out schedule, HCFCs have to be phased out by 2020 in Non-A5 and 2030 in A5 countries. For A5 countries, 2.5% of baseline averaged over 10 years (2030-2040) is allowed, if necessary, for servicing of RAC equipment until 2040.

The Government of India has put together a comprehensive roadmap for HCFC Phase-out Management Plan (HPMP), with concrete goals to meet the schedules. Indian Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014, came into force on 13th March 2014 (MoEFCC, 2014). As per the amended ODS Regulations, manufacturers of RAC products (excluding compressors) have to phase out HCFCs by 1st January 2025. Import of RAC systems containing HCFCs is regulated from 1st July 2015.

With extensive work on alternatives to CFCs and HCFCs, initially HFCs, which are ozone friendly with zero ODP, were considered as long-term solutions. HFCs were used as alternatives while phasing out CFCs, although these fluids have relatively high GWPs.

Kyoto Protocol

Global warming due to Green House Effect has become another major environmental issue. It is well established that global mean temperatures have increased by more than 0.8°C over the past 100 years. Intergovernmental Panel on Climate Change (IPCC) agrees that global warming is primarily due to human activity that has occurred since the industrial revolution. In order to slow down global warming, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1994. The Kyoto Protocol (KP) under UNFCCC, which came into effect in 1997, set out more specific and binding commitments to abate the use and emissions of Greenhouse Gases (GHGs), including HFCs. Currently available HFC options for HCFCs have a very high GWP, typically in the range 600 to 4000. Obviously, there is a linkage between Montreal Protocol and UNFCCC (Kyoto Protocol) and this was studied by IPCC (*Andersen et al*., 2005 and *Devotta and Sicars*, 2005). CFCs and HCFCs are also GHGs. However, as CFCs were phased out and HCFCs are under phase out under MP, these are not included in KP.

The European Union introduced F-gas Regulation in 2006, which was further revised in 2014, to contain the growth of the use of fluoro-chemicals. In Europe, some HFCs have already been substituted by natural refrigerants with low GWP.

HFC Phase Down Proposal under Montreal Protocol

HFC emissions are projected to grow significantly up to 2050, largely due to the increasing demand for RAC sectors in developing countries presumed to use high-GWP HFCs, in the absence of global controls. Therefore, it was emphasised that phasing down HFCs, in conjunction with other GHGs, is essential for stabilizing global temperatures.

Since 2009, there have been proposals to amend the Montreal Protocol to include the phase down of HFCs from North America (the United States, Canada and Mexico), the Federated States of Micronesia and the EU. Both proposals would add HFCs to the list of controlled substances under the Montreal Protocol and establish control measures (i.e. phase-down schedules) for HFCs with grace periods for developing countries.

India has also submitted a proposal to phase down HFCs under MP in 2015 (*UNEP,* 2015). Some of the key elements of the Indian proposal relevant to RAC industry are given below:

(i) Continue to use HCFCs/HFCs and blends of HFCs as transitional substances for phase-out of HCFCs wherever low-GWP/ zero-GWP alternatives are not available.

(ii) Strengthening of financial mechanism and transfer of technology under the Montreal Protocol including full conversion costs and full second conversion costs wherever transitional technologies shall be deployed.

(iii) A grace period of 15 years for A5 Parties to ensure availability of safe, technically proven, energy-efficient, environment friendly, economically viable, commercially available, matured non-HFC technologies.

(iv) The baselines for non-A5 Parties for production and consumption should be the average of 2013-2015 with freeze in 2016 and for A5 Parties should be the average of 2028-2030 with freeze in 2031 and phase-down with a flexible approach to reach the plateau of 15% of the baseline in 2035 and 2050 respectively. Phase-down steps for A5 Parties should be decided 5 years in advance for the next 5 years period.

Alternatives to HCFCs

The accelerated HCFC phase out schedule poses a bigger challenge for developing countries, with multiple dimensions on short term as well as long term technology selections (climate change, energy efficiency, cost, etc.) and policy issues, which were much simpler when CFCs were phased out. Therefore, considerable initiatives have been taken by RAC industry to identify alternatives to HCFCs. Some countries have volunteered to phase out HCFCs much earlier than stipulated in MP.

> The RAC industry is in the midst of a historical technological shift, to comply with very dynamic international environmental protocols and avoid the use of refrigerants that harm the global environment. This has triggered large innovative processes leading to new technology and new solutions in a very short term.

