Safety Issues and Standards for HC-290 in Room Air Conditioners

Introduction

Many of the refrigerants including Hydrochlorofluorocarbons (HCFCs) and Hydrofluorocarbons (HFCs) used in refrigeration and air conditioning (RAC) systems are generally non-flammable, non-toxic and are synthetic fluids. HFCs do not cause damage to the ozone layer but have high GWP and are classified as greenhouse gases (GHGs) under Kyoto Protocol (KP); although HCFCs are also potent GHGs but are not covered under KP as they are scheduled for phase out under MP. HFCs have high global warming potentials (GWPs). Due to the growing national and international concern regarding the resulting atmospheric effects of GHGs as well as due to self-imposed regulations in some of the developed countries, the use of alternative low GWP refrigerants is increasing. As a consequence, the world is now negotiating an amendment to the Montreal Protocol to eliminate the use of high GWP HFCs to keep climate change within manageable limits.

In the context of replacing HCFCs, the alternatives must meet the basic requirement of having zero ozone depleting potential. Developed countries have more or less moved to HFCs from HCFCs and developing countries have started phasing in HFCs. However, Multilateral Fund (MLF) specifically encourages and promotes alternatives that minimise environmental impacts, taking into account global-warming potential (GWP), and energy efficiency. However, for various sub-sectors, there is no single 'one-size-fits all' option to replace HCFCs; each alternative has its own pros and cons and several important issues, particularly relating to safety, need to be addressed.

HFC Phase Down

It is now widely accepted that a phase-down of HFCs has the potential to provide rapid global climate benefits. After some negotiations, the Vienna Convention and the Montreal Protocol have gradually emerged as a suitable platform to discuss this phase-down. Currently there are four different proposals to amend the Montreal Protocol to phase down HFCs. The four amendment proposals put forward by parties to be discussed are:

- Joint proposal by US, Canada and Mexico (North American proposal)
- Joint proposal by Kiribati, Marshall Islands, Mauritius, Micronesia (Federated States of), Palau, Philippines, Samoa and Solomon Islands (the Micronesian or Island States Proposal)
- Proposal submitted by India (Indian proposal)
- The European Union proposal (European proposal)

Low GWP Alternatives

Most of these low GWP alternative refrigerants are some of the synthetic unsaturated Hydrofluoroolefins (HFOs), natural refrigerants like Hydrocarbons (HCs), Ammonia (R-717) and R-744 (Carbon dioxide) and HFC-32 with lower-GWP (675) fluid. Historically, natural refrigerants were used before the introduction of synthetic fluorocarbons and continue to be used in many applications for many decades. Most of the fluids, including some of HFOs, HCs, R-717 and HFC-32, are flammable. There are some standards applicable to flammable refrigerants but there is none in India although Split ACs, using HC-290 up to 5.0 kW, are already in the market but are unable to sell beyond 5.0 kW capacity as there are no Indian standard and international standards are too restrictive. In this context of setting standards for room air conditioning for HC-290 which has zero ODP as well as a very low GWP (3) is extremely important and urgently needed.

Refrigerant Safety Classification

Global standards applicable to refrigeration and air-conditioning are mainly from the International Standardisation Organisation (ISO) and the International Electrotechnical Commission (IEC) in addition to some of the regional (EN) and country specific standards (ASHRAE). It is a common practice that international and regional standards are adopted at the regional and national levels. During this procedure, standards can be modified to suit the best local demands and conditions. All refrigerants are dangerous, if misused or applied incorrectly. While having less impact on the environment, flammable refrigerants are significantly more easily combusted compared with CFCs and HCFCs and some HFCs. HCs are excellent refrigerants in terms of performance and because of their negligible environmental impact aspects. However it is generally acknowledged that their main hindrance is related to their flammability.

All refrigerant gases are classified ISO 817 (2014), IEC 60335 (2012) and ASHRAE 34 into different refrigerant safety groups (see Table below). EN-378, an European Standard, is also being harmonised with the above standards.

