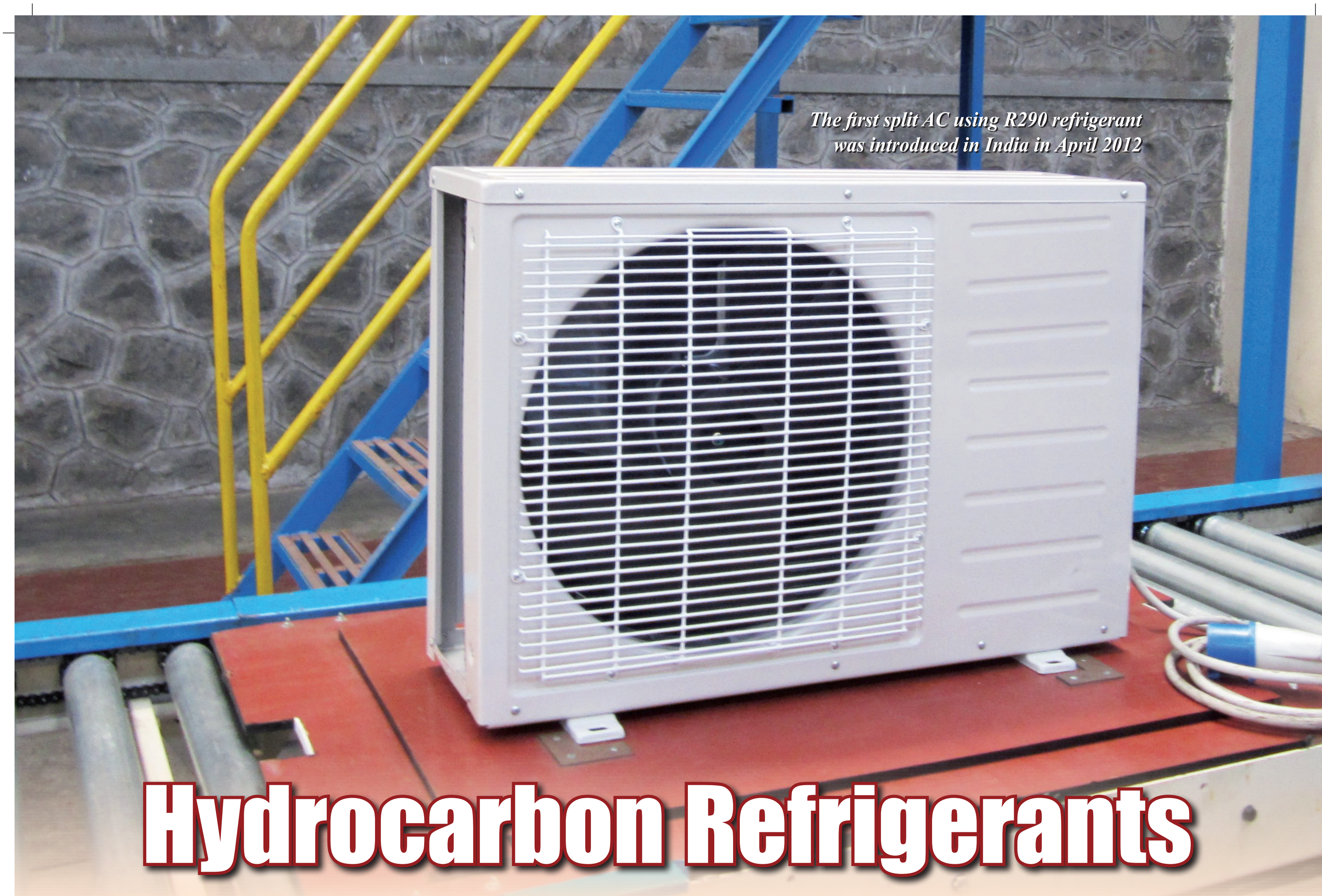

The first split AC using R290 refrigerant was introduced in India in April 2012

# Hydrocarbon Refrigerants

**By D. Ravindra**
*Electrical Engineer*
*Trainer and Consultant, Hyderabad*

## Introduction

Hydrocarbons (HCs) are environment friendly and efficient refrigerants for use in refrigeration. Hydrocarbons are not new and were developed as refrigerants in the early 19th century. However, they were quickly abandoned in favour of CFC/ HCFC refrigerants such as R-11, R-12 and R-22 and so on that were invented in the 1930s, as the latter were easier to use since they had none of the flammability issues of HCs.

