

# The Use of R-407C: Applications and Guidelines

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## **Abstract:**

With the phase-out of R-22 in the EU, R-407C has emerged as the preferred working fluid for the majority of comfort cooling applications. R-407C, while similar to R-22 in many of its physical properties, is a zeotropic mixture of HFCs which does impose certain application restrictions and specific handling and equipment design requirements. This paper discusses the practical implications of using R-407C.

**Background:** EU Regulation 2037/2000 has banned the use of ozone depleting substances in new refrigeration, air conditioning and heat pump applications as from the end of this year. Non-ozone depleting HFC refrigerants have been developed to replace the banned fluids. R-407C was developed to replace R-22 in air-conditioning and heat pump applications and is now the most commonly used refrigerant fluid for new systems in these applications. All major Original Equipment Manufacturers (OEMs) in this application field, represented in the EU, now supply systems for use with R407C.

## **Introduction**

R407C has properties very similar to those of R-22 (which it has replaced in air conditioning applications) in terms of both its operating pressures and its performance in dry expansion air conditioning systems. R407C is very similar, but not identical to R22 in its performance as an air-conditioning refrigerant. For example, system condensing pressures will be somewhat higher (around 1 bar higher at 45°C condensing temperature) than for R22.

R407C is a mixed, zeotropic, refrigerant consisting of 3 HFC components: R32, R125 and R134a in the proportions 23%/25%/52% by weight (a  $\pm$  2% tolerance is allowed for each of the components).

Servicing air conditioning with R-407C should not be a significant issue for most systems provided the guidelines given below are followed.

## **Handling Guidelines**

### **1) General Considerations for HFC Refrigerants**

Systems which use R407C normally have compressors charged with a miscible lubricant such as POE (polyolester). There are many manufacturers and grades of these lubricants. R-407C is generally not used with mineral or alkyl-benzene (i.e. hydrocarbon based) oils as the miscibility is not adequate to ensure satisfactory oil return to the compressor. It is very important that, when servicing a system and oil is needed, the correct oil be used. Seek guidance

from the system or compressor manufacturer on which specific oil to use in a maintenance situation.

a) POE lubricants used with HFCs have a strong affinity for moisture and will absorb water from the atmosphere if allowed to do so. It is very important to minimise the ingress of moisture into the system by following these simple procedural rules:

- Always keep system openings (tube ends, connections, etc.) and oil containers tightly capped until needed. Cap or close immediately after use.
- After brazing purge with Oxygen Free Nitrogen (OFN) to remove residual condensation and dry the system. (Note: excluding air from within the system by purging with OFN during brazing, will minimise the formation of scale, etc.)

Since POE retains moisture as a solution it is not possible to completely remove it by use of vacuum. The only way to remove excess (considered to be more than 50 ppm) moisture from the compressor lubricant is by the use of a filter drier.

b) System contamination with mineral oils, or with R22, can have a serious effect on performance and system reliability. Systems which use enhanced tube heat exchangers (evaporators and condensers) are particularly vulnerable to performance degradation arising from the presence of HC based oils. It is strongly recommended that dedicated service gauge sets are used for R407C to prevent inadvertent contamination.

## 2) General Considerations for Zeotropic Refrigerants

R407C is a zeotropic refrigerant mixture. This is to say that, when the liquid and vapour are at equilibrium i.e. at any saturation Pressure-Temperature condition, the composition of the vapour differs from the composition of the liquid. In the case of R407C the saturated vapour composition is so different from that of the liquid that, if used, it would behave as a different refrigerant.

As an example, the composition of the vapour in equilibrium with liquid R407C at 25°C is close to :

33% R32  
32% R-25  
35% R134a

In a container the mass of refrigerant in the liquid phase is generally very much larger than that in the vapour phase, and so during transfer, the percentages of the constituents of the liquid will remain very close to the correct composition.

For this reason it is very important that **R407C be transferred as the liquid phase when charging a system from a cylinder**. This is done via the dip tube. If the container does not have a dip tube (as in the case of some small refrigerant cylinders) the container should be inverted so that the valve is at the bottom. Only the liquid phase should be transferred. Transfer must be discontinued before all the liquid has been transferred. In an ideal situation when the last drop of liquid has been removed the container will still have around 5% by weight of its net contents present in the vapour phase. In practice it is suggested that transfer is stopped before to reach 5% of residual

content in the container, to ensure that no vapour is transferred. The container will have a positive pressure and should not be evacuated. It should be returned to the supplier with its residual pressure.

