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ISHRAE Position Document on "Refrigerants for Indian Refrigeration and Air Conditioning Industries - Challenges and Responsibilities"

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INTRODUCTION

Refrigeration and Air Conditioning (RAC) applications, in the current era, touch our lives in far reaching areas with 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, the human productivity has increased. Refrigeration and air conditioning 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 synthetic fluids were developed. Safety (toxicity and flammability) issues were till then not well understood. Naturally occurring chemicals including ammonia, carbon dioxide, hydrocarbons, water, and air were used. Use of naturally occurring refrigerants, also called as natural refrigerants, had concerns such as high pressures, toxicity, flammability, corrosion, or lower operating efficiencies.

In 1928, Midgley (1930) discovered that dichlorodifluoromethane (a chlorofluorocarbon or CFC) or CFC-12[1] could be used as a non-toxic and non-flammable refrigerant. This was followed by development of a series of chlorofluorocarbon (CFCs) and hydrochlorofluorocarbon (HCFCs). CFC-11, CFC-12, HCFC-22, CFC-113, CFC-114, CFC-115, and HCFC-123, and these were extensively used as refrigerants. These fluids had many desirable characteristics such as thermal and chemical stability, thermodynamic suitability, lower toxicity, non flammability, material compatibility, low cost, etc. Some of these fluids are or were also used as solvents, foam blowing agents, aerosol propellants, etc. In 1974, Molina and Rowland (1974) identified CFCs (including HCFCs) as the major source of chlorine radical in the stratosphere and their link to the ozone layer depletion. The stratospheric ozone layer acts as a filter to UV-B reaching the earth. The lethal consequences of its depletion include health hazards on human beings and other living creatures, and other ecological as well as environmental problems (UNEP, 2014a). The Montreal Protocol in 1987 and its subsequent amendments have changed the landscape of refrigerants. In the past three decades new environmental criteria were applied to refrigerant selection, and many new substances and blends are invented, tested, and commercialized. CFCs and HCFCs were largely replaced with hydrofluorocarbons (HFCs), many of which are considered to be potent greenhouse gases and whose usage is now being restricted due to their relatively high global warming potential (GWP). In the last decade, hydrofluoroolefins (HFOs) have been introduced, which are non-ozone depleting substances and have ultra-low GWP. Some of these HFOs are mildly flammable or toxic, which has necessitated the revision of standards for equipment and their installation to mitigate risks.

[1] ASHRAE designation

[2] Global Warming Potential (GWP) is the heat trapped on the earth by any greenhouse gas in the atmosphere relative to the heat trapped by the same mass of carbon dioxide. Usually, the time period used to measure the relative impact of a greenhouse gases is 100 years. Carbon dioxide, by definition, has a GWP of 1

MONTREAL PROTOCOL

To control the damage to the stratospheric ozone layer depletion, the Montreal Protocol on substances that deplete the ozone layer was agreed upon in September 1987 and became effective in 1989. The Montreal Protocol specifies some control measures for the reduction and ultimately the phase-out of Ozone Depleting Substances (ODSs), including HCFCs. The Montreal Protocol embodied "the polluter pays" principle with committed but differentiated responsibility and created the Multilateral Fund (MLF) in 1991 for the implementation of the Montreal Protocol based on the contributions made by non-Article 5 countries (developed). The Montreal Protocol also provided a 10-year grace period for Article 5 (developing) countries.

India acceded to the Vienna Convention in 1991, ratified the Montreal Protocol 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 their target date of 2010 (MoEF, 2012). HCFCs have lower Ozone Depletion Potential (ODP), e.g., the ODP of HCFC-22 is just 5% of CFC-12. As per the accelerated Montreal Protocol phase out schedule, HCFCs must 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 the 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) must 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.

MONTREAL PROTOCOL

Global warming due to greenhouse 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. The Intergovernmental Panel on Climate Change (IPCC), agrees that global warming is primarily due to human activity, which has occurred since the industrial revolution. To slow down the global warming, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1994. The Kyoto Protocol, 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 of 600 to 4000. Obviously, there is a linkage between the 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 the Montreal Protocol, these are not included in the Kyoto Protocol.