Any alternative should not only perform efficiently with reliability as long as it is within the system, but also be harmless and benign to the environment, should it leak out of the system. It is well established that HVAC systems account for nearly 40 per cent of total global building energy consumption. The contribution to global warming due to refrigerants is only 3 to 5% considering the product life cycle. Therefore, due consideration ought to be given to the selection of refrigerants to achieve higher efficiency, which is also regulated in India. In order to satisfy environmental regulations, one has to address factors such as flammability, toxicity, cost, etc.

Table 1 presents environmental, thermo-physical and ASHRAE-34 safety classification data for some selected refrigerants. Most of the data have been taken from *UNEP RTOC Report* (2014) except critical temperature, which has been taken from the earlier 2010 report. For choosing the transition, retrofitting or substitution fluid, economical, technical and ecological criteria should be considered. Transition fluids are basically for new systems, while retrofitting fluids are for the replacement of the old refrigerants in existing plants without making major changes. Mixing of refrigerants also enables the use of a refrigerant that would not be acceptable as a pure fluid owing to its flammability or operating pressures.

Table1: Environmental, thermo-physical and safety data of select refrigerants (UNEP, 2014b)

Refrigerant	Chemical Formula	Environmental Parameters			Thermo-physical and Safety Parameters		
		ODP	GWP	Atmospheric Lifetime, Years	Normal Boiling Point, °C	Critical Temperature, °C	ASHRAE 34 - Safety Classification
CFC-11	CCl_3F	1.00	5160	52.0	23.7	198.0	A1
CFC-12	CCl_2F_2	0.82	10300	102.0	-29.8	112.0	A1
HCFC-22	$CHClF_2$	0.04	1780	11.9	-40.8	96.1	A1
HCFC-123	CF_3CHCl_2	0.01	79	1.3	27.8	183.7	B1
HCFC-142b	CH_3CF_2Cl	0.06	2070	18.0	-9.1	137.1	A2
HFC-23	CHF_3	0	12500	228.0	-82.0	26.1	A1
HFC-32	CH_2F_2	0	704	5.4	-51.7	78.1	A2L
HFC-125	C_2HF_5	0	3450	31.0	-48.1	66.0	A1
HFC-134a	CH_2FCF_3	0	1360	14.0	-26.1	101.1	A1
HFC-143a	$C_2H_3F_3$	0	5080	51.0	-47.2	72.7	A2L
HFC -152a	$C_2H_4F_2$	0	148	1.6	-24.0	113.3	A2
HFC-1234yf	$C_3H_2F_4$	0	<1	0.29	-29.5	94.7	A2L
HFC-1234ze	$C_3H_2F_4$	0	<1	0.11	-19.0	109.4	A2L
R-407C (HFC-32/HFC-125/HFC-134a – 23/25/53 wt.%)		0	1600		-43.6	86.0	A1
R-410A (HFC-32/HFC-125 - 50/50 wt.%)		0	2100		-51.4	71.4	A1
HC-290 (Propane)	C_3H_8	0	~20	0.034	-42.1	96.7	A3
HC-600a (Isobutane)	C_4H_{10}	0	~20	0.016	-11.7	134.7	A3
HC-1270 (Propylene)	C_3H_6	0	<20	0.001	-47.6	91.1	A3
R-717 (Ammonia)	NH_3	0	<1	<0.02	-33.3	132.3	B2L
R-718 (Water)	H_2O	0	<1	-	100.0	373.9	A1
R-744 (Carbon dioxide)	CO_2	0	1	>50		31.1	A1

Safety Classification: Globally, ASHRAE standards are followed in consonance with local and national standards, some of which may be equivalent to ASHRAE standards. Flammability and toxicity aspects are covered under ASHRAE Standards 15 and 34. The equivalent ISO standards are ISO 5149 and ISO 817 respectively. Additionally, ASHRAE Standard 147 deals with the reduction in the release of halogenated refrigerants from AC&R systems.

According to ASHRAE 34, toxicity classification is based on chronic (long term) measures as follows:

- Class A with PEL > 400 PPM
- Class B with PEL < 400 PPM

  where PEL: Permissible Exposure Limit

The flammability classification is based on ASTM E 681, with electrically activated match, as follows:

- Class 1 - no flame propagation
- Class 2 - LFL > 0.10 kg/m^3 and heat of combustion < 19 MJ/kg
- Class 2L w/ burning velocity < 10 cm/s
- Class 3 - LFL < 0.10 kg/m^3 or heat of combustion > 19 MJ/kg

  where LFL is the lower flammability limit

Environmental Evaluation of Refrigerants

The following tools are used to assess the sustainability of any RAC system using a chosen refrigerant (*UNEP*, 2014b).

