Preprint draft. Indented to be published in the HPT Magazine.

What can the new safety standard (IEC 60335-2-40 Ed. 7) do for R290 in heat pumps?

— Asbjørn Vonsild

The demand for heat pumps has greatly increased, particularly in Europe, due the fossil fuel crisis (and of course the climate crisis). At the same time, Europe is accelerating the change to environmentally friendly refrigerants. Switching to R290 (propane, safety class A3) is a good option to phase down HFC consumption while growing the number of heat pumps. The flammability of R290 has, however, been a key barrier that needed to be addressed!

The 7th edition of IEC 60335-2-40 which was published in May 2022 has been widely cited for increasing the charge limits for R290. While the charge limits are increased for R290 in some applications, the work on R290 for IEC 60335-2-40 Ed. 7 focused on split A/C. Other applications were only considered superficially, and in many cases the new standard can only be used for inspiration.

I know this because I've been convener (another word for project manager) on issues related to hydrocarbons in IEC 60335-2-40 Ed. 7 since 2015, and from 2019 on the complete standard until its publication.

Although the IEC 60335-2-40 Ed. 7 was not developed specifically with heat pumps in mind, it does contain a number of philosophies that can be useful for various heat pump architectures, and it is the intention of this paper to give a detailed overview of how R290 can be applied, and where the application becomes difficult. It should be noted that there are many heat pump architectures, and only the more common ones can be treated in a paper like this.

The scope of IEC 60335-2-40 Ed. 7 only covers charges up to 4.94 kg of R290, therefore larger systems are not considered here, but the reader might consult EN 378 for larger systems. This paper focuses on safety during the use phase of the product lifecycle. Applying R290 also has implications for manufacturing, storage, installation, servicing and decommissioning of systems, and these can have implications regarding time to market for high volume production.

IEC 60335-2-40 Ed. 7

The philosophy behind any safety standard for systems with flammable refrigerants is to take measures to avoid leakage in the first place, and combine this with mitigation measures to ensure that should a leak occur, then it will not lead to a significant hazard.

The easiest measure to avoid a significant hazard is to limit the amount of flammable refrigerant. Charge optimisation is not mentioned explicitly in IEC 60335-2-40 Ed. 7, it is however the most important mitigation measure. Note that the charge limits in safety standards are per refrigeration circuit as it is highly unlikely that more than one circuit will leak at the same time.

In IEC 60335-2-40 Ed. 7, a significant hazard is, in most cases, defined as a situation where a worst case leak creates a flammable atmosphere in the indoor space at the floor. This implies that the "worst case leak" and the "refrigerant amount released to an indoor space" are two central parameters, which leads to two new mitigation measures:

- Enhanced tightness: With additional construction measures, the worst case leak taken into account can be reduced. A lower leak rate gives more time for the leaked refrigerant to disperse, so a higher charge can be accepted. An important limitation in the requirements for enhanced tightness is that it cannot be applied to the location where the compressor is placed.
- Releasable charge: Adding safety shut-off valves to a system can separate the system into sections, and thereby limit the amount of refrigerant which can be leaked into the occupied space. In principle, any way to limit the amount of refrigerant being leaked is acceptable, for instance absorbing the refrigerant, but the use of valves to partition the system is most commonly discussed.

Note that IEC 60335-2-89 Ed. 3 (commercial refrigerating appliances and ice-makers) has a variation of this, with a surrounding concentration test in which a leak is simulated and refrigerant concentration is measured at floor level. If a flammable atmosphere does not form for a significant period of time, then the amount of charge is acceptable.

If a leak does occur, the refrigerant is heavier than air, and the typical situation seen is one where refrigerant mixes with air and flows down from the unit to form a flammable atmosphere at the floor. This pattern significantly limits the amount of refrigerant charge needed before a hazardous situation can be reached. It takes very little airflow to disturb this down flow, and this leads to a third mitigation measure:

- Airflow: The use of a fan to circulate the air in the room can increase the allowed amount of refrigerant which can be accepted to leak into that room.

A mitigation measure which can be found all the way back in the 2005 IEC 60335-2-40 edition is the concept of ventilated enclosure:

- Ventilated enclosure: If the system is placed in an enclosure, with air blowing through it to the outdoors, then there is very little risk of a leak flowing to the indoors, and a high amount of refrigerant charge can be accepted. For R290 this is 4.94 kg (130 times the Lower Flammability Limit, LFL). A modification in IEC 60335-2-40 Ed. 7 allows for the ventilation airflow to be based on enhanced tightness, which implies that the ventilated enclosure can be applied for split systems, such as the air to water systems addressed below.

Mitigation measures, including the ventilation in a ventilated enclosure, can either run all the time, or only when a leak is detected e.g. with a gas detector.