Flammability	Lower Toxicity	Higher Toxicity
Non flammable (No Flame Propagation)	A1 (HCFC-22, HFC-134a, R-410A)	B1 (includes HFC-123)
Mildly flammable	A2L (includes HFO123yf)	B2L (includes ammonia)
Lower Flammability	A2 (HFC-152a)	B2
Highly Flammability	A3 (includes HCs)	B3

Table 1a: Refrigerant Safety Classification

Safety Classification	Lower Flammability Limit, % in air by volume	Heat of Combustion, kJ/kg	Flame Propagation
1 (Non flammable)	No flame propagation when tested at 60°C and 101.3 kPa		
2 (flammable)	> 3.5	<19	Exhibit flame propagation when tested at 60°C and 101.3 kPa
2L (mildly flammable)	> 3.5	<19	Exhibit flame propagation when tested at 60°C and 101.3 kPa and have a maximum burning velocity of ≤ 10 cm/s when tested at 23°C and 101.3 kPa

3 (highly flammable)	≤3.5	≤19	Exhibit flame propagation when tested at 60 °C and 101.3 kPa

Table 1b: Refrigerant Flammability Classification

The category '2L' is a specific class, which was added in the update of the above standards, for lower-flammability refrigerant with low flame speed. The burning velocity of 2L is less than or equal to 10 cm/s.

Property	HFC-32	Propane, HC-290
GWP	675	~20
ASHRAE 34 Classification	***A2L***	***A3***
Burning velocity	6.7	46
Heat of combustion, MJ/kg	9.5	50.44
LFL (% volume in air)	14.4	2.1
UFL (% volume in air)	29.3	9.5
Minimum Ignition Energy, MJ	30-100	0.25
Auto-ignition temperature, C	648	460

Table 2: Comparative Characteristics of HFC-32 and HC-290

It can be seen from Table 2 that safety designation of hydrocarbon refrigerants is A3 – high flammability and lower toxicity as compared to HFC-32 which is classified as A2L. The LFL and UFL of HC-290 are 2.1 and 9.5 (% volume in air) respectively. These values translate to 0.038 and 0.177 kg/m^3 respectively.

ISO 5149 (2014) was recently revised to include A2L refrigerants and is applicable to all types of refrigerating systems in which the refrigerant cycle in a closed circuit. It specifies the requirements relating to the safety of persons and property for the design, construction, installation and operation of refrigerating systems and puts an emphasis on minimising the leakage of refrigerants.

HCs and Safety Issues

Hydrocarbons (HCs) pose a risk of fire and explosion hazard, if there is a refrigerant leak. The vapour within the closed refrigeration system is not flammable until oxygen (in air), in the required concentration, is present at the location of the leak, or in the location(s) where the hydrocarbon gas travels after leaking from the system. If the gas and air mixture is within the upper and lower flammability limits (UFL and LFL in air respectively) for a particular refrigerant, the mixture is flammable in the presence of an ignition source with sufficient ignition energy. Hot surfaces and electrical arcs, such as those present at the contacts of electrical switching contacts (switches, temperature and humidity controls, etc.), are the principle potential ignition sources in HVAC and appliances.

The flammable refrigerant charge limits are normally established at 20% of the refrigerant's lower flammability limit when leaked into a prescribed volume. The maximum allowable refrigerant charge for a room air conditioner unit depends on the room volume. For safe use of HC-290 a practical limit of 8

g/m^3 (0.23 g/cft) may not be exceeded in a closed space or room. For a typical room of 14'x12'x9'(high), with a volume of 43 m^3 (1512 cft), the safety limit would be about 350 g of HC-290 in a propane air conditioner. Design changes in product could avoid the risks associated with the use of flammable refrigerants. Colbourne and Suen (2003 and 2015) presented a methodology for assessing the risks associated with the use of flammable refrigerants in room air conditioners. Most influencing parameters that contribute to the overall risk are higher concentration of refrigerant at floor level and failure of critical safety components.

To reduce risk of any ignition, the following should be avoided:

- sparking electrical components or take necessary precautions using spark proof or sealed components
- hot surfaces (i.e. above 460°C)
- any static electricity
- a flame, for example from a brazing torch, halide torch leak lamp, match or lighter

The chance of combustion within the air conditioner compressor is almost zero as there will not be sufficient air to form the combustible mixture.

A2 or A3 refrigerants are not usually a suitable drop-in replacement for systems designed for non-flammable (A1) refrigerants. Conversion of systems designed for A1 refrigerants to A2L or A3 refrigerants may be possible only under certain safe conditions and, if implemented without risk assessment and mitigation, is deemed to be unsafe.

Need for an Indian Standard

India faces a number of barriers related to standards for HCs. India does not have a standard for room air conditions and so to make hydrocarbon air conditioners, the Indian HC Air Conditioner manufacturer has apparently followed EN378 standard for its Split ACs using HC-290. Although IEC 60335 is under revision and India is a member of ISO, we need to start the process of similar Indian standards as soon as possible as developing a India specific standard requires significant technical resources, expertise and time..