However, in the 1980s, concerns emerged over damage to the ozone layer due to the chlorine content of CFC/ HCFC refrigerants, which led to the banning of CFCs (R-11, R-12, R-502, etc.) and phase out of HCFCs (R-22, etc.) under the Montreal Protocol. This led to the adoption of HFC refrigerants such as R-134a, R-404A, R-410a, which have zero Ozone Depletion Potential (ODP).

More recently, the debate on the greenhouse gas effect, rising temperatures and climate change have focused attention on the high Global Warming Potential (GWP) of HFC refrigerants, and the need to curb the use of these refrigerants under the Kyoto Protocol. This has brought natural refrigerants like Hydrocarbons, Ammonia and $CO_2$ back into the limelight.

Many European manufacturers of commercial and domestic refrigeration equipment have now changed to HC technology. Every year, over 8 million hydrocarbon based refrigerators are produced in Europe, each using around 30% less energy than refrigerators using fluorocarbon refrigerants. These include companies such as Bosch, Electrolux, Miele, Whirlpool and AEG. Large supermarket chains in the UK have adopted HC refrigerants to refrigerate their entire stores. In Asia, LG produces over 11,000 refrigerators per day using HC refriger-

### About the Author

**D. Ravindra** is an electrical engineer from IIT, Kharagpur and IISc, Bangalore. He has over 35 years of experience in product development, testing and manufacturing of AC&R products and has worked with reputed companies like Blue Star and Voltas. He is currently engaged as a Trainer and Consultant in AC&R equipment. He is a Life Member of ISHRAE and is on the faculty of ISHRAE Institute of Excellence, Hyderabad Chapter of ISHRAE.

ants. In China, hydrocarbon refrigerants are used by 3 out of 4 of the largest refrigerator manufacturers.

## Salient Features of HC Refrigerants

- HC refrigerants are non-toxic, non-ozone depleting and have very low GWP; hence they are truly eco-friendly (see *Table 1).*
- For refrigeration applications, HCs generally give a 5 to 15% improvement in COP in comparison to fluorocarbon refrigerants. In air conditioning systems, the improvement in COP is much higher.
- This improvement arises out of the favourable refrigerant properties of HCs, such as low viscosity, high thermal conductivity, high latent heat and low pressure ratio.
- HCs have good compatibility with compressor lubricants, most metals, elastomers and plastics, with the exception of natural rubber, ethylene propylene diene monomer (EPDM) and silicone rubber. Both mineral oils, which were used with the CFC / HCFC refrigerants, as well as synthetic lubricants like polyolester (POE) oil, are compatible with HC refrigerants.
- HCs are good electrical insulators and are compatible with plastic insulation and sealants used in refrigeration systems.
- HC refrigerants are non-hygroscopic and do not become caustic if contaminated with moisture or oxygen. They extend compressor winding life, produce negligible copper plating and coke formation on valves, and extremely low chemical breakdown.
- They are non-corrosive and chemically stable at temperatures far higher than those which occur in refrigeration equipment.
- HCs can be easily implemented in conventional cooling systems with minimum investment in components and design.

The one factor which has discouraged the use of HC refrigerants is their flammability. However, if used sensibly, they are no more dangerous than the LPG we use daily in our kitchens. Hydrocarbon refrigerants do not spontaneously combust on contact with air. Three elements need to coincide:

- There needs to be a release of hydrocarbons.
- The hydrocarbon needs to mix with the correct proportion of air, the range of flammability being between 2 and 10% approximately. Outside of these limits combustion cannot occur.
- An ignition source exceeding 440°C must be present.

If one of these three elements is absent, combustion cannot occur. Before discussing this aspect further, let us look at the HC refrigerants commonly used in refrigeration and air conditioning.

*Table 1: Environmental properties of HCs and equivalent halocarbon refrigerants*

| Refrigerant | Name | Type | ODP | GWP | Atmospheric Life (Years) | Toxic? | Flammable? |
|---|---|---|---|---|---|---|---|
| R-600a | Isobutane | HC | Zero | 3 | <<1 | No | Yes |
| R-290 | Propane | HC | Zero | 3 | <<1 | No | Yes |
| R-1270 | Propylene | HC | Zero | 3 | <<1 | No | Yes |
| R-12 | Dichlorodifluoromethane | CFC | 1 | 2400 | 102 | No | No |
| R-134a | Tetrafluoroethane | HFC | Zero | 1300 | 14 | No | No |
| R-22 | Chlorodifluoromethane | HCFC | 0.055 | 1700 | 12 | No | No |

