OzonAction Kigali Fact Sheet 10

Technical Issues: Flammability

Background:

The phase-down in the production and consumption of HFCs under the Kigali Amendment will ultimately lead to an 85% cut in the amount of HFCs that can be sold globally. To achieve such significant cuts, the users of HFCs will need to start utilising alternative fluids with much lower global warming potentials (GWPs[1]) than the current HFCs. Many of the low GWP alternatives[2] to HFCs are flammable – this creates potential safety issues and may restrict their usage. Safe and successful application of flammable refrigerants can be achieved providing the related safety issues are properly addressed. This Fact Sheet provides guidance on the impact of using flammable HFC alternatives.

Most HFCs are non-flammable and this is a characteristic that makes HFCs a popular choice for many end user applications. Being non-flammable makes it relatively easy to manufacture, install and maintain equipment such as refrigeration and air-conditioning (RACHP) systems. If some non-flammable refrigerant leaks, there will be no risk of fire. Similarly, an aerosol using a non-flammable HFC propellant may be safer to use in circumstances where there may be a source of ignition.

One of the reasons that most HFCs are non-flammable is that their molecular structure is very stable. Unfortunately, this property also gives HFCs a high GWP. Low GWP alternatives usually have less stable molecules – this results in many alternatives being flammable.

The Spectrum of Flammability:

Prior to the Kigali Amendment there were plenty of non-flammable fluids available and a simplistic approach to flammability was used. If a flammable fluid is undesirable, many safety codes and standards took a conservative view and stated that flammable fluids cannot be used.

This simplistic approach is not ideal when there are fewer non-flammable fluids to choose from. To make more widespread use of low GWP alternatives, it is important to recognise that there are widely varying "levels of flammability". There is a continuous spectrum of flammability which includes:

- **Higher flammability fluids** – these are very easy to ignite and can burn with explosive impacts.
- **Flammable fluids** – these are more difficult to ignite, but once ignited will continue to burn and could create a significant hazard.
- **Lower flammability fluids** – these are very difficult to ignite, burn "gently" and might be extinguished when the source of ignition is removed. Mildly flammable fluids create a smaller fire risk than an equivalent amount of a more flammable fluid.
- **Non-flammable fluids** – cannot be ignited.

Some important international refrigeration safety codes recognise this spectrum of flammability. For example ISO 817, ISO 5149 and EN 378 include four distinct flammability classes. Unfortunately, not all standards take this approach; some simply refer to substances as being either non-flammable or flammable. This means that lower flammability fluids are treated in the same way as higher flammability ones, severely restricting the safe application of some flammable fluids.

Flammability Parameters:

A problem faced by both the authors of safety codes and users of flammable fluids, is that flammability is a complex issue and it is not easy to find a simple way of defining a safe operating envelope for each fluid. Flammability can be measured in a number of ways. The most important parameters include:

1. **LFL, lower flammability limit**. LFL is the minimum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.
2. **UFL, upper flammability limit**. UFL is the maximum concentration of a gas or vapour that is capable of propagating a flame within a homogeneous mixture of that gas or vapour and air.

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[1] See Kigali Fact Sheet 14 for a glossary of all acronyms used

[2] See Kigali Fact Sheet 3 for further information on low GWP alternatives

3. **HoC, heat of combustion**. HoC is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions.
4. **BV, burning velocity**. The BV is the speed at which a flame propagates.
5. **MIE, minimum ignition energy**. The MIE indicates how much energy must be in an ignition source (e.g. a spark or naked flame) to initiate ignition of a gas or vapour.

Some safety codes use LFL, HoC and BV to define the four flammability classes, summarised in Table 1.