It is important for a developing country like India to develop its own version of a standard as it will help the local industry stay independent and take the decision to move in the direction in the best interest of the industry and environment. When doing this, it is advisable to follow an equivalent international standard, or widely acknowledged national or regional (e.g. European) standards.

Limiting the amount of refrigerant charge within a single refrigerant circuit is one approach to achieving a desired level of safety. In general, the limits on the mass of HC refrigerant within a single refrigerant circuit is according to the type of system, the type of location and the size of the space, particularly in respect to occupied areas.

For installations within human occupied spaces, a minimum room size is to be specified for a given refrigerant circuit charge size. Two restrictions apply to refrigerant charge sizes:

- The first is a “maximum” charge size (M_{max}), which is a function of the type of location and its occupancy (or not)
- The second is an “allowable” charge size (M_{al}), which is a function of size of the (occupied) area that the refrigerant could leak into

Most of the existing safety standards, including ISO 60335-2-40, incorporate this approach to some extent.

Allowable charge limits for HC-290 for Room ACs

The methods of the estimation of the allowable charges, which are listed in ISO 60335 are similar to those in EN 378 for A/C and heat pumps for human comforts. The allowable charge sizes, according to ISO-60335-2-40 are typically based on the assumption that under the worst case, the entire refrigerant charge from a circuit will leak into a space almost instantaneously, and as the vapour is denser than air, it will slowly stratify – thus the allowable charge normally accounts for this by adopting a 20% of the quantity corresponding to LFL for safety margin. In certain cases, this safety margin is further limited to factors approaching less than 5%. On the other hand, the values for maximum charge size have been chosen on a broadly arbitrary basis, although it can be seen that there is a general correspondence between lower refrigerant charge sizes and the vulnerability of the occupants.

According to these standards, the maximum refrigerant charge for A3 fluids depends on the occupancy category and on the location of the refrigerant containing parts as defined below.

- Category A: general occupancy not restricted at all. Dwellings and public places, for example, hospitals, prisons, theatres, supermarkets, transport termini, hotels, restaurants, etc.
- Category B: supervised occupancy restricted to a certain number of people, some of whom are aware that the system is charged with an HC. Offices, laboratories, places of work, etc.
- Category C: occupancy with authorised access only. Non public areas in supermarkets, cold stores, manufacturing facilities, refineries, etc.

Furthermore, systems are also defined according to the general positioning of the components in relation to the occupancies:

- entire system within human occupied space which is not a machinery room;
- compressor and liquid receiver in an unoccupied machinery room or in the open air; and
- all refrigerant containing parts in an unoccupied machinery room or in the open air.

Table 3 presents the some of the features of this standard.

Location of refrigerant containing parts	**System type**	**Refrigerant mass**	**Occupancy type**				
			Category A (general occupancy)		**Category B (supervised occupancy)**		**Category C (occupancy with authorised access only)**
			RHPAC	**Comfort HPAC**	**RHPAC**	**Comfort HPAC**	**RHPAC and Comfort HPAC**
Human occupied space which is not a machinery room	Direct	Allowable (Mal)	$PL \times V_{Rm}$	$2.5LFL^{1.25}h\sqrt{A_{Rm}}$ or $0.5A_{Rm}\sqrt{LFL}$	$PL \times V_{Rm}$	2.5LFL1.25h Arm or 0.5ARmLFL	$PL \times V_{Rm}$
		Maximum (Mmax)	1.5 kg, or 1 kg BG	26 × LFL, or 1 kg BG	2.5 kg, or 1 kg BG	26 v LFL, or 1 kg BG	10 kg (or 25 kg*), or 1 kg BG
In an unoccupied machinery room or in the open air or a special ventilated enclosure	Indirect	Allowable (Mal)	5 kg, or 1 kg BG	130 × LFL, or 1 kg BG	10 kg, or 1 kg BG	130 × LFL, or 1 kg BG	No limit, or 1 kg BG
		Maximum (Mmax)	5 kg, or 1 kg BG	131 × LFL, or 1 kg BG	11 kg, or 1 kg BG	131 × LFL, or 1 kg BG	No limit, or 1 kg BG

Table 3: Allowable Charge for various occupancies and applications (EN378)

It is known that some of the clauses for charge limits by the safety standards can be very restrictive, sometimes with good reason and sometimes even without. If there is a certain need for higher charge sizes, then consider certain approaches:

- Use two independent refrigerant circuits rather than one
- Use indirect refrigerant circuits so that the refrigerant charge may be kept in a location away from the occupied space
- Use a safety system, where if there is a leak, only a limited quantity of refrigerant may be released into the occupied space, whilst retaining the substantial part of the refrigerant within

an external (outside or occupancy C) part of the system. If this type of approach is being used, ensure that the mechanism is tested and its reliability proved, and carrying out a thorough risk assessment to confirm that under no circumstances will a failure lead to a flammable atmosphere being created in a location that hasn't already been designed to handle it.

