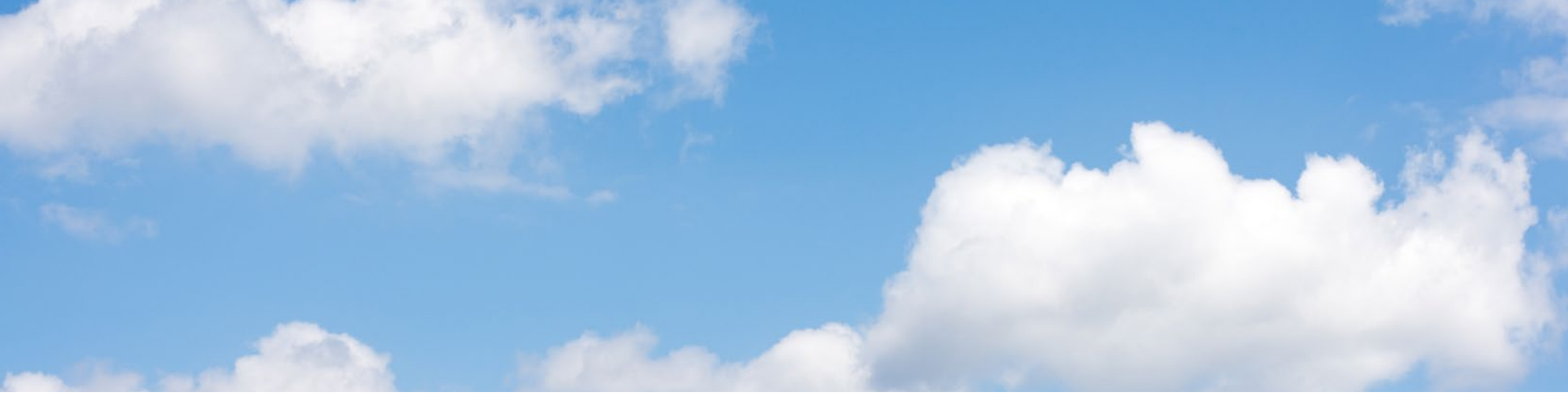
PRACTICAL IMPLEMENTATION OF LOW GWP A2L HFO BLENDS IN COMMERCIAL REFRIGERATION

by Mark Hughes & Neil Roberts



Introduction

As has been well documented, over the last 30 years many regulations have been implemented globally focusing on the environmental impact of refrigerants and equipment. This ever changing legislative landscape has driven a transition from chlorofluorocarbons (CFCs) to hydrochlorofluorocarbons (HCFCs) to hydrofluorocarbons (HFCs), and now due to regulations such as EU 517/2014 (F-Gas) in the European Union and the future regulations that will result from the Kigali Amendment, there is also a need to change to lower global warming potential (GWP) products such as the Opteon™ hydrofluoroolefin (HFO) based products.

Compared to R-404A (GWP 3922), the lower GWP HFO based alternatives range from 45% to 96% reductions in GWP. However, most of the refrigerants with a GWP <500 have a degree of flammability, which adds complexity to the path forward to achieve the necessary transition required to comply with the F-Gas Regulation phase-down. In many cases, a two-step approach will be required to replace the high GWP products such as R-404A and R507A. Initially, non-flammable alternatives such as Opteon™ XP40 can be used for retrofit and in new equipment, but to stay compliant with the phase-down schedule, there will be a need to use the low GWP mildly flammable alternatives such as Opteon™ XL40 (R-454A) in new equipment, taking into account the necessary safety guidance provided in standards and regulations. An additional driver in Commercial Refrigeration is that from 2022, new packs with ≥40kW capacity will need to use refrigerants with a GWP <150. For smaller duty packs used in convenience store format or for modular cooling in supermarkets, it is permitted to use refrigerants such as R-454A with a GWP of 238 to take advantage of the improved efficiency.