Total Equivalent Warming Impact (TEWI): It refers to the combination of direct (release of refrigerant) and indirect (energy consumption) effect, which can be evaluated to determine the TEWI of the refrigeration and air conditioning equipment. TEWI of a particular application over its lifetime can be calculated as described in *www.arap.org*

Life Cycle Climate Performance (LCCP): Life Cycle Climate Performance considers the overall environmental performance of a product, providing a framework of 'cradle to grave' environmental responsibility. LCCP relates to a defined system and provides a comparative measure rather than one that has any absolute significance. This includes the extraction of the raw materials, the manufacture of intermediate products, the manufacture of the substance itself, the phase of use, and waste disposal.

The basic contributors to LCCP are CO_2 emissions due to energy use and the direct warming impact of emissions. For a range of HFC applications, detailed comparisons of LCCP have been made between HFC based systems and non-HFC based alternative systems/technologies.

Although there have been many attempts and studies using both TEWI and LCCP approaches, there is still no consensus as there are wide variations in the results due to various assumptions made, including energy mix and its CO_2 emission, leakage rates, performance during the life cycle of systems, recovery and recycle efficiency, destruction efficiency and so on.

continued on page 44

continued from page 42

Table 2: Low GWP alternative refrigerants for various RAC sectors

Sector	Current Refrigerants Used	Alternative Refrigerants	Low GWP Refrigerants (GWP < 750)	ISHRAE Assessment of Low GWP options for India
Domestic Refrigeration				
Single /Double Door	HC-600a , HFC-134a		HC-600a, HFC-1234yf, HFC-1234ze	HC-600a
Commercial Refrigeration				
Stand-alone units (Display Cabinets, Water Coolers, Bottle Coolers, Visi Coolers, Ice Cream Cabinets and Chest Freezers)	HC-600a, HC-290, HCFC-22, HFC-134a, R-404A, R-744	HFC-134a, HC-600a, HC-290, R-404A, R-507A, R-407 (A, C or F)	HC-600a, HC-290, HFC-1234yf, HFC-1234ze, R-744	HC-600a, HC-290, R-744
Room ACs				
Room ACs (1 to 1)	HCFC-22, R-410A, HFC-32, HC-290	R-407C, R-410A, HFC-32, HC-290, HFC-161	HFC-32, HC-290, R-446A, R-447A	HC-290, HFC-32
Large ACs				
Multi-Split	HCFC-22, R-410A	R-407C, R-410A, HFC-32	HFC-32, R-446A, R-447A	None at the moment
VRF ACs			HFC-32 , R-446A, R-447A	
Ducted, Packaged, Roof Top			HFC-32, HFC-1234yf, HFC-1234ze, R-450A, R-513A, R-451A, R-451B	
Mobile AC				
Car, Van	HFC-134a	HFC-152a, R-744, R-444A, R-445A	HFC-1234yf,R-744	HFC-1234yf, R-744
Bus, Truck, Train	HCFC-22, R-134a, R-407C	R-744, R-450A, R-513A,	HFC-1234yf,R-744	HFC-1234yf, R-744
Transport Refrigeration				
Refrigerated Transport Supply Chain	HCFC-22, HFC-134a, R-404A	HFC-134a, R-407C, HFC-1234yf, R-744		None at the moment
Industrial Refrigeration				
Small and Medium Size	R-717, HCFC-22, HFC-134a, R-404A (for medium temperature)	R-717, HFC-134a, R-407A, R-407F	R-717, HFC-1234ze	R-717
Large Industrial Chiller	R-717, HCFC-22, HFC-134a	R-717, HFC-134a	R-717, HFC-1234ze	R-717
Chillers				
Scroll	HCFC-22, R-407C, R-410A	R-410A, R-450A, R-513A	HFC-1234ze	None at the moment
Screw	HCFC-22, HFC-134a	HFC-134a	HFC-1234ze, HC-1270	
Centrifugal	HFC-134a, HCFC-123	HFC-134a	HFC-1234ze, HCFO-1233zd, HFC-1336mzz	

Note: ISHRAE's assessment is based on the current understanding of open domain data and is not based on any proprietary or commercial information. In this assessment, any refrigerant with GWP <750 has been considered to be a 'Low GWP Refrigerant'

Low GWP Alternative Refrigerants for Various RAC Sectors

Table 2 presents some of the currently used and known alternative refrigerants for various sectors of RAC applications based on global scenarios. Sustainability of refrigeration and air conditioning systems is the key factor in the ultimate choice of alternative refrigerants. Comprehensive details can be found in UNEP RTOC Report (*UNEP*, 2014b).