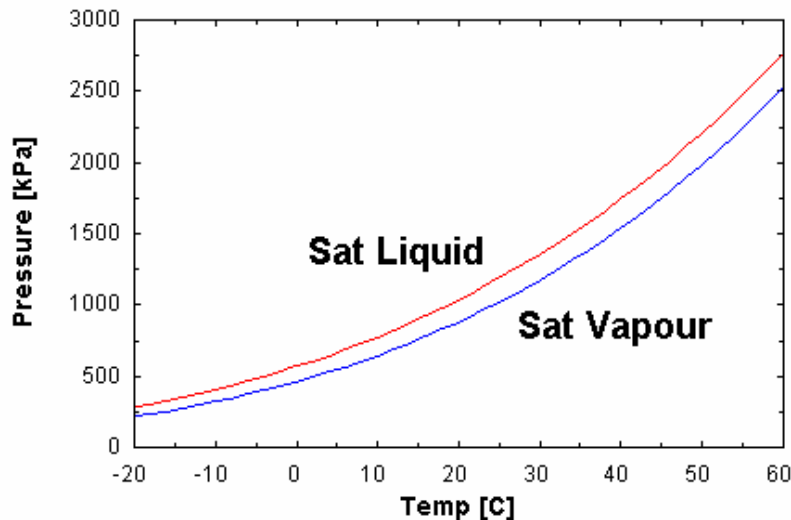
During transfer to a system it is perfectly acceptable to allow the liquid leaving the container to flash to vapour before entering the system (e.g. at the compressor suction).

## Temperature Glide

### 1) What is Temperature Glide?

Because zeotropic mixtures such as R407C have different equilibrium compositions for the liquid and vapour, they have different saturation P-T values for saturated liquid and saturated vapour. For example, at a given pressure, the saturated liquid temperature is different from the temperature of the saturated vapour at the same composition. (Similarly at a given temperature there are two saturation pressures.) – See the R407C P-T Curve below. The value quoted for the temperature glide for a refrigerant is, conventionally, the difference in temperature between the saturated vapour temperature at the evaporating pressure and the temperature at the inlet to the evaporator.

**Fig 1 – Saturation Pressures of R407C**



Temperature Glide is a consequence of the difference in composition between the saturated liquid and vapour phases, but its magnitude can vary. Refrigerants with a significant composition difference can have a very small temperature glide – R410A is an example of such a fluid. The temperature glide of R407C is approximately 6K.

### 2) What are the implications of Temperature Glide ?

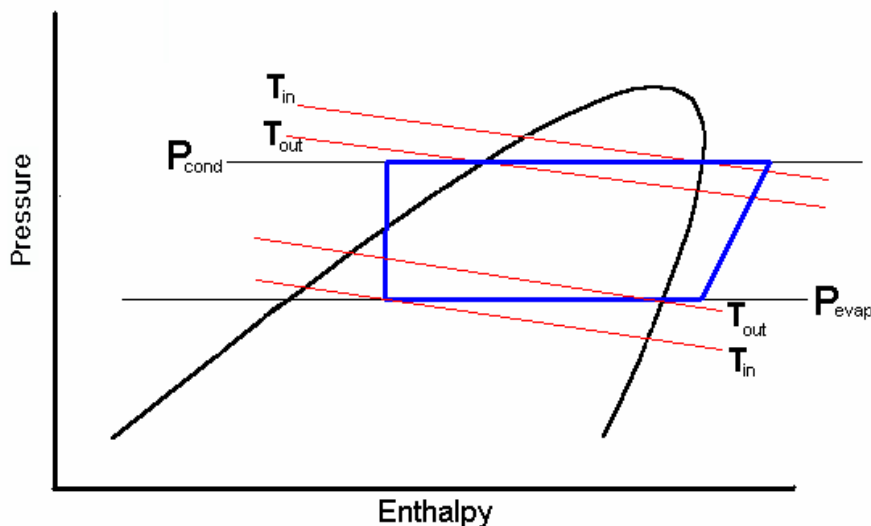
There are certain design and application implications and opportunities arising from the use of refrigerants with a temperature glide.

It has been shown that pool boiling heat transfer is affected by temperature glide. As the temperature glide increases, the pool boiling heat transfer coefficient (HTC) decreases. In the case of R-407C the HTC is reduced by around 50% (compared with HTC in a DX heat exchanger). For this reason it is generally not recommended to use R-407C in flooded evaporator chillers. Similarly, because a significant temperature glide is a consequence of a wide composition shift, R-407C cannot be used satisfactorily in centrifugal chillers. Temperature glide can be harnessed to give performance benefits when used in counter current heat exchangers. Commercial DX water chillers have demonstrated measurable energy efficiency improvements arising from the reduced log mean temperature difference across the evaporator when in counter current configuration.

For system commissioning and servicing, the important practical consideration to be remembered when working with refrigerants with a significant temperature glide is that there is a different pressure-temperature relationship for the saturated liquid and saturated vapour conditions – They have 2 sets of P-T tables.