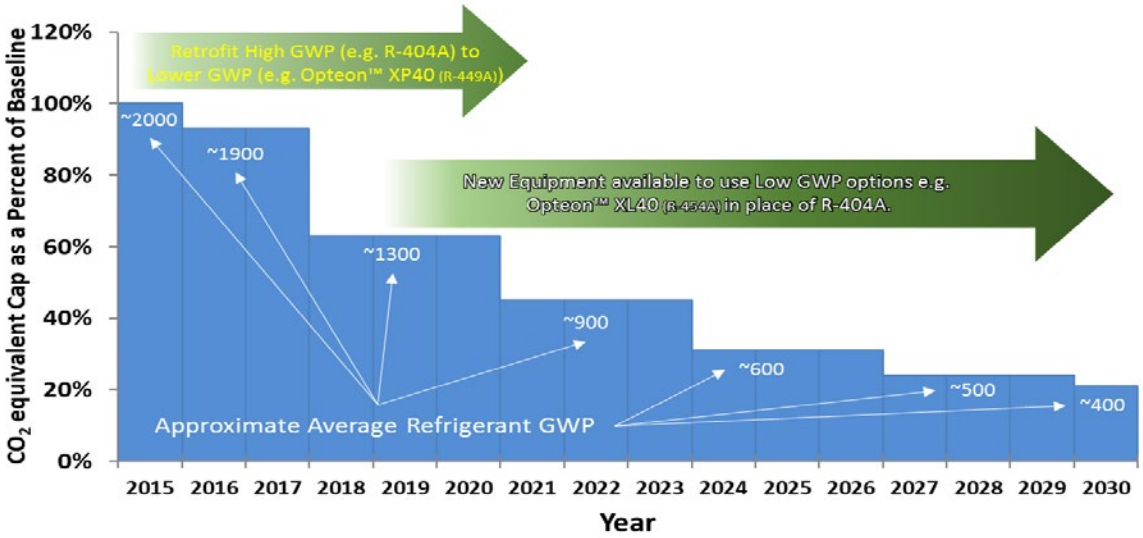
Meeting the F-Gas Phase-Down Challenge in Commercial Refrigeration

The major UK retailer ASDA formed a team with its refrigeration stakeholders to look at the options available to it to ensure the business remained compliant and sustainable under the various F-Gas changes.

ASDA saw that there was a degree of urgency in choosing a way forward with the next phase-down step approaching at the end of 2020 and the need for a marked increase in the use of the low GWP (<300 GWP) refrigerant options across a variety of applications, including Commercial Refrigeration, as shown in *Figure 1* below.

A crucial factor was to choose a solution that not only had a lower GWP but also that at least maintained the performance of the products it replaced with the energy efficiency being especially important as increased indirect emissions from increased power consumption will greatly reduce any net gain of lowering the refrigerant GWP. A popular solution being implemented by some Commercial Refrigeration end users is the use of transcritical CO_2 systems and ASDA did look closely at this for its estate but concluded it did not meet the performance (including risk to trade) and safety criteria it had established for new technologies. In addition,

Figure 1: Ideal transition strategy to reduce average refrigerant GWP in line with the phase-down



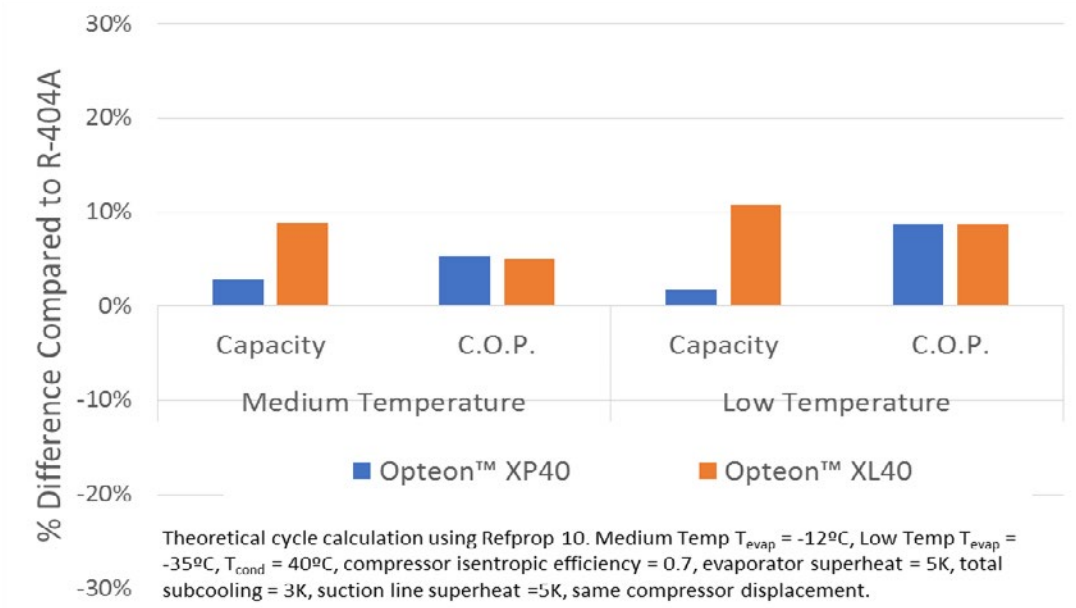
ASDA was looking, if possible, for similar operating characteristics to the common HFCs such as R-404A and R-407F as well as the A1 HFO blends such as R-448A and R-449A being used to retrofit existing systems.