HFCs

HFC-134a is the most widely used across many RAC sectors. R-410A is currently the most popular alternative to HCFC-22 in AC sector. However, in view of the HFC phase down program, the long term future of HFC-134a and R-410A is uncertain. There is no immediate regulation restricting their use within India, but there may be problems when dealing with exports to some countries. Room ACs with HFC-32 are commercially available in many countries including India. It is yet to be approved by US-EPA SNAP for safety reasons. HFC-1234yf seems to be most favoured choice for mobile AC and has already been commercialised. Its use in other sectors is not yet certain. Trials using other HFOs for RACs are being conducted and not yet commercialised.

Natural Refrigerants

Natural substances that exist in our biosphere, e.g. water, ammonia, carbon dioxide and hydrocarbons, are considered as promising alternative refrigerants for some niche areas and applications. However, technologies to use natural refrigerants in some cases need more time to develop or may be restrictive owing to safety issues, but may bring forward robust and long-term solutions. Some countries in Europe have given special considerations for the use of natural fluids and have taken initiatives to either phase down or reduce the use of HFCs in RAC sector using natural fluids.

Hydrocarbons are flammable (A3) and, therefore. safety aspects of their applications must be considered carefully during handling, manufacturing, servicing and disposal of the appliance or equipment. The flammability introduces incremental product design requirements to reduce explosion risks. Owing to its excellent thermodynamic efficiency, HC-600a was chosen and issues related

continued on page 46

continued from page 44

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to safety were addressed through appropriate safety codes. HC-290 is being used, to a limited extent, in room ACs, up to 5 kW complying with applicable codes. However, it is still a greater challenge to use HC-290 in higher capacity systems, as split systems have to be field installed.

Ammonia (R-717) is a thermodynamically attractive fluid, which has been in use for decades in industrial refrigeration and cold storages but is toxic and flammable (B2L). Therefore, proper training for service and maintenance is required. With appropriate application of safety codes in Europe, ammonia has proved to be a viable substitute for other refrigerants in direct and indirect systems for commercial, cold storage and supermarket applications and in some exceptional cases for air conditioning using secondary refrigerants.

Water (R-718) is a thermodynamically attractive, non-toxic and non-flammable refrigerant and, above all, is not detrimental to the environment. However, systems using water suffer from high cost due to relatively large compressor size and other system design issues. Water based refrigeration systems for industrial refrigeration, e.g. mining and air conditioning, are in use in some of the European countries. The use of water is usually achieved through binary ice, which is an ideal secondary refrigerant that can be used as a replacement for directly evaporating refrigerants. In ice slurry, the latent heat of fusion is also used and has a rather large cooling capacity and at the same time, behaves very much like water.

Carbon Dioxide (R-744) is one of the most promising natural refrigerants with zero ODP and GWP of 1. It has no problems arising from toxicity or flammability. However, its vapour pressure is very high and critical temperature (31.1°C) is very low. Therefore, the refrigeration cycle using CO_2 is uniquely operated as a trans-critical

continued on page 48

continued from page 46

cycle. Most of the developments for CO_2 were originally towards mobile (vehicle) AC driven by EU F-gas Regulation limiting GWP to 150. Although there seems to be major support from Mobile Air Conditioning (MAC) industry for HFC-1234yf, a few German manufacturers are still pursuing CO_2 systems. R-744 can be used for the low temperature cycle in commercial systems.

Refrigerant Emission Mitigation

Refrigerant emissions are associated with its handling, fugitive emissions linked to the number of fittings such as valves, flanges etc., circuit openings linked to filter or oil change, repairs during system operation, ruptures of safety valves, rupture discs, heat exchanger tubes and metal recovery during equipment disposal, etc. Therefore, it is imperative to keep the systems leak tight through trained personnel.

The primary option to mitigate HFC emissions may be the use of alternative non-HFC refrigerants, alternative technologies, recovery and recycling and possibly destruction. Some of these are not still cost effective for developing countries.

Zero Leakage and Minimum Charge

Non-Article 5 countries are now targeting minimum refrigerant charge and zero leakage during system life cycle. Limitation of refrigerant emissions depends on efficient recovery policy for end of life equipment, careful refrigerant handling by the OEM and efficient leak fixing during operation and maintenance by the service sector. The only weak link in these preconditions is the service sector. There are concerted efforts globally to train technicians for good service practices towards zero leaks.