Table 1: Flammability Classes in ISO 817, ISO 5149 and EN 378

Flammability Class		**Lower Flammability Limit** **LFL** kg/m^3	**Heat of Combustion** **HoC** MJ/kg	**Burning Velocity** **BV** cm/s
3	Higher flammability	<0.1	or >19	n/a
2	Flammable	>0.1	and <19	n/a
2L	Lower flammability	>0.1	and <19	<10
1	Non-flammable	Cannot be ignited		

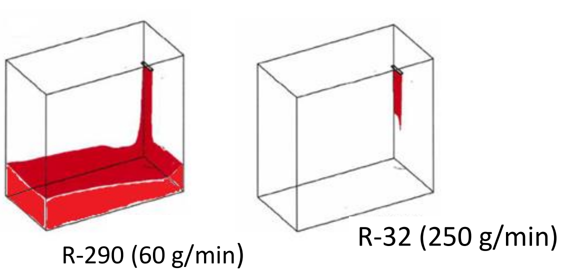
The flammability issue is made even more complicated by various other effects that influence combustion. Three important examples are:

1. The exact geometry of an ignition source can change the MIE.
2. High air humidity can increase the burning velocity of some fluids.
3. A dilution effect occurs when a leaking gas mixes with the air around it.

Figure 1 illustrates how dilution occurs. For a Class 3, higher flammability vapour, the LFL is low (i.e. there only needs to be a small amount of the gas mixed with air for ignition to be possible) and a lot of dilution must occur before the gas concentration drops to below the LFL. For Class 2L lower flammability vapour, the LFL is much higher and dilution below the LFL can occur much more quickly. In this example, the higher flammability propane leak rate is only a quarter of the leak rate for lower flammability HFC-32, but it creates a much greater "ignition risk footprint" (the red area).

These issues have been discussed to illustrate the high complexity of the flammability issue. Safety codes must take a conservative approach in the absence of sufficient technical data.

Figure 1: Modelling of leakage and areas of gas concentration above the LFL[3]



Prediction of the extent of the flammable region, when R-290 (propane, flammability class 3) and HFC-32 (flammability class 2L) leak from a wall-mounted RACHP unit. The areas shown in red represents the zone where the vapour could ignite. Note, the R-290 leak is 60 g/min, whilst the HFC 32 leak is over 4 times larger at 250 g/min.

[3] Osami Kataoka, JRAIA, January 2013, "Flammability of 2L Class Refrigerants "

Likelihood and Severity of Risks: It is important to distinguish between the **likelihood** of ignition and the **severity of the consequences** of ignition. The likelihood of ignition depends significantly on the LFL and the MIE:

- A higher flammability fluid has a low LFL (i.e. there only needs to be a small amount of the gas mixed with air for ignition to be possible) and a low MIE (i.e. a low energy ignition source such as a small spark will cause ignition).
- A lower flammability fluid has a higher LFL – this means there will be a smaller area in which there is risk of ignition (in most normal circumstances, as illustrated in Figure 1). It also requires a much higher MIE, which means there needs to be a much more powerful ignition source located in the risk of ignition area.

The severity of the consequences of ignition depends significantly on the BV and HoC:

- A higher flammability fluid has a high BV – this can lead to explosive ignition within a cloud of gas that is above the LFL. If the HoC is also high, significant damage might be caused.
- A lower flammability fluid has a low BV – if ignition occurs, the burning takes place slowly. Often burning cannot be sustained if the ignition source is removed.

Flammability Class 3 gases (higher flammability) such as propane exhibit both a high likelihood of ignition and a high severity of consequences following ignition.

Flammability Class 2L gases (lower flammability) such as HFO-1234yf or HFC-32 are difficult to ignite (high LFL and high MIE) and their low BV makes the consequences of ignition much less severe.

Table 2 illustrates the variation in some of the key flammability characteristics discussed above.