Chemours has developed several blends for Commercial Refrigeration in the Opteon™ XL range. As a blend of HFO 1234yf and R-32 these blends have low GWP (below 300) but the tradeoff for this is the mild flammability of these newly commercialized refrigerants.

Opteon™ XL20 (R-454C) with a GWP of 148 was developed for applications where a GWP below 150 is required under the upcoming F-Gas equipment restrictions. This product performs well and can be used where the lowest GWP is desired in new equipment to replace a number of existing higher GWP A1 refrigerants including R-404A. In the case of the ASDA project, with packs operating below 40kW capacity, it was not necessary to choose a refrigerant with a GWP below 150 and thus Opteon™ XL40 (R-454A) was considered. This has a higher GWP of 238 but was developed to be a close match for R-404A and its A1 replacements in new equipment. The GWP of 238 is low enough to ensure a sustainable future in new equipment while meeting ASDA stringent performance criteria.

Theoretical performance vs. R-404A is shown below (*Figure 2*).

Figure 2: Performance comparison of low GWP Opteon™ refrigerants against R-404A



ASDA and its stakeholders took the decision to trial the refrigerant in an existing system in an authorized access only zone; the ASDA Merchandising Center of Excellence (MCE) in Leeds over a six-week duration in early 2018. The results from this initial trial were excellent. No system commissioning settings were changed from the systems former refrigerant (R-407A) and very quickly it was established that it would be possible to raise the target suction set-point to improve efficiency without having a detrimental impact on system performance.

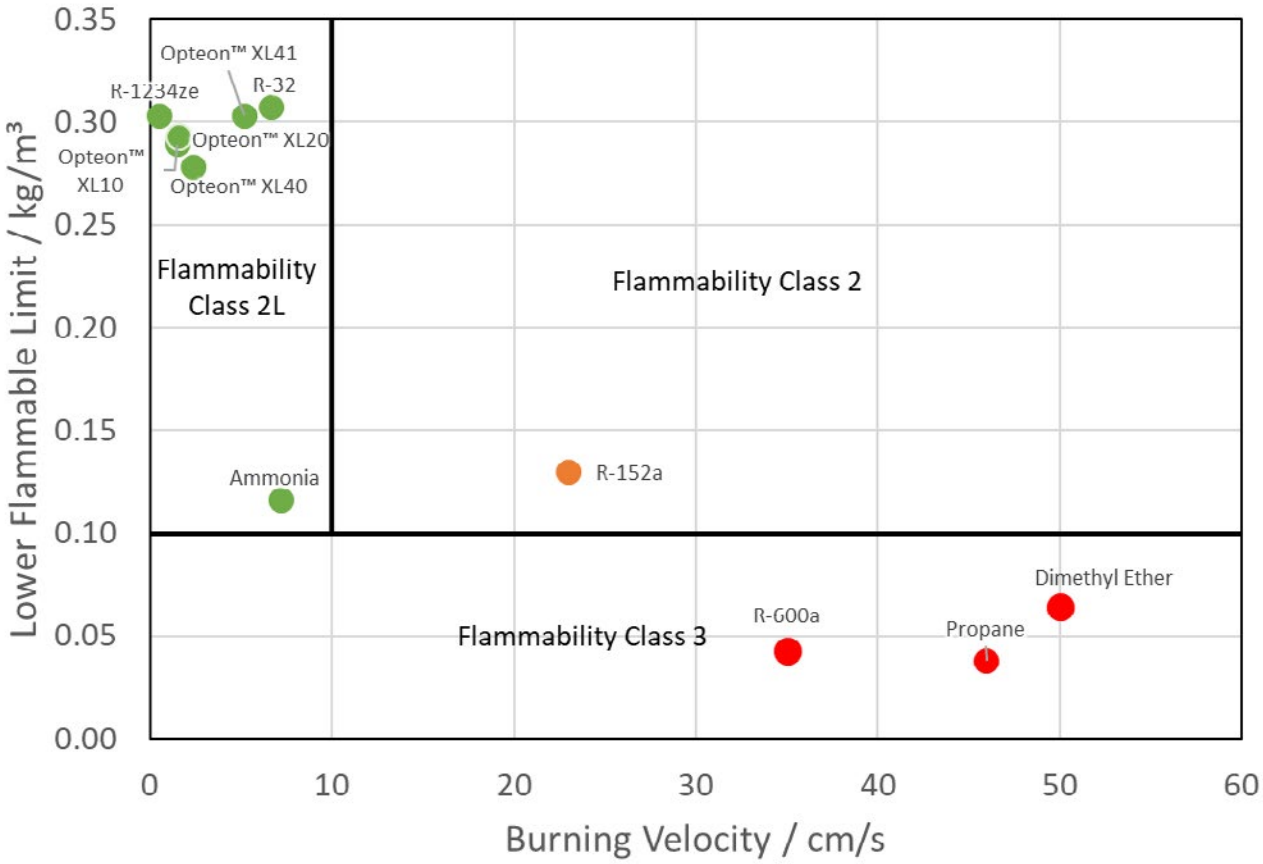
Based on these results ASDA and stakeholders moved onto the next stage; a trial in the new MCE at Pentair in Leeds. For this trial a new plant system was designed and developed by Hubbard Products to ensure compliance to ATEX and DSEAR regulations. Two independent plant systems were incorporated onto a single packaged plant frame – featuring technology designed to minimize charge size. The rational was to ensure that the single plant frame matched the current size and 80kW medium temperature plant capacity – whilst meeting the guidance provided by BS EN-378 as explained below.