IEC 60335-2-40 Ed. 7 contains a number of other mitigation measures, most being applicable for A2L refrigerant only. Two should be highlighted:

- Ducted systems with A2L: A high charge can be accepted if the air flow is sufficient to dilute the worst case leak before the refrigerant-air mixture leaves the system. This is a variation of dilution with airflow, with the dilution happening in the unit instead of in the room.
- Ventilation with A2L: Bringing in fresh air into a room is even better for diluting a leak than circulating the air in the room. This allows even higher refrigerant charges, but the only

ventilation accepted as mitigation measure for hydrocarbons is the ventilated enclosure, because otherwise too much depends on correct installation.

When utilising the new options in IEC 60335-2-40 Ed. 7 for flammable refrigerants, the task is to combine the system design with mitigation measures in a way to reach a safe and cost-efficient design.

Risk assessment

In EU legislation, safety in the use of flammable refrigerants can be ensured by either following harmonised standards or using a risk assessment. The harmonised standard is EN 60335-2-40 Ed. 4, with the latest changes relevant for flammable refrigerants dating from 2006. This implies that the use of flammable refrigerant is highly likely to be based on a “risk assessment” with heavy influence from a newer IEC edition. The process of turning IEC 60335-2-40 Ed. 7 into a harmonised EN standard has begun, how long this will take is uncertain.

Typically this risk assessment will simply conclude that the new edition is assumed to lead to safe equivalent to the harmonised edition. But it is also possible to be creative and mix mitigation measures from IEC 60335-2-40 Ed. 7 with information about the specific system design, to reach an equivalent level of safety without compliance with all of IEC 60335-2-40 Ed. 7. A couple of details and pitfalls should be mentioned here:

- There are many other sources of potential hazards than just flammable refrigerants. It is most practical to follow both the harmonised EN standard and the new IEC 60335-2-40 Ed. 7 as far as possible since this limits the risk assessment to the smallest possible area.
- A leak during standstill conditions, especially due to power interruptions, can be difficult to mitigate. On the other hand, a system without power is very unlikely to suffer from large leaks since there is no source of pressure pulsations or vibrations. This is reflected in the requirements for safety shut-off valves in IEC 60335-2-40 Ed. 7, where power interruptions are disregarded. Standstill conditions are however not disregarded, and need to be included in a risk assessment.
- False detections, also called nuisance trips, can be a problem for hydrocarbons, since hydrocarbons are used for many different applications. A false detection needs to be treated as if there is a leak, but it is only possible for a dangerous real leak to be present for a limited amount of time, since there is only a limited charge in the systems. If, after some time, the leak is no longer detected, then the system can safely try to return to normal operation. If the system does not return to normal operation after false detections, then there is a significant risk that the end-user will override the leak detection system, and that can lead to dangerous situations when there later is a real leak. In IEC 60335-2-40 Ed. 7 this logic is seen in the requirements for safety shut-off valves, which are allowed to be reopened 2 hours after a leak is no longer detected, or alternatively can be reset with the aid of a tool.
- If a mitigation measure intended for A2L is applied to R290 systems, then an additional safety margin is necessary to reflect the fact that R290 is easier to ignite.

Outdoor air to water heat pumps

Air to water heat pumps placed outdoors have been allowed with up to 4.94 kg of R290 since EN 60335-2-40 Ed. 4, and as such there is not much new information to add here. However, there are new methods to avoid ignition sources in IEC 60335-2-40 Ed. 7, which can save R&D resources during development and possibly slightly reduce the cost of the heat pumps.

Note that above 4.94 kg of R290, EN 378-1:2016 can be applied which requires that systems are out of reach of ordinary people, e.g. behind a fence.

Split type air-to-air heat pumps

Applying the IEC 60335-2-40 Ed. 7 in split type air-to-air air conditioners or heat pumps can be done in numerous ways, since this is a system type which was thoroughly considered when the standard was written.

If the compressor can be placed outdoors, then the concept of enhanced tightness can be applied, and often this will be sufficient for the refrigerant charge needed.

If enhanced tightness is insufficient, or for some reason is impractical to apply, then airflow can be used to allow higher charges without compromising safety. Using airflow creates a challenge when it comes to standstill, since standstill implies that the fan will be turned off.

Standstill can be handled by having a shut-down procedure, where the compressor does a pump down and safety shut-off valves are closed before turning off the fan. This reduces the releasable charge significantly, but does require the addition of safety shut-off valves to the design. An alternative approach is to have a leak detection, which switches on the airflow if a leak is detected.

Note that split type R290 A/C systems are sold in the 100,000s in India and China. The safety of these are based on minimising the system charge. With the adoption of IEC 60335-2-40 Ed. 7 we should expect to see higher charges and R290 used in a broader product range, also in products being marketed in Europe.

Ventilation heat pumps

There are several heat pump architectures where heat is taken from exhaust air from a building and applied to heating the intake air or a water tank. Systems with less than 152g of R290 have been on the market for the last couple of years, but to this author's knowledge there are no systems with more than 152g of R290 in mass production.