*Table 2: HC refrigerants used in refrigeration and air conditioning*

| Refrigerant | Application Range | Replacement |
|---|---|---|
| R600a (isobutane) | high/medium temperature; domestic appliances. | (R12, R134a)* |
| CARE30 (R600a/ R290 blend) | high/medium temperature; domestic appliances. | R12, R134a |
| R290 (propane) | high/medium/low temperature; commercial, industrial; freezers, air conditioning, heat pumps. | R22, R404A, R407C, R507A |
| Rl270 (propylene or propene) | high/medium/low temperature; commercial, industrial; industrial and process refrigeration, air conditioning, heat pumps, chillers. | R22, R404A, R407C, R507A |
| CARE 50 (R290/ R170 blend) | high/medium/low temperature; commercial, industrial; industrial and process refrigeration, air conditioning, heat pumps, chillers. | R22, R404A, R407C, R507A |
| R170 (ethane) | Low temperature cacade systems | R13, R23, R503 |

## HC Refrigerants Used in Refrigeration and Air conditioning

The HC refrigerants used in refrigeration and air conditioning products are shown in *Table 2.*

This article will concern itself largely with R600a and R290 refrigerants used in commercial refrigerating appliances.

## Some Properties of HC Refrigerants

The vapour pressure range of HC refrigerants matches that of popular fluorocarbon refrigerants but their significantly lower molecular mass give them superior transport properties. Vapour pressure can be used as a general indication for "equivalent" refrigerant replacement. The vapour pressure and volumetric capacity of R-600a are about half those of R-134a. Hence isobutane systems operate at much lower pressures compared to R-134a systems. Due to the low volumetric capacity, R600a compressor displacement is nearly twice that of R-134a compressors *(Table 3).*

R290 systems have vapour pressures fairly close to those of R-22, while volumetric capacity is somewhat close. R1270 also has vapour pressure fairly close to R-22.

Densities of liquid (and vapour) influence refrigerant charge size. HCs

*Table 3: Physical properties of HCs and other refrigerants*

| Refrigerant | R290 | R134a | R404A | R22 | R600a |
|---|---|---|---|---|---|
| Name | Propane | 1,1,1,2-Tet-raflouro-ethane | Mixture R125, R143a, R134a | Chloro-difluoro-methane | Isobutane |
| Formula | $C_3H_3$ | $CF_3$-$CH_2F$ | 44/52/4 | $CHF_2Cl$ | $(CH_3)_3$ CH |
| Critical temperature in °C | 96.7 | 101 | 72.5 | 96.1 | 13.5 |
| Molecular weight in kg/kmol | 44.1 | 102 | 97.6 | 86.5 | 58.1 |
| Normal boiling point in °C | –42.1 | –26.5 | –45.8 | –40.8 | –116 |
| Pressure at –25°C in bar (absolute) | 2.03 | 1.07 | 2.50 | 2.01 | 0.58 |
| Liquid density at –25°C in kg/1 | 0.56 | 1.37 | 1.24 | 1.36 | 0.60 |
| Vapour density at $t_0$–25/+32°C in kg/m³ | 3.6 | 4.4 | 10.0 | 7.0 | 1.3 |
| Volumetric capacity at –25/55/32°C in kJ/m³ | 1164 | 658 | 1334 | 1244 | 373 |
| Enthalpy of vaporisation at –25°C in kJ/kg | 406 | 216 | 186 | 223 | 376 |
| Pressure at +20°C in bar (absolute) | 8.4 | 5.7 | 11.0 | 9.1 | 3.0 |

have approximately half the density of fluorocarbons. Charge quantities too are a little less than half those of equivalent fluorocarbon refrigerants.

## Safety Considerations: Flammability and Charge Limits

The main (or only) argument for avoiding the use of HC refrigerants is their flammability. ASHRAE 34 (ISO 817) classifies HC refrigerants as A3, i.e. with low toxicity and high flammability. Safety classification dictates system positioning, charge sizes, safety features, and so on.

The limiting factor in the use of HC refrigerants is the refrigerant charge quantity, occupancy category and room size. From *Table 5,* it may be observed that both R600a and R290 form an explosive mixture with air when present in the range of approximately 2 to 10% of the volume of air in an enclosed space. Below about 2%, the refrigerant-air mixture is too lean to form an explosive mixture. Above 10%, it is too rich, i.e. the quantity of oxygen available in the air is insufficient to form an explosive mixture. If we consider 20% of the Lower Explosion Limit (LEL) as reasonably safe, this would amount to about 8 gm/m³ of an enclosed space. Considering 8 gm/m³ as a safe limit, a room size of 10m³, which is a small enough room, would limit the charge quantity to 150 gm per sealed system. This is the basis for limiting the HC refrigerant charge to 150 gm per sealed system in domestic and commercial refrigerators, as per EN Standard 60335-2-24.