Working with A2L Refrigerants in Commercial Refrigeration

Until 2010, there were three flammability classes recognised i.e. 1: no flame propagation (e.g. R-134a), 2: flammable (e.g. R-152a) and 3: highly flammable (e.g. Propane). With the need to move to lower GWP refrigerants, it was realised that although many of the low GWP candidates were flammable, a number presented a lower safety risk than R-152a or propane, and therefore research was performed to study what the relative flammability risks were and how a sensible boundary may be drawn between categories.

The conclusions of these studies presented a proposal to add a subdivision of the 2 classification where, in addition to the heat of combustion (HOC)<19,000 kJ/kg and a lower flammable limit (LFL) of >0.1kg/m^3 requirements, refrigerants with a burning velocity (BV) <10 cm/s would be classified as 2L (*Figure 3*).

Figure 3: Refrigerant flammability classification based on burning velocity and lower flammable limit



While the use of flammable refrigerants is well known, e.g. virtually all domestic refrigerators in Europe use R-600a, all the standards and regulations on the use of flammable refrigerants had been developed based on the flammability classes 2 and 3, which required more stringent safety precautions than the new 2L classified refrigerants. As can be seen in *Table 1*, the flammability properties of the A2L refrigerants present a significantly lower risk. For example, in addition to the lower burning velocity and heat of combustion, A2L refrigerants require a larger quantity of refrigerant to reach the LFL, the range of flammability is reduced, and the minimum ignition energy (MIE) required is orders of magnitude larger than that required to ignite an A3 product.

Table 1: **Comparison of flammability properties of typical A3, A2 and A2L refrigerants**

Parameter	Propane	R-152a	Opteon™ XL40
Safety Classification	A3	A2	A2L
Lower Flammable Limit (vol. %) [kg/m^3]	2.2 [0.038]	3.9 [0.130]	8.0 [0.278]
Upper Flammable Limit (vol. %) [kg/m^3]	10.0 [0.192]	16.9 [0.563]	15.0 [0.522]
UFL – LFL (vol. % - range)	7.8	13.0	7.0
Minimum Ignition Energy (mJ)	0.25	0.38	300-1000
Burning Velocity (cm/s)	46	23	2.4
Heat Of Combustion (MJ/g)	46.3	16.5	10.04

After formal adoption of the 2L class by ASHRAE Standard 34 (2010) and ISO 817 (2014) standards, the classification was recognised by ASHRAE Standard 15 "Safety Code for Mechanical Refrigeration" (US) and ISO 5149 "Refrigerating systems and heat pumps — Safety and environmental requirements" and eventually incorporated into the European standard EN 378:2016. This will be the basis for assessing what is required for the safe use of A2L refrigerants. Part 1 of the standard is of particular interest, as it details the maximum charge sizes that are allowed within the guidance of this standard. It should be noted that compliance with EN 378 does not remove the need for risk assessments to be performed at the design, installation, use and maintenance phases, and that equipment components used with A2L must conform to the Pressure Equipment Directive (PED, 2014/68/EU).