[3] The ozone depletion potential (ODP) of a substance or compound is a measure of degradation to the ozone layer relative to CFC-11 (trichlorofluoromethane)

The European Union introduced the F-gas Regulation in 2006, which was further revised in 2014, to contain the growth of the use of HFCs. In Europe, HFCs have already been banned in many new types of equipment where less harmful alternatives are widely available. The EU MAC Directive prohibits the use of fluorinated gases with a global warming potential > 150 in new types of cars and vans introduced from 2011, and in all new cars and vans produced from 2017. Besides bans on new equipment with high GWP refrigerants, service bans are also used to put pressure on the industry to stop using high GWP refrigerants. For example, from 1st January 2020, the use of fluorinated greenhouse gases with a global warming potential of 2,500 or more to service refrigeration equipment with a charge size ≥ 40 tonnes of CO2 equivalent have been prohibited. Such restrictions affects both owners and the users of commercial refrigeration units that contain F-gases.

HFC PHASE DOWN PROPOSAL UNDER THE MONTREAL PROTOCOL

HFC emissions are projected to grow significantly up to 2050, largely due to 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.

At the 2015 United Nations Climate Change Conference in Paris, COP 21 or CMP 11, nations agreed to keep the global temperature rise this century well below 2 degrees Celsius above pre-industrial levels. Within a year of this conference, a historic climate change deal was signed in Kigali, Rwanda. Under the Kigali amendment of the Montreal protocol, actions to limit the use of HFCs was agreed upon. This amendment will avoid up to 0.5 °C increase in global temperature by the end of the century.

The Kigali amendment has split the Montreal Protocol parties into on four groups (listed in Table 1, following ratification by 65 countries), each with a separate legally binding target phasedown schedule. India is in Group 2 and has a later freeze and phase-down steps compared with Group 1. The freeze date is four years later (2028 compared with 2024).

Table 1: Kigali amendment groups and phase-down schedule

	Non-Article 5 (developed countries)	Article 5 (developing countries) Group 1	Article 5 (developing countries) Group 2
Baseline years	2011-2013	2020-2022	2024-2026

Baseline Calculation	Average production /consumption of HFCs in 2011, 2012, and 2013 plus 15% of HCFC baseline production /consumption	Average production /consumption of HFCs in 2020, 2021, and 2022 plus 65% of HCFC baseline production /consumption	Average production /consumption of HFCs in 2024, 2025, and 2026 plus 65% of HCFC baseline production /consumption
Freeze	-	2024	2028
1st step	2019 -10%	2029 -10%	2032 -10%
2nd step	2024 -40%	2035 -30%	2037 -20%
3rd step	2029 -70%	2040 -50%	2042 -30%
4th step	2034 -80%	-	-
5th step	2036 -85%	2045 -80%	2047 -85%
	For Belarus, the Russian Federation, Kazakhstan, Tajikistan and Uzbekistan. 25% of HCFC baseline production/ consumption First two steps are later: 5% in 2020 and 35% in 2025.		Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates.

ALTERNATIVES TO HCFCs and HFCs

The accelerated HCFC phase out and planned HFC phase down 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 the RAC industry to identify alternative refrigerants.

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 but also be harmless and benign to 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 fugitive emissions of refrigerants from the equipment varies depending on the application. For large, field-installed commercial refrigeration systems, the direct Green House Gases (GHG) emissions contribution can be as high as 40% of the total GHG emissions. In contrast, direct GHG emissions contribution can be lower than 1% for factory-sealed systems. On average, around 80% of annual global RAC equipment GHG emissions are indirect and only 20% are direct (UNEP, 2018). Therefore, due consideration should be given for the selection of refrigerants to achieve higher efficiency, which is also regulated in India. To satisfy the environmental regulations, one must address factors such as flammability, toxicity, cost, etc.