For systems with charge size more than 150 gm, the room size should be such that a sudden loss of refrigerant should not raise the mean concentration in the room above the practical limit (of 8 gm/m³). *Table 6* gives the charge quantities for different occupancy categories according to EN 378:2007.

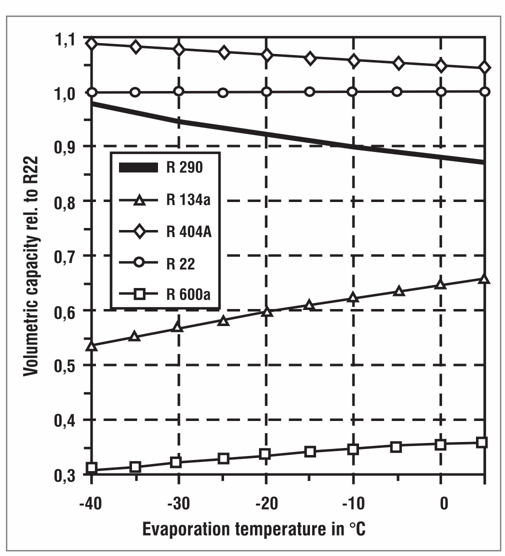

*Figure 1: Comparison of vapour pressures*

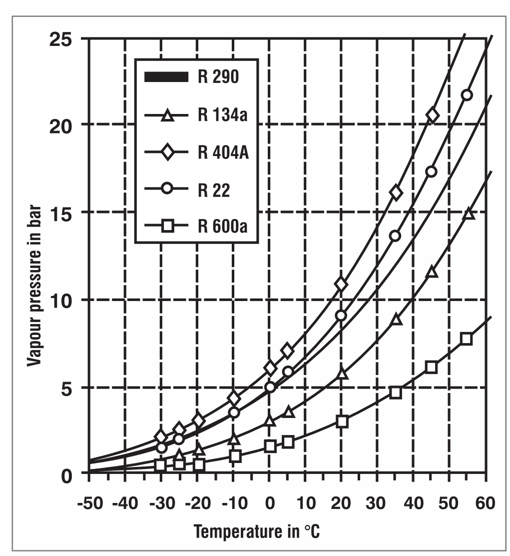

*Figure 2: Comparison of volumetric capacities*

## System Design and Component Selection for HC Refrigeration Systems

### *Compressors*

In order to compensate for the low volumetric capacity of R600a, isobutane compressors have their displacements increased by 65 to 70% relative to R-134a compressors of equivalent capacity.

For R290 and R1270, conventional R404A or R22 compressors are suitable (although internal optimisation is preferred) with appropriate modification of their electrical components.

HC compressors are provided with the Association for Electrical, Electronic & Information Technologies (VDE) approved gastight, sealed relays complying with EN/IEC Standard 60335-2-24. The external overload protector is also sealed in order to render it gastight. Alternately, it may be provided internal to the compressor.

Both mineral and synthetic lubricating oils, which are used with HCFC and HFC systems respectively, are fully compatible with HC systems. Higher viscosity grade oils may be used if the solubility is too high.

### *Heat Exchangers*

The refrigeration system efficiency will normally not cause a need for changing evaporator or condenser size, i.e. the outer surface can be left the same as with R134a, R22 or R404A. In

continued on page 56

continued from page 54

Table 4: ASHRAE safety classification of refrigerants

| ASHRAE 34 - Safety Classification Groups | | |
|---|---|---|
| | Safety Group | |
| Higher Flammability | A3 | B3 |
| Lower Flammability | A2 | B2 |
| No Flame Propagation | A1 | B1 |
| | Lower Toxicity | Higher Toxicity |

order to provide for the higher refrigerant volume flow, R-600a evaporators may have tubes of larger cross-section or more parallel paths to limit the pressure drop.

Evaporators for R-290 may be similar to those for R-22. Aluminium roll bond panels are, as a rule, not used with R290 systems because of the high demand on burst pressure.

***Filter Drier***

The commonly used desiccants in filter driers of systems for R12 (XH-5 and XH-6) and R134a (XH-7 and XH-9) are fully compatible with R600a and are recommended.