Maximum Charge Size Calculations Under EN 378-1:2016

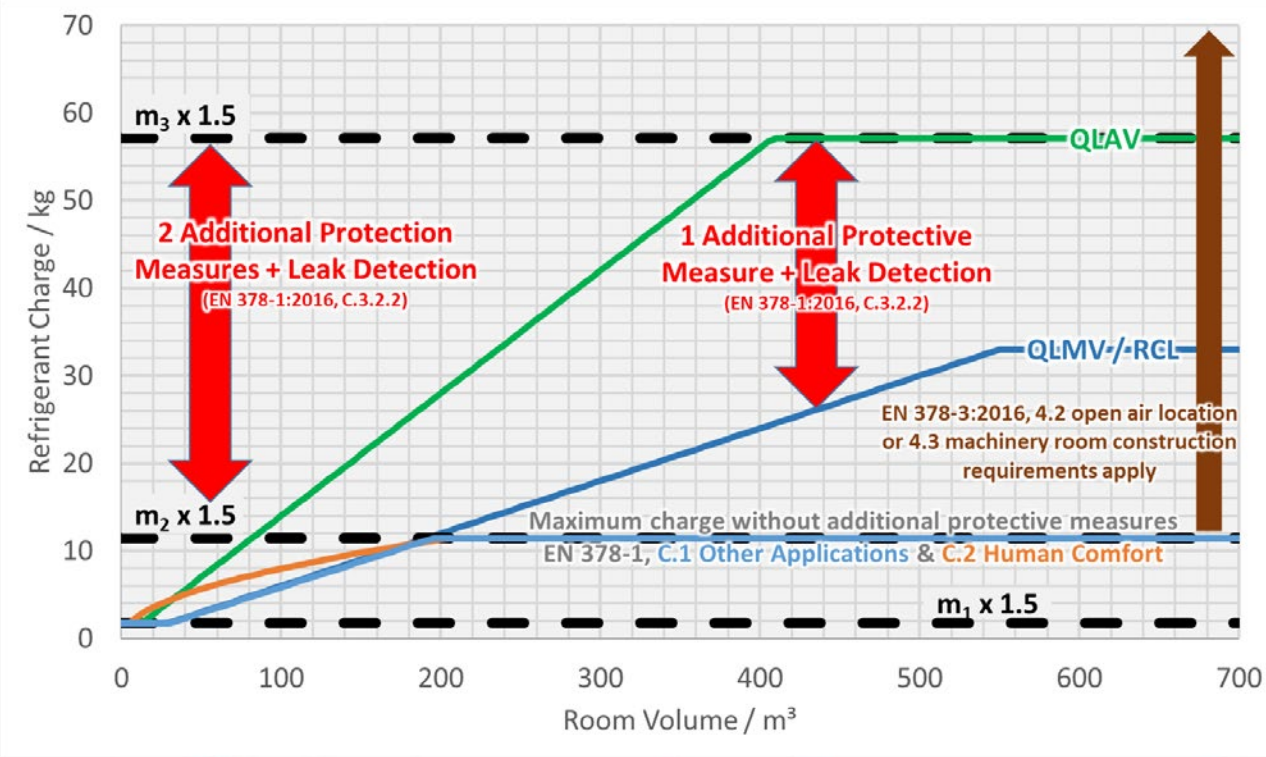
Annex C of EN378-1:2016 sets out the criteria for determining the maximum allowable refrigerant charge. Within Annex C, Table C.2 specifically addresses the use of A2L classified refrigerants. The charge calculations are determined by assigning specific Access categories, Location classifications and Application. “Other applications” covers the use of A2L refrigerants for a commercial refrigeration pack.

Increased Charge Sizes Implementing Additional Protective Measures — Quantity Limit Additional Ventilation (QLAV)

As previously mentioned, there are provisions within EN 378:2016 that will allow larger charge sizes to be used with A2L refrigerants in other applications, provided additional safety measures are put in place. The provisions are set out in EN 378-1:2016 Annex C.3 and require that:

- the system is in Location Class II, Compressors in machinery room or open air;
- the charge does not exceed 150kg and does not exceed m_3 x 1.5 (where m_3 = 130m³ x LFL kg/m³);
- rated cooling capacity of each of the indoor units is not more than 25% of the total cooling capacity of the outdoor system;
- indoor unit has protection against ice damage and fan breakage;
- only permanent joints are used within the occupied space (except for site-made joints directly connecting the indoor unit to the piping;

Figure 4: Example with Opteon™ XL40 showing maximum refrigerant charge using QLAV calculation (EN 378-1:2016, Annex C.3) compared to no additional protective measures calculation (EN 378-1:2016, Annex C.1or C.2).