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. The Indian standards are IS 16678 and IS 16656, 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 OEL ≥ 400 ppm

• Class B with OEL < 400 ppm

where OEL (Occupational Exposure Limit) is the 8-hour time-weighted average (TWA) concentration to which nearly all workers can be repeatedly exposed for a normal 8 h workday and a 40 h workweek without adverse effect. It is based on the OSHA PEL, ACGIH TLV-TWA, TERA OARS-WEEL, or consistent value

The flammability classification is based on ASTM E681, *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapors and Gases)* using a spark ignition source as follows

- Class 1 - exhibits no flame propagation
- Class 2L - exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL > 0.10 kg/m^3 and burning velocity ≤ 10 cm/s at 23 C and 101.3 kPa, and heat of combustion < 19 MJ/kg,
- Class 2 - exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL > 0.10 kg/m^3 at 23 °C and 101.3 kPa, and heat of combustion < 19 MJ/kg
- Class 3 - exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL ≤ 0.10 kg/m^3 or heat of combustion ≥ 19 MJ/kg,

where LFL is the lower flammability limit

Table 2 presents environmental, thermodynamic and safety classification data for some selected refrigerants as per IS 16656 (international equivalent ISO 817). The composition data, normal boiling point and critical temperature data has been compiled from the AHRI-700 (2019) standard. The atmospheric life and GWP data have been compiled from Myhre et al. (2013). The ozone depletion potential and safety classification has been compiled from the UNEP Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (2018). For new refrigerants, where data is not available in above references, data has been compiled from manufacturer's technical data sheets. For choosing the transition, retrofitting or substitution fluid, economical, technical, and ecological criteria should be considered. The transition fluids are basically for the new systems while the retrofitting fluids are for the replacement of the old refrigerants in the 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 many technical, health, safety and environmental limitations such as flammability, GWP, operating envelope, performance, etc.

Table 2: Environmental, Thermodynamic and Safety Data of Select Refrigerants

Refrigerant	Chemical Formula/ Composition (wt%)	Environmental Parameters			Thermodynamic and Safety Parameters		
		ODP	GWP (AR5)	Atmo- -spheric Lifetime, Years	Normal Boiling Point ,°C	Critical Tempera- -ture, °C	Safety Classifi- -cation
CFC-11	CCl_3F	1.00	4660	45	23.7	198.0	A1
CFC-12	CCl_2F_2	0.82	10200	100	-29.8	112.0	A1
HCFC-22	$CHClF_2$	0.04	1760	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	1980	17.2	-9.1	137.1	A2
HFC-23	CHF_3	0	12400	222	-82.0	26.1	A1
HFC-32	CH_2F_2	0	677	5.2	-51.7	78.1	A2L
HFC-125	C_2HF_5	0	3170	28.2	-48.1	66.0	A1
HFC-134a	CH_2FCF_3	0	1300	13.4	-26.1	101.1	A1
HFC-143a	$C_2H_3F_3$	0	4800	47.1	-47.2	72.7	A2
HFC -152a	$C_2H_4F_2$	0	138	1.5	-24.0	113.3	A2
HFO-1234yf	CH2=CF-CF3	0	<1	0.029	-29.5	94.7	A2L
HFO-1234ze(E)	(E)CHF=CH-CF3	0	<1	0.045	-19.0	109.4	A2L
HCFO-1233zd(E)	(E)CF3-CH=CCIH	0	1	0.07	18.3	165.6	A1
HFO-1336mzz(Z)	(Z)CF3CH=CHCF3	0	2	0.06	33.4	171.3	A1
HC-290 (Propane)	C_3H_8	0	3	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 (Carbondioxide)	CO2	0	1	>50		31.1	A1
R-404A	R-125/R-143a/R-134a (44/52/4)	0	3943	-	-46.2/-45.5	72.1	A1
R-407A	R-32/R-125/R-134a (20/40/40)	0	1923	-	-45.2/-38.7	82.25	A1
R-407C	R-32/R-125/R-134a (23/25/52)	0	1624	-	-43.6/-36.6	86.0	A1