***Capillary Tube***

There is no significant change in capillary from equivalent halocarbon systems. The capillary used with R-134a (for isobutane) or R-404A (for propane) systems is a good starting point for the capillary optimization tests.

***Suction-Liquid Heat Exchanger***

An effective internal heat exchanger is very important to optimize the COP: the capillary should be in good thermal contact with the suction line for as long a length as possible. *Figure 3* illustrates the increase in COP with suction gas temperature for a low temperature system at -25°C evaporating, 45°C condensing and zero subcooling.

***Refrigerant Charge***

Because of the lower density of HC refrigerants, charge quantities are about 40 to 45% of the equivalent R-134a or R-22 systems. Charging accuracy should preferably be better than that for equivalent HFC systems and should be limited to 1 or 2 grams, especially for R-600a.

Evacuation of R-290 systems, prior to charging, is similar to the vacuum practice for R-22 or R-134a systems. However, R-600a systems require a higher degree of evacuation, since these systems operate at low pressures and non-condensables left behind in the system will have a far more adverse effect. Evacuation times have to be longer. It is preferable to evacuate the system from both high and low sides in order to keep evacuation times reasonably low.

***Tubing***

Specific hydrocarbon refrigerant pipe sizing literature should be perused when selecting refrigerant line sizes. Despite most hydrocarbon refrigerants having similar operating pressures to the "equivalent" fluorocarbon refrigerants, thermodynamic and transport properties can differ significantly; thus data for other refrigerants will not be directly applicable.

All tube joints should be brazed. Flared connections should be avoided in order to minimize the possibility of leaks. Lock-ring pressed fittings may be used as an alternative to brazing,

***Electrical Components***

A fundamental difference between systems using flammable refrigerants and non-flammable refrigerants is the use of suitable electrical equipment that will not pose a risk in the event of a release, since any source of ignition coming into contact with the flammable mixture, formed by a leaking refrigerant with surrounding air, may cause a fire or explosion. An ignition source can be a loose electrical connection, on-off switch, thermostat, unsealed compressor relay and overload, capacitor with unprotected lead, fan motor, defrost heater and controller, etc.

To ensure absolute safety, all electrical components located inside the cabinet, or near the compressor, should be sealed or spark-free and comply with IEC Standard 600079-15. Fans should be safe and spark-free even when blocked, and also comply with IEC 600079-15. EC motors and induction motors may be used. Capacitors, if used, should have flying leads. Electrical connections should use crimped lugs and screwed connections. Wire joints should be soldered and encased in heat shrinkable sleeves. Special lamp holders with rubber lids should be used.

## Safety in Refrigerant Charging and Rework Areas

Certain basic principles must be adopted to ensure safety in refrigerant charging and rework areas where there is a high probability of leakage of HC refrigerant:

- Forced ventilation must be provided to avoid local accumulation of gas.
- Standard electrical equipment may be used for lighting and power, except for the ventilation fans and safety systems, which must be explosion proof.
- The safety system includes gas sensors located in and continuously monitoring possible leakage areas, with alarm and doubling of ventilation at 15 to 20% of LEL, and with disconnection of all non-explosion proof electricals in the monitored area at 30 to 35% of LEL, leaving the fans running at full speed.
- Refrigerant leakage test on appliances before charging, to avoid charging of leaking systems.
- Charging stations designed for flammable refrigerants and connected to the safety systems.

The following procedure should be followed for removing the refrigerant charge and carrying out any brazing operation on previously charged units:

Table 5: Explosion limits and ignition temperature

| | R 600a | | R 290 | |
|---|---|---|---|---|
| Lower explosion limit (LEL) | 1.8% | ca. 38 g/m³ | 1.7% | ca. 37 g/m³ |
| Upper explosion limit (UEL) | 8.5% | ca. 203 g/m³ | 9.5% | ca. 177 g/m³ |
| Minimum ignition temperature | 494°C | | 470°C | |

continued on page 58

*continued from page 56*

*Table 6: Charge size requirements for various location categories*

| Category | Examples | Requirements |
|---|---|---|
| A (domestic/ public) | Hospitals, prisons, theatres, schools, supermarkets, hotels, dwellings | • <1.5kg per sealed system<br>• <5kg in special machinery rooms or in the open air for indirect systems |
| B (commercial/ private) | Offices, small shops, restaurants, places for general manufacturing and where people work | • <2.5kg per sealed system<br>• <10kg in special machinery rooms or open air for indirect systems |
| C (industrial/ restriced) | Cold stores, dairies, abattoirs, non-public areas of supermarkets, plant rooms | • <10kg in human occupied spaces<br>• <2.5kg if high pressure side (except air cooled condenser) is located in a special machinery room or in the open air<br>• No limit if all refrigerant is contained in a special machinery room or in the open air |