For such refrigerants it is important to remember that the evaporation and condensation processes do not occur at constant temperature, although the pressure of these transformations is constant. This is best visualised on a Pressure-Enthalpy Diagram:

P-H Diagram - Zeotropic Blend



In the condenser, condensation starts at the saturated vapour temperature which is higher than the saturated liquid temperature, and the temperature progressively falls along the condenser until the saturated liquid temperature is reached. This progressive change in temperature gives rise to the term "Glide". The effective condensing temperature (as seen by the medium into which the

heat is being rejected) is the average of the saturated liquid and vapour temperatures.

In the evaporator the reverse occurs. The feed to the evaporator is not saturated liquid, however, due to the flash gas generated at the expansion device, but it is at a lower temperature than the saturated vapour temperature. The temperature of the evaporating liquid rises along the evaporator. The effective evaporating temperature is the mean of the evaporator inlet (flashed liquid) temperature and the saturated vapour temperature. The evaporator inlet temperature is dependent on the sub-cooling. Accurate calculation of the evaporator inlet temperature, if needed, requires the use of specialised software. (Such software is readily available.)

When measuring system performance parameters it is important to use the correct saturation table for R407C:

The evaporator (or compressor suction) superheat is derived from the Saturated Vapour (often known as the Dew Point) P-T table.

Sub-cooling of the condensed liquid is derived from the Saturated Liquid (Bubble Point) table.

## **Servicing Systems With R-407C**

### **What should a service engineer do if a system has lost part of its charge (leaked)?**

It goes without saying that the first action should be to locate and correct the leak. Once the leak is eliminated, for normal (not critically charged) systems it is usually appropriate to "top off" the system to return to the standard refrigerant charge level, using R-407C, provided this charge is correctly transferred from the liquid phase in the container. System performance will return to normal.

In the case of critically charged systems (e.g. in many split systems including VRF systems) then, just as in the case of R-22 systems, the residual charge has to be recovered (removed from the system), and the precise specified quantity of R407C charged to the system.

In this respect the procedure for R407C is similar to that for R-22.

### **Can the composition of R407C in a system change?**

R-407C is a zeotropic mixture. Its EQUILIBRIUM vapour and liquid compositions are different. What are the implications?

**a) Refrigerant leaks:** If the leak is only of vapour, at a location where both liquid and vapour co-exist in thermodynamic equilibrium then, as a consequence of the leak, a change in composition can occur.

In an operating system this scenario is uncommon. In practice leakage from the vapour phase only (where two the phases are in contact) is most likely to occur at a liquid receiver (or possibly an accumulator during transient conditions when liquid is present).

Leaks which occur in either the evaporator or condenser, where the liquid and vapour phases are in thermodynamic equilibrium during operation, do not result in composition shifts in practice because the leak is of **both** liquid and vapour – the two are not separate in the region of the leak. This has been confirmed by extensive testing.

A vapour leak can result in a change in composition of the residual charge during system shut-down (e.g. of an air conditioning system during the winter).

Extensive computer modelling, confirmed by field tests, has shown that "topping off" the charge with R407C (adding R407C to the depleted charge in the system to restore the charge to its correct mass level) will always tend to bring the composition back close to its correct formulation. The refrigerant, after such topping off, will have performance parameters very close to those for the standard composition. The performance of the system after a leakage which caused composition shift, and subsequent topping off with new R407C is not noticeably different from that of the system with standard composition charge. After a series of leak/recharge cycles in a fully instrumented test system under standard conditions, cooling capacity had dropped by ~5% and with even less impact on system energy efficiency. These tests and subsequent experience in the field has shown that **R407C systems can be "topped off" after a leak and will operate normally**. There is no need, except in the case of critically charged systems, to replace the entire charge after a leak.

**b) "Segregation" within a system.** One of the principal reasons that R407C is not used in "flooded evaporator" chiller systems is that liquid pooling occurs in the evaporator, resulting in a composition of the operating (circulating) refrigerant being variable and different from standard. This results in loss of proper control.

There have been a few isolated cases of anomalous operating behaviour reported in DX Air-Air systems which suggest that segregation with composition shifting might be occurring. The symptoms are manifested as sustained high condensing pressures and sometimes high compressor discharge temperatures. Such segregation can only occur if there is the opportunity for a significant volume of liquid refrigerant to "pool" – to remain static in physical contact with the circulating refrigerant mass. Pooling might occur in an accumulator, in a rising evaporator or other similar situation.

**It must be emphasised that this will happen in only a very few exceptional circumstances**

The solution to such a problem would be to modify the circuit (or correct an obstruction) to ensure that the whole refrigerant mass circulates through the system.

**Conclusions:** With some restrictions on its application use (namely for centrifugal compressors and flooded evaporator chillers) R-407C is now successfully used in the majority of air conditioning and comfort heat pump applications. Servicing R-407C systems can be carried out as if it were R-22, bearing in mind the additional care needed for moisture management and the use of the two (dew point and bubble point) saturation P-T relationships.

#### **References:**

Bivens D.B., Patron D.M., Yokozeki A., ASHRAE Trans. 1997, Vol 103