Note: QLAV (Quantity Limit Additional Ventilation), QLMV (Quantity Limit Minimum Ventilation), RCL (Refrigerant Concentration Limit).

- refrigerant pipes in the occupied space are protected against accidental damage from environmental factors (e.g. water, temperature, debris, etc.) or movement of system components or items around the system (e.g. vibration, moving furniture etc.);
- doors of the occupied space are not tight-fitting; and
- effect of flow down (to floors beneath the system) are mitigated with ventilation in those areas.

Additional protective measures such as additional ventilation (natural or mechanical), safety shut-off valves, or safety alarms in conjunction with leak detection devices, must be employed. As can be seen in *Figure 4*, applying the required additional protective measures results in maximum charges above 50kg.

The maximum charge size can easily be calculated using a spreadsheet developed by Chemours, an example of which is shown in *Figure 5*.

Figure 5: Example of the maximum refrigerant charge size calculator for Other Applications based on EN 378-1:2016

Opteon™ XL Refrigerant Charge Calculator

Enter the Location, Access Categories and Refrigerant using the drop down list. Type in the room dimensions and estimated refrigerant charge.
(Always refer to the full EN 378:2016 standard to ensure all the necessary requirements are fulfilled)

Location Classification:	Class II	Compressors in machinery room or open air If all compressors and pressure vessels are either located in a machinery room or in the open air then the requirements for a class II location shall apply unless the system complies with the requirements of class III. Colls and pipework including valves may be located in an occupied space.	
Access Category:	a	Rooms, parts of buildings, building where — sleeping facilities are provided, people are restricted in their movement, — an uncontrolled number of people are present, any person has access without being personally acquainted with the necessary safety precautions	Example Hospitals, courts or prisons, theatres, supermarkets, schools, lecture halls, public transport termini, hotels, dwellings, restaurants
Other Applications or Low Occupancy:	Other Applications		
Refrigerant:	Opteon™ XL40	(R454A, GWP[1] = 239)	
Room Dimensions / m	Height: 3 m Width: 20 m	Length: 10 m Room Volume: 600 m³	
Estimated Required Refrigerant Charge / kg:	50kg		

Refrigerant Charge Limits / kg

EN 378 Appendix C1:	10.84kg
EN 378 Appendix C3 (QLMV):	36.00kg
EN 378 Appendix C3 (QLAV):	54.21kg

Systems where the rated cooling (heating) capacity of the indoor unit is not more than 25 % of the total cooling (heating) capacity of the outdoor unit systems and where pipes serving equipment in the occupied space in question are not oversized relative to the capacity of that equipment, where the heat exchanger in the indoor unit and the control of the system are designed to prevent damage due to ice formation, where the refrigerant-containing parts of the indoor unit are protected against fan breakage or the fan is designed to prevent breakage, systems where only permanent joints are used in the occupied space in question except for site-made joints directly connecting the indoor unit to the piping,where the refrigerant-containing pipes in the occupied space in question are installed in such way that it is protected against accidental damage in accordance with EN 378-2:2016, 6.2.3.3.4 and EN 378-3:2016, 6.2, alternative provisions to ensure safety are provided in accordance with EN 378-1:2016, C.3.2.2 and C.3.2.3, doors of the occupied space are not tight-fitting and the effect of flow down is mitigated in accordance with C.3.2.4.
If the value exceeds the QLMV, appropriate measures such as ventilation (natural or mechanical), safety shut-off valves and safety alarm, in conjunction with a gas detection device, see in EN 378-3:2016, Clauses 6, 8, 9 and 10. A safety alarm alone shall not be considered as an appropriate measure where occupants are restricted in their movement. (see EN 378-3:2016, 8.1) shall be taken.

1. GWP values are from Intergovernmental Panel for Climate Change (IPCC) Assessment Report 4 as specified in EU 517/2014 legislation.
Note: The information provided is intended only as a guide and should not be taken in isolation. All assessments should be made with reference to the full text contained within the current EN 378:2016 standard. Also the above calculations do not remove the need for a risk assessment before installing or using equipment utilising Opteon™ 2L Flammable refrigerants.