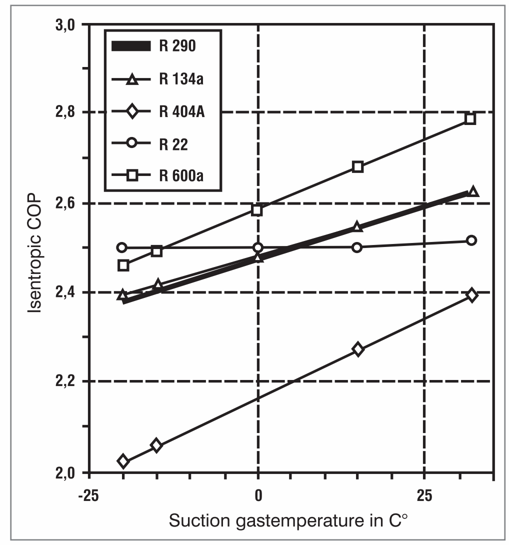


*Figure 3: Theoretical COP vs. suction gas temperature*

- The refrigerant charge may be released into the atmosphere outdoors. If this operation is performed indoors, the charge should be vented out of the room.
- Flush the system with an inert gas like "dry" oxygen-free nitrogen. Dry air must not be used.
- The system should be evacuated with a suitable vacuum pump whose electrical components (such as drive motor and switch) do not form a possible ignition source and are spark-free. The vacuum pump outlet should not be near a potential ignition source and should preferably be vented outdoors.
- Repeat the flushing operation with inert gas.
- Open the refrigerant circuit by cutting or brazing.
- After brazing and rework is performed on the system, it should be pressure tested with dry nitrogen using soap solution.

It needs to be emphasized, that only specially-trained and qualified engineers and technicians should be allowed to service and repair units with HC refrigerants. This is all the more important, given the casual attitude towards safety in India. The equipment of the service technician has to meet the requirements of R 600a and R 290 in terms of evacuation quality and refrigerant charge accuracy, which are more stringent than for R-134a, particularly for R-600a.

## Safety Standards and Guidelines

Several international standards have been prepared to ensure safety to the users and the general public in the application and use of HC refrigeration systems. These standards mainly cover maximum and allowable charge sizes, installation locations, room sizes, ventilation, safe electrical components, pressure tests and safety devices. Some of these standards are listed below.

- EN 378:2008, *Refrigerating Systems and Heat Pumps – Safety and Environmental Requirements*
- EN (& IEC) 60335-1, *Household and Similar Electrical Appliances – Safety: General Requirements*
- EN (& IEC) 60335-2-24, *Electrical Safety for Domestic Refrigerators*
- EN (& IEC) 60335-2-40, *Electrical Safety for Air Conditioners and Heat Pumps*
- EN (& IEC) 60335-2-89, *Electrical Safety in Commercial Refrigerators*
- IEC 6007 9, *Electrical Apparatus for Explosive Gas Atmospheres*
- IEC 60079-15, *Electrical Apparatus for Explosive Gas Atmospheres with Type of Protection 'n'*
- *Code of Practice for A2 and A3 Refrigerants:* Institute of Refrigeration (UK)

These Standards are in addition to the relevant national standards for mechanical refrigeration and for the specific products.

## Conclusion

India has lagged behind other countries in promoting the use of HCs as refrigerants. Only one manufacturer, Godrej, has been successfully producing refrigerators with HC refrigerants since 2002. Very recently, Godrej have introduced split AC units with R-290 refrigerant in the Indian market, in which they claim an energy saving of over 20%. Other Indian manufacturers too are seriously contemplating the introduction of appliances with HC refrigerants.

The rapid implementation of HC refrigerant technology in India will be a win-win-both for consumers as well as for the nation. On the one hand, it will benefit consumers in terms of significant energy savings, while on the other, it will help the country in curbing greenhouse gas emissions which cause global warming and adverse climate change.

## References


1. *Guidelines for the use of Hydrocarbon Refrigerants,* ACRIB, UK
2. *Practical Applications of Refrigerants R-600a and R-290 in Small Hermetic Systems,* Danfoss.