R-407F	R-32/R-125/R-134a (30/30/40)	0	1674	-	-46.1/-39.7	82.60	A1
R-410A	R-32/R-125 (50/50)	0	1924	-	-51.4	71.4	A1
R-422D	R-125/R-134a/R-600a (65.1/31.5/3.4)	0	2473	-	-43.20/-38.34	78.21	A1
R-438A	R-32/R-125/R-134a/R-600a/R601a (8.5/45/44.2/1.7/0.6)	0	2059	-	-42.33/36.14	83.82	A1
R-448A	R-32/R-125/R-134a/R-1234yf/ R-1234ze(E) (26/26/21/20/7)	0	1273	-	-45.9/-39.8	83.6	A1
R-449A	R-32/R-125/R-134a/R-1234yf (24.3/24.7/25.3/25.7)	0	1282	-	-46/-39.9	81.5	A1
R-450A	R-134a/R-1234ze(E) (42/58)	0	547	-	-23.4/-22.8	104.4	A1
R-452A	R-32/R-125/R-1234yf (11/59/30)	0	1945	-	-47/-43.2	74.9	A1
R-452B	R-32/R-125/R-1234yf 67/7/26 wt%	0	675	-	-51/-50.3	75.7	A2L
R-454A	R-32 /R-1234yf (35/65)	0	238	-	-48.4/-41.6	78.9	A2L
R-454B	R-32 /R-1234yf (68.9/31.1)	0	467	-	-50.9/-50	76.5	A2L
R-454C	R-32 /R-1234yf (21.5/78.5)	0	148	-	-46/-37.8	82.4	A2L
R-455A	R-32/ R-1234yf/R-747 (21.5/75.5/3)	0	146	-	-51.6/-39.1	85.6	A2L
R-507A	R-125/R-143a (50/50)	0	3985	-	-46.74	70.61	A1
R-508B	R-23/R-116 (46/54)	0	13396	-	-87.16	11.20	A1
R-513A	R-1234yf/R-134a (56/44)	0	573	-	-29.47	94.91	A1
R-514A	R-1336mzz(Z)/R-1130(E) (47.1/25.3)	0	2	-	37.85	178.1	B1
R-515B	R-1234ze(E)/R-227ea (91.9/8.9)	0	299	-	-18.80	108.9	A1

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 is calculated as the sum of greenhouse gas emission from direct release of refrigerant from the equipment over the lifetime and indirect use of carbonaceous fuel for generate the electricity to operate the equipment throughout its lifetime.

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 CO2 emission (emission factor), leakage rates, performance during the life cycle of systems, recovery and recycle efficiency, destruction efficiency and so on.

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, 2018). ISHRAE's assessment is based on the current understanding of the open domain data and is not based on any proprietary or commercial information. Lowest GWP options that meets the requirements of safety, performance in Indian ambient conditions and wide availability of systems and components have been recommended.