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Risk Assessment — Flammability Considerations

Compliance with EN-378:2016 does not remove the requirement for a risk assessment. Although often overlooked, it has always been a requirement for risk assessments to be performed for any equipment utilising refrigerants, irrelevant of the flammability classification. The use of flammable refrigerants obviously poses potential additional risks and therefore any standard risk assessment processes used for A1 rated refrigerants must be reviewed to ensure that assessment of risks related to flammability are fully covered.

For the ASDA project, individual risk assessments were performed at all stages of use, from design and manufacture, to installation/decommissioning, maintenance and normal usage stages. The risk assessment methodology was applied, including ATEX, with help and guidance from Business Edge consultant expertise. The knowledge gained from this process is providing a standard within ASDA and its refrigeration collaborators, as well as for commercial refrigeration users more generally interested in applying A2L technology.

Within the European Union, the ATEX 137 Workplace Directive (1999/92/EC) is the primary guidance for consideration. This directive will be implemented at a national level in each country and may have a different name e.g. in the UK, the ATEX 137 Directive exists as the "Dangerous Substances and Explosive Atmosphere Regulations (DSEAR)". Interestingly, the UK DSEAR Regulation requires a DSEAR (ATEX) risk assessment for any pressurised gas, whether it is flammable or not, which means the risk assessment process when using a mildly flammable refrigerant, is fundamentally no different than using a non-flammable refrigerant, although using a mildly flammable refrigerant is likely to add some complexity to the process. It should be noted that in some countries additional national requirements may exist and users should ensure these are also considered.

The fundamental principles of the risk assessment, with regards to the formation of possible flammable atmospheres, are outlined in standard EN 60079-10-1:2015, which requires identification of:

- possible sources of release;
- rate, frequency and duration of any release;
- effectiveness of any ventilation;
- zone type (flammable atmosphere is present continuously, occasionally or not during normal operation);
- extent (size) of the zone.

The primary forms of ignition sources to be considered for refrigeration applications are those that produce energy in the form of heat, electricity, mechanical and chemical, although a full list and description of potential ignition sources can be found in EN 1127-1:2012.

Once the zones had been defined, any ignition sources within the zone were identified and removed, or controls put in place, to prevent an ignition event occurring should a flammable atmosphere occur.

As was shown earlier in *Table 1*, the flammability properties are significantly different to those of A3 refrigerants such as propane. Many potential ignition sources that would cause an ignition with propane are not ignition sources for many of the A2L refrigerants. The results from testing performed by the Air-conditioning, Heating & Refrigeration Institute (AHRI) are shown in *Table 2*, which clearly show that many domestic electrical appliances and even friction sparks and smouldering cigarettes may not be considered as ignition sources when using A2L refrigerants. In fact, the cigarette was extinguished by the refrigerant within two minutes of being placed within the flammable refrigerant mixture.

Table 2: **Results of ignition tests using A2L refrigerants at the stoichiometric mixture with air (flammable atmosphere) from AHRI Report no. 8017**

Potential Ignition Source	R-32	Opteon™ XL55	Opteon™ XL10
Hot wire	**D**	**D**	**D**
Safety match	**D**	**D**	**L**
Lighter flame insertion	**D**	**L**	**L**
Leak impinging on candle	**L**	**N**	**L**
Cigarette insertion	**N**	**N**	**N**
Barbeque lighter	**N**	**N**	**N**
Plug and receptacle	**N**	**N**	**N**
Light switch	**N**	**N**	**N**
Hand mixer	**N**	**N**	**N**
Cordless drill	**N**	**N**	**N**
Friction sparks	**N**	**N**	**N**
Hair dryer	**N**	**N**	**N**
Toaster	**N**	**N**	**N**
Hot plate insertion	**N**	**N**	**N**
Space heater insertion	**N**	**N**	**N**

Legend: **D** – Deflagration (flame propagated away from the ignition source), **L** – Localised flame (no flame propagation), **N** – No refrigerant combustion

New MCE Trial 2019

The trial in the new MCE commenced in February 2019 and consisted of two purpose built packs by Hubbard using compressors supplied by Emerson and approved for use with HFO blend refrigerants. The packs delivered <40kW and contained approx. 50kg of refrigerant. One pack was run on R-448A, an A1 HFO blend, and the other on Opteon™ XL40 (R-454A). As well as a test of the performance of the A2L refrigerant, the set up was used as a test bed for the risk assessments, including DSEAR, and specifically of the measures to mitigate risk in such a system. These included ventilation, leak detection and developing a shutdown protocol should a leak be detected. This also gave an opportunity to optimise display cabinet design to accommodate A2L refrigerants, including the installation of leak detection equipment.