Table 2: Examples of Key Parameters

Fluid	Flammability class	LFL kg/m^3	MIE [4] mJ	HoC MJ/kg	BV cm/s
Propane	3	0.038	0.3	46	43
HFC-152a	2	0.130	10	16	23
Ammonia	2L	0.116	100	19	7
HFC-32	2L	0.307	1000	9	6
HFO-1234yf	2L	0.289	5000	9	1.5

It is interesting to note that ammonia has been widely used in large industrial systems for many years. It is a Class 2L, lower flammability fluid. There are very few documented cases of fire following an ammonia leak (due to the difficulty of ignition).

Ultra-low GWP fluids such as HFO-1234yf and moderate GWP fluids like HFC-32 are important alternatives that could help meet the Kigali Amendment HFC phase down targets. The data in Table 2 indicates that these fluids are much more difficult to ignite than ammonia (much higher MIE and LFL) and that consequences of ignition are more limited (low BV and low HoC). These are encouraging characteristics, although it must be stressed that until there is more operating experience with these new refrigerants it is difficult to define the safe "operating envelope" for fluids of this type.

HFC-152a has a higher LFL and lower HoC than ammonia. Based on previous safety codes that would indicate that HFC-152a is "less flammable" than ammonia. However, practical experience indicates that HFC-152a is much more readily flammable than ammonia. This can be explained by the low MIE (making ignition much easier) and the high BV (making the consequences more severe). This shows the importance of avoiding a simplistic way of categorising flammability.

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[4] These MIE values are only approximate – they can vary considerably depending on test conditions

Current Use of Flammable Fluids: There is already widespread use of flammable fluids as alternatives to both ODS and HFCs. Some well-established examples include the use of:

Higher flammability fluids:

a) iso-butane in domestic refrigerators
b) propane in stand-alone commercial refrigerators
c) pentane for manufacture of PU insulation foam
d) hydrocarbon mixtures as propellants in aerosols

Lower flammability fluids

a) Ammonia in industrial refrigeration plants
b) HFO-1234yf in car air-conditioning
c) HFO-1234ze in water chillers
d) HFC-32 in small split air-conditioning

For the Kigali Amendment to be a success it will be necessary for considerable growth in the use of flammable fluids requiring concerted efforts at both international and national levels.

Dangers related to retrofitting existing equipment: New equipment can be properly designed to use flammable fluids, taking relevant safety issues fully into account. Using a flammable refrigerant to retrofit existing equipment that was designed for a non-flammable fluid, creates significant safety risks and is generally not recommended. At a recent meeting of the Executive Committee, Decision 72/17 was agreed, which stated: "*anyone engaging in retrofitting HCFC-based refrigeration and air-conditioning equipment to flammable or toxic refrigerants and associated servicing, does so on the understanding that they assume all associated responsibilities and risks*"[5]. Bodies under the Montreal Protocol will not take responsibility for any adverse consequences arising from the choice to use flammable refrigerants in equipment not intended for their use.

Actions Required at International Level: Several actions are required including:

1) International standards bodies need to make continuing efforts to update standards to properly reflect the opportunities to safely use flammable fluids in a range of applications, especially in the refrigeration and air-conditioning market. Those standards that do not recognise the spectrum of flammability need to be reconsidered.

2) Research bodies need to carry out more in-depth investigations into the effective and safe use of flammable fluids, to provide evidence to support the update of standards.

3) Equipment manufacturers need to redesign some of their products to make safe use of flammable fluids.

4) Data on the successful use of flammable fluids needs to be disseminated to increase confidence in their further application.

Actions Required in Article 5 Countries: Many A5 countries need to take further actions to support increased use of flammable fluids. In particular:

1) Raise awareness and improve understanding, to explain that flammable fluids can be used safely and were widely introduced in some markets during CFC phase-out.

2) Ensure that training is available for installation and maintenance technicians

3) Ensure that specialised equipment and tools are available (e.g. tools that are design to be used safely in an area where a flammable vapour may be present)

4) Assess any national or local legislation / standards that may need to be updated to be harmonised with updated international safety standards.

[5] See www.multilateralfund.org/72/English/1/7247.pdf

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