Table 2: Low GWP Alternative Refrigerants for Various RAC Sectors

Sector	Current Refrigerants Used	Alternative Refrigerants*	ISHRAE Assessment of Low GWP options for India (Lowest GWP feasible options that provide high energy efficiency)
Domestic Refrigeration Single/ double door	HC-600a, HFC-134a	HC-600a	HC-600a
Commercial Refrigeration Self-contained units (Display cabinet, water cooler, bottle cooler, visi-coolers, ice cream cabinets and chest freezers)	HC-290, HCFC-22, HFC-134a, R-404A, R-507	R-22, R-404A and R-507 replacement options: 407 (A, C and F), R-448A, R-449A, R-454A, R-454C, R-455A R-134a replacement options: HFO-1234yf, HFO-1234ze(E), R-450A, R-513A, R-515B Others: HC-290, R-744	Non-flammable: R-448A, R-449A, R-513A, R-515B Mildly-flammable: HFO-1234yf, HFO-1234ze, R-454A, R-454C, R-455A Flammable: HC-290
Room Air Conditioners Mini-split and window air conditioners	HCFC-22, R-410A, HFC-32, HC-290	HFC-32, HC-290, R-452B, R-454B	HC-290, HFC-32
Large Air Conditioners Multi-Split, VRF ACs, ducted, packaged, roof top	HCFC-22, R-407C, R-410A	R-410A, HFC-32, R-452B, R-454B	R-410A, HFC-32, HFO-452B, HFO-454B
Mobile AC Car, Van Bus, Truck, Train	HFC-134a HCFC-22, R-134a, R-407C	HFO-1234yf, R-744, R-152a HFO-1234yf, R-744, R-450A, R-513A	HFO-1234yf, R-152a HFO-1234yf, R-450A, R-513A
Transport Refrigeration Refrigerated reefer Containers	HCFC-22, HFC-134a, R-404A, R-507	R-404A alternatives: R-448A, R-449A, R-452A R-134a alternatives: R-513A	R-452A as an option for new equipment and retrofit. R-448A and R-449A with liquid injection. R-513A

Industrial and Commercial Refrigeration Direct expansion systems (A1 options only) Flooded systems	HCFC-22, R-404A, R-507, HFC-134a (for medium temperature only) R-717, HCFC-22, R-507, HFC-134a	R-407C, R-407F, R-407H, R-448A, R-449A, R-450A, R-513A, R-515B, R-744 (for low ambient only) R-717, HFO-1234ze(E), R-513A, R-515B, R-744 (for low ambient only)	R-448A, R-449A, R-450A, R-513A, R-515B R-717, R-513A, R-515B, HFO-1234ze(E).
Chillers Scroll Screw Centrifugal	HCFC-22, R-407C, R-410A HFC-134a HFC-134a (medium pressure), HCFC-123 (low pressure)	HFC-32, R-452B, R-454B R-1234ze, R-515B, HFO-513A R-1234ze, R-515B, HFO-513A HFO-1233zd, HFO-514A	HFC-32, R-454B R-1234ze, R-515B, HFO-513A Medium pressure: R-1234ze, R-515B, R-513A Low pressure: HFO-1233zd, R-514A

* The alternative refrigerant list is limited to options that were commercially adopted in the last 2 decades

HFCs and HFOs

HFC-134a is the most widely used refrigerant across many RAC sectors. R-410A is currently the most popular alternative to HCFC-22 in the 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 OEMs may face problems when dealing with exports to some countries. Room ACs with HFC-32 are commercially available in many countries, including India. In medium size DX air-conditioning systems, such as VRF, ducted, roof-top, A2L options can be used in compliance with IS/IEC 60335-2-40:2018 and IS-16678:2018. HFO-1234yf is the most favoured choice for mobile AC and has already been commercialised in non-A5 countries. Its use in other sectors is not yet certain. Since scroll chillers are installed outdoors, A2L replacement options for R-410A such as R-32, R-452B and R-454B are being adopted. They provide improvement in performance over R-410A. Chillers using HFO-1234ze(E), R-515B, R-513A, R-514A and HFC-1233zd(E) are now commercially available. Lower GWP refrigerants, such as R-407F, R-452A, R-448A, R-449A, R-454C and R-455A are now widely used for medium to large commercial refrigeration applications.

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 the 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 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 mini-split systems must be field installed.