Service Sector

As the refrigerant scene is undergoing continuous transition, the servicing, operation and maintenance of different products/ systems face multiple challenges. Some of the challenges faced by the service sector are:

(a) At any given time, a technician will have to handle multiple refrigerants such as HCFC- 22, HFC-134a, R-407C, R-410A, HFC-32 and HC-290.
(b) The product technology is also changing fast, e.g. from fixed to variable speed, which in itself is a challenge for the technician.
(c) In case of flammable refrigerants such as HC-290, there is a restriction on the quantum of refrigerant that can be carried in small cylinders.
(d) Retention of trained technicians is a challenge because of seasonality of room AC.

As the currently used HCFCs and HFCs are mostly non-flammable and non-toxic, service personnel tend to be lax with safety issues. One major task is to train these technicians to change their attitude to safety and to follow the new and more difficult safety measures as stringently as possible. Products should be designed to avoid leakage of flammable fluids and, most importantly, eliminate possible sources of ignition.

Recovery, Recycling and Reclamation

For the sake of sustainability, there has been an increasing emphasis on conservation of refrigerants and reduction of emissions through recovery, recycle, reclamation and destruction. More detailed discussion on these topics may be found in UNEP Report (*UNEP*, 2014b).

Recovery

This is a process to remove a refrigerant in any condition from a system for further processing. Refrigerant recovery systems are readily available, including in India. Recovery of refrigerant, especially from systems with relatively large quantities, has become an integral part of servicing practices in most countries with the main incentive as the cost of refrigerants, besides environmental protection. In non-A5 countries, regulatory framework is driving recovery of refrigerants.

Recycling

This is the process to clean the extracted refrigerant using oil separator and filter-drier to reduce moisture, acidity and particulate matter. Recycling is usually carried out at the field site. Since the quality of recycled refrigerant cannot be proven by analysis, some restrictions are imposed on the use of recycled refrigerants in some countries. Currently, MAC industry reuses recycled refrigerant. Refrigerant recovery and recycling equipment have been made available to some OEMs, service stations and technicians in India through MLF funding and are being used.

Reclamation

This is to reprocess used refrigerants to virgin product specifications. Chemical analysis of the refrigerant is made to ensure that certain specifications are met. Reclamation extends the lifespan of the refrigerant and decreases the dependency on virgin refrigerant. Small portable refrigerant reclamation systems, capable of reclaiming about 80 kg of refrigerant per hour are available, with varying features. Reclamation is typically carried out in a designated facility. Reuse of recovered refrigerant requires adherence to certain good practices. For most refrigerants there is a lack of affordable

continued on page 58

ISHRAE Position on Refrigerants

ISHRAE is committed to the following:

- Environmental parameters are more critical than the traditional thermo-physical, thermodynamic and engineering parameters for the choice of refrigerants.
- To protect the environment, promote the use of refrigerants with zero ODP and low GWP, wherever suitable alternatives are available.
- For climate change benefits, energy efficiency is a key parameter for a given application.
- Use of flammable and toxic refrigerants mandates special requirements with respect to safety for systems and installations, for the place where they are located, and for the community who use or handle them.
- Develop and use advanced design and installation codes, guidelines and practices to reduce direct refrigerant emissions.
- Develop and use advanced practices and standard operating procedures and guidelines as well as use appropriate tools and trained personnel to minimise refrigerant losses during installation, operation, maintenance and decommissioning.
- Promote recovery, recycle, reclamation and destruction through appropriate mechanisms.
- Train personnel and support student community, through information dissemination and collaborative research, towards responsible use of refrigerants.
- Promote sustainable RAC practices with a holistic approach.

continued from page 48

field instruments to measure the contaminant levels of recycled refrigerant after processing. Reclamation does require investment, which may only prove viable when the financial return of recovered refrigerant is sufficient. There are a few reclamation centres in India established through MLF funding.

Destruction

This process is to transform used refrigerant into benign chemicals in an environmentally responsible manner. There is a worldwide need for destruction of ODS refrigerants because of environmental benefits from the avoided emissions. The destruction of ODS may have the potential to earn carbon credits through global carbon markets. The most common method of destruction is based on incineration. UNEP, recognizing the benefits of ODS destruction in an environment friendly manner, has approved certain processes. Presently, there are 16 approved destruction processes. There are a number of approved destruction facilities, in both non-A5 and to a limited extent in some A5 countries, including India.

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