Current formula is assuming 4 minutes to release all refrigerant and is given by Equation 1:

$$m_{max}=2.5 \times (LFL)^{(5/4)} \times h_o \times (A)^{1/2} \quad (1)$$

where: m_{max} = allowable maximum charge in a room (kg); A = room area (m^2); LFL = Lower Flammable Limit ($kg\ m^{-3}$); h_0 = installation height of the indoor unit (m).

As per this standard, the maximum allowable charge in a single circuit system should be 1 kg when system is located below ground.

Air conditioner Capacity, kW		3.52	5.27	7.04
Floor area as per BEE(m^2)		9.29 to 13.92	13.93 to 20.92	20.93 to 30.1
		Allowable charge size (kg)		
Installation Height (m)	0.6 (floor location)	0.150	0.150	0.150
	1.8 (wall mounted)	0.230	0.282	0.345
	1.0 (window mounted)	0.150	0.157	0.192
	2.2 (ceiling mounted)	0.281	0.344	0.422

Table 4: Allowable HC-290 charge sizes as per EN 378 for different capacity ACs

Table 4 prescribes allowable HC-290 charge calculated for different installation heights and different capacity split ACs. The factory sealed single packaged air conditioner, the allowable refrigerant charge per independent circuit can be determined from equation (3) if charge is less than 300g.

Leakages of HC-290 into Closed Spaces

It is well known that there are several potential hazards associated with the application of flammable refrigerants but the concerns with leakages can be addressed with providing necessary safety features. Multiple studies have been performed to show that the charge size of the hydrocarbons is overly restrictive.

A study was carried out by Li (2014) in a specially built test room of dimensions: 4.8 m × 3.6 m with height 2.6 m; the size simulated a typical master bedroom in China. An extensive series of experimental and numerical studies were carried out to assess the flammability hazards of using HC-290 in room air conditioners. These studies involved measuring HC-290 concentrations arising from a leak under different scenarios (different locations of indoor units, height of the unit, different hole sizes, and charge sizes), the consequences arising from ignition, the severity of a secondary fire developing from ignition and the effect of an external fire on air conditioners. Similar tests have been carried by Zhang et. al. (2013 and 2016)

Based on these investigations, the following general conclusions were drawn:

1. The flammable range of release of R-290 is only located within the close proximity of the indoor unit, implying that only sources of ignition present in the immediate vicinity of the indoor unit have the possibility to ignite a leak of refrigerant.
2. It is only possible for ignition to occur within the immediate vicinity of the indoor unit and only when the mass flow rate is extremely high and there are some measures by which the released refrigerant can be diffused to a sufficiently large volume.
3. In the event of ignition, the maximum overpressure within the room is about 6.5 kPa, which was insufficient to damage doors or windows.
4. The most dangerous situation is if HC-290 is ignited during the leak process and continuous burning of the refrigerant occurs. Under this scenario, it is feasible that the secondary event of the plastic casing of the indoor unit could be ignited. If this occurs, a lot of smoke can be generated, which can have a significant impact on the personal safety of room occupants.
5. If an external fire is to engulf the air conditioner charged with HC-290, the total heat release of the burning indoor unit may increase by about 12%, compared to a unit charged with no refrigerant. It was observed that the refrigerant piping joints can give way soon after the indoor unit is ignited, acting as a sort of pressure-relief device, leading to a release of refrigerant, avoiding a dangerous build-up of high pressure within the system.

It is well established that the greatest obstacle to the adoption of HC-290 as a refrigerant in air conditioners is its flammable characteristics. Corberana et. al (2008) through risk assessment has proposed a number of mitigation measures:

1. Ensure that the indoor unit is installed away from any potential sources of ignition
2. Include a sensor to identify whether there is a leak of refrigerant from the indoor unit (or any other part of the system)
3. Include a cut-off valve in the refrigerant pipeline of the Out Door Unit, which can immediately shut off the refrigerant pipelines once a loss of refrigerant is detected; this will minimise the quantity of refrigerant leaked into a closed space
4. Minimise the use of combustible materials for the construction of the indoor units
5. Use of a highly reliable joining technique for the connection between the refrigerant pipes between indoor and outdoor units.