Ammonia (R-717) is a thermodynamically attractive fluid which is in use for decades in industrial refrigeration and cold storages but is toxic and mildly-flammable (B2L). Therefore, proper training for service and maintenance is required. With appropriate application of safety codes in Europe, ammonia has proved itself 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 economics 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, GWP of 1 and an A1 safety class. However, its vapour pressure is much higher and critical temperature 31.1 C is very low. Therefore, the refrigeration cycle using CO2 is uniquely operated as a trans-critical cycle. The efficiency of R-744 systems will depend on ambient temperature. Today it is widely used for refrigeration in supermarkets in EU and its use is growing in the USA, where the ambient is mild (e.g., less than around 20 C) and the resulting COP of the system may be higher than that of R-404A. However, in warm and hot conditions, such as in India, the efficiency starts to fall and is lower than R-404A. The other development of R-744 systems is in transport air-conditioning, such as in trains and bus, in the EU region. R-744 can be used for the low temperature cycle in commercial cascade 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 the system operation, ruptures of safety valves, rupture disc, 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 yet cost effective for developing countries.

Zero Leakage and Minimum Charge: Non-Article 5 countries are now targeting at minimum refrigerant charge and zero leakage during the life cycle of the system. The limitation of refrigerant emissions depends on efficient recovery policy for end-of-life equipment, careful refrigerant handling by OEM and efficient leak fixing during operation and maintenance by service sector. Of these, the service sector has been identified as the primary area in need of improvement. There are concerted efforts globally to train technicians for good service practices towards zero leaks.

Service Sector: As the refrigerant scene is undergoing continued transition, the servicing, operation, and maintenance of different products/systems faces multiple challenges. Some of the challenges faced by the service sector are listed below:

(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, R-404A, HC-290, etc.

(b) The product technology is also fast changing, e.g., from fixed to variable speed, which is a challenge for the technician.

(c) In case of flammable refrigerants, such as HC-290, there is a restriction on the amount of refrigerant that can be carried in small cylinders.

(d) Retention of trained technicians is challenge because of seasonality of room AC usage.

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 rigorous safety measures as stringently as possible. Products should be designed to avoid leakage of flammable fluids and most significantly 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) and IS/ISO 11650: 1999.

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 a conventional part of servicing practices in most countries with the main incentive being the cost of refrigerants, besides environmental protection. In non-A5 countries, regulatory framework is driving recovery of refrigerants.

Recycling - This process is to clean the extracted refrigerant using oil separators and filter-driers 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, the 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 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 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. There are several approved destruction facilities, in both non-Article 5 and to a limited extent in some Article 5 countries, including India.

ISHRAE POSITION ON REFRIGERANTS

ISHRAE is committed to the following:

- ISHRAE advocates a responsible selection of refrigerants, which minimize the environmental impact of refrigeration and air conditioning systems, ensures occupational safety and result in low total ownership cost.
- Refrigeration and air conditioning equipment consumes electricity and thereby indirectly contributes to CO2 emission. Seasonal energy efficiency ratio is an important consideration when selecting an equipment to minimize its lifetime greenhouse effect contribution.
- Emission of high GWP refrigerants into the atmosphere during operation, maintenance and end-of-life of refrigeration and air conditioning equipment can have significant greenhouse effect contribution. To protect the environment, promote the use of refrigerants with zero ODP and low GWP, wherever suitable alternatives are available.
- 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
- Conduct risk assessment for Indian conditions and develop industry guidelines, standards, and codes for the safe adoption of low GWP flammable refrigerants
- Develop and use advanced design and installation codes, guidelines, and practices to reduce the 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

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ABOUT ISHRAE:

The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE), was founded in 1981 at New Delhi by a group of eminent HVAC&R professionals. ISHRAE today has over 30,000 HVAC & R professionals and Student -members. ISHRAE operates from 44 Chapters and Sub-chapters spread across India with its Head Quarters in Delhi. ISHRAE is led by a team of elected officers, who are members of the Society, working on a voluntary basis, and collectively called the Board of Governors.

ISHRAE's Objectives:

- Advancement of the Arts and Sciences of Heating, Ventilation, Air Conditioning and Refrigeration Engineering and Related Services.
- Continuing education of Members and other interested persons in the said sciences through Lectures, Workshops, Product Presentations, Publications and Expositions.
- Rendition of career guidance and financial assistance to students of the said sciences.
- Encouragement of scientific research.

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ACKNOWLEDGEMENTS :

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