Performance Results

Energy monitoring data was collected by consultant engineers, Wave, from the two medium temperature packs following optimization of set points and running with comparative loads to ensure a valid comparison over a stable operation period.

Analysis of the data by Wave showed an energy saving of 3.65% on the Opteon™ XL40 R-454A pack compared to the R-448A pack.

It has already been reported that the A1 HFO blends R-448A and R-449A (Opteon™ XP40) show a significantly improved energy performance when compared to R-404A in medium temperature operation and the implementation of the A2L refrigerant R-454A has given a further small improvement.

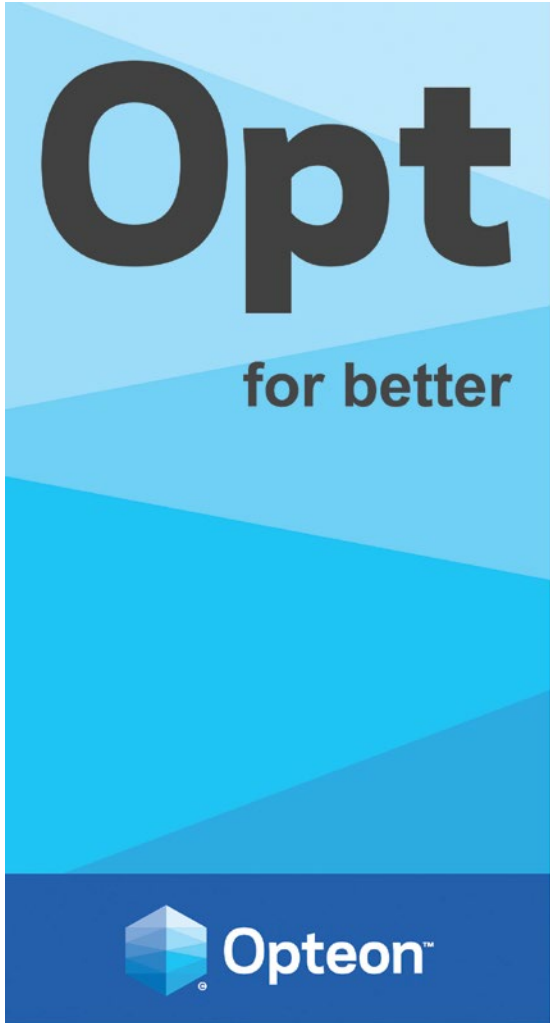
Conclusions

ASDA, with the help of Chemours and its other key stakeholders, have developed a commercial refrigeration system that:

- Meets the challenges of the F-Gas phase-down and bans on the use of high GWP refrigerants.
- Is in line with the recommendations of EN378 regarding charge size and system safety.
- Has very low risk by using an A2L refrigerant and implementation of risk mitigation measures that have come from extensive risk assessments.
- Is commercially viable as it uses similar components to traditional HFCs, which also simplifies installation and maintenance.
- Has improved energy performance compared to the HFCs it replaces and to the A1 HFO blends currently used for retrofit, while having a better than 80% reduction in GWP.
- Provides a long term and sustainable solution to small pack commercial refrigeration applications.
- Provides a signpost to other potential end users regarding safe use of A2L refrigerants.

The next steps will be to translate this into a live store environment in the second half of 2019 using all the knowledge from this practical demonstration.

About Opteon™ Refrigerants



The Opteon™ refrigerants portfolio offers the optimal balance of environmental sustainability, performance, safety, and cost to help meet both regulations and business goals.

Specifically, in Europe, the very low GWP Opteon™ XL refrigerant portfolio supports the market transitions required by the F-Gas Regulation and enables customers to select their optimal solution – considering performance, safety, sustainability and total cost of ownership.

Businesses trust Opteon™ Refrigerants because they offer:

Low GWP:
Up to a 99% reduction compared to previous refrigerant generations.

Zero ODP:
The HFO-based refrigerant family is non-ozone depleting.

Ease-of-Conversion:
Minimizing conversion costs and downtime.

Excellent Capacity:
A near match to many HCFC- and HFC-based technologies.

Energy Efficiency:
Reduced energy use creates long-term savings over the system's life.

Long-Term Regulatory Compliance:
HFO-based refrigerants can meet or exceed global and local regulatory standards.

Knowledgeable Experts:
With more than 85 years of industry experience, Chemours refrigerant experts can help customers achieve both compliance and peak performance.

Visit Opteon.com/regulations for more information on HFC replacements or to contact our experts.

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