Conclusions

It is now well established that HC-290 is a very efficient refrigerant for room air conditioners and there are commercial units in the market, however limited to capacities up to 1.5 TR as the current standards are too restrictive for HC-290. Some of the recent studies have highlighted the undue restrictiveness of the standards and the need for relaxation. There are also some recent studies indicating the possible ways to mitigate the risks posed by HC-290 in room ACs. Rightly so, the safety standards for refrigerants are under revision and this process may time considerable time considering the procedures. Therefore, there is an urgent need to develop India specific standards for room air conditioners using HC-290. This will facilitate the expansion of the use of HC-290, a long term refrigerant without any uncertainty with respect to emerging environmental regulations, in higher capacity ACs.

References:

ASHRAE Standard 15-2013 (packaged w/ Standard 34-2013) - Safety Standard for Refrigeration Systems and Designation and Classification of Refrigerants

ASHRAE 34 – 2013 Designation and Safety Classification of Refrigerants and 2015 Addenda Supplement to ANSI/ASHRAE Standard 34-2013, Designation and Safety Classification of Refrigerants

Colbourne D., Suen K. O. Equipment design and installation features to disperse refrigerant releases in rooms - part I: experiments and analysis, International Journal of Refrigeration, 2003, 26(6): 667-673.

Colbourne D., Suen K. O. Equipment design and installation features to disperse refrigerant releases in rooms - part II: determination of procedures, International Journal of Refrigeration, 2003, 26(6): 674-680.

Colbourne D., Suen, K.O., Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants [J]. International Journal of Refrigeration, 2015, 59(9): 295-303.

Corberana,J.M., Seguradoa,J., Colbourne, D. And lveza, G., Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment International J Refrigeration, 31 (2008) 748-756

EN378 - Refrigerating Systems & Heat Pumps-Safety & Environmental Requirements

IEC 60335-2-40:2013 Household and similar electrical appliances - Safety Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers

ISO 817:2014 Refrigerants - Designation and safety classification

ISO 5149:2014 Mechanical refrigerating systems used for cooling and heating

Li, T., Indoor leakage test for safety of R-290 split type room air conditioner, International J Refrigeration, 40 (2014) 380 -389.

Zhang,W., Yang. Z., Zhang, X., Lv, D., and Jiang, N., Experimental Research on the Explosion characteristics in the indoor and outdoor units of a split air conditioner using the R290 refrigerant, , International Journal of Refrigeration (2016).

Zhang,W., Yang. Z., Li, J., Ren, C., Lv,D., Wang,J., Zhang, X. and Wu, W., Research on the flammability hazards of an air conditioner using refrigerant R-290, International Journal of Refrigeration (2013) 36(5): 1483-1494.

APPENDIX
Indian Standards for Air Conditioners

AC and its Components

- Specification for Packaged Air Conditioners, IS 8148 2003
- Room Air Conditioners – Specification (Part 1 and 2), IS 1391 1992 (Amended in 2010)
- Specification for Hermetic Compressors, IS: 10617 (Part 1, 2 & 3) 2013
- Safety Code for Mechanical Refrigeration, IS: 660 – 1963
- Code of Practice for Compressor Safety, IS: 11467 – 1985.
- Code of Practice and Measurement Procedures for Testing Refrigerant Compressors, IS: 5111 – 1993.
- Specification for Finned Type Heat Exchanger for Room Air Conditioner, IS: 11329 - 1985
- Specification for Thermostats for Use in Refrigerators, Air Conditioners, Water Coolers and Beverage Coolers, IS: 11338 – 1985
- General and Safety Requirements for Household and Similar Appliances, IS: 302 – 2011
- Wrought Copper Tubes for Refrigeration and Air-Conditioning Purposes – Specification, IS 10773: 1995

HC Handling

- Code of Practice for Liquefied Petroleum Gas Cylinder Installations, IS: 6044 (Part I) – 2000 & (Part II) – 2001
- Code of Practice for the Selection, Installation and Maintenance of Electrical Apparatus for Use in Potentially Explosive Atmospheres (Other than Mining Application or Explosive Processing and Manufacture), Part 1 General Recommendation, IS: 13408 (Part I) & (Part II) – 1992
- The Gas Cylinders Rules 2015.
- The Static and Mobile Pressure Vessels (Unfired) Rules, 2015.
- The Central Motor Vehicles (Amendment) Rules, 2015

General

- Factories Act, 1948
- The Public Liability Insurance Act, 1991 (amended 1992)

Note: Wherever applicable, the latest standards and regulations should be used.