The architectures of ventilation heat pumps are typically very similar to a ventilated enclosure. IEC 60335-2-40 Ed. 7 (and the harmonised EN standard) allows up to 4.94 kg of R290, provided that the airflow is sufficiently high and creates a negative pressure of at least 20 Pa in the appliance relative to the indoor space. Since the purpose of the appliance is ventilation, it is normally not a problem to reach this airflow, but for some appliances the 20 Pa can harm energy efficiency.

In cases where 20 Pa cannot be reached, the IEC 60335-2-40 Ed. 7 can only be used as inspiration for a risk assessment, where the focus is on showing that leaks always flow to the exhaust outlet.

A risk assessment can also be relevant for leaks during standstill if there is no airflow, or cases where part of the refrigerating circuit is outside the exhaust airflow.

Leaks during standstill can be handled by having sufficient room in the installation space for the refrigerant in question, but this is usually only relevant for very small units. Inspiration can be taken from the requirements for a surrounding concentration test in IEC 60335-2-89 Ed. 3.

Leaks in parts of the system that are not in the exhaust airflow are trickier. In some cases, the design can be made to avoid piping connections outside the airflow, and this reduces the risk of leaks significantly. IEC 60335-2-40 Ed. 7 provides guidance in Annex FF on which types of piping and piping connections can be ignored when evaluating potential leak points.

In other cases, there will be sufficient airflow on these parts to ensure that a leak will be diluted below the lower flammability limit before it leaves the unit. This can be supported by using the enhanced tightness concept for the part outside the exhaust airflow, increasing the airflow if a leak is detected, or even applying safety shut-off valves to limit releasable charge when a leak is detected. For most ventilation heat pumps the airflow needed for diluting R290 is not prohibitive, but since this option only covers A2L in IEC 60335-2-40 Ed. 7, applying it for R290 will not lead to compliance with the standard, and will need to be based on a risk assessment as discussed above.

In all cases there is plenty of inspiration to be taken from IEC 60335-2-40 Ed. 7 for the risk assessment.

Water-to-water heat pumps

Water-to-water heat pumps, including ground source heat pumps are normally placed indoors, and often in very small rooms. This implies that using the room size to allow leaks to dilute is not a viable approach.

Instead the charge either needs to be reduced to 152g of R290 per circuit, or the whole system needs to be placed in a ventilated enclosure. Both options are possible, although reducing charge to 152g is challenging.

If the unit is placed in a ventilated enclosure, then the ventilation often needs to be activated by leak detection. Otherwise the energy consumption for ventilation will compromise the energy efficiency of the unit. That said, it might be relatively easy to apply a ventilated enclosure when replacing gas boilers, since they already have piping in place for fresh air and exhaust.

Alternatively, the unit can be placed in an insulated enclosure outdoors. This allows for 4.94kg of R290 and the risk of freezing water is easier to handle than for outdoor air-to-water units.

Split air-to-water heat pumps

Split air-to-water heat pumps consists of an outdoor part connected to an indoor unit. The indoor unit will often be installed in a very small room, and as such the challenges are similar to a water-to-water heat pump.

One of the new features of IEC 60335-2-40 Ed. 7, is that it allows for enhanced tightness systems to be placed indoors in a ventilated enclosure. This has two implications; firstly it implies that it is acceptable to have only part of the system placed in a ventilated enclosure, since enhanced tightness cannot be applied to the part of the system where the compressor is, and secondly it can be used to allow a much smaller airflow in the ventilated enclosure, with one condition being that the compressor is placed outdoors and refrigerant charge is no more than 4.94kg of R290.

Other types of heat pumps

There are a very large number of heat pump types. For instance, combined ventilation, sanitary and hydronic heating heat pumps that can switch from heating sanitary water or water for floor heating to providing air-conditioning in a ventilation system. These units can seldom comply with the wording of IEC 60335-2-40 Ed. 7, instead they would typically need to use a risk assessment.

The risk assessment will need to cover all operating states, and finding the right combination of mitigation measures can be a creative exercise. Inspiration may be taken from some of the above system types.

Finally, it should be remembered that not all possible heat pump types can be safely built using R290 currently. Systems with multiple indoor units, or large heat pumps placed indoors (but not in a machinery room) will be difficult and in these cases, R290 can only be applied by changing to a different system architecture. Whether this is socially optimal depends on how energy and resource efficiency is affected by changing the architecture.

Conclusion

The 7th edition of IEC 60335-2-40 was published in May 2022 and the sections relevant for R290 were written with a focus on split A/C. For many types of heat pumps the standard can be readily applied to allow for R290, but in some cases it can only be used for inspiration when applying a risk assessment approach. That said, the new standard offers plenty of inspiration for systems up to around 5 kg of R290 per circuit, as is shown in the above. The majority of heat pump applications can, in principle, be converted to R290 using risk assessments. Such a risk assessment will of course need to be thorough and documented.

Based on this, it is clear that heat pumps can grow dramatically in numbers without a parallel growth in high-GWP fluorinated refrigerants.